Christian-Albrechts-Universität zu Kiel

Diploma Thesis

A quantitative analysis of Statechart aesthetics and Statechart development methods

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Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe.

Kiel,

"Objects have both behavior and state or, in other words, they do things and they know things. Some objects do and know more things, or at least more complicated things, than other objects. Some objects are incredibly complicated, so complex that developers can have difficulty understanding them."

–Scott W. Ambler [3] on Statecharts

This thesis would not appear in its present form without the kind assistance and support of the following people:
Prof. Dr. Reinhard von Hanxleden for his input and the equally generous and wise guidance during its conclusion; My advisor, Steffen Prochnow, for his unstinting commitment to help see this project through to its completion; Christiane Gross for her much appreciated pointers to the right statistical methods and her time spent on explaining them; Prof. Dr. Jürgen Golz for his advice on data analysis; All my friends, especially the ones that proof-read my thesis, Falk Starke and Sandro Esquivel; My parents for their continuing support and patience; Fia for making me happy.

I have also benefited from many discussions with members of the Real-Time and Embedded Systems group. Thank you all for your time and ideas.

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List of Used Acronyms

ADL	Alternating Dot Layout
ADBL	Alternating Dot Layout Backwards
AL	Arbitrary Layout
ALL	Alternating Linear Layout
CLT	Central Limit Theorem
CSV	Comma Separated Values
IQR	Interquartile Range
KIEL	Kiel Integrated Environment for Layout
KIT	KIel statechart extension of doT
LLL	Linear Layer Layout
LOWESS	Locally Weighted Scatterplot Smoothing
mRMR	minimal-redundancy-maximal-relevance
PDF	Portable Document Format
SNF	Statechart Normal Form
SSM	Safe State Machines
SVG	Scalable Vector Graphics
UML	Unified Modeling Language
VIF	Variance Inflation Factor
WYSIWYG	What You See Is What You Get
XML	eXtensible Markup Language
XSLT	eXtensible Stylesheet Language Transformations

1. Introduction

Finite state machines depict the dynamic behavior of a system and its reactions to various events depending on its current state. Traditionally, state transition diagrams have been used to describe finite state machines (Appelgren and Hvannberg [6]). To improve the notation of these diagrams, Statecharts have been proposed by Harel [28].

1.1. Statecharts

The aforementioned state transition diagrams represent a directed graph. In essence, so do Statecharts. However, Statecharts extend transition diagrams with concurrency, synchronization, and a hierarchical refinement, and use the concept of *superstates* to counteract the effects of exponential diagram growth seen in traditional finite state machines. All Statecharts consist of the following basic elements (for a graphical representation see Figures 1.1 and 1.2):

- A filled circle, denoting the initial state of the diagram
- A hollow circle with another circle in it, denoting the final state (if a final state is designated)
- Rounded rectangles, denoting states. Each state has a name, printed in the center or at the top of that state. States can be either simple states or superstates:
  - Hierarchical states, representing a hierarchical structure of state machines
  - Parallel states, representing concurrency of independent state machines.
- Arrows, denoting a transition between states. Transition labels have the form $E[C]/A$, where E is the event that triggers the transition, C is a condition that guards the transition from being taken unless it is true, and A is an action that is executed when the transition is taken.

Statecharts encourage the repeated decomposition in substates and superstates, i.e. simple, hierarchical, and parallel states. With hierarchical states, Statecharts can be drawn with different levels of abstraction, revealing more or less of the behavior and functionality of a system. These qualities make them ideal for the modeling process of complex *reactive systems* (Harel and Pnueli [29]). Reactive systems are event driven and react constantly to internal and external events. They find widespread use in safety critical realtime applications such as anti-lock brakes or flight control systems. As the number of such systems is rising steadily in modern life, Statecharts

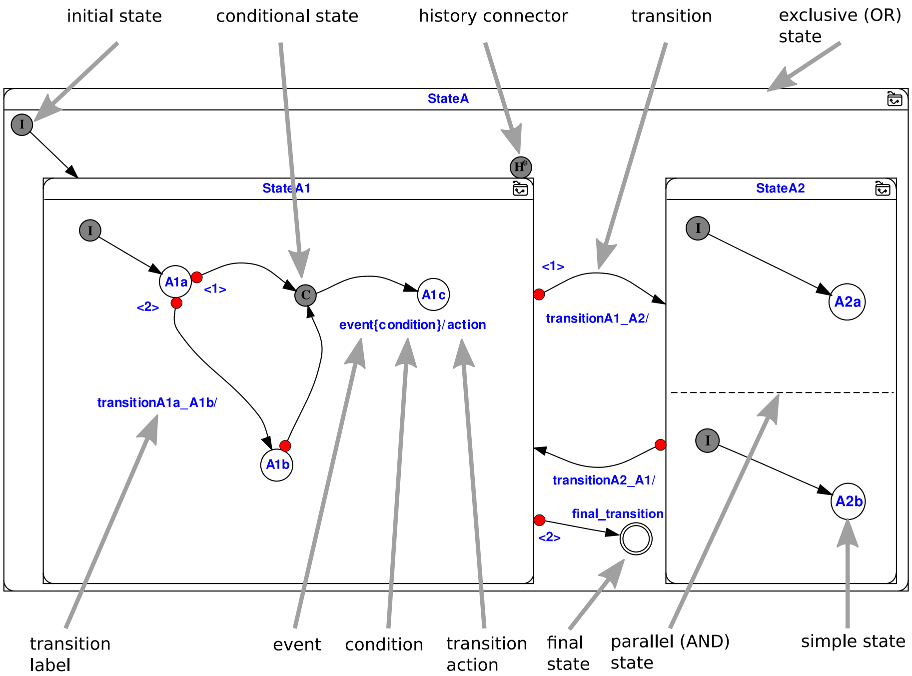


Figure 1.1.: A sample chart that shows Statechart elements from *Esterel Studio* [22]

have rapidly gained importance in the industry. Today it is impossible to ignore them in real-time system design, as they are an integral part of the Unified Modeling Language (UML) [58], which is used by most major companies.

The wide usage in the industry leads to the daily creation of an abundance of Statecharts. Modern projects often include many Statecharts (Krut, jr. and Wood [38]). This implies that modelers often have to work with several charts at a time, self-created and externally made. To effectively create and modify Statecharts, modelers need an environment that supports the designer in the creation process. Major software companies, such as IBM, have developed such environments, which can be used to create and modify Statecharts. Mostly, these are part of a software suite which encompasses the whole modeling process (for instance IBM's *Rational Rose Realtime* [56]). However, only Statechart editors are considered here instead of complete modeling frameworks. Furthermore, only a Statechart dialect called *Safe State Machines (SSM)* is considered, as the data basis used here solely consists of SSM Statecharts. Multiple dialects have evolved from the original notation. However, looking at the Figures 1.1 and 1.2, one can see thatmost differences are in design, not in essence. For the purpose of this work, the SSM dialect is interchangeable with almost any other form of Statechart design. The following text will concentrate on different approaches to Statechart creation and the Statechart editors associated with them.

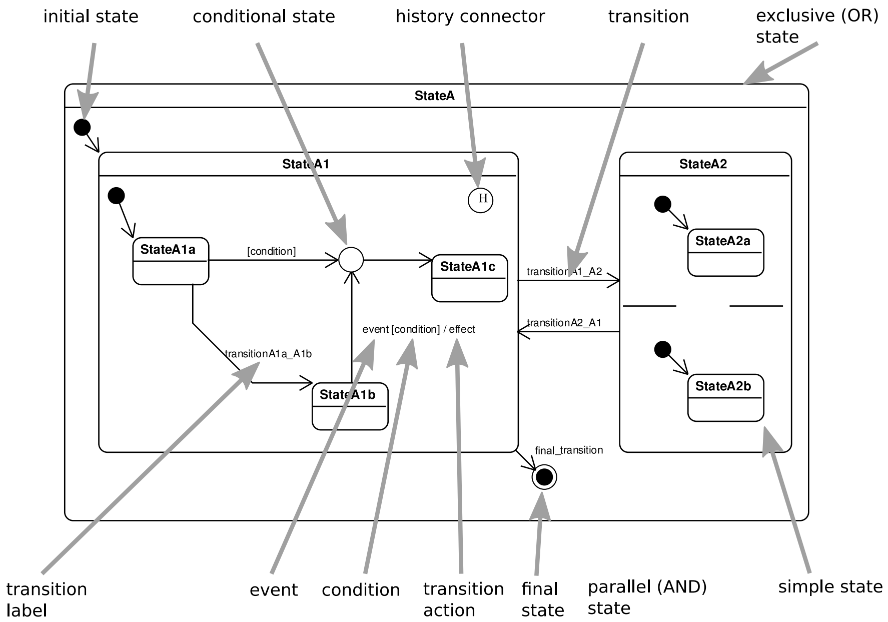


Figure 1.2.: A sample chart that shows Statechart elements from *ArgoUML* [7]

1.2. Conventional Statechart Editing Methods

Commonly known are What You See Is What You Get (WYSIWYG) editors, where the Statechart layout is almost completely in the hands of the modeler. Only few syntactic restraints, such as the prevention of state placement on already occupied spaces, prohibit a total freedom of layout. This leads to a large variety of Statechart layouts, each according to the individual designer's taste. With the growing importance of Statecharts, it is most crucial that a Statechart can be easily read, understood, and edited. This minimizes errors and ensures maintainability, as it facilitates the exchange between developers. However, a developer working with a Statechart formerly edited by someone else might rearrange the Statechart to her or his own liking, even if the previous Statechart design was already understandable. Although nothing is changed in the Statechart structure, time is consumed in the process. This is a common problem of WYSIWYG editors, as they interact directly with the Statechart's layout and structure.

1.3. The KIEL Approach to Statechart Editing

To speed up the editing process, a different approach to Statechart development is taken by two editors from the *Kiel Integrated Environment for Layout (KIEL)* [34] framework. The editors try to counteract the problem of comprehension issues, which are originating from layout differences. This is done by removing control over the layout to let users focus on the structure of the Statechart under development. The following two paragraphs describe the approaches utilized by the editors.

The Textual KIT Editor The first editor uses a structural description language for Statecharts, called *KIel statechart extension of doT (KIT)*. In KIT, Statecharts are expressed as a series of Statechart element declarations. KIT statements can be easily edited by a simple text editor. To obtain a graphical representation of the Statechart described with KIT, another component of the modeling framework has to generate the visual Statechart components. This approach allows the graphical form to be used for efficient internal and external communication, as the layout is standardized. The problem of different Statechart design is shifted from the graphical Statechart representation to the textual representation. This reduces the comprehension problem to the editing process. As the description language is based on Statechart structure, the representation of Statecharts in KIT follows strict style guidelines. This facilitates the exchange of Statecharts between developers.

The Structure-Based Editor Instead of editing the Statechart structure in the textual representation, one can also manipulate the Statechart structure directly. This is the approach followed by the macro-based editor (referred to as *KIEL-macros*) implemented in the KIEL. The location for the modification is selected in a graphical representation of a Statechart, then a key macro is used to initiate a structural change. This lets the user concentrate on the modeling of Statecharts, leaving the layout process to the framework. This approach to Statechart design is relatively new. With the data gathered from an experiment (Prochnow and von Hanxleden [49]), the different editing techniques will be examined and compared to the WYSIWYG approach.

1.4. Style Guides and Aesthetic Criteria

Requiring Statecharts to be created with a uniform layout helps to reduce the time and effort, and in turn the cost, of Statechart design and maintenance. Maintainability has become an elementary part of development, not only for Statecharts, but all object oriented software systems. A common set of standards and guidelines should be agreed to and followed in a software project. The intention of these guidelines is to enable the modeler to create diagrams that are easier to understand and work with. The benefit would be an increase in productivity for the modeler and the whole business. Interestingly, there are only few commonly used uniform Statechart layout criteria. Ambler [4] proposes a set of guidelines for Statechart notation and drawing. He emphasizes the importance of guidelines in his foreword and encourages software companies to purchase his book, instead of creating and implementing own style guides. This would be a step towards a more uniform Statechart design, however, it is not likely that all software companies comply.

If a uniform layout is proposed to enhance the understandability of Statecharts, one has to ensure that the chosen uniform layout surpasses the layout capabilities of human Statechart developers. This requires a knowledge of what is perceived "good" by developers and which Statechart layout criteria influence the understanding. Research on the influence of aesthetic criteria on the understandability of diagrams has been conducted (e.g. by Purchase [51]). Furthermore, the correlation of UML diagram layout with preference and performance of human subjects was tested in experiments (Purchase et al. [55]). However, the researched UML diagram types were class and collaboration diagrams, not Statecharts. This still leaves the problem of understanding the effects of Statechart aesthetics on human preference and performance to be explored.

To lessen this problem, a set of Statechart layout metrics—a measurement of certain Statechart properties—is developed in this thesis from commonly accepted and validated aesthetic criteria (as in Purchase et al. [55]). For the empirical validation of these metrics, data from the above mentioned experiment was used. The details of this experiment will be discussed in Section 5.

The experimental data, combined with the collected aesthetic criteria, reveals which metrics have an influence on the preference and understanding of Statecharts. Based on the results, a ranking of these criteria can be found, as it is unlikely that all aesthetic criteria have the same effect on a user. With the ranked metrics a model will be derived that encompasses part of the examined metrics. This model can be used to rate Statecharts regarding the preference and performance of a user (See Figure 1.3 for an illustration of the process). Such a model could encourage modeling tool authors to implement a set of style rules in their application. This rule set could be used to test if the Statechart conforms with the aesthetic criteria defined. The application could then give direct feedback to the developer by showing him graphically where her or his model conflicts with predefined criteria. Another possibility would be to use the findings as parameters for an automated layout process, such as the one implemented in KIEL. Thus, an easier to understand and uniform Statechart could be generated, which would save a lot of time in maintenance and communication.

1.5. Implications and Outline

To conclude, the "right" design of Statechart becomes increasingly important in industrial development. The maintainability and communicability of Statecharts is closely related to the design. Furthermore, "good" design is not supported by commercially available editors. As there are currently only few data sources available, an study based on empirical data to find Statechart properties that lead towards such a "right" Statechart design is beneficial to not only the industry, but all Statechart designers.

This thesis investigates the influence of aesthetic criteria and Statechart development methods on the *preference* and *performance* of test subjects. Preference indicates the subjective rating of Statecharts without semantic evaluation of the Statechart elements. Performance represents the ability to understand a Statechart's

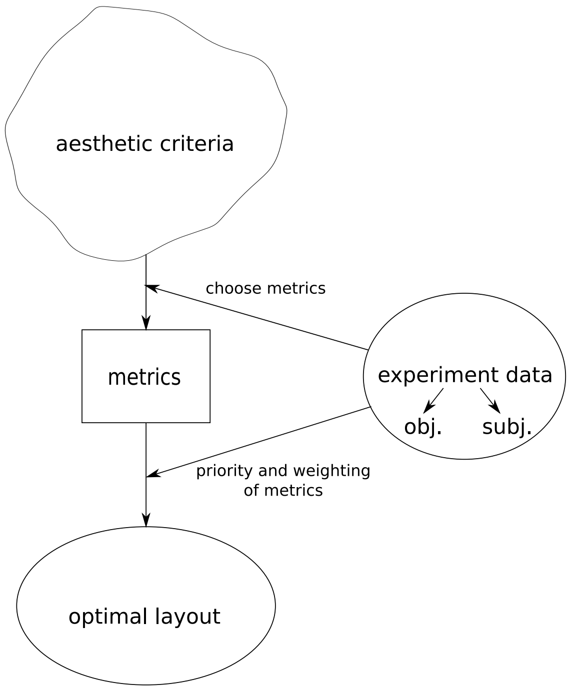


Figure 1.3.: A figure that shows a way to generate an "optimal" layout from aesthetic criteria. Layout metrics are used to quantify the aesthetic criteria and composed to generate the layout. The choice of metrics is decided by experimental data.

semantic, i.e. how much time was needed to correctly construct a sequence of Statechart responses to signal events. In the context of development methods, performance denotes the ability to work productively with a given tool. The focus of this work is to find influential aesthetic criteria. The combination of them into a formula can be used to calculate the rating a Statechart would receive from the participants of the experiment mentioned above, representing Statechart developers in general.

The remainder of this work is partitioned as follows: First, related work concerning this thesis is reviewed. In Chapter 3, aesthetic criteria for different types of diagrams (e.g. graphs, Statecharts and class diagrams) are collected and discussed. Although the reviewed diagrams differ from each other in intent, they share similar construction elements. These similarities can be used to find applicable layout aesthetics not originally intended for Statechart diagrams. Chapter 4 reviews already existing and defines different layout metrics gained from the inspected aesthetic criteria. The experiment introduced in Chapter 5 and the data acquisition in Chapter 6 provide the data basis for the analysis and composition of the presented metrics. The composition of the metrics into a rating formula is described in Chapter 7, the analysis of editing techniques in Chapter 8. Chapter 9 concludes this work and presents an outlook on future applications of the gained information.

2. Related Work

This chapter relates work that has already been done on subjects that are of importance to this thesis. A quick survey on Statechart related work is followed by a look on the literature published in the field of aesthetic criteria. Closely related is the work on layout of Diagrams (especially so called *node-link diagrams*). However, the layout mechanisms are not always validated to be beneficial to human users. The last paragraph gives insight on empirical validation of layout criteria.

2.1. Related Work on Statecharts

To specify the behavior of reactive systems, Harel [28] developed the graphical notation of Statecharts as an extension to finite state machines. Many Statechart dialects have emerged, such as *SyncCharts* [5] or *Argos* [39]. Today, Statecharts (now called *State Machines*) are part of the UML and are used by various commercial applications, such as IBM's *Rational Rose* [56], Mathwork's *Simulink* [40] or *Esterel Studio* [22]. While Statechart semantics have been defined by well-formedness rules in the UML context by the Object Management Group [58], no formal layout criteria are given. On the other hand, formal layout rules are in effect at software development companies (Kreppold [37]) and available in the literature (Ambler [4]).

2.2. Research on Aesthetic Criteria

Aesthetic criteria for graph layout have been mentioned as far back as 1987, when Roberto Tamassia researched the importance of placing a graph on a grid with the minimum number of bends [57]. A graph drawing tutorial from Cruz and Tamassia [15] incorporates this aesthetic criterion. A good overview of the literature in the area of graph drawing can be found in a survey on this subject written by Di Battista et al. [20]. Coleman and Parker [14] call aesthetics a "measure of desirability" which is to be maximized, if a graph is meant for human consumption. To that end, they constructed and implemented a graph layout method which views graph layout as an optimization problem.

While it is commonly accepted in the graph drawing community that these aesthetics improve the readability of graph drawings, little experimental proof has been offered as far as aesthetic criteria for graph layout are considered. The most complete studies in this field have been conducted by Purchase et al. [52, 51, 55]. Other work concentrates on the cognitive aspects (Ware et al. [60]) or uses eye tracking to gain knowledge about the way people read graphs (Huang and Eades [31]). However, the focus of this research has always been on graphs, not Statecharts (although Purchase, Carrington, and Allder [55] research *UML* elements). If the research was focused on Statecharts, aesthetic criteria used for graph layout have been used without much consideration (Appelgren and Hvannberg [6]).

2.3. Work on the Layout of Diagrams

General Layout A formally defined set of layout rules can be beneficial for a company, as the maintainability of Statecharts goes hand in hand with its layout (Ambler [4]). A Statechart which can be clearly visually perceived and understood has an advantage over Statecharts with random layout. Textual programming languages often define coding conventions in the form of a secondary notation, such as indentation, structure etc. In graphical programming languages such as Statecharts, there have been several attempts to induce such conventions, for example by introducing a Statechart Normal Form (SNF) (Prochnow and von Hanxleden [47]). Of these, none has found widespread use so far. The first tool to use this SNF is the KIEL modeling tool, developed by the aforementioned authors.

As the layout of a Statechart is so important, there has been work on the visualization and layout of Statecharts. Castelló, Mili, and Tollis [11] researched the visualization of Statecharts and treated them as graphs, applying graph layout algorithms. While not explicitly stated, aesthetic criteria, in combination with floor-planning algorithms and hierarchical drawing, are used to generate an user-friendly layout. The results are evaluated with a series of examples, but there has been no evaluation by experiment.

Layout Metrics Purchase [50] chose to deduct a definition of metrics from aesthetic criteria. She examined graph layout algorithms and applied the designed metrics to them. This thesis follows her idea of devising metrics from aesthetic criteria. In earlier research, Purchase validated some aesthetic criteria, such as edge crossings and edge bends with experiments, proving for the first time the importance of aesthetic criteria for the understanding of graphs. The metrics found from these studies have been defined "objectively", i.e. independent of the authors or other judgement. On the other hand, this implies that no empirical study about the perception of what metric appears to be "good" has taken place. Experimental research to determine whether human perception conforms with these objective measurements is left for a later study. Purchase et al. further researched aesthetic criteria and metrics, now looking at UML class diagrams [54]. There has been research on Statechart metrics for usability evaluation (Genero et al. [26], further researched by Appelgren and Hvannberg [6]), although their work is looking at the structure of a Statechart, not at its layout. There has been work based on structural metrics to predict the understandability of a Statechart by using fuzzy logic (Cruz-Lemus et al. [16]).

Automated Statechart Layout There have been several approaches to automatically layout graphs. One very important contribution is the GraphViz (Gansner and North [25]) layout framework, which has found its application in numerous other projects. The creator of Statecharts, David Harel, researched the automated layout of hierarchical "blob" models (defined as "rounded-corner rectilinear shapes" [30]), which include Statecharts. He applied subjective (though customizable) criteria to his drawings, for example the uniformity of blob dimension, symmetry, and space utilization. In addition to graph layout, there has been work on Statechart layout. Several commercial tools (for example Rational Rose Realtime [56]) offer a layout function for UML components, including Statecharts. Their implementation is rather rudimentary, neither regarding aesthetic criteria, nor accepting parameters to let the user influence the layout. Regarding user interaction, Castelló et al. [11] have developed a framework for the static and interactive visualization of Statecharts, based on hierarchical drawing and floorplanning. They do not, however, incorporate aesthetic criteria.

The KIEL modeling tool [34] has been developed at the group of *Real-Time and Embedded Systems*, Department of Computer Science, Christian-Albrechts-Universität zu Kiel to investigate different Statechart development methodologies. The research on effective Statechart creation methods is central to a dissertation at the Real-Time and Embedded Systems group (Prochnow [46]). A lot of research and diploma theses have flown into this tool [49, 47, 61, 35].

2.4. Empirical Evaluation and Experiments on Layout Criteria

Prechelt [45] states that a lot of the published work in practical informatics has not been supported by empirical evaluation. This applies also to diagram layout research. Aesthetic criteria and layout guidelines are often presented without further evaluation or taken from simple questionnaires (Koning et al. [36]). The individual proposals are justified rationally, not by empirical validation. An experimental approach is the exception for the—sometimes vast—variety of design and style guidelines presented in various papers. One of the exceptions are the works of Purchase et al. [53]. They state that it is important for aesthetic criteria to be evaluated by experiments with humans, so the aesthetics can be judged with respect to how much they assist the human comprehension. Another experiment on graph aesthetics was performed by Ware et al. [60]. Extensive experiments about Statechart composition were conducted by Genero et al. [26] and Cruz-Lemus et al. [17]. However, these concerned the structural aspects of Statecharts. Genero researched the influence of various structural Statechart elements, such as the number of entry actions in a state. Her colleague Cruz-Lemus researched the impact of hierarchical states on the understandability of a Statechart. There has been an evaluation of the preferred layout of the KIEL developers, called Alternating Dot Layout (ADL). This layout was empirically compared to other layouts in an experiment with graduate-level students

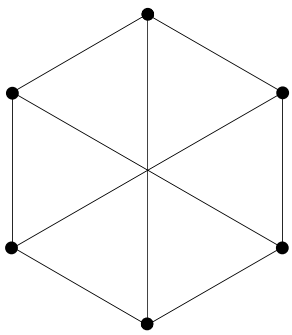
(Prochnow and von Hanxleden [48]).

3. Survey and Selection of Aesthetic Criteria

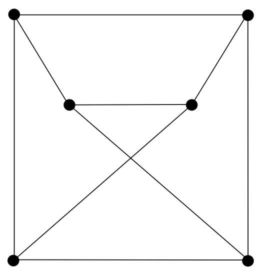
The general idea of understandable Statecharts is that they have to fulfill two criteria: Good structure and good layout. If a Statechart gets too complex, it is almost impossible to understand. However, if the layout is confusing, it takes very long to understand even simple Statecharts, as the important information does not present itself immediately. The aspects which influence the perception of a Statechart are called *aesthetic criteria*.

To identify which criteria of layout appeal to Statechart designers, a survey of conducted work follows. The aesthetic criteria collected are presented in the following sections. The individual sections correspond to the diagram types that were researched in the related literature. In addition, aesthetic criteria suggestions for Statechart layout have been gathered from questionnaires, filled out by graduate-level computer science students [49]. The questionnaires and the related experiments will be discussed in Section 5.

Often, more than one aesthetic criterion is affected when a drawing is created. The different criteria have to be considered and prioritized to maximize the understandability. The example in Figure 3.1 shows that the minimizing of edge crosses may lead to a decline in symmetry (Fruchterman and Reingold [24]). Therefore, it is important to know which aesthetic criteria have the highest impact on the human comprehension.



(a) Three crossings, highly symmetrical



(b) One crossing, only one symmetry axis

Figure 3.1.: Two graphs explaining the conflict between edge crossing and symmetry: The minimizing of edge crossings may lead to a decline in symmetry.

Much work has been done in the field of aesthetic criteria for graph layout (Görg et al. [27], Purchase [50], Davidson and Harel [18], Di Battista et al. [20]). However, Statecharts have been mostly overlooked (with a few exceptions [17, 6, 55]) or simply taken for a special form of graph. Likewise, there has been little research on class diagram aesthetics, collaboration diagrams etc.

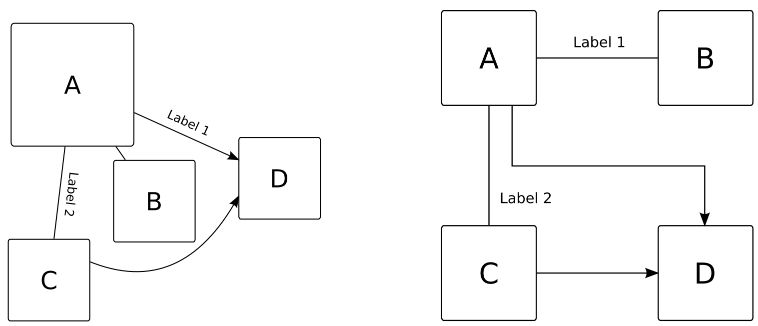
To give a general overview, aesthetic criteria found in literature are presented here. They are differentiated by the type of diagram that they were originally conceived for.

3.1. General Aesthetic Criteria for Diagram Creation

First, some general style guidelines. These apply to all kinds of diagrams, UML or otherwise. The terms *lines*, *symbols*, and *labels* are used to represent the appropriate element in other diagrams:

- Symbols represent diagram elements such as nodes, class boxes, and states.
- Lines represent the connection elements such as edges, associations, and transitions.
- Labels represent diagram elements such as names, association roles, and conditions.

Most of the following criteria can be found in *The Elements of UML 2.0 Style* by Scott W. Ambler [4].



(a) A diagram without applied layout criteria

(b) The same diagram laid out according to aesthetic criteria

Figure 3.2.: Two diagrams that depict the improvement of aesthetic criteria (figure inspired by Ambler [4])

Aesthetic Criterion 3.1.1 (Avoid Crossing Lines)
When two or more lines cross in a diagram, the possibility to misread either of them exists.

Aesthetic Criterion 3.1.2 (Depict Crossing Lines as a Jump)
It cannot always be avoided to cross lines in a diagram. Sometimes this is even the better solution, as seen in Figure 3.1. However, to clearly indicate which line is which, crossings should be depicted as a jump, with one line "hopping" over the other.

Aesthetic Criterion 3.1.3 (Use Straight Lines, Place Symbols on a Grid)
Avoid diagonal or curved lines, place symbols on a grid. Horizontal or vertical straight lines are easier for the eye to follow than diagonal or curved lines. The placement of symbols on a grid facilitates the use of straight lines. In Figure 3.2b, the lines are improved in this manner. Many tools offer a function which restricts symbol placement to a fixed a grid.

Aesthetic Criterion 3.1.4 (Arrange Symbols Symmetrically)
In the first version of the diagram shown in Figure 3.2, the symbols are placed almost randomly. Organizing symbols and lines in a symmetrical matter makes the diagram easier to read. A clear pattern will make the diagram easier to understand.

Aesthetic Criterion 3.1.5 (Apply Consistently Sized Symbols)
In Figure 3.2a, symbol A is larger than the others. The size of a symbol is often associated with its importance. If all symbols of one type are of the same importance, their size should be kept identical. Only draw individual symbols bigger if the emphasis is intentional.

Aesthetic Criterion 3.1.6 (Attach Lines to the Middle of Symbols)
The middle of a symbol is expected to be the origin of all protruding lines. A consistent design makes the diagram easier to read.

Aesthetic Criterion 3.1.7 (Align Labels Horizontally)
Text is much more readable if it is printed horizontally. The labels in Figure 3.2 are easier to read in the second diagram. A Labels should be drawn horizontally, even if the line it is associated with is vertical.

Aesthetic Criterion 3.1.8 (Minimize the Number of Symbol Types)
Koning et al. [36] recommend that the number of different symbols in a diagram is to be kept under seven. If more symbols types are used, the risk of confusing the modeler is too high.

Aesthetic Criterion 3.1.9 (Include White Space in the Diagram)
White space is the area between drawing elements in a diagram. A crowded diagram is harder to read, the space for labels is not sufficient, etc. Notice the improved readability of 3.2b.

Aesthetic Criterion 3.1.10 (Organize Diagrams Left to Right, Top to Bottom)
In western cultures, the usual reading direction is left to right or top to bottom. Therefore, this is the way most diagrams will be read. If a diagram has a starting point, it should be placed in the upper left corner (Eades and Sugiyama [21]).

Aesthetic Criterion 3.1.11 (Avoid Many Close Lines)
The eye loses track of individual lines if there are other in close vicinity. This can be avoided by keeping a reasonable distance between all symbols and lines.

Aesthetic Criterion 3.1.12 (Apply Color or Different Fonts Sparingly)
Although color is a good way to indicate specialties in diagrams, an overuse can be overwhelming. Koning et al. [36] propose a restriction of six or less colors.

3.2. Aesthetic Criteria in Graph Drawing

As mentioned before, the majority of work on aesthetic criteria is in the field of graph layout. This is understandable, as graph layout concerns researchers for much longer than Statechart design. However, various aesthetic criteria can be adopted for Statecharts, as they resemble a directed graph in many ways. The following aesthetic criteria for graph drawing have been suggested in the literature:

Aesthetic Criterion 3.2.1 (Node Distance)
Davidson and Harel [18] state that nodes placed too close to each other have a negative influence on the readability. This corresponds to the white space aesthetic from section 3.1. The opposite is also true. If nodes are placed too far from each other, the distance traveled between them might abate the concentration of the observer Coleman and Parker [14].

Aesthetic Criterion 3.2.2 (Nodes Should be Placed on a Grid)
The placement of nodes is also widely researched. Tamassia [57] and Papakostas and Tollis [43] propose a grid placement of nodes. The orthogonality is said to help the user track edges.

Aesthetic Criterion 3.2.3 (Nodes Should be Placed Symmetrically)
In all graphic standards, the display of symmetries is found to be desirable (Di Battista et al. [20]). A uniform distribution of nodes is proposed. Also, symmetrical information should be represented in a symmetrical way.

Aesthetic Criterion 3.2.4 (Edge Length)
Edges in a graph should be short (Tamassia [57]), but not too short (Coleman and Parker [14]). This corresponds with the node distance above. If edges get too long, they might be hard to follow. On the other hand, if an edge is too short, it might not allow enough space for labels or arrowheads in directed graphs. Furthermore, Di Battista et al. [20] propose that edge lengths should be consistent in a graph drawing. This leads to a clear pattern, which in turn makes the graph easier to read.

Aesthetic Criterion 3.2.5 (Edges Should not Intersect Each Other)
The intersection of lines mentioned above is also found in graph layout (Di Battista et al. [20]). Aside from planar graphs, intersections are frequent in graph drawing. If they can be avoided, one should do so. However, the graph with the least crossings is not always the most intuitive (see Figure 3.1).

Aesthetic Criterion 3.2.6 (Avoid Bends in Edges)
Tamassia [57] comes to the conclusion that edge bends should be avoided. Straight edges are easier to follow for the human eye. Edge bends are an interruption of the reading direction and distract the eye while tracking the edge.

Aesthetic Criterion 3.2.7 (Label Placement)
The placement of a label has to satisfy the following criteria (Imhof [32], Kakoulis and Tollis [33], Yoeli [63]): It should under no circumstances overlap with any other graphical component, except with its associated edge. The placement of the label has to ensure that it is identified with just one edge in the drawing. Therefore, it must be very close to its associated edge. Finally, each label must be placed at the best possible position among all acceptable positions.

3.3. Aesthetic Criteria for Class Diagram Creation

Class diagrams have been subject to research on aesthetics. Purchase et al. [55] validated aesthetic criteria, taking some criteria from graph drawing aesthetics. The following criteria were tested in their experiments :

Aesthetic Criterion 3.3.1 (Draw Diagrams With Fewer Line Crossings)
In an experiment, test subjects preferred class diagrams with a low number of line crossings.

Aesthetic Criterion 3.3.2 (Draw Diagrams With Fewer Line Bends)
The same subjects found diagrams easier to read if there were less line bends.

Aesthetic Criterion 3.3.3 (Prefer Horizontal Text)
Diagrams with only horizontal labels were rated better than ones with both horizontal and vertical text.

Aesthetic Criterion 3.3.4 (Use Joined Inheritance Lines)
The use of joined inheritance lines (as the UML notation specifies) was preferred to the usage of separate lines (as it would be done in graph drawing).

Aesthetic Criterion 3.3.5 (Prefer a Narrow Layout Over a Wide Layout)
The test subjects preferred a narrow layout, an aesthetic criterion originally proposed by Coleman and Parker [14].

Aesthetic Criterion 3.3.6 (Draw Orthogonal Diagrams)
Test subjects preferred orthogonal diagrams over diagrams that were non-orthogonal.

3.4. Aesthetic Criteria for Statechart Creation

As mentioned earlier, there are only a few aesthetic criteria in literature specifically related to Statecharts. The UML style guidelines proposed by Ambler [4] touch the subject of Statecharts—the rules applying to the aesthetics of a Statechart are listed here.

Aesthetic Criterion 3.4.1 (Minimum Distance Between States and Transitions.)
Keep a reasonable minimum distance between states and transitions. It can be hard to follow transitions if there are many lines in close vicinity. This applies to other transitions as well as to states. Especially bad is the intersection of transitions with states.

Aesthetic Criterion 3.4.2 (Placement of the Initial State)
The initial state should be placed at the top left of the Statechart. Placing the initial state in the upper left corner reflects the way that people in western cultures read. Alternatively, the placement in the center at the top of the Statechart is acceptable.

Aesthetic Criterion 3.4.3 (Placement of the Final State)
The final state should be placed at the bottom right of the Statechart. This also reflects the left–to–right, top–to–bottom approach to reading.

Aesthetic Criterion 3.4.4 (Place Labels Near Source States)
A visual closeness to the state helps to identify the labels with their corresponding source state.

Aesthetic Criterion 3.4.5 (Place Labels on the Basis of Transition Direction)
Place Transition Labels on the Basis of Transition Direction. As a Statechart often is full of transitions, a placement heuristic for labels can help to identify labels with their transitions. Ambler proposes the following:
Place transition labels

- above transitions that go from left to right
- below transitions that go from right to left
- right of transitions that go down
- left of transitions that go up

Note that this consistently places labels to the left of a transition, relative to its orientation.

3.5. Selection of Aesthetic Criteria

It can be seen that some aesthetic criteria apply to all kinds of diagrams. These include the use of straight lines, an orthogonal layout, and the reduction of crossing lines.

Application to Statecharts Not all aesthetic criteria can be applied to Statecharts. Some are not applicable because they are too specifically designed for a type of diagram, such as the usage of joined inheritance lines (Criterion 3.3.4). Others would make sense for Statechart design, but are not used in Statechart development. This is the case with Criterion 3.1.2, which proposes a “jump” representation of crossing lines.

Some of the aforementioned aesthetic criteria are applicable to Statecharts, but will not be considered in this work. Part of this omission is caused by the data basis, which does not contain suitable data for certain aesthetics, such as symmetry or color. Another cause is the focus of this work, which concentrates on various layout aspects. This led to the exclusion of almost all label related aesthetic criteria.

For the rest of the criteria, an appliance to Statecharts seems feasible. Edges and lines are translated into transitions, nodes and symbols into states where appropriate. This work will concentrate on the basic Statechart construction elements and related criteria: States and transitions.

Criteria that Concern States States are the building blocks of a Statechart. The first thing that comes to mind is the placement of states. In the criteria mentioned, the placement of initial and final state is mentioned specifically in 3.4.2 and 3.4.3. This is also a general criterion for the creation of diagrams (3.1.10). The more states are placed, the more area is needed to display the Statechart. Criteria 3.1.9 and 3.2.1 state that a Statechart should not be overly crowded with states. However, Criterion 3.3.5 declares that users prefer narrow Statecharts. This could also indicate a preference for sequential placement of states. Indirectly, this is supported by the preference for orthogonal state placement (3.2.2, 3.3.6). Regardless of the Statechart's shape, one has to keep a minimum distance between the elements of a Statechart. This is the intention of Criteria 3.4.1, 3.1.11, 3.1.9 and 3.2.1.

Criteria that Concern Transitions If states are the building blocks of a Statechart, transitions are the cement that hold it. Various aesthetic criteria concern themselves with aspects of transitions. Transition length is mentioned in Criterion 3.2.4. An indirect relation can be seen with the distance between states, Criteria 3.1.9 and 3.2.1. The distance influences the transition length. Although transitions can be drawn with arbitrary length, the usual approach is to connect two states with the fewest bends possible. This also implicates a short transition between them. The bends in a transition are subject of another criterion, mentioned for almost every diagram type (see Criteria 3.1.3, 3.2.6, and 3.3.2). The change in transition direction is also mentioned in many criteria. However, the change of direction *between* two transitions is also a bend that might be hard to follow. The number of transitions correlates with the risk of transition intersection. This is often considered detrimental to the understanding of a Statechart, as mentioned in Criteria 3.1.1, 3.2.5, 3.3.1, and 3.2.7.

Measurement of Aesthetic Criteria To express the extend of the selected criteria in a given Statechart, one has to define a formal way of measuring them. This will be done in the following section, where such measurements, called *metrics*, will be discussed.

4. Defining Metrics for Statechart Properties and the Modeling Process

"You can't control what you can't measure."

–Tom DeMarco [19]

As stated before, a Statechart has to be easily readable and interchangeable between developers. The most important property for this is the Statechart layout. To measure the aesthetic quality of a Statechart, some kind of measurement is needed to quantify different aspects of that chart's layout.

If all relevant aspects can be measured and presented to the Statechart's designer, she or he could optimize the drawing of a Statechart. Going further, the tool used to create the Statecharts could not only provide this analysis, but also alter the Statecharts accordingly. The most beneficial aesthetic aspects have to be identified. Therefore, a selection of aesthetic criteria has been taken from the literature and adapted to Statecharts in the previous section. The ranking of these aspects has to be evaluated on the basis of the data gained from user ratings of Statecharts. This will be further discussed in Section 7.

With the influential aspects known, a defined way of measuring them could be specified, a formal metric. This metric is a function that takes a Statechart as input and returns a numerical evaluation of that Statechart, considering the aesthetic criteria under observation. If such metrics could be found, it would be feasible to adapt them to other visual languages, such as UML activity charts. This could be done by varying the parameters of the metrics to make them applicable to other diagram types.

In addition to layout metrics, there are metrics concerning Statechart structure. They have been researched by Appelgren and Hvannberg [6] as well as Cruz-Lemus et al. [17] and Genero et al. [26]. No details will be addressed here, as this thesis focuses on layout metrics. However, it is possible that beside layout metrics, a tool could incorporate the use of structural metrics. This is a topic to be examined in further research. The following section gives an overview of various metrics concerning layout.

4.1. Layout Metrics

The following metrics can be found in the literature, regarding graph layout difference (Branke [9], Bridgeman and Tamassia [10]). The metrics presented are applicable to Statecharts in general, as they concern the layout of graphs. However, they describe the change between two versions of the same graph. For this reason they are not applicable for the Statecharts used in this work.

- Absolute vertex positions: The total distance each node has moved.
- Orthogonal ordering / relative vertex positions: The distance a node has moved in relation to its neighbors.
- Proximity: Use proximity information to measure the number of neighbor changes for each node.
- Edge routing: Edges are used as a distance measure. The change in edge routing represents a change in distance.

There has been research in the field of validating graph drawing and also *UML* aesthetics with metrics, mainly by Purchase [50, 51]. She proposes seven different metrics for aesthetic criteria:

- An edge crossing metric $\aleph_c$: The edge crossings aesthetic metric for a graph is based on the number of edge crossings in that graph, where an edge crossing is defined as a point on the plane where two edges intersect. When calculating the number of crossings, only pairwise edge intersections are considered. In the case where $k \geq 2$ edges cross at a single point, it is treated as though $\frac{1}{2}k(k-1)$ individual pairwise crossings have occurred.
- An edge bends metric $\aleph_b$: The aesthetic metric for bends in a graph is based on the number of bent edges in the drawing; that is, internal points of an edge whose coordinates do not lie on the straight line between the two end nodes of the edge.
- A symmetry metric $\aleph_s$: Purchase proposes a computational aesthetic metric ($\aleph_s$), which takes into account assumptions about the human perception of symmetry. The proposed algorithm returns a numerical value between 0 and 1, which represents the extend to which the drawing can be considered symmetric.
- A minimum angle metric $\aleph_m$: Purchase bases the minimum angle aesthetic metric for a graph on the average deviation of adjacent incident edge angles from the ideal minimum angle.
- Orthogonality metrics $\aleph_{ne}$ and $\aleph_{eo}$: The concept of orthogonality in a graph drawing is separated into two independent measurements:
  - the extent to which edges and edge segments follow the lines of an imaginary Cartesian grid (*edge orthogonality*, $\aleph_{eo}$),

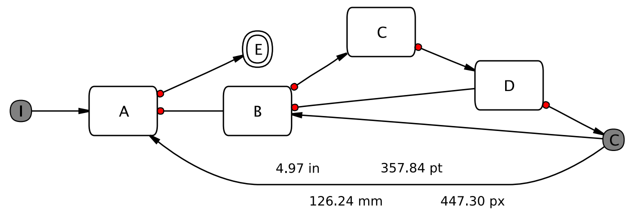


Figure 4.1.: A Statechart with measures added in different size units. The Statechart is scaled down to half its original size

  - the extent to which nodes and bend points make maximal use of the grid points in an imaginary Cartesian grid (*node orthogonality*, $\aleph_{no}$).

- An upward flow metric $\aleph_f$: This metric determines the proportion of edge segments of a directed graph, which have a consistent direction. The desired direction is described to be usually upwards or downwards along the vertical axis.

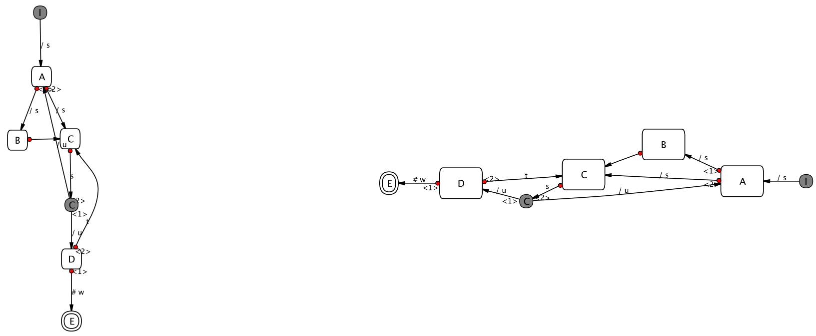
The cited author presents these metrics in detail, but makes several restrictions in the definition. The metrics are designed to work on graphs with at most one edge between any two nodes, which is something not commonly found in Statecharts. Furthermore, the different metrics are not set in relation to each other, giving seven independent measurements for the graph's aesthetic criteria instead of one overall measurement.

The consistency of the measurement used was a problem. Several tools had to be utilized to measure distances, angles, etc. There are different measurements used in computer graphics. One of the most widely used measures is the *point*. However, at least three different *point* definitions are known: The french *Didot's point*, the *traditional American point*, and the *desk-top publishing (dtp) point*. The difference stems from the different definition of the unit *foot* in various countries. Not all tools supported the unit *dtp point*, so the unit *pixel* (px) was used, as a dtp point is equivalent to 1.25 px in the used tools. (A dtp point is 1/72 of an inch or 0.353 mm, whereas 1 pixel equals 1/90 of an inch or 0.2822 mm in all tools used. See Figure 4.1 for a Statechart with a transition that is measured in all four units.)

$$\frac{1}{72} \text{ inch} = 0.353 \text{ mm} = 1 \textit{ dtp} \text{ point} = 1.25\text{px}$$

The unit pixel is usually a relative measurement, depending on the resolution of a picture and the viewing device. However, the used unit pixels is a so called *user unit* and fixed to 90 pixels per inch.

After evaluating the metrics found in the literature, some seemed applicable for Statechart aesthetics, such as the number of edge bends. Others were specific to diagrams other than Statecharts. The various metric definitions from the literature



(a) A Statechart with a width to height ratio of 0.28

(b) A Statechart with a width to height ratio of 5.47

Figure 4.2.: Two Statecharts that differ in width to height ratio

inspire the following ten metrics for Statechart layout, based on the aesthetic criteria collected in Chapter 3:

Layout Metric 1 (Transition Length)
The transition length is thought to have an influence on the user rating of a Statechart. Therefore, the following metric *TRL* is proposed:

$$\text{TRL} = \frac{1}{n} \sum_{i=1}^{n} |\text{transition}_i|$$

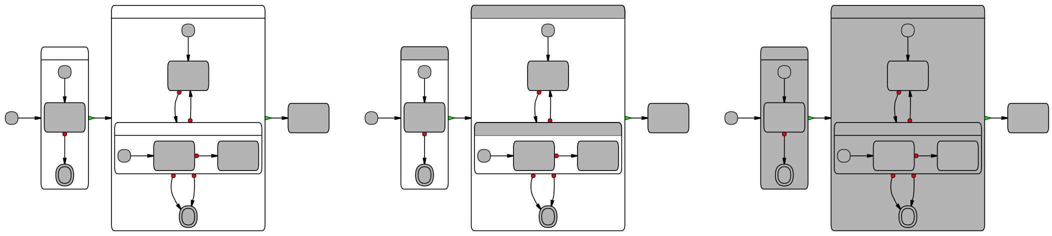
with n being the total number of transitions in the given Statechart and $|\text{transition}_i|$ being the length of transition i. This metric measures the average transition length for a given Statechart in px.

Layout Metric 2 (Width to Height Ratio)
Aesthetic criterion 3.3.5 states that users prefer narrower diagram layouts. Two possible layouts come to mind: A Statechart that has a very low width to height ratio, and one that has a very high ratio. Therefore, a metric *WHR* is devised that measures the ratio between width and height. See Figure 4.2 for two Statecharts depicting the difference between a low and a high ratio. The metric is defined as:

$$\text{WHR} = \frac{\text{width of Statechart}}{\text{height of Statechart}}$$

Layout Metric 3 (Usage of Available Space)
The number of states and the space left between them inspired this metric. The aesthetic criteria suggest that a reasonable amount of “white space” is beneficial for the understanding of a Statechart. The amount of used space *SU* is measured by the following metric:

$$\text{SU} = \frac{\text{amount of space taken up by Statechart elements}}{\text{area of the Statechart}}$$



(a) Space usage: Only Simple States (SU_S)

(b) Space usage: Simple States and State Attribute Space (SU_A)

(c) Space usage: Only Topmost States (SU_T)

Figure 4.3.: Three figures used to illustrate the "usage of available space" metric. The shaded areas of the Statecharts depict the measured areas.

As it is unknown which elements of a Statechart are perceived as "white space", this metric was split up in three variants SU_S, SU_A, and SU_T, differing by the types of elements that were measured. $\mathrm{SU_S}$ measures only the simple states of a diagram, $\mathrm{SU_A}$ takes all simple states and adds the state attribute space of hierarchical states. The last metric, $\mathrm{SU_T}$, measures only the topmost states, considering them opaque. The intention is to let the experimental results decide which one gives the best fit. See Figure 4.3 for a visualization of the different spaces that are considered. The particularities of the variants are discussed in Section 6.2.3.

Layout Metric 4 (Placement of the Initial and Final State)

The establishment of a reading direction from left to right, top to bottom has been mentioned twice in Chapter 3. Explicitly mentioned were the initial and final state of a Statechart in Criteria 3.4.2 and 3.4.3. This metric measures the compliance of the state placement to these aesthetic criteria. The upper left corner of the Statechart is defined as 0% width and height. Consequentially, the lower right corner is identified with 100% Statechart width and height. The aesthetic criterion mentions an equivalence of left to right and top to bottom reading direction. Therefore, this metric rewards both positions, top and left of the chart with the same rating.

The following two metrics have been devised:

$$\mathrm{P_I} = 100 - \frac{\text{hor. position of initial state in }\% + \text{vert. position of initial state in }\%}{2}$$

$$\mathrm{P_F} = \frac{\text{hor. position of final state in }\% + \text{vert. position of final state in }\%}{2}$$

P_I measures the placement quality of the initial state, P_F does the same for the final state.

Layout Metric 5 (Distance to Nearest Node Borders)

Criteria 3.2.1 and 3.1.9 state that there should be a minimum and maximum distance between states. This metric tries to represent the crowdedness of a Statechart by

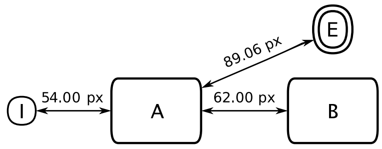


Figure 4.4.: A section of a Statechart that illustrates the nearest node borders of state A.

measuring the distance between Statechart nodes. The specification *node* is necessary, as there are elements in the Statecharts under observation, that are not a state but might be perceived as one. This metric measures the minimum distance between each state in the Statechart and its nearest neighbor (see Figure 4.4). Again, several variants of this metric are proposed. They only differ in the treatment of the data. NB_{MIN} selects the minimum distance found in a Statechart. NB_{MAX} selects the maximum found when distances are calculated. NB_{AVG} is the average of all distances between states and their nearest neighbor.

$$\mathrm{NB_{MIN}} = \min_{i=1,\dots,n} \{d(s_i)\}$$

$$\mathrm{NB_{MAX}} = \max_{i=1,\dots,n} \{d(s_i)\}$$

$$\mathrm{NB_{AVG}} = \frac{1}{n} \sum_{i=1}^{n} \{d(s_i)\}$$

with $d(s_i)$ being the distance from state s_i to its nearest neighbor in px.

Layout Metric 6 (Distance of States to Straight Lines)

The preference for orthogonal and narrow Statecharts could be an indicator for another preference: The placement of states in a manner that resembles a sequential progression in the Statechart, e.g. a straight line.

The adherence to a placement on a straight line is measured (in px) by the distance of state centers to an imaginary straight line placed in the Statechart under observation. The position of the state centers and the straight line is measured in absolute coordinates (i.e. pixel units). The line was placed horizontal or vertical, according to the layout of the given Statechart. The straight line placement was subject to much discussion and was finally decided to be measured in three different variants. The first variant, D_I, places the line through the initial state:

$$\mathrm{D_I} = \frac{1}{n} \sum_{i=1}^{n} d(\text{initial line}, \text{statecenter}_i)$$

The second variant, D_M, places the line through the arithmetic middle of the Statechart:

$$\mathrm{D_M} = \frac{1}{n} \sum_{i=1}^{n} d(\text{middle line}, \text{statecenter}_i)$$

The last variant, called D_N, calculates a *normal line*, which is a straight line—horizontal or vertical—through the calculated mean of all state centers. This rewards Statecharts that are drawn in a very linear way, even if the states are not placed on a line in the horizontal or vertical center of the Statechart.

$$\mathrm{D_N} = \frac{1}{n}\sum_{i=1}^{n} d(\text{normal line}, \text{statecenter}_i)$$

with d being a suitable distance metric, here the minimum difference between either the horizontal or vertical coordinates, and n being the number of states.

However, Statecharts of higher complexity posed another question: How are hierarchical states handled? Is the center of a hierarchical state counted when calculating a normal line? Should every hierarchical substate be treated as a Statechart of its own? All of these possibilities were considered and the $\mathrm{D_N}$ metric was split into three. Now, metric D_{NA} accounts for all state centers, simple or hierarchical. The D_{NS} metric only takes simple states into account, as hierarchical states are containers for simple states and the offset of their state center from a straight line might not be perceived as detrimental to the linearity of a Statechart.

The last metric, D_{NR}, acts exactly like $\mathrm{D_{NS}}$. The only difference is that the metric calculates the distance to a normal line in each hierarchical state recursively, as if the hierarchical state was a simple complexity Statechart. The results for each substate are then summed up and divided by the number of substates encountered. The original Statechart is treated as the first hierarchical state.

Layout Metric 7 (Number of States and Hierarchy Levels)
This is very straightforward. The number of simple and hierarchical states is counted for each complexity level.

$$\mathrm{N_S} = \mathrm{N_{SS}} + \mathrm{N_{HS}}$$

$$\mathrm{N_{SS}} = \text{number of simple states}$$

$$\mathrm{N_{HS}} = \text{number of hierarchical states}$$

Layout Metric 8 (Intersection of Components)
Again, this is a counting metric. The number of intersections is recorded for various components, i.e. transitions, states, and labels. These were the intersection faults that occurred in the Statecharts used. The following metrics count the number for each category:

$$\mathrm{IF_{TN}} = \text{number of transition—node intersection faults}$$

$$\mathrm{IF_{TT}} = \text{number of transition—transition intersection faults}$$

$$\mathrm{IF_{TL}} = \text{number of transition—label intersection faults}$$

$$\mathrm{IF_{LL}} = \text{number of label—label intersection faults}$$

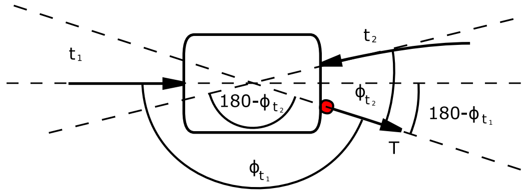


Figure 4.5.: An example of the flow metric: The angle ϕ between outgoing transition T and incoming transitions t_i is measured. The directional change is 180°- ϕ_{ti}. Only the minimum of directional change is recorded for outgoing transition T.

$$\mathrm{IF} = \mathrm{IF}_{\mathrm{TN}} + \mathrm{IF}_{\mathrm{TT}} + \mathrm{IF}_{\mathrm{TL}} + \mathrm{IF}_{\mathrm{LL}}$$

Additionally, there were intersections between labels and states. However, these were too infrequent to be considered significant enough for a metric.

Layout Metric 9 (Directional Statechart Flow)
The aesthetic criterion regarding edge bends (3.2.6) states that the eye is interrupted each time the user has to follow changes in transition direction. This metric translates this to the disruption caused by the directional change between two transitions when entering and leaving a state. This is done because the comprehension of a Statechart could be related to the "flow" of states that are visited when tracing a series of events.

Therefore, the following metric *FL* is conceived, representing the average directional change of transitions in all state of a given Statechart:

$$\mathrm{FL} = \frac{1}{n}\sum_{i=1}^{n} \min_j\{(180 - \phi(T_i, t_{ij}))\}$$

with $\phi(T_i, t_{ij})$ being the angle between outgoing transition T_i and incoming transition t_{ij}. The outgoing and incoming transitions T_i and t_{ij} always connect to the same state. An example is shown in Figure 4.5.

Layout Metric 10 (Number of Transitions and Transition Bends)
The metrics presented here count the number of bends in the Statechart's transitions. The used Statecharts contained only three types of transitions. Two of them had countable transition bends. These were the straight transitions, measured with metric N_{ST}, which do not bend, and polyline transitions, counted with metric N_{PT}. The polyline transitions in the experiment all had two bends. The last category were transitions consisting of splines. For these, it was not possible to count the bends. The transitions of the latter category were counted as "more than two bends", the number of these transitions was counted with the metric N_{SPT}. To get a complementary metric for the number of states metric, all transitions were summed up in a separate metric called N_T.

This following metrics were used:

$$\mathrm{N_T} = \mathrm{N_{ST}} + \mathrm{N_{PT}} + \mathrm{N_{SPT}}$$

$$\mathrm{N_{ST}} = \text{number of straight transitions}$$

$$\mathrm{N_{PT}} = \text{number of polyline transitions}$$

$$\mathrm{N_{SPT}} = \text{number of spline transitions}$$

Table 4.1 contains the complete selected metrics, their variations, and their associated abbreviations.

This concludes the metrics for Statechart layout aesthetics. The following will describe metrics devised for the modeling process of Statecharts. The user actions are considered and metrics will be generated to compare the editors against each other.

4.2. Modeling Metrics

These metrics were not inspired by aesthetic criteria and they are not used to find an optimal layout. Modeling metrics are useful to gain insights into the influences of different Statechart design approaches on the user. The metrics are designed to measure editing aspects of the three tools mentioned in Chapter 5. Therefore, errors and actions of the test subjects from the experiment are analyzed.

The metrics reviewed here are divided into two different categories: The first category, consisting of Modeling Metrics 1 to 3, are counting metrics, like the *number of states* metric (Layout Metric 7) above. Metrics belonging to the second category are derived from the metrics in category one. They combine the generated data to gain insight into modeling processes. For example, the effectiveness of an editor is given by the ratio of productive actions to total actions. If the key-centered approach used in the KIEL-KIT editor is more effective than the mouse-centered one, future modeling tools could incorporate a more key-centered interface.

The metrics from the first category are presented in the following:

Modeling Metric 1 (User Input Actions)
This metric counts the number of user actions in four categories:

- number of keystrokes,
- number of key macros[1] used,
- number of mouse clicks, and
- number of mouse drags[2].

[1]More than one key pressed at a time to access special functions, such as copy and paste, undo, and macros of the structure-based editor.
[2]Hold down the mouse button and drag the mouse, then release the button.

Table 4.1.: Reference chart for metric abbreviations

Metric Abbreviation	Metric Definition
TRL	Average transition length
log.WHR	Logarithmized width to height ratio of the Statechart
SU_S	Usage of available space, simple states only
SU_T	Usage of available space, Topmost States only
SU_A	Usage of available space, simple states plus state Attribute space
P_I	Placement of initial state
P_F	Placement of final state
NB_{AVG}	Average distance to nearest node border
NB_{MIN}	Minimum distance to nearest node border
NB_{MAX}	Maximum distance to nearest node border
D_I	Distance to a straight line through the initial state
D_M	Distance to a straight line through the middle of the Statechart
D_{NA}	Distance to a straight line through the arithmetic middle of all states (either horizontal or vertical)
D_{NS}	Distance to a straight line through the arithmetic middle of all simple states (either horizontal or vertical)
D_{NR}	Distance to a straight line through the arithmetic middle of all states (either horizontal or vertical), calculated recursive for each hierarchical state
N_S	Total number of states
N_{SS}	Number of simple states
N_{HS}	Number of hierarchical states
IF	Total number of intersection faults
IF_{TN}	Intersection faults, transition—node
IF_{TT}	Intersection faults, transition—transition
IF_{TL}	Intersection faults, transition—label
IF_{LL}	Intersection faults, label—label
FL	Directional Statechart flow
N_T	Total number of transitions
N_{ST}	Number of straight transitions
N_{PT}	Number of polyline transitions
N_{SPT}	Number of spline transitions

Modeling Metric 2 (Errors Made)
The errors were divided into several categories as well:

- errors that require action in the making and action in correcting (for example the insertion of a wrong Statechart element): *normal errors*;
- errors that do not require action in the making, but require action to correct (for example the insertion of a wrong kind of state and a subsequent change to the correct state type via the state's properties): *delayed errors*;
- errors that have no consequences (such as stray mouse clicks): *unnecessary errors*;

The first three items were recorded separately. Additionally, the number of actions done for each item was recorded. Not possible are errors that do not require action to make and take no action to correct.

Modeling Metric 3 (Number of Actions Done to Improve the Statechart Visually)
Actions done to improve the Statechart visually will be called *nicefy* actions from now on. These include all movement of Statechart elements to make room for another state or to ensure readability of labels. However, actions done to simply improve the visual appeal of the Statechart are also counted.

All metrics are compared for the three editors. Further metrics can be devised from the metrics above, such as the ratio between the number of productive actions and the number of total actions.

Modeling Metric 4 (Editor Efficiency)
The efficiency of the editor can be described as the ratio between benefit and cost, i.e. productive actions and total number of actions.

$$\text{efficiency} = \frac{\text{number of productive actions}}{\text{number of total actions}}$$

A high percentage indicates that only few actions were performed for unproductive tasks. This correlates to the inefficiency metrics below, which divide the unproductive part of the performed actions into subclasses.

Modeling Metric 5 (Minimum Number of Actions)
The minimum number of actions needed to create a specified Statechart. This is related to the *intuitiveness* of the editor, measured by the number of actions needed compared to the minimum possible number.

Modeling Metric 6 (Editor Inefficiency I)
The ratio between error actions and total actions is considered in this metric, called *inefficiency I.*

$$\text{inefficiency I} = \frac{\text{number of error actions}}{\text{number of total actions}}$$

This measure indicates how much the number of error actions impacts the total number of editing actions.

Modeling Metric 7 (Editor Inefficiency II)
The relation between unnecessary actions and total actions is considered in this metric, called *inefficiency II.*

$$\text{inefficiency II} = \frac{\text{number of unnecessary actions}}{\text{number of total actions}}$$

This metric reurns the amount of total time that is spent without changing the Statechart layout or structure of a Statechart, but trying to do so. High values in this metric indicate faults in the user guidance of an editor, because the user is trying to do something, but cannot execute her or his intention.

Modeling Metric 8 (Editor Inefficiency III)
The relation between actions to improve the layout (called *nicefy* actions) and total actions is considered in this metric, called *inefficiency III.*

$$\text{inefficiency III} = \frac{\text{number of nicefy actions}}{\text{number of total actions}}$$

Originally, the nicefy actions fell into the category "unnecessary actions", but they were separated to investigate the reasons for the time spent in the WYSIWYG editor. How much time is spent on improving the Statechart layout? Only values for the WYSIWYG editor are calculated, as this is not really comparable between editors. The other two editors arrange the Statechart elements on their own, preventing a layout alteration by the user. However, the concept of nicefy actions could be translated to the KIEL-KIT editor as the users might choose to improve their code layout. This was not investigated further, because these actions were infrequent and some code layout rules (such as *one statement per line*) were enforced by the editor. Although not comparable between editors, it might be interesting to know what partition of the actions performed in the WYSIWYG editor is used for nicefy actions.

Modeling Metric 9 (Error Costs)
If an error is made, how much of a nuisance is the correction of this error? This concerns the number of error actions per error, and in consequence the amount of time spent on errors. The metric gives an overview how much an error "costs".

Before the metrics of the latter category can be implemented, a conversion factor between the different input actions had to be found. This factor would allow keystrokes to be expressed as a fraction of mouse clicks. This would lead to a reduction of complexity and time, as the different actions could be expressed as abstract actions of uniform type. This could be a measure for the amount of user interaction needed to create a Statechart.

The process of data acquisition will be described in Chapter 6. The conversion into the abstract input actions is explained in Chapter 8.

4.3. Application of the Defined Metrics

Definition 4.3.1 (User Rating)
The user rating *is a measure of the Statechart performance by the user. It includes a* subjective *and an* objective *rating. The Statechart is rated subjectively by the user's liking of this chart and objectively by the time the user needs to understand it.*

In the context of this work, the subjective user rating is associated with the dependent variable awarded points*. This indicates the points that were awarded by users to a specific Statechart in comparison to other Statecharts. The objective user rating is associated with the dependent variable* needed time*, in seconds, indicating the time needed to understand a given Statechart.*

With the collected aesthetic criteria transformed into metrics, it still has to be decided which aesthetic criteria have the most influence on the user rating. To find out which metric is most important and how to combine them, the following Chapters discuss the application of the above specified metric to Statecharts used in an experiment and the correlation of the gained data with user ratings.

5. Previous Experimental Evaluation of Statechart Layout

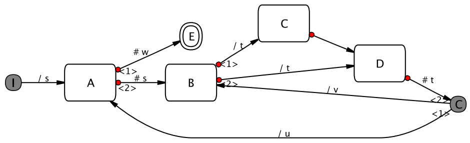
The data describing user preference in this work was collected by an experiment, conducted in late 2006 and early 2007 (Prochnow and von Hanxleden [49]). The experiment was designed to investigate two questions proposed by the authors of the experiment:

1. "Do the macro-based and text-based editing techniques make the Statechart construction process easier and faster than the conventional WYSIWYG method?"
2. "Are the resulting Statecharts more readable and comprehensible?"

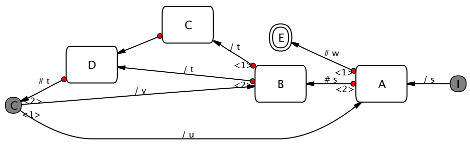
The mentioned Statecharts were laid out according to an algorithm contained in the KIEL framework. The resulting layout was compared with four other layouts to answer the second question proposed by the authors of the experiment. Figure 5.1 shows an example Statechart laid out according to the favored layout (i.e. ADL) and four layouts it is compared with. The layouts used in the experiment were:

- Alternating Dot Layout (ADL): An automatically generated layout, featuring amongst others a clockwise layout, a minimization of back transitions, and a consistent placement of initial and final states (see Figure 5.1a)
- Alternating Dot Layout Backwards (ADBL): The same as ADL, drawn backwards (see Figure 5.1b)
- Alternating Linear Layout (ALL): Another automatically generated layout that lines up all states in a hierarchy level either horizontally or vertically. This layout uses only straight lines for transition routing (see Figure 5.1c)
- Linear Layer Layout (LLL): A manually drawn layout that places states on layers, trying to avoid back transitions (see Figure 5.1e)
- Arbitrary Layout (AL): A layout that is drawn manually without style guidelines (see Figure 5.1d)

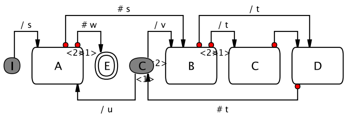
The Statechart layouts were presented in three different complexities: Simple, hierarchical, and parallel. *Simple Statecharts* contain only simple states and no parallelism. *Hierarchical Statecharts* add hierarchical states to the simple complexity. Statecharts of *parallel* complexity add orthogonality to the chart, now containing



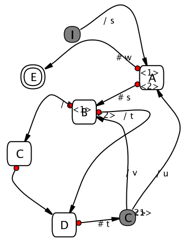
(a) Statechart laid out according to the ADL



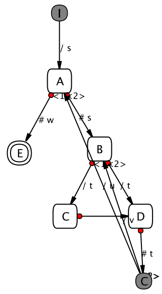
(b) Statechart laid out according to the ADBL



(c) Statechart laid out according to the ALL



(d) Statechart laid out according to the AL



(e) Statechart laid out according to the LLL

Figure 5.1.: A simple complexity Statechart, laid out according to five different layout strategies

simple, hierarchical, and parallel states. Figure 5.2 shows the different complexities for a Statechart laid out according to the ADL.

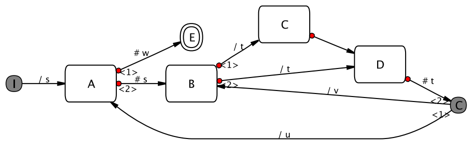
The experiment was divided into two parts. The first part was conducted with 24 students participating in a course on model-based design and distributed real-time systems, having only little knowledge of Statechart formalism and modeling concepts. The second part was conducted with 19 students that completed the course. In the following, the participants of the first experiment will be referred to as *beginners*, the participants of the second experiment as *advanced users*.

In the following, the design of the experiment and the tasks the participants were assigned will be described (Section 5.1). Next will be a brief look at the editors used for the third task (Section 5.2). Finally, the experiment's approach to internal and external validity are described in Section 5.3 and the experiment's results are evaluated in Section 5.4.

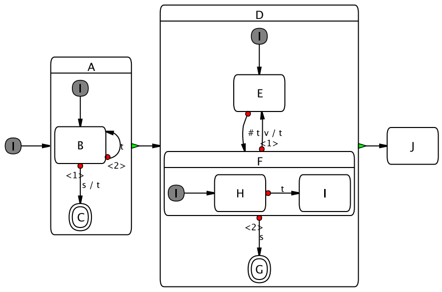
5.1. Experiment Design

The participants were given tasks to complete. In sequential order, they had to complete the following assignments:

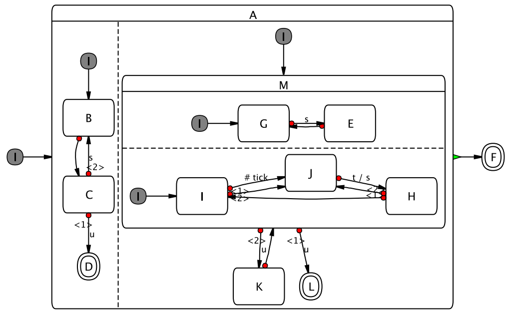
Subjective Layout Rating The experiment subjects were given pairs of Statecharts and had to rate them against each other. The participants were asked to rate according to the readability and comprehensibility of the presented Statecharts. Each participant had to rate 5 Statechart layouts in a series of 30 comparisons, 10 for each complexity level. This provides the subjective user rating *awarded*



(a) Statechart of simple complexity



(b) Statechart of hierarchical complexity



(c) Statechart of parallel complexity

Figure 5.2.: Three Statecharts of varying complexity, laid out according to the Alternating Dot Layout (ADL)

points, which will be used as a dependent variable for the analysis of aesthetic criteria in Chapter 7.

Objective Layout Rating This assignment tested the understandability of Statecharts. The experiment participants had to analyze the Statecharts they had rated before. The time they needed to answer questions about the activation sequence of the Statechart correctly was recorded. This provides the objective user rating *needed time*, which will be used as the second dependent variable in Chapter 7. In Chapter 8, the time needed will be used as a comparative variable for the number of user actions.

Modeling of a given Statechart The experiment participants had to create and modify a Statechart according to given specifications. The task was assigned three times with different editors (see next section) to analyze the different modeling techniques.

Two of the three parts, the objective rating and the modeling, were controlled by the experiment supervisor and solutions were rejected in case of incorrectness. After completion of the tasks, the subjects were given a questionnaire to record their comments on the experiment. The experiment was performed in sessions of one to two hours with one participant at a time. To ensure traceability of the extracted data, the complete sessions were recorded on videotape with the written consent of the participants.

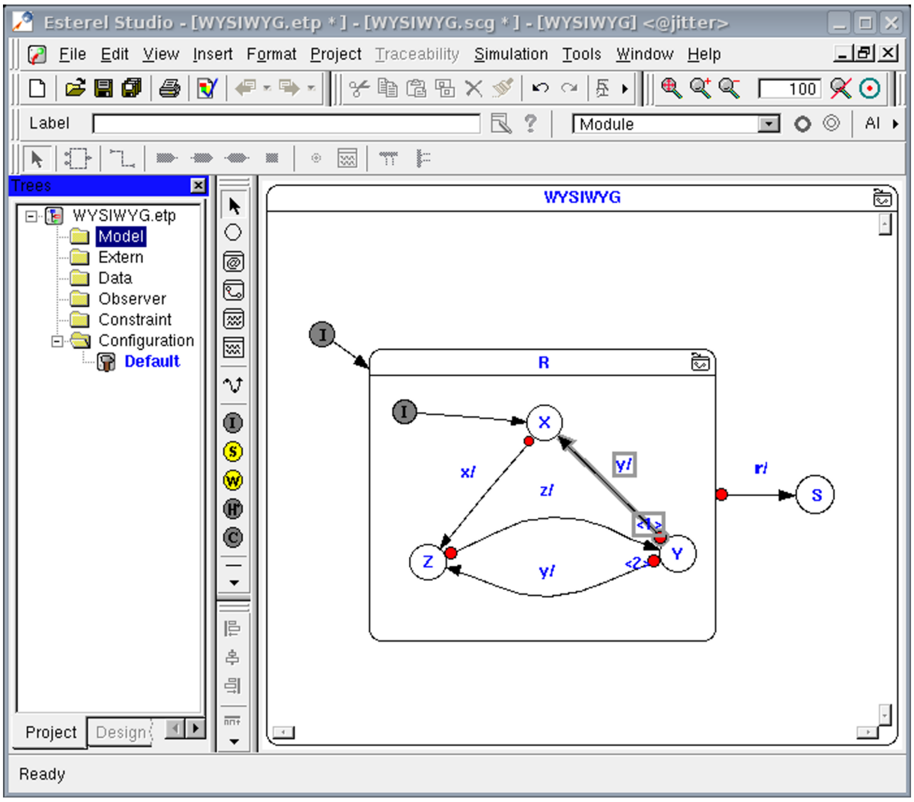


Figure 5.3.: A screenshot that shows the WYSIWYG editor of *Esterel Studio*

5.2. Editors Used

The WYSIWYG Editor The WYSIWYG editor used is an element of the *Esterel Studio* modeling suite (see Figure 5.3 for a screenshot of the user interface). The user is presented with three areas: The workspace, the menu bar, and the tool bar. The WYSIWYG editing paradigm requires the user to spend much time with layout-related activities in addition to the task of constructing the correct underlying Statechart structure. Most elements of the editor are only accessible with the mouse and each structural change in the edited Statechart requires several actions to perform.

Both remaining editors are implemented in the KIEL tool, where they are accessible simultaneously and may be placed side by side. However, the test subjects were presented with reduced functionality and had to use the two editors in sequence, not simultaneously. In normal operation, the user can choose to work with either editor at any time and the tool keeps the other editor synchronized with the changes.

The two editors follow the concept of *structure based editing*, i.e. directly editing the Statechart's structure instead of both, layout and structure at the same time, relieving the developer of the layout actions.

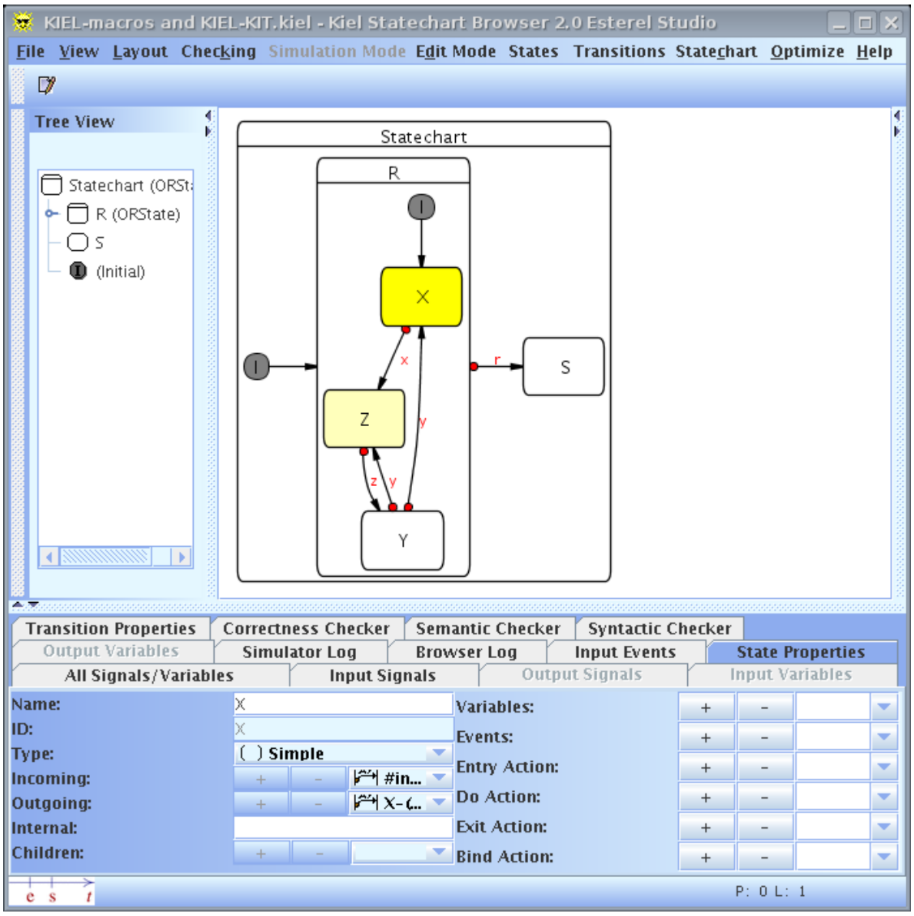


Figure 5.4.: A screenshot that shows the components of the KIEL Tool that are used by the KIEL-macros editor

The KIEL-macros Editor The KIEL-macros editor (see Figure 5.4) features a workspace, which takes up the center of the program window. The users were given a reference sheet with the keyboard macros and were asked to complete the task, if possible, with only these commands. Some tasks required the use of the mouse, for example the labeling of transitions. The editor features an input area for this task, where transition labels, state names, etc. can be assigned to the selected element.

The KIEL-KIT editor The textual editor is located at the right of the graphic area. Every change made here is shown instantly in the workspace, where a Statechart representation of the code is displayed (see Figure 5.5). Aside from basic techniques like *copy and paste* and positioning the cursor with the mouse, all editing was performed with the keyboard only.

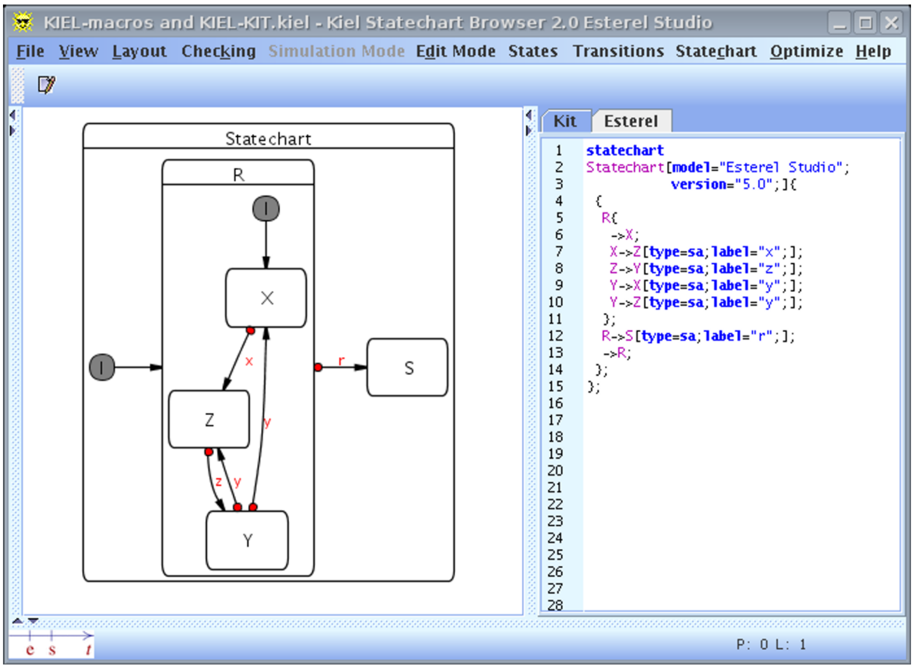


Figure 5.5.: A screenshot that shows the cooperation between the KIEL-KIT editor and the graphic area

5.3. Internal and External Validity of the Experiment

Internal validity refers to the extent to which it can be accurately stated that the independent variable produced the observed effect. In contrast, *external validity* refers to the extent to which results of an experiment can be generalized to and across different persons, settings, and times Christensen [13].

The participants were divided into five groups, which received similar but different Statechart models to ensure the internal validity of the experiment. The variables interfering with the internal validity (modeling experience, motivation, environmental conditions, etc.) were controlled by equalizing them between appropriate groups. This was done by randomized group assignment.

The external validity was considered to be intact, even though the experiment preconditions differ somewhat from real Statechart modeling. Some of the mentioned differences are the usage of inexperienced participants and the limitations of the Statecharts used .

5.4. Results and Collected Data

The experimental results are presented here in a brief form. For an interpretation of the results, see the paper written by Prochnow and von Hanxleden [49]. The correctness of the data was validated by the author of the experiment with statistical methods.

5.4.1. Evaluation of Statechart Layouts

The assessment of the awarded points showed a clear preference for Statecharts laid out according to the ADL, so question 2 can be answered with a “yes”. proposed by the author of the experiment in question . Experiment participants stated that they liked “short and traceable” transitions and that the “element structure has to follow the Statechart meaning”. Translated to the Statechart layouts, this implies that the ALL scored lower than the LLL because of unnecessarily long transitions.

The authors speculate that the better rating for the ADL Statechart is a result of better micro and macro layout, e.g. better label placement and a compact, white space avoiding layout.

5.4.2. Evaluation of Modeling Techniques

The beginners were able to use the WYSIWYG editor without the aid of a reference sheet, whereas the reference sheets for the other two editors were frequently consulted. On average, the novices needed less time to complete their tasks when using the WYSIWYG editor. Regarding the advanced users, participants needed slightly less time using the KIEL-KIT editor. The authors of the experiment suggest that using expert practitioners would increase the difference in time between the WYSIWYG and KIT editors.

Performing modifications on an existing Statechart took less time using either one of the KIEL editors instead of the WYSIWYG editor—this was related to the focus of the editing work in the different editors. As mentioned in Section 5.2, the advantage gained by the WYSIWYG editor through its intuitive usage is counteracted by the time needed to rearrange Statechart elements on the workspace. Users modifying the existing Statechart with the macro-based editor needed the least number of operations. However, performing the operations with the textual editor needed less time . This discrepancy is explained with the frequent consultations of the reference sheet while working with the KIEL-macros editor.

5.4.3. Further Analysis of the Experimental Data

By looking at the experimental results, one can immediately recognize the implicit preference of the experiment subjects, i.e. which Statechart layout was preferred over the others. However, to gain information about the actual criteria the subjects preferred (the explicit preference), further research was essential. The data contained much unused information. To access this information, the experiment’s materials were processed again during this diploma thesis. To quantify the apparent aesthetic criteria, the metrics constructed in Chapter 4 were applied to the experiment’s Statecharts. This process is described in the next chapter. The gained data is then visualized and validated, before it is used in the analysis of aesthetic criteria and the modeling process. Additionally, the subjective and objective user ratings from the exoeriment are set into relation with the measured aesthetic criteria.

6. Analysis of the Experiment's Records

After choosing the aspects of Statechart layout aesthetics to be analyzed, data had to actually be collected from Statecharts. The ratings of the test subjects were also needed. Regarding aesthetic criteria, the awarded points and used time were the response to the change in aesthetic criteria. Looking at the modeling process, the time needed to create a specified Statechart (and then modify it) was of interest, as well as the actions the user took to do this.

6.1. General Remarks

The starting point to collect the data needed was always the material and records from the experiment described in Chapter 5. The awarded points as well as the time needed was already recorded in this experiment. However, the focus of the research done was on the specific layouts, subsuming multiple Statecharts into five categories. Therefore, the data had to be processed and user ratings assigned to the individual Statecharts instead of the layouts. As the experimental data were meticulously recorded, this was easily calculated in a spreadsheet.

Subsequently, a set of aesthetic criteria was chosen and transformed into concrete metrics as described in Chapters 3 and 4. The chosen metrics were then applied to all Statecharts, returning a set of aesthetic properties. As the data acquisition was different for each chosen criterion, this will be addressed in the individual sections.

The editing data were recorded in a different way. Except for the time used to create and modify the specified Statechart, all data were gained from video tapes. The tapes were recorded during the experiment and show the computer screen during the individual participants' part. From this video data, all actions could be counted.

All data collected were either stored directly in a Comma Separated Values (CSV) file or recorded in a spreadsheet and then converted to a CSV file. To ease the creation and handling of linear regression models, all data were then assembled into one data structure for each part of the experiment under observation (layout aesthetics and development methods). These structures were also stored as CSV files. All plots, as well as the statistical analysis in Chapters 7 and 8 were performed with the statistical software *R*, version 2.6.2 [**?**].

Principles of the Data Analysis To minimize the error in the data collection, all data acquisition was done very carefully. However, even the most careful acquisition cannot avoid erroneous data. Therefore, the collected data were validated. Prechelt proposes an outline in six steps for the data analysis of controlled experiments in information technology, which will be reproduced in abbreviated form in the following paragraphs. For a more complete version and more valuable advice on experiment design, see his book on controlled experiments (Prechelt [45]).

As a general principle, the data analysis should preferably be performed with the most basic and demonstrative methods available. This keeps the error rate down as well as helping to find errors made nonetheless. Graphical methods are to be preferred, as the human eye is very good at data analysis on its own.

6.1.1. Data Acquisition and Validation

This subsection describes the handling of problems that may occur in the acquisition of data generated in an experimental context, i.e. the part of data analysis that accounts for the correctness of acquired data.

Assessment of the Acquired Data (Step 0) The acquisition of data has to be done with great accuracy, especially when entering data manually. The acquisition process should be planned ahead with an evaluation scheme in mind, tested first on sample data points before applying it to the complete data.

The acquisition of the data used in this thesis was planned and discussed, individual schemes were devised and tested. If a scheme proved to be inapplicable on the tested data, it was altered to ensure consistency.

Consistency Testing (Step 1) To test the consistency of the data, the following items were considered (as proposed by Prechelt):

- Is the number of data sets for each group correct?
- Are data sets missing?
- Are there negative values where they could not be?
- Are there null values where they could not be?
- Are values higher than they could be? Example: Percentages higher than 100, time values longer than the experiment duration.
- Are there unexpected values in enumeration variables? Example: A misspelled name of a programming language or a misspelled group name.
- Are all constraints between several variables satisfied? Example: Are there less given answers than correct ones?

All these tests check if the data meet conditions that fortify the assumption of correctness. These points have been addressed by automatically testing the collected data with a script and by testing random samples manually.

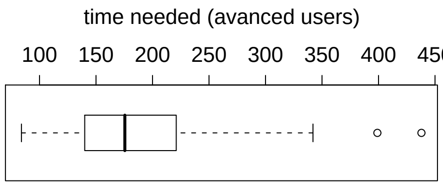


Figure 6.1.: An exemplary boxplot

Definition 6.1.1 (Boxplot)
A boxplot *(also known as a box–and–whisker plot, definition taken from Prechelt [45]), as seen in Figure 6.1, is a one–dimensional plot utilized to display the distribution of data in a given sample. The width of the "box" contains the central fifty percent of the observations, with the thick line indicating the median. Explained intuitively, a quarter of the observations lies to the left of the box, two quarters inside the box (separated by the median) and the final quarter to the right of the box. The length of the box is called the Interquartile Range (IQR). The bars at the end of the dashed lines to the sides of the box indicate the last observations inside 1.5 times the IQR. If an observation lies more than this distance from the box, it is indicated by small circle and called* outlier*.*

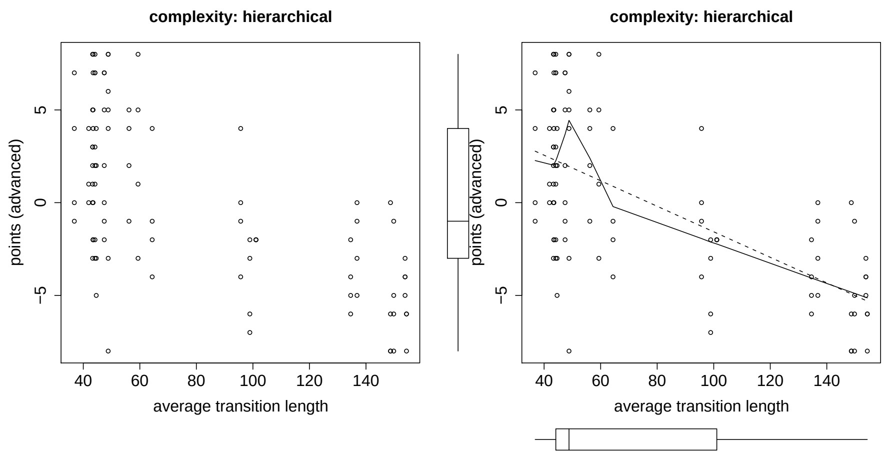
The boxplot is useful in a quick visual comparison of different sets of data, regarding the dispersion (spread) and skewness of their distribution.

Definition 6.1.2 (Scatterplot)
A scatterplot *is a two–dimensional point plot in Carthesian coordinates for two variables of a set of data (See Figure 6.2, examples created with the* R *statistical software, package* `car` *[23]). The horizontal position of a data point is determined by one variable, the vertical position by the other. The plot can be augmented by various regression lines (linear regression, Locally Weighted Scatterplot Smoothing (LOWESS), etc.) to show linear or nonlinear relations between the variables. Another variant used in this work also displays boxplots next to the axes.*

Plausibility Testing (Step 2) The testing of plausible data attributes to find data that seem unlikely is called *plausibility testing*. Data that seem implausible is sometimes correct but often erroneous.

These plausibility test were done (as proposed by Prechelt):

- Looking at a single variable:
  - Are there only a few unusual high / low values? Tools: One-dimensional plot, boxplot.
  - Are there more than a few unusual high / low values? Tools: Histograms and density plots.



(a) A simple scatterplot

(b) A scatterplot with regression lines and boxplots

Figure 6.2.: Two exemplary scatterplots that show different levels of detail

    – Is there a single value that occurs often? Tools: Histograms, density plots and one-dimensional plots.

- Looking at the relation of two variables:
    – Are there unlikely combinations? Tools: Two-dimensional plots (scatterplots), one-dimensional plots of coefficients, differences, etc.

This was done by creating numerous plots for each data row. A selection of them can be viewed in the individual data validation sections for each metric under observation. Note that the complexity and metric names had to be shortened in the plots, as they did not always fit the drawing space. Mostly, the names are intuitive. Complexities simple, hierarchical, and parallel were encoded as complexity 1, 2, and 3, respectively.

Definition 6.1.3 (Q–Q Plot)
A Q–Q plot *(or Quantile–Comparison Plot, definition in part taken from Fox [23]) is a graphical method of deciding whether a data sample differs from a given distribution, for example the normal distribution. In essence, the Q–Q plot resembles a scatterplot. For a sample with n observations, n points are plotted. The ordered data is plotted on the horizontal axis against the corresponding quantiles of the reference distribution. If the two distributions are the same, this approximates a straight line. If there is a substantial deviation from linearity, one can assume that the distributions are different from each other. See Figure 6.3 for an exemplary Q–Q Plot.*

This concludes the testing of the data. After ensuring that the data is valid, the actual analysis can commence. The following steps described here are performed in the following two chapters.

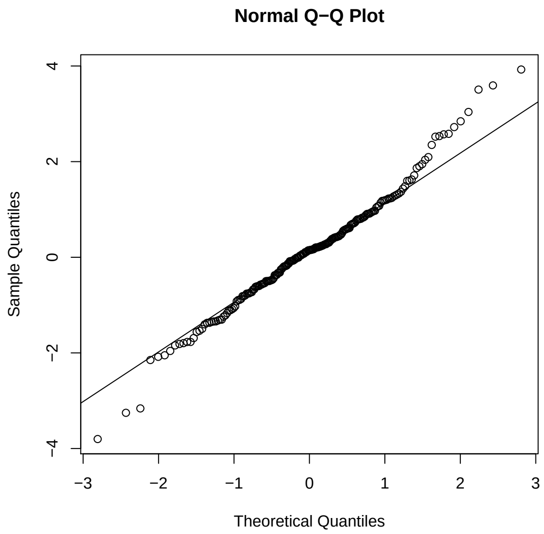


Figure 6.3.: A Q–Q plot showing nearly normal distributed data

Illustration of Results (Step 3) The first step in the analysis of the validated data is the graphical representation of the assumed interrelations to asses the conformity of the data with the expected correlations. This was done by generation of scatterplots depicting almost every relation between the collected data. These can be found in Appendix E. The relations of the investigated metrics to the awarded points and needed time are analyzed in individual subsections of Chapters 7 and 8.

Numerical representation of Results (Step 4) The numerical evaluation should be performed after the illustration of the data, as the optical representation gives clues to the kind of test that works best with the data at hand. In the case of the data analyzed in this thesis, this was the (multi-) linear regression with dummy variables, explained in Chapter 7.

Find Possible Explanations (Step 5)) In this step, look for clues indicating the mechanism behind findings whether they are expected or unexpected. An analysis should start with the confirmation (or its rejection) of the hypothesis stated in the experimental design (*hypothesis-driven analysis*) and proceed with the search for causes of the findings (*speculative analysis*). The second analysis is most important for results that contradict the hypothesis.

Data Browsing (Step 6) After the scientific analysis, it is often valuable to browse the data for not researched correlations. This can be done by creating pairwise scatterplots between all data collected, looking for surprising effects in the illustrated data such as non-expected correlations between variables. The pairwise plotting was

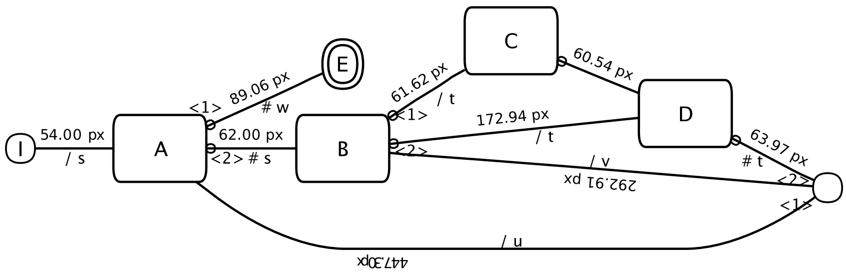


Figure 6.4.: A Statechart with transition lengths labels added by *Inkscape*

done as a side effect of the analysis of multivariate correlations. See the correlation matrices in Appendix D for all combinations.

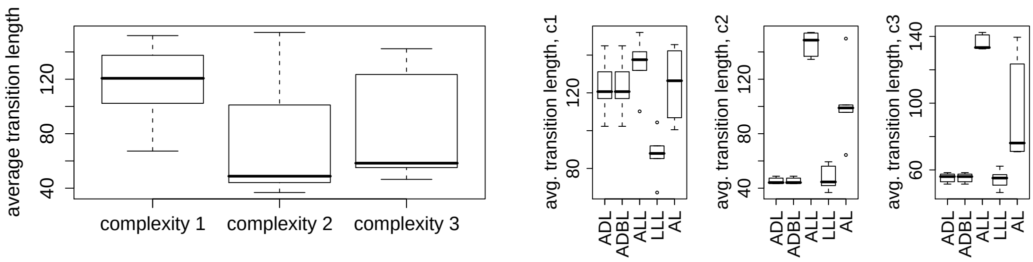
6.2. Data Used for the Analysis of Aesthetic Metrics

The following subsection titles indicate in parentheses the metric from Chapter 4 in question. The label also indicates the column in Appendix C. E.g., the column labeled TRL corresponds to the transition length data.

6.2.1. Transition Length Data (TRL)

The transition lengths were only available implicitly from the Statecharts used in the experiment. The charts are stored in a computer graphics format, and the transition lengths had to be extracted from them. This was done in the following way: First, the chart files had to be converted from Portable Document Format (PDF) to Scalable Vector Graphics (SVG) [59]. These files were then opened in the *Inkscape* application and the individual transition lengths of each Statechart were measured. *Inkscape* was used, as it features a convenient tool for this purpose. To make repetitions in case of errors or missing values easier, the process of extracting the values was automated. For this purpose, the Statecharts were saved with the added measurements for each transition (see Figure 6.4 for an example), instead of simply recording the measured transition lengths. The created SVG files with added measures were transformed by XSLT (as SVG files are essentially eXtensible Markup Language (XML) [62] files) into a list of transition lenghts and subsequently stored in CSV files. The transformation and conversion into CSV was done by a *JAVA* program written for this purpose. The average, minimum, and maximum transition lengths for each chart were calculated from this data and again stored as a CSV file.

The average of all transitions for each Statechart was calculated. This data were displayed in the form of various boxplots (see Figure 6.5), to spot outliers. The outliers could indicate faults in the data, such as values which are too high or too low. Also, the shortest and longest transitions for each chart were determined and tested for unlikely values.



(a) A boxplot diagram that shows the data spread for the different complexities

(b) Three boxplot diagrams that show the data spread for individual layouts for each complexity

Figure 6.5.: Several boxplots that show the distribution of the average transition length data

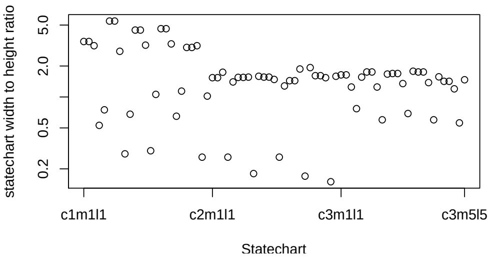
It is evident from the plots that the different complexities, as well as the layouts, vary greatly in their average transition length. The higher complexities show a much lower average, with the exception of the Alternating Linear Layout (ALL).

To verify that all transitions were measured, the number of transitions measured for each Statechart was calculated and compared to the correct number. This proved to be necessary. As every transition had to be manually selected (clicked on in *Inkscape*), one transition was not measured at all. The missing transition was noticed in the reliability testing, as the number of transitions differed from that of other charts with the same complexity.

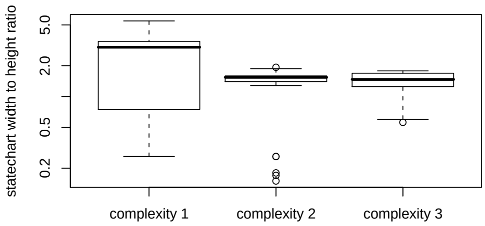
6.2.2. Width to Height Ratio Data (WHR)

For this measure the exact width and heigth of the Statecharts was needed. The data were read by a simple shell script from LaTeX files containing size information of the Statecharts. These files were already existent, as they were used to include the Statecharts into the questionnaires handed to the subjects of the experiment. The files include parameters for lower left and upper right coordinates of each Statechart. With this information, the width to height ratio (and the area, see next subsection) was calculated. However, the mentioned LaTeX files contained rather generous fitting viewport information. The viewports had to be adjusted to fit the Statechart boundaries exactly. See Figure 4.2 for Statecharts with very different width to height ratios. As seen in Figure 6.6a, most of the charts stay close to a ratio of about two times the width to height.

The data were displayed as a scatterplot and a boxplot (see Figure 6.6). Note that the y-axis has a logarithmic scale (ratios of 0.5 and 1 have the same distance as ratios 1 and 2). The few outliers were manually verified to be true. Random samples were measured by hand and compared to the automatically generated ratios. The mentioned logarithmic scale has to be considered in the calculations in the next section. Therefore, the logarithm of the width to height ratio was calculated. This



(a) A scatterplot that shows the width to height ratio for all Statecharts used in the experiment



(b) Three boxplots that show the distribution of the width to height ratio data for the different complexities

Figure 6.6.: Statechart width to height ratio data plots. Subfigure 6.6a shows that the ratio of almost all charts nears two with increasing complexity. Only the Linear Layer Layout differs.

transformation of the data allows the correlation with linear terms. Furthermore, the construction of linear regression models is simplified by this.

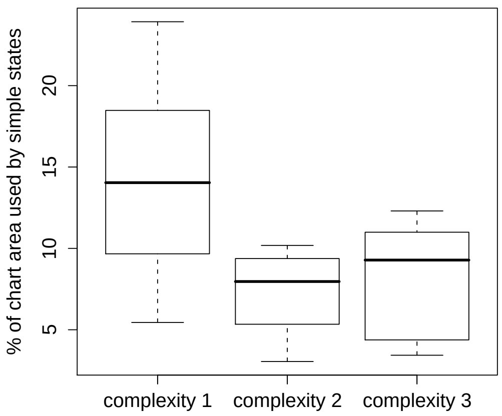
For the remainder of this work, the metric width to height ratio identifies this modified definition. Whenever the data will be used, it will be the logarithmized version.

6.2.3. Usage of Available Space Data (SU_S, SU_A, SU_T)

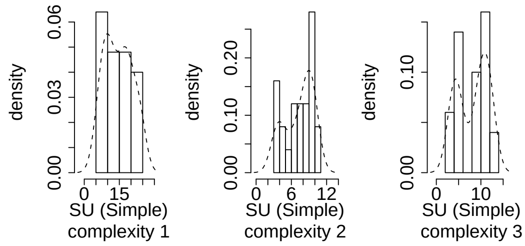
This metric measures the percentage of Statechart space taken up by states. To calculate the Statechart area, the width and height of the Statechart are taken from the same data source as the width to height ratio. Furthermore, the area occupied by Statechart elements was calculated. The various elements of a Statechart occupy a characteristic amount of drawing space. The area occupied by each is shown in Table 6.1.

Several methods were used to calculate the occupied space, as it was not known how the occupation was perceived by the participants. The first method only considered the topmost states, considering them opaque to the human observer. If this showed the greatest significance, a user would consider the Statechart space as almost completely taken up by states, if there are one or more big macrostates. Next, only simple states and connectors were considered to take up space. This stems from the idea that macrostates are not considered to consume space, as they contain other states. The last method calculated the space as before and added the space taken by the attribute space of macrostates. The idea behind this method was to consider every space that cannot contain another state. See Figure 4.3 for a visualization and comparison of the three methods. The amount of used space was then set in relation to the Statechart drawing area and stored in a file as the percentage of a Statechart's area that was used.

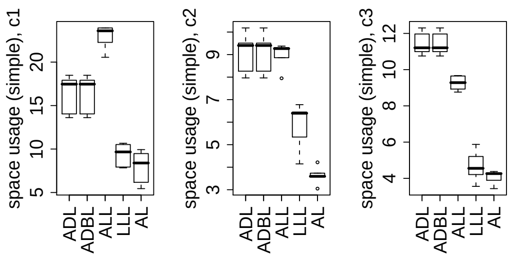
There are differences in the size of states between two sets of layouts: The first set



(a) A boxplot diagram that shows the data spread for the different complexities



(b) Three histograms that show the distribution of the data for all three complexities



(c) Three boxplot diagrams that show the data spread for individual layouts for each complexity

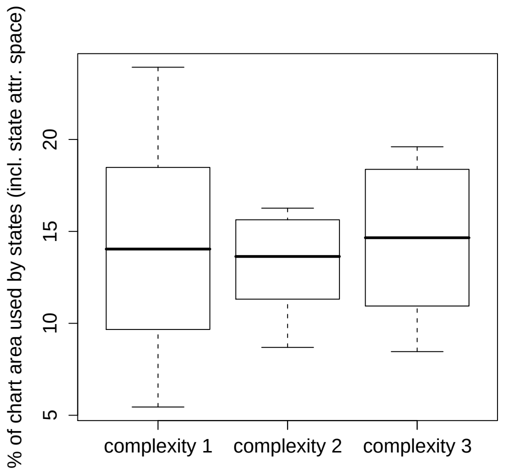
Figure 6.7.: Several subfigures that visualize the data gained from the metric *usage of Statechart drawing space* (SU_S), counting only simple states

Table 6.1.: Component sizes with regard to the layout used.

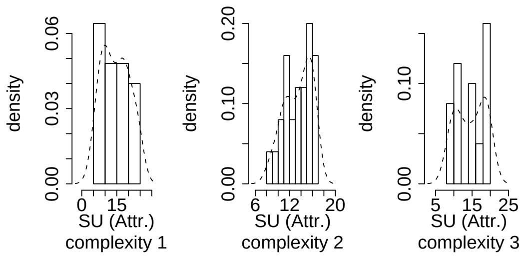
Component	**Size (in px^2), Layouts ADL, ADBL, ALL**	**Size (in px^2), Layouts LLL, AL**
Simple state	3075	946
Connector	356	356
Final State	855	825

containing the Alternating Dot Layout (ADL), Alternating Dot Layout Backwards (ADBL), and ALL, the second containing the Linear Layer Layout (LLL) and Arbitrary Layout (AL) (see Chapter 5 for Statecharts of the different layouts). The size of simple states, connectors and final states for each were measured (see Table 6.1). The rounded edges of States were approximated, as their area is in the range of a few pixels. Round connectors were approximated by circles or ellipses. The size of the Statechart attribute space is not noted in Table 6.1, as it varies for each macrostate. However, it has a fixed height (at least in the data gained from the experiment) and can be calculated by multiplying the width of the macrostate with this fixed height.

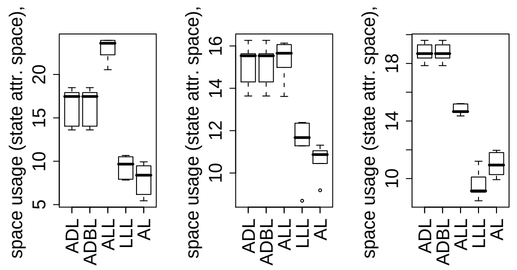
Three Figures are shown here, wich were used to validate the data: Figure 6.7, 6.8,



(a) A boxplot diagram that shows the data spread for the different complexities



(b) Three histograms that show the distribution of the data for all three complexities

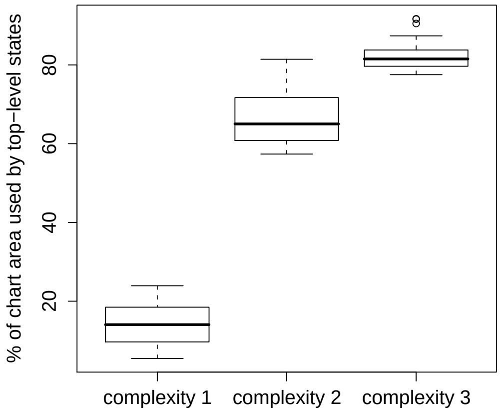


(c) Three boxplot diagrams that show the data spread of individual layouts for each complexity

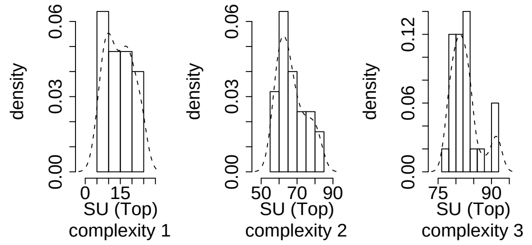
Figure 6.8.: Several subfigures that visualize the data gained from the metric *usage of Statechart space* (SU_A), counting simple states and the state attribute space

and 6.9. The data were tested for reliability by generating boxplots (See Subfigures 6.7a, 6.8a, and 6.9a) from the data. Also, the frequency distribution was generated and is shown in Subfigures 6.7b, 6.8b, and 6.9b Immediately noticeable in the three boxplot diagrams is the difference between the metrics regarding the complexity level. Metric SU_A shows a divergence between Statecharts of simple complexity and Statecharts of complexities hierarchical and parallel. Data gained through metric SU_A has a more homogeneous spread. The aforementioned divergence is enlarged in the third boxplot (showing metric SU_T). From the position and size of the boxplots, it is assumed that the SU_A data will be the most valuable data, as the spread indicates that there is a diversity of measured data and the position hints that the data is comparable over complexity boundaries. However, this has to be verified by correlation of the data with user ratings.

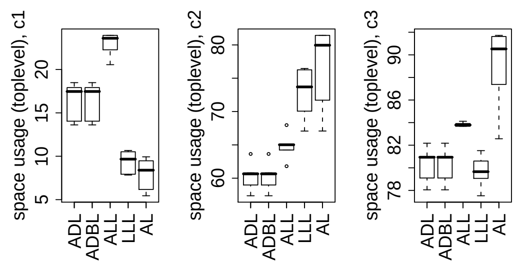
There is a inconsistency regarding the connector area of the ALL layout: If there is more than one transition entering or leaving the connector on one side, the area of that connector is enlarged by 150 % for each transition added. This accommodates the additional transitions. This has been considered in the data acquisition process, the bigger connector was taken into account with the enlargement factor.



(a) A boxplot diagram that shows the data spread for the different complexities



(b) Three histograms that show the distribution of the data for all three complexities



(c) Three boxplot diagrams that show the data spread of individual layouts for each complexity

Figure 6.9.: Several subfigures that visualize the data gained from the metric *usage of Statechart space* ($\mathrm{SU_T}$), counting only top-level states

6.2.4. Placement of Initial and Final States Data ($\mathbf{P_I}$, $\mathbf{P_F}$)

The initial and final states are important spots in a Statechart. If they are not in the expected places, it may take time to find them. The measurement of the initial and final states placement was done by recording the absolute position of initial and final states in cartesian coordinates. The lower left coordinates of the initial and the final state were read from the Statechart graphics files. *Inkscape* displays these coordinates for each object on the drawing space. Only the first initial and the last final states in a hierarchical Statechart have been taken into account, since these can be viewed as the starting and end point of the Statechart. The data recorded and stored in a file. This data had to be converted into relative values before usage, as the different Statechart dimensions prohibit a direct comparison of the positions.

During data conversion, the dimensions of the initial/final state had to be considered. A state touching the left border of the Statechart should be registered with a horizontal value of 0 %. A state touching the right border should be registered with a horizontal value of 100 %. Figure 6.10 shows the chart transformation. A margin is removed from the sides to compensate for the state dimensions. This margin has to be half the width of the initial or final state. The same applies for the vertical placement. Not shown in the Figure is the margin for final states. However, this is analogous to the transformation for initial states. To evaluate these data, it has

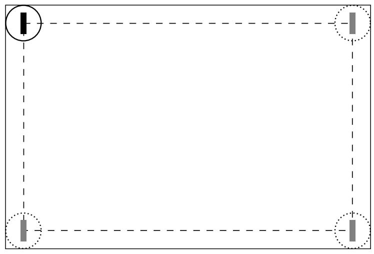
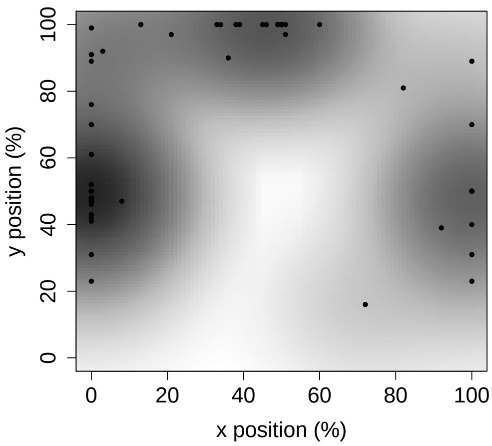
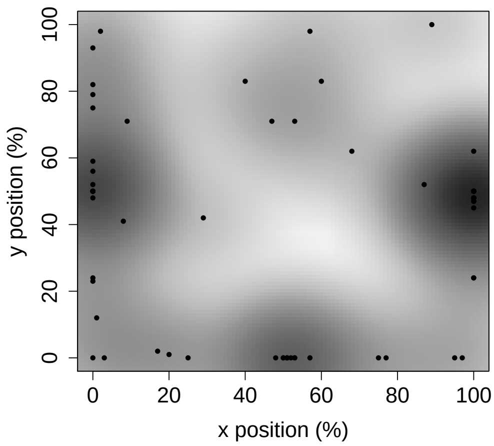


Figure 6.10.: A figure showing the transformation of Statechart borders. The new boundaries have to be half an initial state smaller to position the center of the initial state at 0 % (respectively 100 %).



(a) A scatterplot that shows initial state positions



(b) A scatterplot that shows final state positions

Figure 6.11.: Two scatterplots depicting the placement of initial and final state. Placement density is shown with a color gradient. Higher density is represented with darker color.

been visualized as seen in Figure 6.11. The figure also shows the density of state placement with a color gradient. Selected random samples were tested manually to validate the data.

6.2.5. Distances Between Node Borders Data (NB_{MIN}, NB_{MAX}, NB_{AVG})

The distances between each node's border and its closest neighbor's border was measured for each chart. The data were then stored in separate files for each chart. Parallel borders are interpreted as state borders, as they are visual boundaries, according to aesthetic Criterion 3.1.11. After the data has been collected, the average, maximum, and minimum distances from each chart were calculated. The data were measured in *Inkscape* by hand, which is more susceptible to errors than automated data generation. However, it was not feasible to implement the automated generation in this case, as the SVG format internally uses relative measures. The average, minimum, and maximum distances were stored in a single file, whereas the individual data were stored in several files, one for each Statechart. The content of such a file is shown in Table 6.2 (see Figure 4.4 for a visualization).

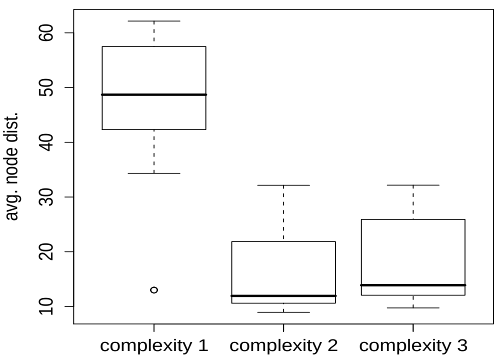
It was expected to see a clustering of smaller distances according to the nesting of macrostates in higher complexity Statechart. Figures 6.12, 6.13, and 6.14 show the spread and distribution of the data.

6.2.6. Distance of States to Straight Lines Data (D_I, D_M, D_{NS}, D_{NA}, D_{NR})

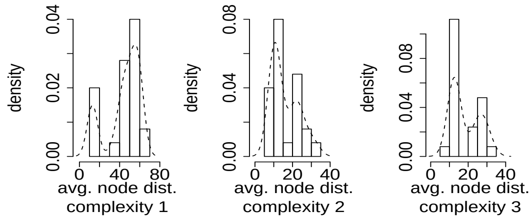
The research on aesthetic criteria showed a favor for straight lines in state placement. Several authors recommended the placement on an orthogonal grid. To see if users prefer Statecharts with lined-up states, a straight line (or more, see Metric 6 variant D_{NR}) was placed in the chart, and the distance of each state to this line was measured. However, as mentioned in Section 4, it was not clear where such a line should be placed. Various placements were tested in this metric. The line was drawn through the initial state, through the arithmetic middle of the chart, and

Table 6.2.: Individual distance to nearest neighbor for each state in Statechart c1-m1-l1 (shown in Figure 6.4)

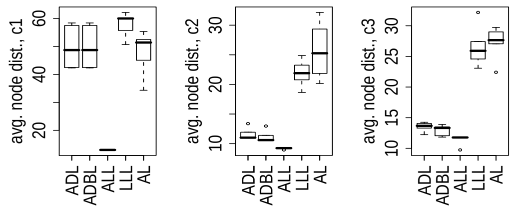
State	Nearest Neighbor	Distance (in px)
initial A	A	54.00
A	initial A	54.00
B	E	16.43
C	D	57.05
D	C	57.05
E	B	16.43



(a) A boxplot diagram that shows the data spread for the different complexities

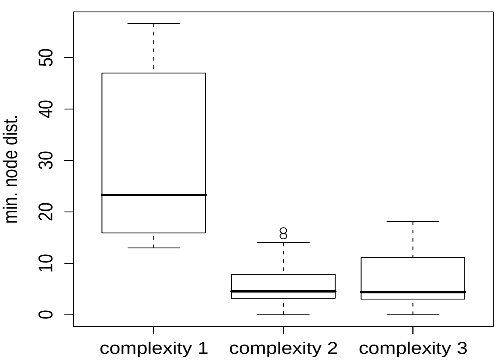


(b) Three histograms that show the distribution of the data for all three complexities

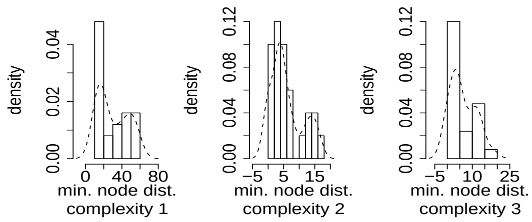


(c) Three boxplot diagrams that show the data spread of individual layouts for each complexity

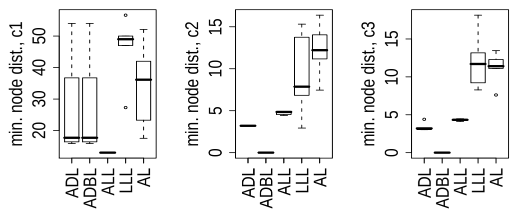
Figure 6.12.: Several Subfigures that visualize the data gained from the average distance between two node borders metric



(a) A boxplot diagram that shows the data spread for the different complexities

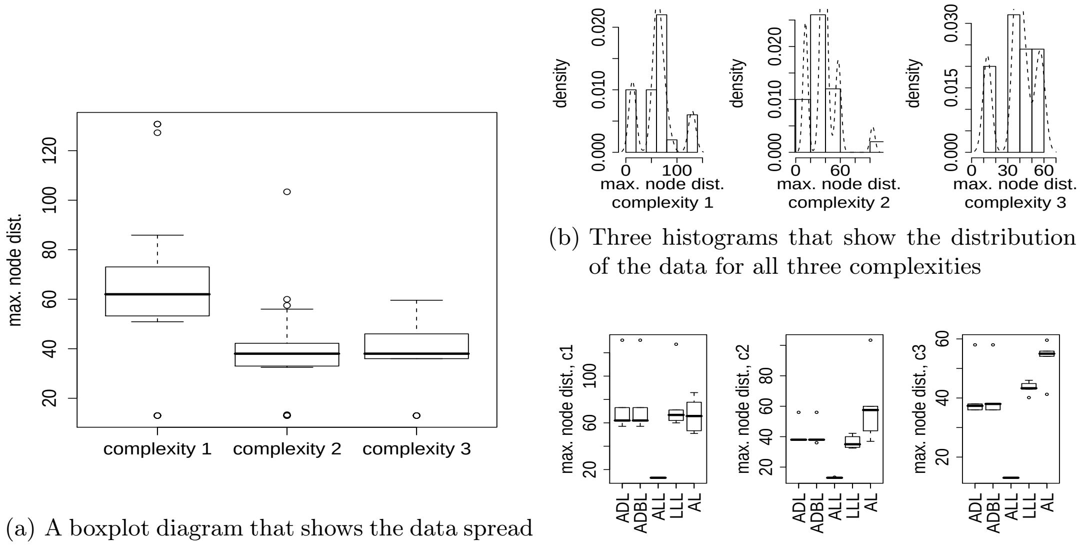


(b) Three histograms that show the distribution of the data for all three complexities



(c) Three boxplot diagrams that show the data spread of individual layouts for each complexity

Figure 6.13.: Several Subfigures that visualize the data gained from the minimum distance between two nodes metric

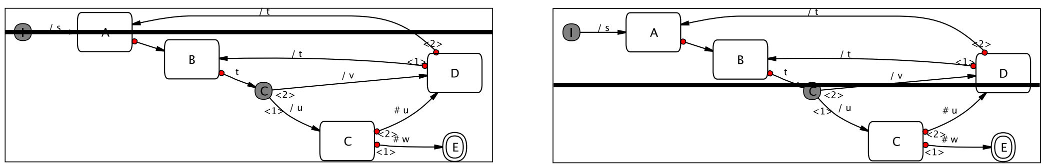


(a) A boxplot diagram that shows the data spread for the different complexities

(b) Three histograms that show the distribution of the data for all three complexities

(c) Three boxplot diagrams that show the data spread of individual layouts for each complexity

Figure 6.14.: Several Subfigures that visualize the data gained from the maximum distance between two node borders metric



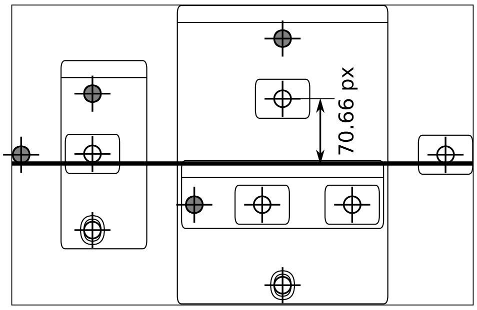
(a) A Statechart with a line through the initial state

(b) A Statechart with a line through the middle of the Statechart

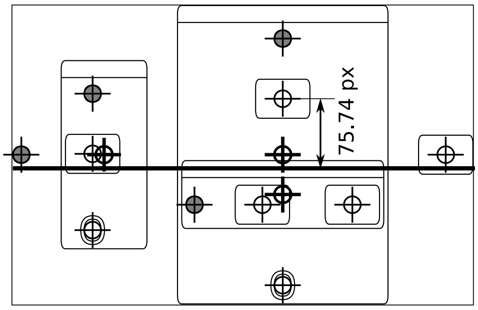
Figure 6.15.: Two Statecharts illustrating the distance of states to a straight line metrics D_I and D_M

through the arithmetic middle of all state centers. The line orientation had to be compensated for different chart layouts, i.e. horizontal or vertical. This was done by drawing either a horizontal or a vertical line, regarding the positioning of the states in the Statechart (see Figures 6.15 and 6.16 for examples).

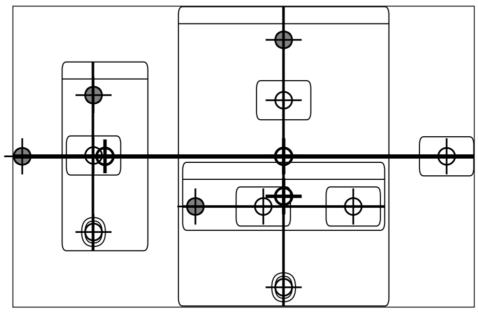
Hierarchical Statecharts had to be handled differently, as they can contain more than one axis. A recursive approach for hierarchical Statecharts seemed feasible. Therefore, another metric (Layout Metric 6) calculated the distance to a normal line for each hierarchical substate as if it was a simple Statechart (see Figure 6.16c for an example). The best location for the straight line has to be revealed by the tests in Chapter 7.



(a) Statechart with a normal line drawn, only simple states considered



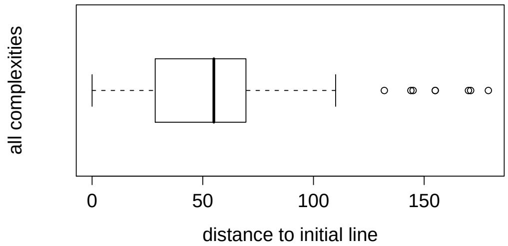
(b) Statechart with a normal line drawn, all states considered



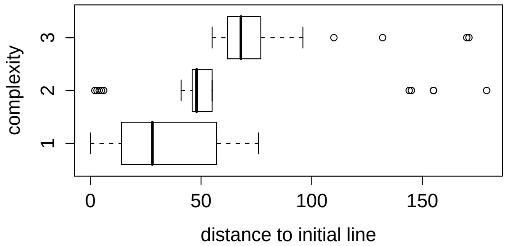
(c) Statechart with a normal line drawn, hierarchical states recursively processed

Figure 6.16.: Three Statecharts illustrating the *distance to a normal line* metric. The finer crosshairs indicate simple state centers, the coarser crosshairs indicate hierarchical state centers. Transitions and labels have been removed to avoid confusion.

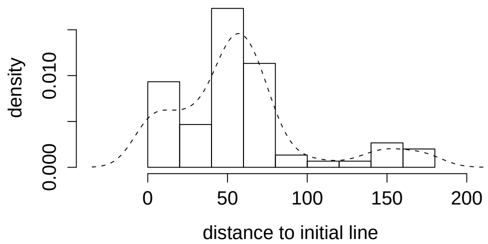
Figure 6.15a shows the distance to a straight line drawn through the initial state. A straight line positioned at the vertical middle of the Statechart is shown in Figure 6.15b. The plotted data for initial and middle line is shown in Figures 6.17,6.18, and 6.19 the plotted data for the normal line metrics is shown in Figures 6.20, 6.21, and 6.22. Figure 6.23 shows the normal line data by layout. The number of outliers in Figures 6.17a and 6.17b indicates that the initial state might not be a good place to draw the line on which the distance of states is measured. The distribution of the data gained through the Metrics D_{M}, D_{NS}, and D_{NA} is rather similar in spread and position. As there are no hierarchical states in simple complexity Statecharts, the data gained for this complexity is identical for metrics D_{NS}, D_{NA}, and D_{NR}. The special nature of metric D_{NR} sets the data gained through it apart from the rest. The boxplots for each of the three complexities are completely different from each other. If this has a negative influence on the analysis remains to be seen.



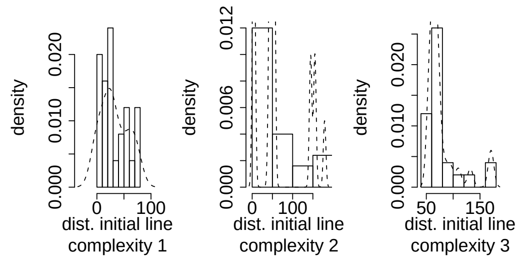
(a) A boxplot that shows the data spread for Metric 6, variant D_I



(b) A boxplot diagram that shows the data spread for Metric 6, variant D_I, in different complexities



(c) A histograms that shows the distribution of the D_I data



(d) Three histograms that show the distribution of the D_I data for all three complexities

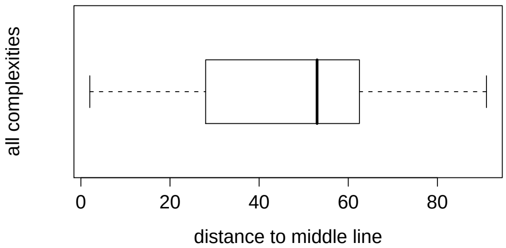
Figure 6.17.: Several plots that visualize the data collected from Layout Metric 6 (distance to a straight line). The distribution and spread for variant D_I is shown.

6.2.7. Number of States and Hierarchy Level Data (N_S, N_{SS}, N_{HS})

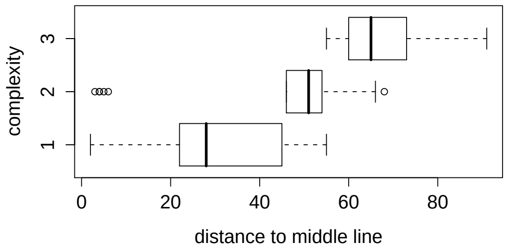
Layout Metric 7 required basic counting. In our sample, Statecharts of simple complexity consist of 7 simple states (actually, these are 7 *nodes*, including the connector) and no hierarchical states. Statecharts of hierarchical complexity include 11 simple states and 3 hierarchical states. Statecharts of parallel complexity consist of 16 simple states and 2 hierarchical states. These hierarchical states have two parallel regions inside, which were counted as separate hierarchical states. This complies with the human viewpoint, which perceives parallel states as two separate functional areas. The different Statechart complexities and their number of states can be seen in the previous chapter (Figure 5.2).

6.2.8. Intersection of Components Data (IF, IF_{TS}, IF_{TT}, IF_{TL}, IF_{LL})

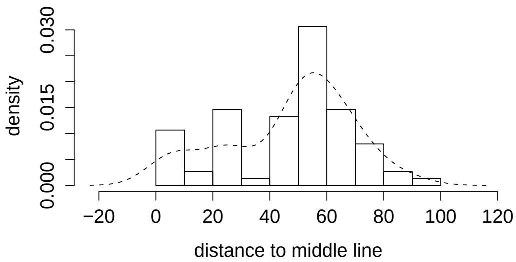
There are only some intersections between components of the Statecharts under observation. Most intersections were seen between labels and transitions. As this was noted as a bad thing by the participants of the experiment, the intersections were counted and will be related to the user preference.



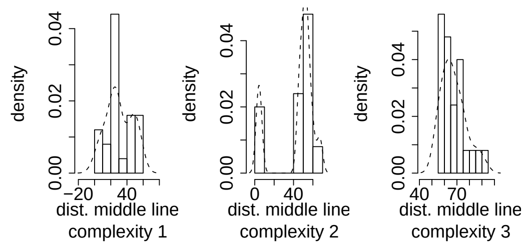
(a) A boxplot that shows the data spread for Metric 6, variant D_M



(b) A boxplot diagram that shows the data spread for Metric 6, variant D_M, in different complexities

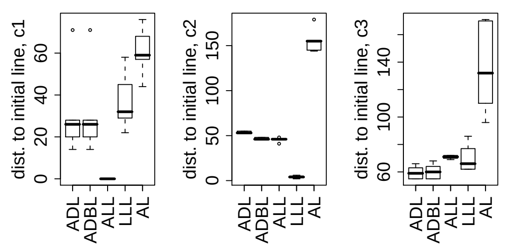


(c) A histograms that shows the distribution of the D_M data

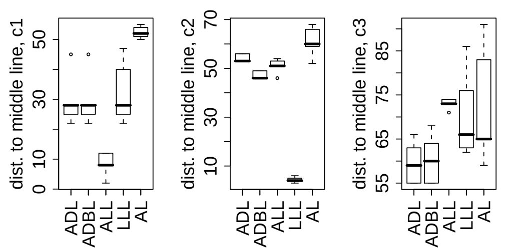


(d) Three histograms that show the distribution of the D_M data for all three complexities

Figure 6.18.: Several plots that visualize the data collected from Layout Metric 6 (distance to a straight line). The distribution and spread for variant D_M is shown.

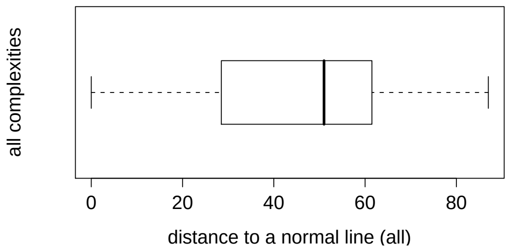


(a) Variant D_I

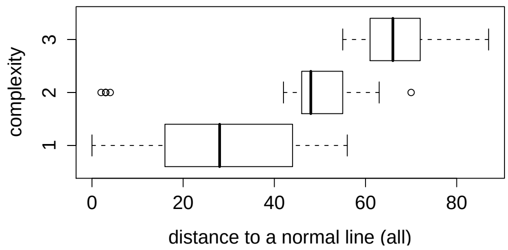


(b) Variant D_M

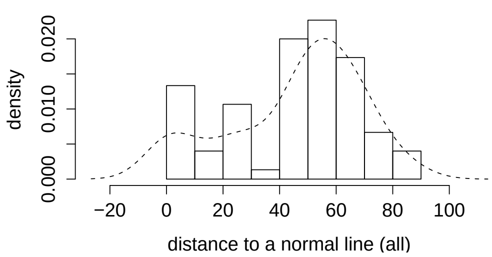
Figure 6.19.: Multiple boxplots diagrams that show the data spread of the different layouts for the *distance to a straight line: Initial and middle line* metric



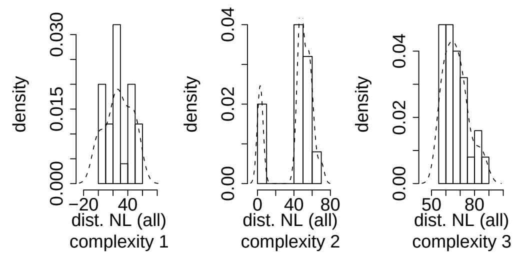
(a) A boxplot that shows the data spread for Metric 6, variant D_{NA}



(b) A boxplot diagram that shows the data spread for Metric 6, variant D_{NA}, in different complexities



(c) A histograms that shows the distribution of the D_{NA} data

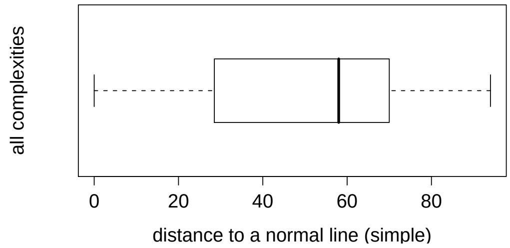


(d) Three histograms that show the distribution of the D_{NA} data for all three complexities

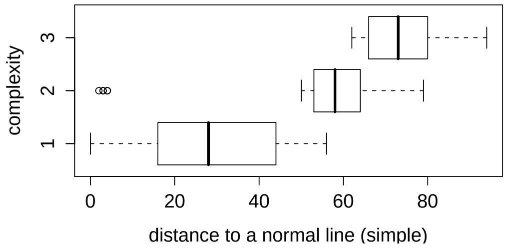
Figure 6.20.: Several plots that visualize the data collected from Layout Metric 6 (distance to a straight line). The distribution and spread for variant D_{NA} is shown.

Table 6.3.: Number of states per complexity level

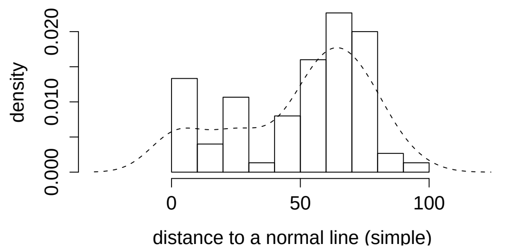
Complexity	Number of Simple Nodes	Number of Hierarchical States
Simple Statecharts	7	0
Hierarchical Statecharts	11	3
Parallel Statecharts	16	6



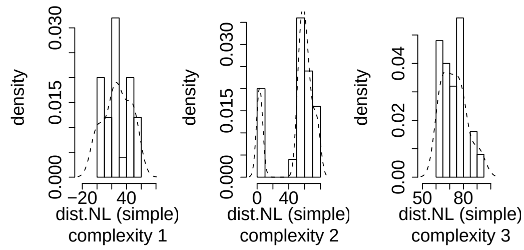
(a) A boxplot that shows the data spread for Metric 6, variant D_{NS}



(b) A boxplot diagram that shows the data spread for Metric 6, variant D_{NS}, in different complexities



(c) A histograms that shows the distribution of the D_{NS} data



(d) Three histograms that show the distribution of the D_{NS} data for all three complexities

Figure 6.21.: Several plots that visualize the data collected from Layout Metric 6 (distance to a straight line). The distribution and spread for variant D_{NS} is shown.

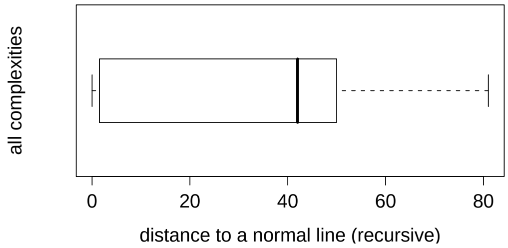
All crossings were counted manually. The different intersection faults considered were:

1. Intersections between transitions and states (see Subfigure 6.24a);
2. Transitions intersecting with other transitions (see Subfigure 6.24b);
3. Intersections between labels and transitions (see Subfigure 6.24c);
4. Two or more labels intersecting (see Subfigure 6.24d).

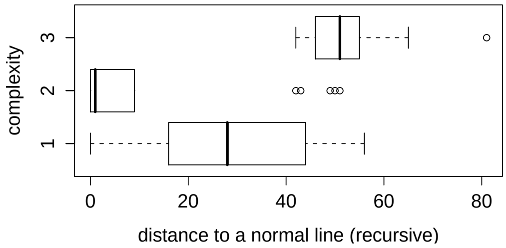
The total intersection faults are shown in 6.24, for an example of the individual faults see Figure 6.25. Transitions are the key element of the intersection faults: For every type of Statechart element there was a Statechart in which the element was intersected by a transition. The data were recorded in a spreadsheet and saved. Figure 6.25 shows an overview of total distance problems encountered.

6.2.9. Directional Statechart Flow Data (FL)

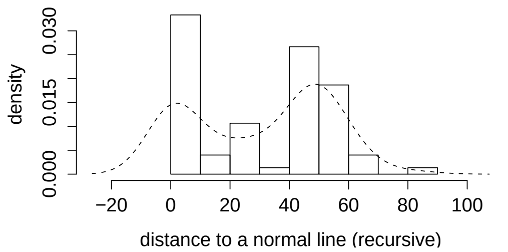
If a high level of directional change occurs between incoming and outgoing transitions of a state, it might interrupt the reading of a Statechart. In this metric, the degrees



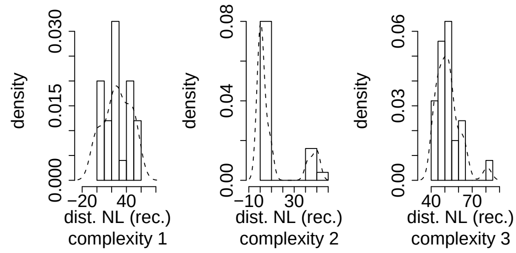
(a) A boxplot that shows the data spread for Metric 6, variant D_{NR}



(b) A boxplot diagram that shows the data spread for Metric 6, variant D_{NR}, in different complexities



(c) A histograms that shows the distribution of the D_{NS} data



(d) Three histograms that show the distribution of the D_{NS} data for all three complexities

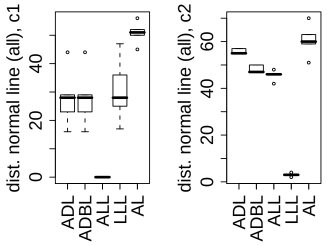
Figure 6.22.: Several plots that visualize the data collected from Layout Metric 6 (distance to a straight line). The distribution and spread for variant D_{NR} is shown.

between all outgoing transition of a state and every incoming one was measured, thus finding the minimum amount of directional change for each outgoing transition. To get a measure for the whole Statechart, the degrees of each state are summed up, then divided by the number of outgoing transitions. Therefore, the mean minimum angles between outgoing and incoming transitions for each Statechart were calculated. See Figure 4.5 for an illustration. Figure 6.26 shows the distribution and spread in two boxplots, separated by complexity and layout, together with a histogram of the data.

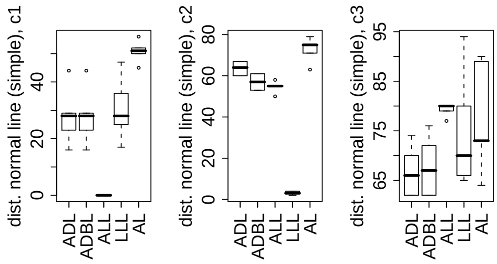
6.2.10. Number of Transitions and Transition Bend Data (N_T, N_{ST}, N_{PT}, N_{SPT})

The subject of this metric is the number of edge bends in a transition. However, this is not applicable here. The Statechart layouts that were used in the experiment provided indifferent data. The used Statecharts have one of three transition types:

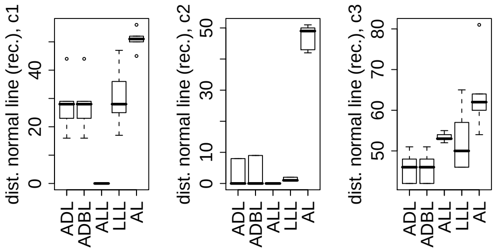
1. straight line
2. polyline



(a) A boxplot diagram that shows the data spread for Metric 6, variant D_{NA}, separated by layout

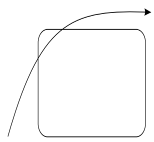


(b) A boxplot diagram that shows the data spread for Metric 6, variant D_{NS}, separated by layout

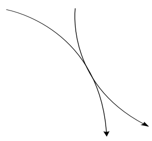


(c) A boxplot diagram that shows the data spread for Metric 6, variant D_{NR}, separated by layout

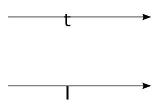
Figure 6.23.: Distance to a straight line. The data distribution for different layouts is shown in multiple boxplots for each of the three variants D_{NA}, D_{NS}, and D_{NR}.



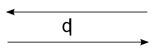
(a) Transition crossing State



(b) Transition crossing Transition



(c) Transitions crossing or touching Labels



(d) Labels crossing Labels

Figure 6.24.: The possible distance problems in a Statechart.

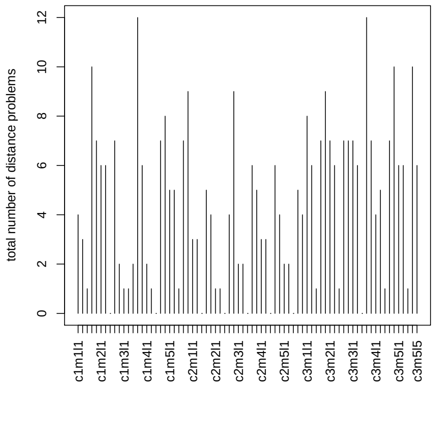


Figure 6.25.: Number of overall distance problems in the experiment's Statecharts (overview)

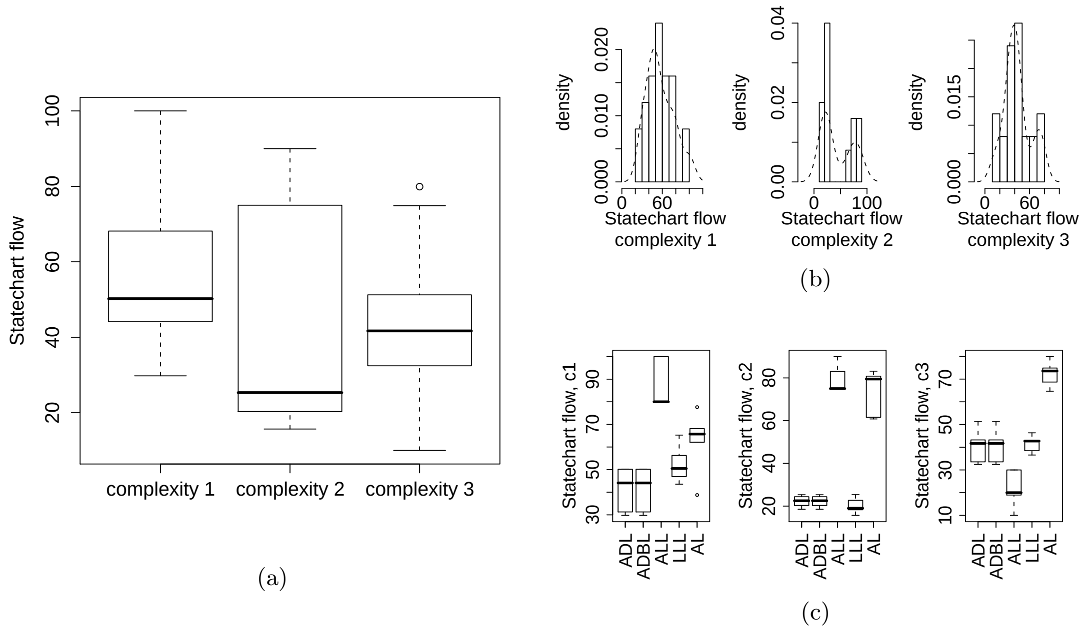


Figure 6.26.: Directional Statechart flow. Subfigures 6.26a and 6.26b show the boxplots, respectively histograms, for the different complexities. Subfigure 6.26c divides the complexities into the separate layouts.

3. spline

This is a problem. The number of edge bends is only countable for polyline transitions. The straight transitions have obviously no bends, the spline transitions consist solely of bends. The polyline transitions used in the experiment all have exactly two bends. So, instead of the edge bends, the respective number of straight, polyline and spline transitions is counted. The spline transitions are considered to represent transitions with more than two bends. This abstraction is necessary to generate ordinal values. Figure 6.27 shows an overview of the data for each Statechart.

6.3. Data Used for the Analysis of the Modeling Process

Acquiring the data for this analysis was done manually. The questions asked in the original experiment did not include the number of keystrokes or mouse clicks, so they were not measured automatically at the time the experiment took place. Ideally, the number of user actions would be recorded by the computer used in the experiment. However, the machine cannot separate error actions from productive ones, so at least the error actions would have to be counted manually. However, if the computer would record the time of each action, the observer could denote the start and end time of an error and let the computer display the actions that are inside this timeframe.

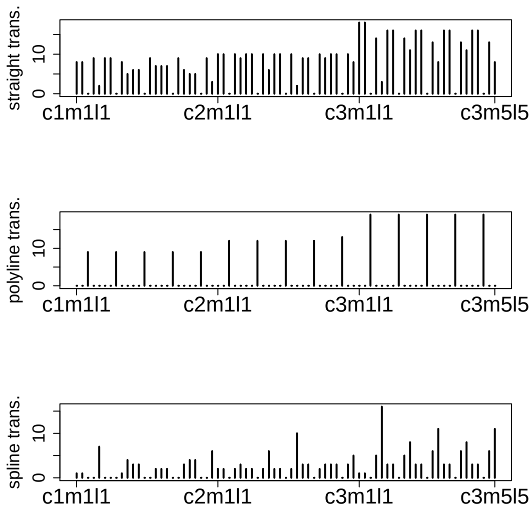


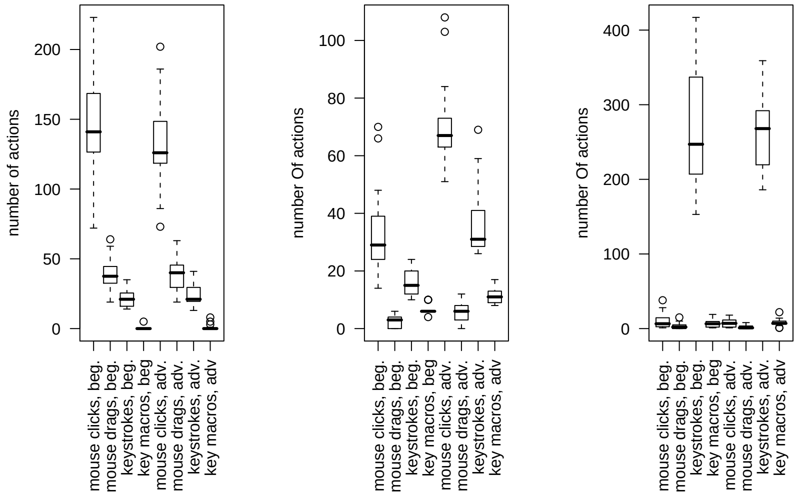
Figure 6.27.: Three plots that show the number of transition types for each Statechart.

Table 6.4.: Key mapping for user actions

Key	User Action
y	mouse click
x	mouse drag
c	keystroke
v	key macro

6.3.1. Mouse Click and Keystroke Data

The keystrokes and mouse clicks, as well as mouse drags and key macros were counted while watching the videos. For this task, one computer was used to play the video, while another computer was used to record the four different events. To retain traceability, the actions of the participant were recorded as a stream of characters, each representing an action. Table 6.4 shows the mapping of keys to user actions. For example, a simple complexity Statechart can be created (as required in the experiment, see Section 5.1) in the WYSIWYG editor with the actions represented by the string `yyxcyyyyyyyyyyyyyyyyyyyyyyyycycycycycycycyc`. Note that only input actions are recorded, not movement. Figure 6.28 shows the number of input actions for each tool.



(a) User actions in the WYSIWYG editor

(b) User actions in the KIEL-macros editor

(c) User actions in the KIEL-KIT editor

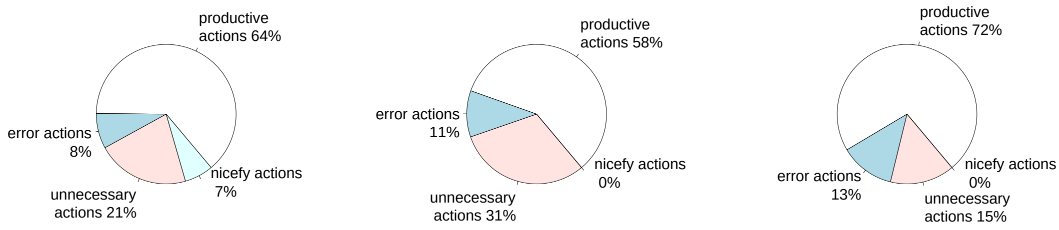
Figure 6.28.: Three boxplot diagrams that show the number of input actions for each editor used

6.3.2. Error Data

Errors were recorded in a similar way as mouse clicks and keystrokes. An error consists of multiple actions, called error actions, so the process of recording the error actions was the same as mentioned above. However, each error had to be recorded separately to get the absolute number of errors made by each participant. To do so, the video was halted after each error and the recorded stream of multiple actions belonging to this individual error was terminated by a marker indicating the intention the user had. For instance, the addition of a state in the WYSIWYG editor would be `yyAS`, indicating two mouse clicks (`y`) leading to the addition of a state (`AS`). For all markers see Table 6.5.

Figure 6.29 shows the percentage of actions belonging to the different action categories. Instead of the no error category, the number of actions that is left when all error actions are subtracted is shown: *productive actions*, actions that lead to the creation of the specified Statechart.

Every error may consist of different actions, such as typing a wrong identifier or selecting the wrong state to insert into a Statechart. Also, to resolve the error made, one has to perform one or several actions. The number of these error actions are shown in Figure 6.30. The total number of the errors made in categories one and two can be seen in Figure 6.31. To categorize the errors made in the experiment (Prochnow and von Hanxleden [48]), the categories shown in table 6.6 are chosen.

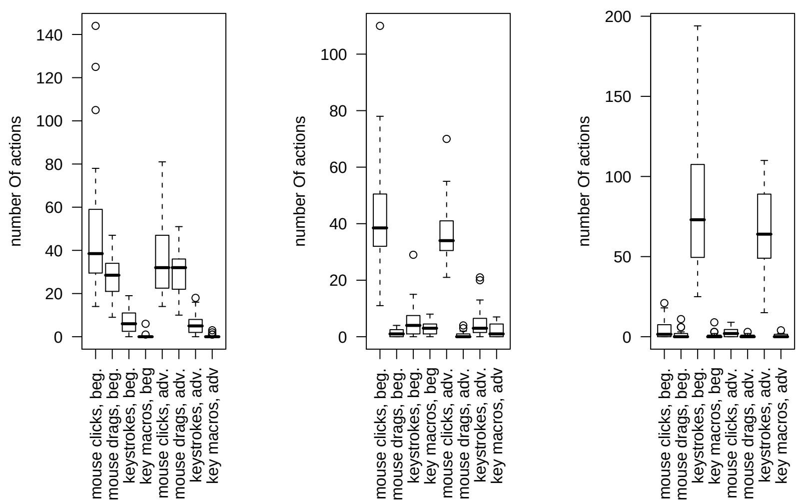


(a) Partitioning of user actions in the WYSIWYG editor

(b) Partitioning of user actions in the KIEL-macros editor

(c) Partitioning of user actions in the KIEL-KIT editor

Figure 6.29.: Pie charts that show the partitioning of user actions into categories for each editor used



(a) Error actions in the WYSIWYG editor

(b) Error actions in the KIEL-macros editor

(c) Error actions in the KIEL-KIT editor

Figure 6.30.: Three boxplot diagrams that show the number of error actions for each tool.

Table 6.5.: Identification markers for the editing process

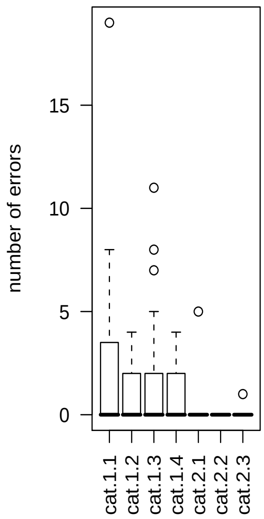
Marker	Intention
SS	Select State
AS	Add State
MS	Modify State
DS	Delete State
ST	Select Transition
AT	Add Transition
MT	Modify Transition
DT	Delete Transition
SL	Select Label
AL	Add Label
ML	Modify Label
DL	Delete Label

Table 6.6.: Different types of errors made in the experiment

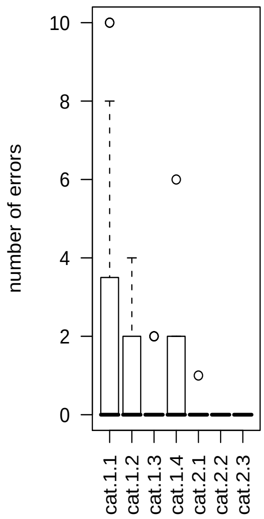
Category	Description
0	unnecessary
1.1	wrong state modified / added / deleted
1.2	typing error
1.3	wrong transition modified / added / deleted
1.4	wrong label modified / added / deleted, abbreviation instead of label added
1.5	wrong other element modified / added / deleted
2.1	wrong type of state added
2.2	left out characters
2.3	inserted text / elements at wrong position

6.4. Summary of the Data Acquisition Process

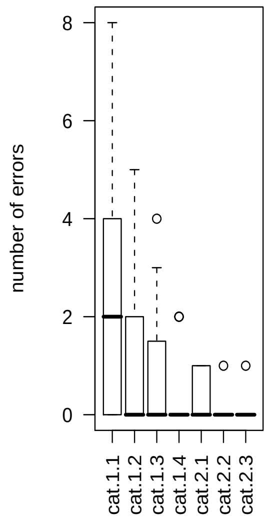
The acquisition of the above data was a long process which often led to the definition of a new variant or even a new metric, as new aspects were found and had to be incorporated. After the data was collected, it still had to be validated. This was a challenge of its own, as the correct visualization for the gained data was not evident. However, suited visualization techniques was needed to asses errors in the data. The tests proposed by Prechelt [45] were a great help for the validation. After all data was collected and validated, the analysis of aesthetic criteria could commence. The next chapter first explains which data was used for the analysis and why, then the individual criteria are related to the points that were awarded and the time required by the participants in the experiment described in Section 5.



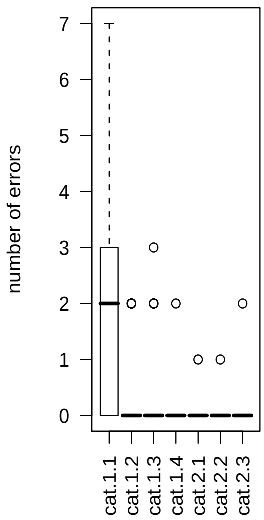
(a) Number of errors made with the WYSIWYG editor by beginners



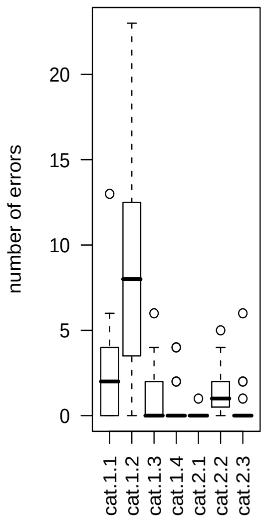
(b) Number of errors made with the WYSIWYG editor by advanced users



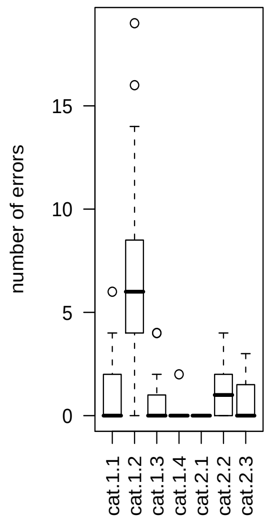
(c) Number of errors made with the KIEL-macros editor by beginners



(d) Number of errors made with the KIEL-macros editor by advanced users



(e) Number of errors made with the KIEL-KIT editor by beginners



(f) Number of errors made with the KIEL-macros editor by advanced users

Figure 6.31.: Six boxplots diagrams that show the number of errors made in the different categories.

7. Analysis of Statechart Aesthetics

To gain an answer to the question of aesthetic influence on user ratings asked earlier a quantitative analysis of the recorded data is performed. The experiment concluded that users preferred a certain Statechart layout (the Alternating Dot Layout (ADL)) over others. This work tries to answer the question why the layouts were rated differently, based on the criteria selected from the numerous aesthetics of Chapter 3. The intention is not to decide which of the layouts presented in Chapter 5 is best (as this was clearly answered by the experiment), but to explore the reasons of user rating for Statecharts.

Definition 7.0.1 (Statistical Error and Residuals)
The amount by which an observation differs from its expected value is called the statistical error*. The expected value is based on the whole population from which the statistical unit was chosen randomly. It is typically unobservable because the whole population cannot be tested. The difference between the measure of the sample and the unobservable population mean is a statistical error. A* residual *(or fitting error), is an estimate of the statistical error and can be observed. The difference between the measure of a sample and the observable sample mean is a residual.*

A Statechart is perceived as an entity. The combination of different aesthetic criteria leads to a general aesthetic quality of the chart. To represent the fact that multiple aesthetic criteria form the perception of the whole Statechart, the selected metrics are first reviewed individually and then combined into a model.

In the following part, several statistical terms are used informally. Their definitions will be introduced before the first use, as seen below.

Remark 7.0.2 (Statistical Decision)
A remark on the preconditions of a statistical decision: In statistical decision theory for linear models, there are usually five assumptions that are verified to be true for the used data (Bortz [8]). These are:

1. *The distribution of the statistical error and the residuals has to follow normal distribution.*
2. *The statistical errors have to be uncorrelated.*
3. *The dependent variables have to be uncorrelated with the statistical errors.*
4. *There is no heteroscedasticity, i.e. a fixed variance for all predictor variables and no correlation between them.*

5. *The data is stationary, i.e. the joint probability distribution does not change when the data are shifted in time or space.*

Regarding (1): The data collected in this work is only a sample of the much larger population and therefore has a limited variance. As the Central Limit Theorem (CLT) states that the sum of a large number of independent and identically-distributed random variables will be approximately normally distributed (Bortz [8]), the normal distribution assumption is accepted to be true. Assumptions (2) to (4) are accepted as well, as they are reasonable for the collected data. The last assumption (5) is necessarily true, as the data is defined to be stationary by the statistical model assumed here.

Definition 7.0.3 (Statistical Hypothesis Testing)
A statistical hypothesis test *is a method of making statistical decisions by looking at experimental data. The data is tested for a given property by stating a* null hypothesis H_0 *and calculating the probability of the experimental observations, given* H_0 *is true. If this probability p is very small, one can argue that the null hypothesis is not true. Instead, the opposite of the null hypothesis (called the* scientific *or* alternate hypothesis H_1*) is accepted. The lower p, the lower is the probability of rejecting* H_0*, when* H_0 *is actually true.*

Remark 7.0.4 (Statistical Significance)
If p is small enough to consider it unlikely that the data has occurred by chance, it is called statistically significant*. The threshold is essentially defined arbitrarily and called the* significance level*. Commonly accepted levels of significance are 0.05, 0.01, and 0.001. For values smaller than 0.001, p is considered numerical zero and represented by a 0.*

7.1. Selection of the Data Set

The general idea is to describe the influence of all Statechart aesthetics on the user in one model. However, there are several categorial variables. Can they be studied together, or do they have to be separated? The categories which have to be brought together are:

- Dependent variable under observation (points, time);
- Knowledge of test subjects (beginner, advanced);
- Complexity of Statecharts (simple, hierarchical, parallel).

7.1.1. Selection of Dependent Variables

First, the handling of the user ratings has to be decided. The subjects of the experiment were presented two tasks: Rate the Statecharts according to their preference[1]

[1] Two Statecharts were compared at a time, a Statechart could be awarded between -8 and 8 points. This is the *subjective* user rating.

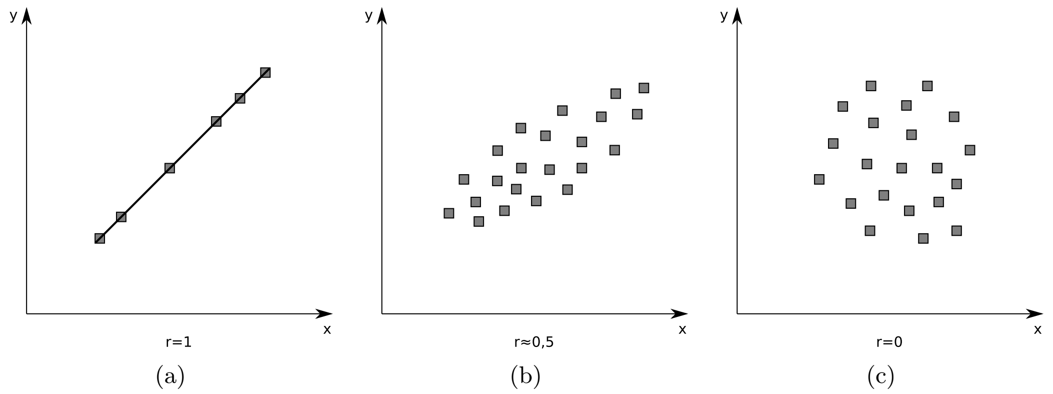


Figure 7.1.: Data plots with different correlation coefficients (simplification)

and understand the given Statecharts[2].

Definition 7.1.1 (Correlation Coefficient)
The correlation coefficient r *is a measure of the linear correlation between two variables, that is, a measure of the tendency of the variables to increase or decrease linearly together. It can take values between* -1 *and* 1*, indicating a negative or positive correlation (see Figure 7.1). A value of* $r = 0$ *indicates that there is no linear correlation between the variables, whereas a value of* $r = 1$ *indicates a completely linear correlation. A value of* $r = -1$ *indicates a completely reverse linear correlation.*

Definition 7.1.2 (Coefficient of Determination)
The coefficient of determination r^2 *(also* R^2 *or R-squared) measures the proportion of the variation in the dependent variable accounted for by the independent (explanatory) variables; i.e. the ratio of explained deviation and total deviation. This calculation returns a percentage. The Coefficient can be used to rate the goodness-of-fit of a linear model. However, it has its deficiencies. The denominator does not change and the numerator can only increase. Therefore, each additional variable added to the model will probably increase the numerator at least slightly, resulting in a higher* r^2*, even when the new variable causes the model fit to become worse.*

The adjusted r^2 *value is an attempt to correct this deficiency by adjusting both the numerator and the denominator by their respective degrees of freedom. For this reason, adjusted* r^2 *is generally considered to be a more accurate goodness-of-fit measure than* r^2 *[1].*

This delivers two dependent variables: The awarded points and the time needed to understand a given Statechart. Looking at the scatterplots of the two variables and the various independent variables, no similarity can be seen (see Figure 7.2). However, to test for correlation between paired samples of the dependent variables,

[2] The time needed to correctly interpret the Statechart's response to signals was measured. This is the *objective* user rating.

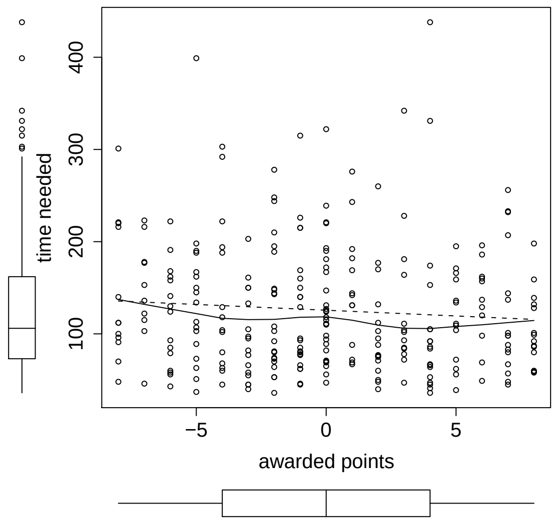


Figure 7.2.: A scatterplot that shows the awarded points for the analyzed Statecharts plotted against the needed time to understand these Statecharts

a correlation test is performed. A variant of the correlation coefficient, called *Spearman's Correlation Coefficient*, is used as the data is not normally distributed. The distribution was verified qualitatively by plotting histograms and Q–Q plots (see Definition 6.1.3). The correlation test supports the assumption of no correlation. With a correlation coefficient of $r = 0.08$, one can assume that there is no correlation between the awarded points and the time needed to understand a Statechart. It seems that a pleasing layout is no guarantee for easy understanding. This also implies that the two dependent variables have to be viewed separately. For each variable to be explained, a separate model has to be constructed.

The number of cases to study has to be reduced, as there should be only one model for each dependent variable under observation (points awarded to the Statecharts and time used to understand the Statecharts).

The next category concerns the experience of the test subjects. To test whether different models should be constructed for beginner and advanced users, an independent variable (transition length) is tested, while controlling if the test subjects' experience has an influence.

Dummy Variable Regression

To do this, *dummy variable regression* (Miller and Erickson [41]) is applied. Dummy variable regression uses categorial predictors or *factors*[3] as they are called in the used

[3]An example of a factor would be the complexity of a Statechart.

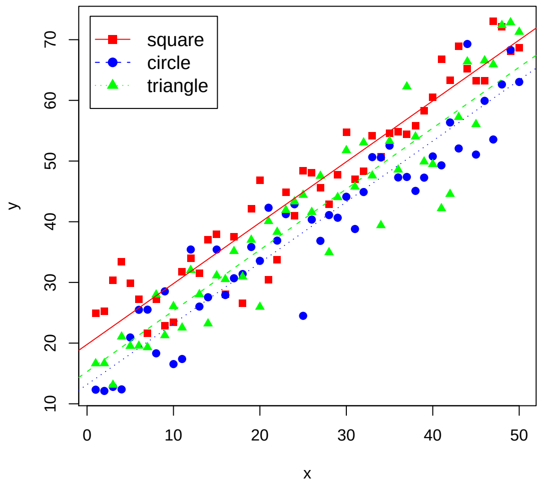


Figure 7.3.: Dummy variable regression example

statistical software. The categories of these factors are called *levels*[4]. Statistical tools offer functions to calculate a linear regression model where the dependent variable in the regression equation is modeled as a function of the independent variables. Note that "linear" regression denotes a linearity in the composition of the model, not in the regression terms themselves. The tool automatically uses factors in linear regression if they are included in a model. The first level of a factor is always used as a baseline level against which the other levels are tested, so it is not shown in the output. For k categories, $k-1$ dummy variables are needed.

Simply speaking, the dummy variable acts as a switch whether a variable is included in the model or not. If the dummy variable is set to 1, the factor is included, if it is set to 0, the factor is excluded.

A simple example might help to understand the concept. Figure 7.3 shows exemplary data as a scatterplot. The data is partitioned into three groups, depicted by the different symbols. These groups can be represented by different linear regression lines. Instead of creating three regression models, one can add dummy variable factors to the linear model, encoding the group of the data point with the associated symbol (see Listing 7.1, the names of the symbols `triangle` and `square` are used as dummy variables, `circle` is the baseline).

A function call in the statistics software returns the coefficients for all three groups of data points. Listing 7.2 provides a sample printout. From this point onwards, the printouts are not displayed. Instead, the important information is presented as an equation containing the coefficients rounded to three decimal places. Furthermore, the adjusted r^2 value is given to indicate the goodness-of-fit. The coefficients returned

[4]The factor *complexity* has the levels simple, hierarchical, and parallel.

Listing 7.1: Exemplary dummy variable levels

```
              triangle      square
circle               0           0
triangle             1           0
square               0           1
```

for the example regression model are 13.17 for the baseline intercept, 2.126 for the triangle symbols, and 6.606 for the square symbols. The coefficient for the slope is 1. The baseline level is the circle group, giving the following formula for a regression line:

$$y_{circle} = 13.17 + x$$

To find the formulas for the other groups, the intercepts returned for the different symbols are added to the intercept of the original regression line:

$$y_{triangle} = 13.17 + 2.126 + x$$

and

$$y_{square} = 13.17 + 6.606 + x$$

This is how dummy regression encodes three different functions in one model.

Listing 7.2: A summary of an exemplary linear regression model

```
Call:
lm(formula = y ~ x + symbol)

Residuals:
     Min       1Q   Median       3Q      Max
-14.2398  -2.9939   0.1725   3.5555  11.9747

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     13.16989    1.01710  12.948  < 2e-16 ***
x                1.00344    0.02848  35.227  < 2e-16 ***
triangle         2.12586    1.00688   2.111   0.0364 *
square           6.60586    1.00688   6.561  8.7e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.034 on 146 degrees of freedom
Multiple R-squared: 0.898,    Adjusted R-squared: 0.8959
F-statistic: 428.6 on 3 and 146 DF,  p-value: < 2.2e-16
```

If complexity levels are tested instead, the dummy variables would look like the ones shown in Listing 7.3.

As one can see, the first level of the factor (`simple`) is taken as the baseline category. If the first dummy variable is set to 1, the effects of observing hierarchical

Listing 7.3: Dummy variable levels for complexity

```
             hierarchical parallel
simple                  0        0
hierarchical            1        0
parallel                0        1
```

Statecharts would be added to the intercept. The second dummy variable does the same for parallel Statecharts.

If

$$y = \alpha + \beta_1 x_1 + \cdots + \beta_n x_n + \epsilon_i$$

is a simple linear equation, the correct model for the dummy regression takes the form

$$y = \alpha + \beta_1 x_1 + \cdots + \beta_n x_n + \gamma_1 d_1 + \cdots + \gamma_n d_n + \epsilon$$

where y denotes the dependent variable, x_i the independent variables, and d_i the dummy variables (or *contrasts*).

7.1.2. Selection of Data Based on Test Subject Experience

The test revealed that experience is not a significant factor in the user's rating. It can be seen that TRL (the average transition length) has a significant influence, while the experience does not. This does not hold for the second test, modeling the time taken, which differs significantly between beginners and advanced users. This has been expected, as learning and experience significantly lower the time taken to understand a Statechart. However, the difference in time needed is only in intercept value (about 70 seconds), not a change in slope.

The test subjects for the first and second experiment are the same persons, with the exception of five students who did not participate in the second experiment. Therefore, the data from the first and second experiment can not be brought together into a single model. The data would be influenced by the learning effect of the participants, also the sample size would not be enlarged, as the participants are the same. If the effect of learning on user ratings was the goal, another experiment would have to be designed. The effect of learning on the dependent variable time was already part of the experiment conducted earlier, and the effect of experience influences the regression line for the time needed to understand a Statechart and the independent variables only by an offset. It was decided that the target group for the application of the analyzed aesthetic criteria are experienced users. Therefore, the data for participant of beginner level were discarded.

7.1.3. Separation of Complexity Levels

Looking at data scatterplots depicting the relation between dependent and independent variables for the different complexities (shown in Appendix E), it can be observed that the hierarchical and parallel plots look similar. To test whether this is true in a statistical sense, this was also tested by *dummy variable regression*. Here, complexity was used as a factor and tested for differences.

Apparently, hierarchical and parallel Statecharts differ significantly from simple Statecharts. The result shows that hierarchical and parallel Statecharts were awarded about 2.3 points less in the experiment than simple Statecharts if they share the same average transition length. It was observed that hierarchical and parallel Statecharts return similar results (their results differ only 0.15 points from each other), whereas simple Statecharts are rated statistically better.

If the effect of complexity from the viewpoint of simple Statecharts is regarded, another model with simple Statecharts encoded as a dummy variable has to be tested. Now, hierarchical and parallel Statecharts form the baseline together. If the dummy variable is set to 1 (indicating a simple Statechart), the response of the linear model is about 2.3 points higher.

Definition 7.1.3 (Wilcoxon Rank-Sum Test)
The Wilcoxon rank-sum test *(also called the Mann-Whitney U, or Mann-Whitney-Wilcoxon (MWW) test) is a non-parametric statistic test of significance to decide whether two samples of observations are distributed the same way. H_0 states that the two samples are drawn from a single population, indicating that their probability distributions are equal. It requires the two samples to be independent, and the observations to be ordinal or continuous measurements, i.e. it can be decided between any two observations which one is greater.*

Looking at the other independent variables, the separation of simple and more complex Statecharts seems reasonable for the dependent variable *awarded points*, i.e. the subjective user rating. Further testing shows, that this holds for statistical significant and nearly significant variables.

As they do not differ significantly from each other (a Wilcoxon rank-sum test returns a p value of 0.649, indicating no significant difference), parallel Statecharts are considered a special form of hierarchical Statecharts for all future tests. The dummy variable regression is updated in Listing 7.4 to reflect this change.

Listing 7.4: Dummy variable levels, updated

```
                  higher complexity
simple                            0
higher complexity                 1
```

7.1.4. Wanted and Unwanted Data Correlation

The first step in the analysis was to produce scatterplots of awarded points and needed time in dependency of each independent variable. The scatterplots containing the variable *awarded points* were separated into simple and higher complexity (the scatterplots can be found in Appendix E). Examination of these scatterplots revealed no obvious relationships between the dependent variables and any of the

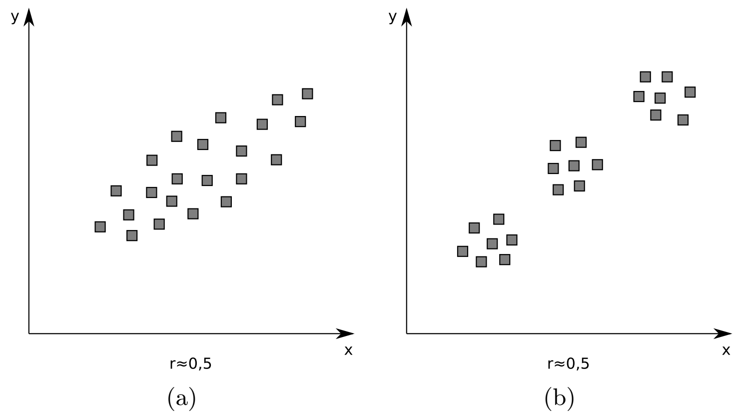


Figure 7.4.: Two plots that show an example of linear correlation between two variables. Both have a correlation coefficient for x and y of about 0.5. However, Subfigure (b) in reality has three independent data sets with a correlation coefficient near zero.

regressors although some relationships were suggested. Specifically, there appeared to be a negative relationship between awarded points and average transition length (TRL) as well as awarded points and the number of intersection faults (IF) at simple complexity. Furthermore, a slight positive correlation between time and the distance to a normal line (all states included, D_{NA}), can be seen.

Correlation matrices were generated from the collected data. This helps to inspect the connection between user preference (respective time needed to understand a given Statechart) and the variables under investigation. The entries in these matrices are correlation coefficients.

The correlation coefficients alone might be ambiguous, as shown in Figure 7.4. If the data from the experiment is used without distinction between different layouts and complexities, the data might look like Subfigure 7.4b. The correlation coefficient may fail to describe the data correctly if for example the correlated values are clustered. This was ruled out by reviewing the scatterplots of the different variables. The partitioning of complexities took care of this matter in all existing cases.

While a strong correlation of independent variables with our dependent variables (awarded points and time needed) is good, correlations between the independent variables is not, as it cannot be said specifically which of the correlated variables caused the effect apparent in the dependent variable under observation. The effect of correlated independent variables has to be considered when combining the different metrics into a single model. Therefore, this will be discussed in the corresponding section.

To formally define when a correlation is declared to be present, the following hypotheses are formulated:

- *Null hypothesis, H_0*: There is no significant correlation between the tested

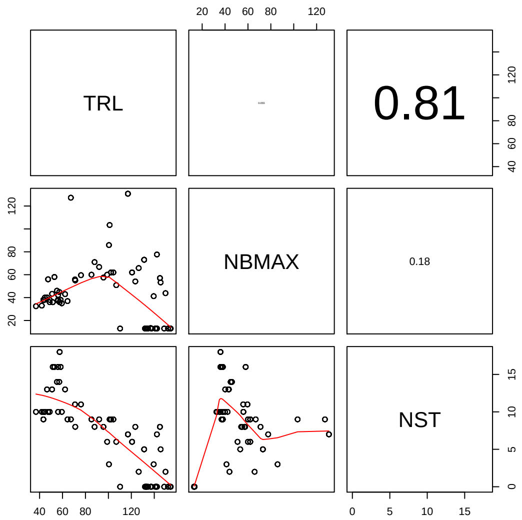


Figure 7.5.: Example of a correlation matrix: The main diagonal line contains the different variables which were tested for bivariate correlation. The upper triangular matrix contains Spearman's correlation coefficients at the intersection of the two tested variables. Greater coefficients are represented by bigger numbers. The lower triangular matrix contains scatterplots at the intersection of the two plotted variables. A regression line is shown in the scatterplots. The scales for the scatterplots are placed on either side of the matrix for spacing reasons. This placement is specified in the plotting function and cannot be changed.

variables.

- *Alternative hypothesis,* H_1: There is a significant correlation between the tested variables.

The correlation coefficient were tested with a level of significance $p = 0.05$, which means the level of confidence is 95 percent (i.e. the probability that H_0 is rejected when H_0 is false is at least 95 percent, which is statistically acceptable). For a sample size of 19 (the number of participants) and $p = 0.05$ the threshold for accepting the null hypothesis is 0.4555 [12].

The correlation between dependent and independent variables is shown in Table 7.1. The matrices generated for the correlations between the independent variables are given in Appendix D. An exemplary correlation matrix is shown in Figure 7.5. Notice the strong linear correlation between the average transition length (TRL) and the number of straight transitions ($\mathrm{N_{ST}}$) in the Statechart, which causes the high correlation coefficient seen in the upper part of the matrix.

Other work simply correlates the different metrics with a dependent variable and records the observations. From the results, assumptions about the effect of these variables are made. All metrics are essentially examined separately. This work takes a closer look at the independent variables. Furthermore, it is a goal of this work to study the relations between the metrics. With these observations, a composed model of various metrics might explain the user rating even better.

The table shows a noticeable difference between simple and higher complexity Statecharts in subjective user rating as well as in objective user rating. No significant variable appears in more than one column. Still, the representation of each dependent variable with a single model is possible.

Again, *dummy variable regression* is used to combine the different complexities of the subjective rating into one model. As noted before, one can use the dummy variable as a switch to turn different parts of the regression equation on or off. As the independent variables behave very different when complexity levels are concerned, one has to describe the change in intercept as well as the change in slope of the model. To include different slopes for different variables, the dummy variable equation has to be updated:

$$y = \alpha + \gamma d + \left(\sum_{i=1}^{n} (\beta_i + \delta_i d_i) \cdot x_i \right) + \epsilon$$

Now, the dummy variable d not only affects the intercept, but the slope as well. This is represented in the equation with the coefficient δ. Therefore, it is possible to include both, simple and higher complexity Statecharts, in the same model for subjective rating.

The correlation tests in Table 7.1 only show the isolated correlation coefficient of an independent variable with the observed dependent variable. However, another test is needed to decide whether the variable is still significant when the complexities are combined. Furthermore, quadratic influences can be seen in the plots. These influences can be tested in linear regression by adding squared terms to the equation. To find the significant components for the complete model, it has to be decided which metrics to include. Each metric is tested in a separate linear model with each of the dependent variables. From this it can be concluded which metrics have a significant impact on the users' rating in a combined complexity model. To decide if there is an influence, the significance and the adjusted r^2 are considered. If there is more than one alternative for a metric, the one with the most significant effect in the model is chosen.

7.2. Analysis of Individual Aesthetic Criteria

The primary objective is to gain insight into the influence of various Statechart aesthetics on the user rating. A secondary objective is to combine these criteria to form a model which describes the observed effects. If such a model would fit the data good enough, it could be used to predict the user rating of future Statecharts. This would prove beneficial for the automatic generation of a Statechart layout.

Table 7.1.: Spearman's correlation coefficients for combinations of dependent and independent variables. Significant correlations are shown in boldface.

Metric Name	**awarded points simple complexity** r	**awarded points higher complexity** r	**needed time all complexities** r
TRL	0.0995	**-0.5415**	-0.0739
log.WHR	**0.4759**	-0.0712	-0.1444
SU_S	0.4466	0.0564	-0.2018
SU_T	0.4466	-0.2063	**0.5553**
SU_A	0.4466	-0.0162	-0.014
P_I	0.0126	-0.2342	-0.1051
P_F	**0.4908**	0.0022	-0.0162
NB_{AVG}	-0.0753	0.1946	-0.133
NB_{MIN}	-0.2827	-0.0157	-0.2814
NB_{MAX}	-0.0295	0.2535	-0.189
D_I	-0.2684	-0.1711	0.3949
D_M	-0.3191	-0.1707	**0.5385**
D_{NA}	-0.3174	-0.1163	**0.5427**
D_{NS}	-0.3174	-0.1737	**0.5179**
D_{NR}	-0.3174	-0.1394	**0.4598**
N_S	NA	0.002	**0.612**
N_{SS}	NA	0.002	**0.612**
N_{HS}	NA	0.002	**0.612**
IF	-0.4284	0.2352	0.2264
IF_{TN}	-0.3276	-0.2218	-0.0016
IF_{TT}	**-0.5341**	-0.1942	0.0379
IF_{TL}	-0.1595	0.2451	0.1898
IF_{LL}	**-0.6036**	0.2463	0.1827
FL	-0.175	-0.2959	-0.0219
N_T	NA	0.0107	**0.6018**
N_{ST}	0.0662	**0.4736**	0.2507
N_{PT}	0.088	-0.4378	0.0789
N_{SPT}	-0.1711	0.1778	0.1728

As work published about layout aesthetics for Statechart is sparse, there are no given layout metrics for Statechart aesthetics. This was the cause for the development of the metrics in Chapter 4. To investigate these, a general strategy is followed:

Given a set of data points, a linear regression is utilized to calculate a best fit for a straight regression line. If a quadratic correlation shows in the variable's scatterplots, the independent variable is squared and also added to the model to adapt the regression line. The regression coefficients are taken from a linear regression model given by the statistic software and displayed as an equation for a regression line. If more than one alternative of a metric is reviewed, only the best fitting metric is explained in detail. However, the adjusted $r^2$of the alternatives is stated for comparison purposes.

If there are correlations between the independent variable under observation and other independent variables, they are discussed in the later part of each variable's section. After each of the metrics is investigated, a multivariate regression model is built. The multivariate linear regression is a linear regression with more than one independent variable.

7.2.1. Transition Length

The goal of this metric is to find out whether the transition lengths of a Statechart influence the user rating. It is expected that the users prefer shorter transition lengths as they did so in experiments regarding graph aesthetics (Coleman and Parker [14]). As far as understanding a Statechart is concerned, shorter transition lengths might help to track the activation of states. However, very short transitions could be counterproductive, as states are not readily discernible if placed too close to each other (Davidson and Harel [18]).

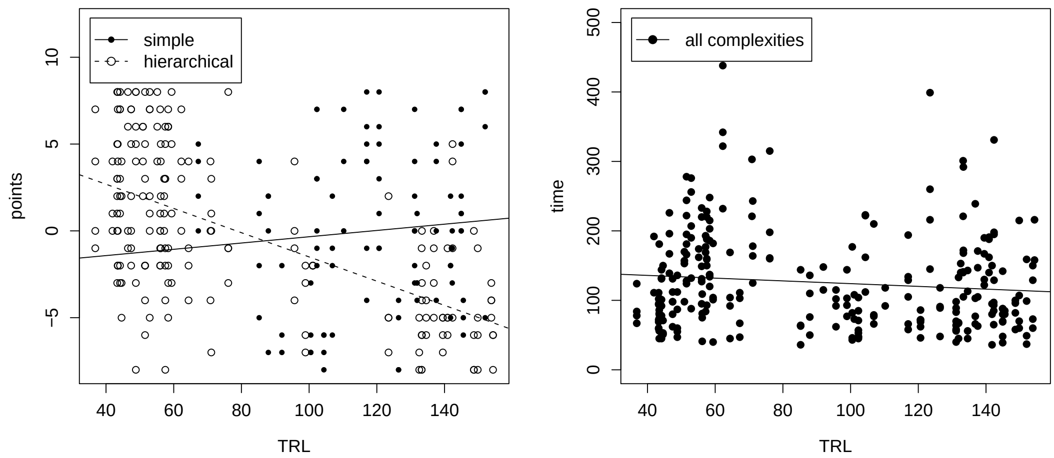
To find out if the transition length has a significant influence on the user rating, the independent variable TRL was tested against the dependent variables points and time.

To test for a significant correlation, two simple linear regression models are calculated. However, controlling for complexity, another term has to be added: the dummy variable mentioned before, encoding the complexity.

The linear model reveals no unexpected results. The transition length is only significant in higher complexity Statecharts. The model returns a quite large adjusted r^2 value of 0.234 with $p = 0$. The following equation represents the linear model:

$$\text{points} = -2.147 + 7.624 \cdot d + (0.018 - 0.088 \cdot d) \cdot \text{TRL}$$

The linear model for the dependent variable points shows a good linear fit (see Figure 7.6a for a plot of the model function). This is consistent with the regression line seen in the scatterplots (see Appendix E), which shows an almost linear relation between the average transition length and the awarded points. The result indicates that in simple Statecharts the average transition length is not a factor for the subjective user rating (or maybe there was not enough variance of transition lenghts).



(a) Points as a function of TRL, at different complexities

(b) Time as a function of TRL

Figure 7.6.: Two scatterplots that shows user ratings in dependence of average transition length. The lines represent linear model functions.

In higher complexity Statecharts, which already burden the user with more components, longer average transition lengths receive bad ratings. The reason for this could be the growing disorientation in the already complex Statecharts.

The second linear model for the dependent variable time shows no significant correlation between the time needed to understand a Statechart and its average length of transitions (see Figure 7.6b for a plot of the model function). This has been expected, as the original scatterplot showed a nearly horizontal regression line, indicating no relation between the two variables. As the metric is nearly significant with $p = 0.0626$, the linear model plot is shown here. The regression line is given by:

$$\text{time} = 143.82 - 0.198 \cdot \text{TRL}$$

A rather strong correlation can be seen (correlation coefficient of 0.81) between this variable and the number of straight transitions. This can be explained by looking at the more complex hierarchical Statecharts. The states are more clustered in Statecharts of higher complexity. As they have more states and more transitions, the average length of a transition is shorter than it is in Statecharts of simple complexity. The same holds true for polyline transitions, although the correlation is weaker (correlation coefficient of 0.58). Last, a notable correlation with the Statechart flow is apparent (correlation coefficient of 0.55). It seems that Statecharts with short average transition lengths possess smaller angles of directional change between incoming and outgoing transitions. However, as noted above, Statecharts with small average transition lengths tend to be ones of higher complexity. A reason might be the relatively linear construction of many Statecharts of higher complexity.

7.2.2. Width to Height Ratio

The general shape of a Statechart seems to have an influence on the user preference. By looking at the ratio between width and height, it might be possible to find out if the user prefers square or oblong Statecharts.

Again, the linear regression models are fitted in *R*. This time, the logarithmized WHR is tested, since the original WHR contains logarithmic data. In contrast to the correlation coefficient in Table 7.1, the ratio is now significant in both complexities for the subjective user rating. The adjusted r^2 is 0.09543, $p = 0$. A quadratic correlation can be seen in the scatterplot for points and log.WHR, so the squared width to height ratios are added to the model (shown as log.WHR^2 in the equations), testing for a quadratic influence. This raises the significance, as well as increasing the adjusted r^2 value to 0.105. The increased value indicates a better fit. The equation for the regression line is given by the returned coefficients as:

$$\begin{aligned} \text{points} &= -2.557 + 3.198 \cdot d \\ &\quad +(3.869 - 8.796 \cdot d) \cdot \text{log.WHR} \\ &\quad +(6.453 - 10.417 \cdot d) \cdot \text{log.WHR}^2 \end{aligned}$$

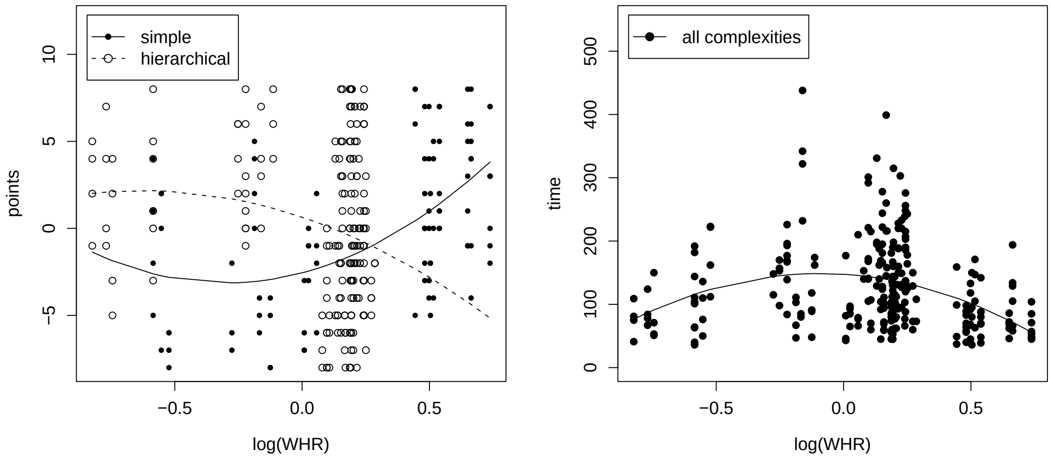
The model for the dependent variable time containing log.WHR is also significant if a squared term is added. The adjusted r^2 is 0.116, with a probability $p = 0$. The coefficients are used to construct the regression equation:

$$\text{time} = 147.50 - 24.73 \cdot \text{log.WHR} - 134.68 \cdot \text{log.WHR}^2$$

The fitted models for the two dependent variables can be seen in Figure 7.7.

Regarding the subjective user rating, the quadratic fit indicates that users prefer their simple Statecharts rather oblong. The lowest points were awarded to Statecharts with a ratio of about 0.5, Statecharts which were narrower or wider received better ratings. For complex Statecharts, the preference seems to have changed to charts with a very low ratio of 0.25. However, the only Statecharts with this kind of ratio were the charts of Linear Layer Layout (LLL) design (the Statechart layouts are shown in Appendix B). The correlation may stem from the sheer number of Statecharts with a width to height ratio of about 2. As almost every other layout shared this ratio, the lower ratings from Alternating Dot Layout Backwards (ADBL), Alternating Linear Layout (ALL), and Arbitrary Layout (AL) have an effect on the good ratings of the ADL, making the narrow charts seem more attractive.

A ratio close to one seems to lessen the understandability. Most time needed to understand a Statechart was seen in Statecharts of ratios 0.75 to 1.25. This further encourages the theory that oblong Statechart are easier to understand. The placement on a straight line might be a possible explanation, see Subsection 7.2.6.



(a) Points as a function of log.WHR, different complexities shown

(b) Time as a function of log.WHR

Figure 7.7.: Scatterplots that show user ratings in dependency of width to height ratio. The lines represent the regression model functions.

Correlation with other independent variables:
There is a correlation between log.WHR and the space usage metrics SU_S and SU_A with $r \approx 0.6$. A possible explanation is found in the type of Statechart. A ratio below 1 indicates a Statechart with a smaller width than height. This is usually found in Statecharts in the LLL style. These Statecharts all have small states, leading to a low space usage compared to Statecharts of layouts ADL, ADBL, and ALL.

7.2.3. Usage of Available Space

This metric was created to find an optimal ratio between the area occupied by states and the Statechart area. If a Statechart is dense, it gets hard to see what is important. On the other hand, it might be a waste of space if the Statechart is wide and sparse.

This is the first aesthetic criterion measured with alternative metrics. The SU_S and SU_A metrics try to describe the occupation of the Statechart with the smallest drawing units. The SU_T metric takes a different approach. It assumes that users perceive the space delimited by hierarchical states as entirely occupied, thus adding their area to the space taken up by states on the top level.

To decide which metric gives the best model fit, three different linear models are constructed for each dependent variable. As the metrics do not differ from each other at simple complexity, the intercept and slope are the same for all three models at base level. Without squared terms, the model explaining the awarded points with the used space when considering only topmost states (metric SU_T) seems to be the most significant (adjusted r^2 0.05774, $p = 0$). This is consistent with the correlation table (Table 7.1), where it fared best. However, the relation between the used space and the subjective rating seems to be quadratic. A model including quadratic terms using the $\mathrm{SU_A}$ definition of the metric has an higher adjusted r^2 value of 0.0982 ($p = 0$) and will be used in the linear regression. The coefficients gained from the linear regression model indicate the following equation:

$$\begin{aligned} \text{points} \quad = \quad & -15.15 + 31.394 \cdot d \\ & (1.94 - 4.348 \cdot d) \cdot \mathrm{SU_A} \\ & (-0.054 + 0.138 \cdot d) \cdot \mathrm{SU_A}^2 \end{aligned}$$

The results for the linear model explaining the needed time with metric $\mathrm{SU_T}$ gives a surprisingly high adjusted r^2 value of 0.3389 with $p = 0$. However, the strong correlation between time and $\mathrm{SU_T}$ seems to be an effect of intercorrelation between $\mathrm{SU_T}$ and the complexity of the Statechart. A strong correlation between $\mathrm{SU_T}$ and the number of transitions as well as the number of states can be seen. It seems logical that the time needed to understand a Statechart increases with the complexity of that Statechart.

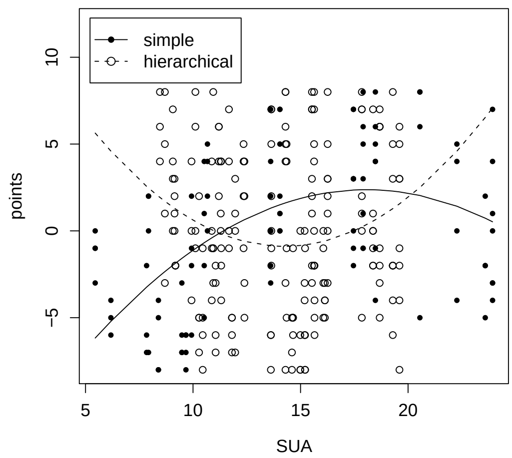
The $\mathrm{SU_T}$ metric does not seem to be a good way to describe the space usage. If the $\mathrm{SU_T}$ model is dismissed, the next best fit is the $\mathrm{SU_S}$ model. The correlation between $\mathrm{SU_S}$ and the time used is almost linear. The model has an adjusted r^2 value of 0.0613 and $p = 0$. The linear model returns the coefficients for the regression line:

$$\text{time} = 160.301 - 3.451 \cdot \mathrm{SU_S}$$

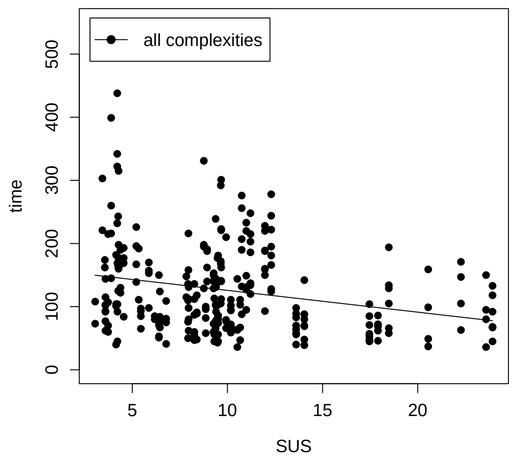
The slope might be irritating. It indicates that Statecharts with a low space usage need more time to understand than those with more occupied space. Intuitively, one associates more states with a higher space usage, which is technically correct. However, the space usage metric gives the percentage of used space. The Statecharts with more states (hierarchical Statecharts) actually have a lower usage of Statechart space. This stems from the usage of hierarchical states, which need a lot of drawing space, but are not counted in the calculation. This leads to a large Statechart area in comparison to the number of states. It seems that this metric is also correlated with the complexity and might not be representative for the time needed.

The model fits are displayed in Figure 7.8. Subfigure 7.8a indicates an optimal space usage of about 20 % for simple complexity Statecharts, whereas Statecharts of higher complexity receive the lowest ratings at 15 %. Their rating rises with lower space usage, indicating that the inclusion of white space is important. The rise in awarded points towards higher space usage should be regarded with caution, as the rating is only interpolated for percentages beyond 20 %.

The three different variants of this metric are naturally correlated. Only one can be used in a linear model at the same time. Other correlations include the distance to a straight line, which is heavily correlated at simple complexity (with Spearman's correlation coefficient r between 0.78 and 0.83), the number of transitions with $\mathrm{SU_T}$,



(a) Points as a function of SU_A at different complexity levels



(b) Time as a function of SU_S

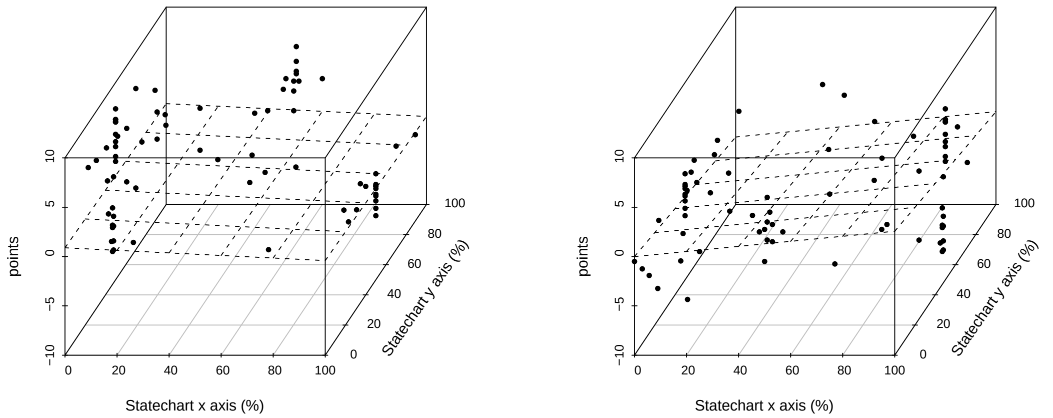
Figure 7.8.: Two scatterplots that show user ratings in dependency of the used Statechart space.

$r = 0.91$, and the number of simple states (N_{SS}) with SU_T ($r = 0.92$). This is expected, as the highest number of states is with the charts of highest complexity, which in turn implies a large hierarchical state, taking up a large amount of Statechart drawing space. Furthermore, the number of intersection faults IF is strongly correlated with a correlation coefficient of 0.78. This is because of the correlation between N_S and N_T, which is almost completely linear. The high number of transitions causes a rise in intersection faults. A correlation with the number of states would seem logical, but cannot be seen in the correlation matrix for metric SU_A and SU_S. With this amount of correlation, this metric would be a bad candidate for the composite metric.

7.2.4. Placement of Initial and Final States

It is assumed that the ideal position for an initial state is in the upper left corner and the ideal position for the final state is at the bottom right of the Statechart as proposed in Chapter 3. To verify this, the positions of both were measured and are now related to the user preference.

Figure 7.9 shows the placement of initial and final states together with the awarded points. A regression plane shows the gradient in both figures. The figures support the hypothesis: The upper left corner of a Statechart seems to be a preferred position of the initial state. The second figure indicates that users prefer a placement of the final state in the lower right corner.



(a) 3D scatterplot depicting the rating of initial state placement in a Statechart.

(b) 3D scatterplot depicting the rating of final state placement in a Statechart

Figure 7.9.: Rating of initial and final state placement, displayed in a 3D scatterplot. The grid depicts a regression plane through the data points. The z axis represents awarded points.

The correlation table indicates $\mathrm{P_I}$ to be insignificant. This is confirmed by the linear model (see Figure 7.10). The only significance can be found in the position of the final state. The coefficient for the intercept is not significant in higher complexities. However, contrary to the correlation table, the placement of the final state seems to have an effect on the awarded points in higher complexities. The adjusted r^2 value is 0.1038, with $p = 0$.

This gives the equation

$$\text{points} = -4.028 + 1.693 \cdot d + (0.042 - 0.021 \cdot d) \cdot \mathrm{P_F}$$

The linear model for time shows no significant influence of the placement of either state on the objective user rating. The time needed to understand a Statechart seems not to depend on the position of either initial or final state.

The insignificance of the initial state placement is unexpected. If one compares only the ADL and ADBL charts, an advantage in the subjective user rating can be seen for the ADL charts. The ADL places the initial state at the left border of a Statechart, in contrast to the ADBL which places it at the right. However, the advantage of top left initial state placement does not seem to be significant for general Statechart layout, although a tendency towards higher ratings could be seen in Subfigure 7.8a.

At higher complexity levels, the placement of the initial state is correlated with the usage of available space in the $\mathrm{SU_S}$ and $\mathrm{SU_A}$ metric ($r = 0.62$ resp. 0.65). Another correlation can be seen with the $\mathrm{NB_{AVG}}$ and $\mathrm{NB_{MIN}}$, returning a correlation coefficient of $r = 0.70$. However, this can be accounted to a few data points that are

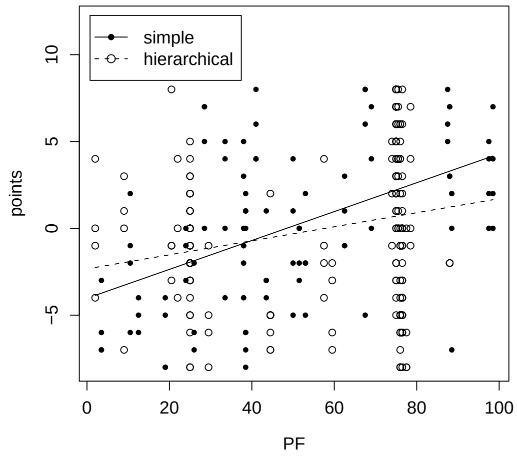


Figure 7.10.: A scatterplot that shows points in dependency of the final state placement. The lines represent linear model functions at different complexity levels.

separated from the rest (see the correlation matrices in Appendix D). The placement of the final state does not seem to be significantly correlated with any other metric. However, slight correlations can be seen with the number of transitions (N_T) and the number of label–label intersection faults (IF_{LL}).

7.2.5. Distances Between Node Borders

The metrics NB_{AVG}, NB_{MIN}, and NB_{MAX} evaluate the space between a state or connector border and its nearest neighbor (not to be confused with the meaning of neighbor in graphs). The distance indicates whether a Statechart is dense or spare. It would seem that a Statechart is easier to read if there are not as much parallel lines in direct vicinity of a state. Also, state borders which are not immediately recognizable as such may be mistaken for transitions or vice versa.

The data gives a significant model for NB_{MIN}, in both dependent variables points and time.

The subjective rating model returns an adjusted r^2 value of 0.02494 with $p = 0.01775$. The NB_{MAX} metric returned a higher adjusted r^2. However, the NB_{MIN} metric was chosen, as it is significant in all complexities, whereas the NB_{MAX} metric was only significant in higher complexities. NB_{AVG} was not significant in any complexity. The linear regression line is given with the following equation:

$$\text{points} = 2.659 - 3.063 \cdot d + (-0.089 + 0.156 \cdot d) \cdot \text{NB}_{\text{MIN}}$$

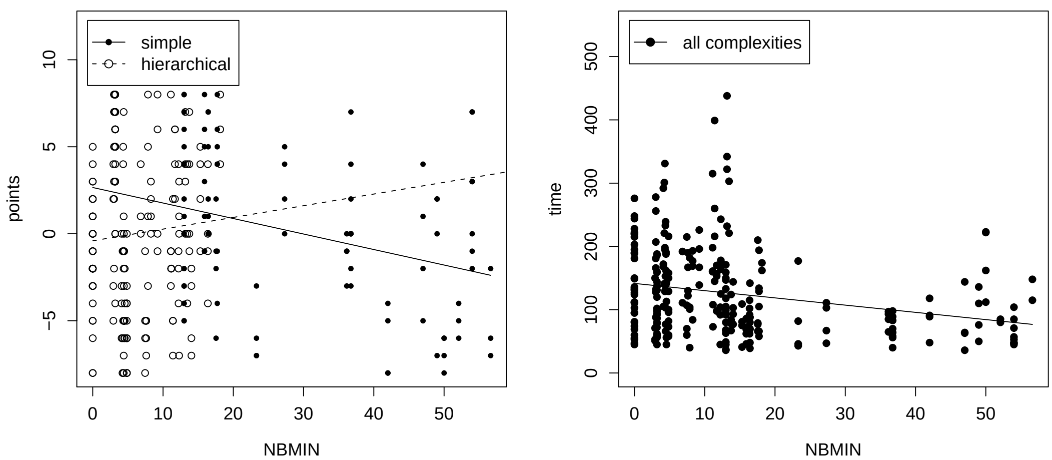
Which gives a descending slope for simple complexity Statecharts and an ascending slope for Statecharts of higher complexities. Users seem to dislike widely spaced

Statechart, if they are relatively simple. In higher complexities, the number of states makes it harder to separate the individual components. Therefore, added space improves the perception and in turn affects the rating.

The linear model for the time needed is also significant. With an adjusted r^2 value of 0.05837 ($p = 0$), it exceeds the other NB metrics. The coefficients for the regression line form the equation

$$\text{time} = 141.542 - 1.143 \cdot \text{NB}_{\text{MIN}}$$

This indicates that less time is needed for the understanding of a Statechart with a higher minimum node distance. This confirms the aesthetic criteria 3.1.9. The "white space" in a Statechart has an influence on the understandability. More white space seems to lessen the time needed to understand a Statechart. An upper bound to this can not be estimated, as the Statecharts under observation all contained a reasonable amount of white space. However, it is expected that a large amount of white space is detrimental to the understandability. The model functions are shown in Figure 7.11.



(a) Points as a function of NB_{MIN} at different complexity levels

(b) Time as a function of NB_{MIN}

Figure 7.11.: Two scatterplots that show user ratings in dependency of distance to nearest node border. The lines represent linear model functions.

As noted in the sections above, NB_{MIN} and NB_{AVG} are correlated with the placement of the initial state and the SU_{A} and SU_{S} metrics. Furthermore, there seems to be a correlation with the number of transitions. At simple complexity, the number of polyline transitions (N_{PT}) is correlated with all three variants of this metric. The correlation coefficient is 0.7 for each. At higher complexities the correlation is moved to the number of spline transitions (N_{SPT}). Although NB_{MIN} is no longer highly correlated with N_{SPT}, the correlation coefficient of NB_{MAX} and NB_{AVG} are increased to 0.83 and 0.79 respectively. An explanation is the increasing number of lines in a Statechart, which naturally shortens the distances to the next node border.

7.2.6. Distance of States to Straight Lines

The log.WHR metric confirmed that users prefer Statechart of oblong shape, in accordance to the Aesthetic 3.3.5. Maybe that is because the resulting linear placement facilitates the tracking of consecutive states. This metric is investigated to verify that the placement of states on straight lines has an effect on the user rating.

The subjective rating does not seem to be influenced significantly by the positioning of states. A significant influence can be seen at simple complexity for all five variants of this metric. However, the adjusted r^2 of the best model fit is only 0.05282 for the D_M metric ($p = 0.0003$). At higher complexity, no significant effect can be seen. The coefficients returned by the statistics tool are used in the equation

$$\text{points}_{simple} = 3.09 - 0.102 \cdot \mathrm{D_M}$$

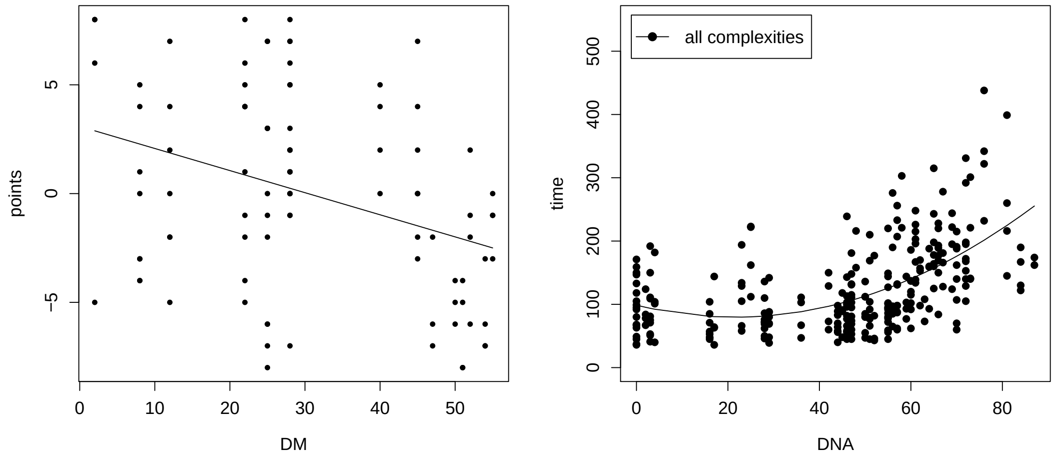
The correlation with the time needed to understand a Statechart shows a completely different picture. Every metric is highly significant in the linear regression, the best fit being the D_{NA} metric. This is consistent with the correlation in Table 7.1, except for the D_I metric. However, D_I is almost significant in the table. The D_I metric showed the least goodness-of-fit of the models. As the visual analysis of the data's scatterplot showed a quadratic influence, a squared term was added to the model. This increased the adjusted r^2 to 0.3115, the probability decreased to 0. The equation for the regression line is given as:

$$\text{time} = 98.665 - 1.763 \cdot d \cdot \mathrm{D_{NA}} + 0.041 \cdot \mathrm{D_{NA}}^2$$

The model fit is visualized in Figure 7.12.

The plot visualizes nicely the expected relation between time needed and the placement of states on a straight line. The closer the states stay to a imaginary line, the better the user can follow the sequential action. The model function shows a slight rise towards a complete zero deviation. This may stem from the fact that the Statecharts with all states on a single line are almost exclusively of ALL design. This design has its own deficiencies, such as transitions that are hard to follow. However, they are still better rated than 50 % of all Statecharts. If one follows the idea of states placed on lines further, even non-straight lines come to mind (such as a circular placement of states). However, this is left to further research.

These five variants of the distance to a straight line metric are closely related to each other. At simple complexity, the three *normal line* variants are identical. Other significant correlations exist with the usage of Statechart space and the number of transitions. At simple complexity, a significant correlation (coefficient higher than 0.78) is seen. At higher complexities, this only holds for the SU_T metric. The



(a) Points as a function of D_M at simple complexity

(b) Time as a function of D_{NA}

Figure 7.12.: Two scatterplots that show user ratings in dependency of distances to straight lines. The lines represent linear model functions.

coefficient is mostly lower, between 0.62 and 0.85. The highest correlation is the D_{NR} metric. It seems that Statecharts with a high space usage of topmost states are the ones with distributed simple states in their hierarchical states. This is the case with the layouts LLL and AL. These were drawn by hand, so the layout algorithm of Kiel Integrated Environment for Layout (KIEL) seems to be more economic with the Statechart space. The borders of hierarchical states are drawn closer around the contained states. Furthermore, states are not placed arbitrary inside the hierarchical state, which leads to a better D_{NR} rating.

7.2.7. Number of States and Hierarchy Levels

This relates directly to the level of Statechart complexity. The number of simple states and the number of hierarchical states of each complexity level is counted. With these, the different complexity levels are compared against each other. Three options are examined: only simple states, only hierarchical states and the total number of states as the combination of both.

It is not possible to generate a model to describe the relation between awarded points and the number of states in a Statechart. The reason is found in the experiment design: Each complexity level has a fixed number of states. As the whole range of possible ratings is found on each complexity level, no conclusions can be drawn. Figure 7.13 illustrates this fact.

The time is highly correlated with the number of simple states in a Statechart. This is expected, as part of the Statechart complexity can be described by the number

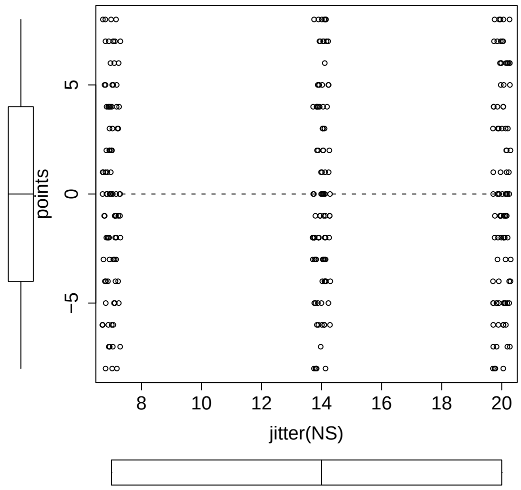


Figure 7.13.: A scatterplot that shows points in dependency of the number of states. The data is jittered on the x axis to show overplotted data points.

of states in the chart. The increase in time consumption seems to be non-linear. A model containing a squared term gives an excellent fit with an adjusted r^2 of 0.4324. The linear model coefficients are used to construct the following equation:

$$\text{time} = 222.349 - 31.971 \cdot \mathrm{N_{SS}} + 1.871 \cdot \mathrm{N_{SS}}^2$$

The model function is shown in Figure 7.14.

This metric is highly correlated with the distance to a straight line metrics (correlation coefficient between 0.58 and 0.8). The conclusion drawn from this is that Statecharts with more states have a higher average distance to a straight line, which seems reasonable. A look at the scatterplots reveals that the different complexity levels each have a distinct cluster of points. Higher complexity Statecharts are generally rather quadratic in layout, as there are more states to distribute and connect with transitions. Also, the "alternating" layout strategies, which alternate between horizontal and vertical layout, tend to produce a layout that increases the distance to a straight line in Metrics $\mathrm{D_I}$, $\mathrm{D_M}$, $\mathrm{DN_A}$, and $\mathrm{DN_S}$. This was compensated for in Metric $\mathrm{DN_R}$ which was the only distance to a straight line metric not strongly correlated with the number of states. Another very high correlation can be seen with the $\mathrm{SU_T}$ metric, as already described in Subsection 7.2.3.

7.2.8. Intersection of Components

Labels have to be clearly recognizable and readable, transitions should be unambiguous to grasp the meaning of a Statechart. The impact of four different influences on the readability of Statecharts is researched:

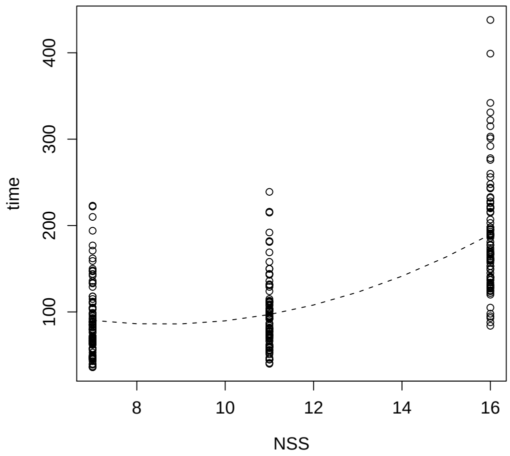


Figure 7.14.: A scatterplot that shows needed time in dependency of the number of simple states. The line represents the linear model function.

- Transition crossing state: It is difficult to follow the transition through the state, as the state interrupts the eye tracking the transition (see Subfigure 6.24a).
- Transition crossing transition: The path of two or more transitions crosses, blending the transitions into another. This makes it impossible to tell which transition continues on which side (see Subfigure 6.24b).
- Transitions crossing/touching labels: If a transition touches a letter, it can change the appearance of that letter. Is the letter in the upper part of Subfigure 6.24c a l or a t, the letter in the lower part of the figure an I or a T?
- Labels crossing labels: If a label is superimposed on another label, it is hard to discern the single letters (see Subfigure 6.24d).

The individual categories have been put into linear models. The total number of intersection faults is correlated significantly with the subjective user rating. The linear model returns an adjusted r^2 value of 0.08838, $p = 0$. Every coefficient is highly significant. The equation

$$\text{points} = 2.829 - 4.306 \cdot d + (-0.615 + 0.947 \cdot d) \cdot \text{IF}$$

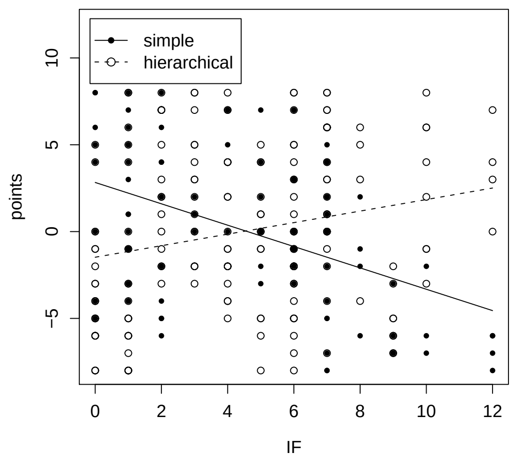
is gained from the linear regression model coefficients.

As seen before in other metrics, the resulting regression line has an ascending or descending slope based on the Statechart complexity. The model for simple complexity Statecharts indicates a decrease in points as the number of intersection faults increases. This was the expected behavior. However, Statecharts of higher complexity are rated better if they posses more intersection faults (see Figure 7.15a for a graphical representation of the regression model). The behavior of the higher complexity linear model could be explained by the few outliers with a very good rating, but plenty intersection faults. They are caused by Statecharts with Linear Layer Layout which generally received good subjective ratings.

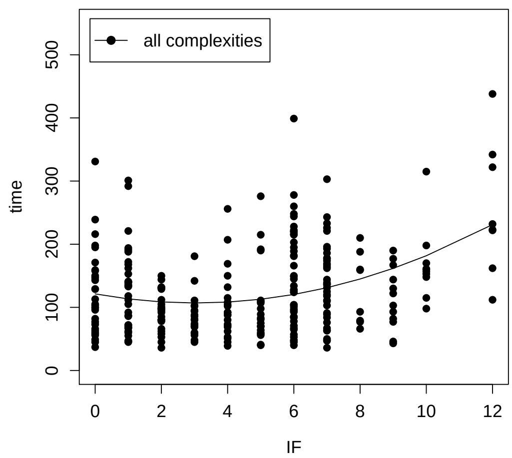
The linear regression model for the objective user rating shows an increase in the time needed to understand a Statechart if there are more intersection faults. The regression line is given as

$$\mathrm{time} = 121.29 - 9.438 \cdot \mathrm{IF} + 1.548 \cdot \mathrm{IF}^2$$

which gives a quadratic regression line, shown in Figure 7.15b, indicating that users have no problems with a few intersection faults. The higher the number of intersection faults, the more time is needed to compensate for the Statechart's shortcomings. The quadratic nature of the regression line indicates that high numbers of intersection faults are far worse than small numbers.



(a) Points as a function of IF at different complexity levels

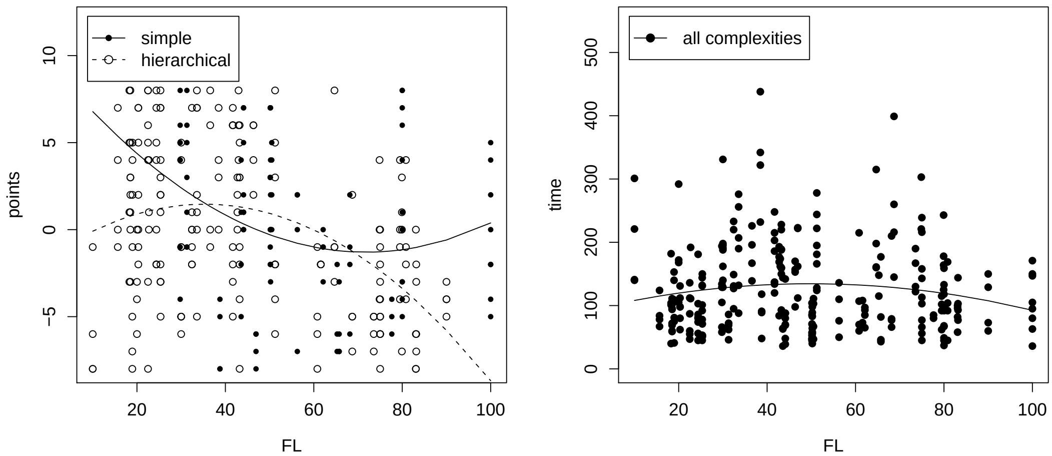


(b) Time as a function of IF

Figure 7.15.: Two scatterplots that show user ratings in dependency of total intersection faults. The lines represent linear regression model functions.

Taking a more detailed look at the specific fault categories, the number of label–label crossings is the most significant. Its adjusted r^2 is 0.1324, $p = 0$. Second to $\mathrm{IF}_{\mathrm{LL}}$ is the number of transition–transition crossings $\mathrm{IF}_{\mathrm{TT}}$. The intercept of this model is not significant in higher complexities, lowering the adjusted r^2 to 0.09996 for this metric. The transition–label crossing affects only higher complexities, although it is nearly significant in simple Statecharts, $p = 0.054428$. The crossing of nodes by transitions is only significant in simple complexity Statecharts. This can be explained by the low number of node–transition crossings in higher complexity Statecharts.

Looking at the correlations between the various intersection faults and other metrics, a strong negative correlation can be seen for IF and IF_{TL} with the usage of Statechart space metrics. They were already discussed in Subsection 7.2.3. For the regression model of time, there are no significant correlations, except for NB_{AVG}. This correlation can be ignored, as the influence of NB_{AVG} is insignificant on the dependent variables.



(a) Points as a function of FL at different complexity levels

(b) Time as a function of FL

Figure 7.16.: Two scatterplots that show user ratings in dependency of Statechart flow. The lines represent linear model functions.

7.2.9. Directional Statechart Flow

Directional Statechart flow describes the amount of directional change the eyes have to follow while reading a Statechart. This is considered important for the reason that it is easier to follow a line of states going into the same direction, without having to search for the next state at an unpredicted location.

As a quadratic relation is seen in the scatterplots for this metric, a squared term is added to the model. The linear regression model returns an adjusted r^2 of 0.1208, $p = 0$. The metric is significant in all terms. With the coefficients gained in the regression, the following equation is constructed:

$$\begin{aligned} \text{points} &= 9.606 - 11.163 \cdot d \\ &\quad +(-0.304 + 0.475 \cdot d) \cdot \text{FL} \\ &\quad +(0.002 - 0.005 \cdot d) \cdot \text{FL}^2 \end{aligned}$$

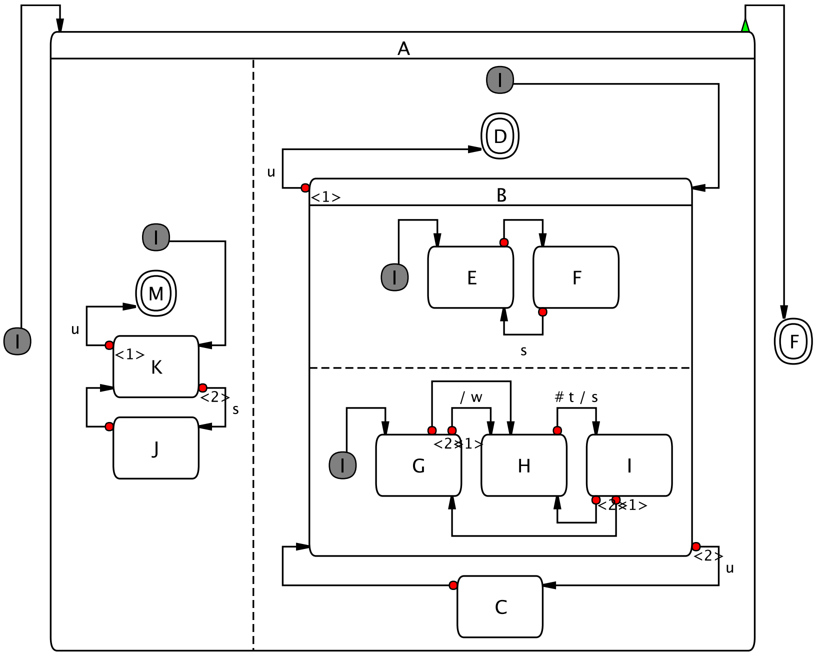


Figure 7.17.: A Statechart with a "good flow" and low subjective ratings

The model functions plotted in Figure 7.16a show a general decrease in rating for Statecharts with a high directional change, as expected. The increase in rating for simple Statecharts with a flow value over 70 is explainable by the type of Statecharts that returns such a high value for the flow metric.

The linear term in the model describing time in dependency of the Statechart flow is only nearly significant. However, the squared term is significant at the 0.05 level. This justifies the inclusion of the coefficient for the linear term in the following equation:

$$\text{time} = 93.211 + 1.657 \cdot \text{FL} - 0.017 \cdot \text{FL}^2$$

The adjusted r^2 value for this model is 0.009675, indicating a small influence on the objective user rating. This can be seen in Figure 7.16b, where the model function is shown.

The participants seem to dislike hierarchical Statecharts with very low flow metric ratings. This might be a fault of this metric. Its design incorporates only the angle of incoming and outgoing transitions for a state. The directional change of the transition between two states is not measured. This leads to a high rating for Statecharts which look like the one shown in Figure 7.17. One can see that almost every outgoing transition has an incoming transition directly in line. This leads to the good flow rating. However, the high amount of directional change makes the transition hard to follow. This could be a reason for the low rating of Alternating Linear Layout Statecharts.

The flow metric is only correlated with the average transition length at higher complexities and with NB_{MAX} at simple complexity. As NB_{MAX} is only significant at higher complexities, this should be no problem. However, the correlation coefficient of 0.55 with TRL has to be kept in mind when composing a composite model.

7.2.10. Number of Transitions and Transition Bends

A transition is easier to follow if it has fewer bends. Straight transitions are therefore the easiest to follow. It is expected that Statecharts with (short) straight transitions are easier to understand.

The total number of transitions is consistent at each complexity level. As the partition in simple and higher complexity Statecharts reduces the amount of transition differences even further, the total number of transitions is not a good indicator for the subjective user rating. Furthermore, the this would constitute a structural metric instead of a layout metric. To gain more variability, the individual number of straight, polyline and spline transitions per Statechart is investigated, as these represent layout decisions. Of the three types, the number of straight transitions is the most significant indicator for the subjective rating of a Statechart. Users seem to prefer Statechart with more straight transitions. However, the significance is only given for Statecharts of higher complexity. With such small sample sizes, one has to be careful with the interpretation of the linear model. This metric suffers from the limitations of the data. As the type of transitions seems to be correlated with the layout of the Statecharts, the affinity of the participants to a specific layout can be a factor in this metric, adding unwanted correlations. Also, the use of absolute numbers makes this metric dependant on the complexity of the Statechart. The use of a relative measure might have been better suited.

The coefficients calculated in the regression model lead to the equation

$$\text{points}_{hierarchical} = -3.167 + 0.315 \cdot \mathrm{N_{ST}}$$

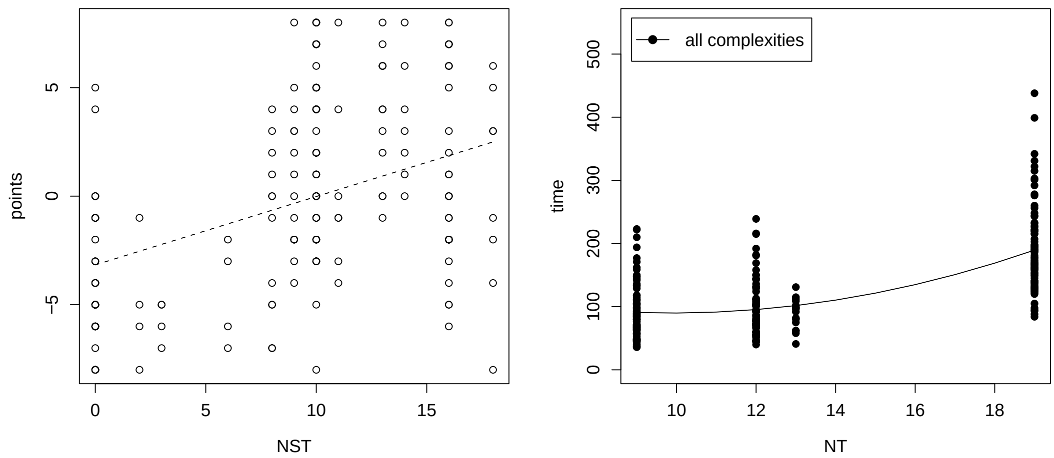
Even though the significance is rather low, a very good adjusted r^2 value of 0.1575 is returned, with a p numerical zero. See Figure 7.18a for a graphical representation

The model for the dependent variable time shows a high significance in the number of transitions. The adjusted r^2 of 0.4023 is very high. This value increases even more with the inclusion of a squared term. The adjusted r^2 value for this linear model with included squared term is 0.4304 (see Figure 7.18b). The linear model function is given as

$$\text{time} = 205.407 - 23.457 \cdot \mathrm{N_T} + 1.191 \cdot \mathrm{N_T}^2$$

by the model coefficients.

The number of transitions is correlated with many other metrics. The most prominent correlation can be seen between the total number of transitions (N_T) and the SU_T metric, indicating that a high usage of available space by topmost states correlates with a high number of transitions. However, as the number of transitions and the SU_T metric are correlated with the number of states (N_S), the correlation is not unexpected. The number of transitions and number of states can be used as



(a) Points as a function of N_{ST} at higher complexity

(b) Time as a function of N_T

Figure 7.18.: Two scatterplots that show user ratings in dependency of the number of transitions. The lines represent linear model functions.

a complexity measure. This explains the correlation between both and accounts for the high correlation coefficient of 0.81 with TRL, as the transition length is smaller in higher complexity Statecharts. Other correlations can be seen with the number of intersection faults. The more transitions are in a chart, the more intersection faults they can cause.

7.3. Composition of Multivariate Regression Models

After testing each metric independently, the ones to be included in the final model had to be chosen. The data from the individual metrics is collected in Table 7.2. The previous testing removed insignificant variables and chose between the different alternative metrics.

The approach used for variable selection is similar to the feature selection process *minimal-redundancy-maximal-relevance (mRMR)* described by Peng et al. [44]. One of the most popular approaches to feature selection is to select the features with the highest relevance to the dependent variable. Relevance is usually characterized in terms of correlation. This is known as *maximal relevance*. In feature selection, it has been recognized that the combination of individually good variables does not necessarily lead to a good model fit. Even if the variables are significant individually, the combination of two significant variables could result in them being no longer significant, if they are correlated too strongly. Therefore, *minimum redundancy* is

Table 7.2.: Comparison of significance levels for bivariate models

Metric	awarded points p value	awarded points Adjusted R^2	needed time p value	needed time Adjusted R^2
TRL	0^{**}	**0.234**	0.0626	0.009196
log.WHR	0^{***}	**0.105**	0^{***}	**0.116**
SU_S	0^{*}	0.07603	0^{***}	0.0613
SU_T	0^{***}	0.05774	0^{***}	**0.3389**
SU_A	0^{***}	**0.0982**	0.7334	-0.005153
P_I	0.1754	0.006947	0.2786	0.002108
P_F	0^{***}	**0.1038**	0.653	-0.002973
NB_{AVG}	0.2898	0.004233	0^{***}	0.04287
NB_{MIN}	0.0178^{***}	**0.02494**	0^{***}	**0.05837**
NB_{MAX}	0^{**}	0.04843	0.0236^{***}	0.01589
D_I	0.001^{*}	0.04578	0^{***}	0.121
D_M	0^{*}	**0.05282**	0^{***}	0.2881
D_{NA}	0.006^{*}	0.03258	0^{***}	**0.3115**
D_{NS}	0.003^{*}	0.03945	0^{***}	0.2784
D_{NR}	0.006^{*}	0.03365	0^{***}	0.217
N_S	—	—	0^{***}	0.4324
N_{SS}	—	—	0^{***}	**0.4324**
N_{HS}	—	—	0^{***}	0.4324
IF	0^{***}	0.08838	0^{***}	**0.1276**
IF_{TN}	0^{*}	0.05756	0.982	-0.003729
IF_{TT}	0^{***}	0.09996	0.1791	0.003018
IF_{TL}	0.002^{**}	0.04046	0^{***}	0.04582
IF_{LL}	0^{***}	**0.1324**	0^{***}	0.06389
FL	0^{***}	**0.1208**	0.1008	0.009675
N_T	—	—	0^{***}	**0.4304**
N_{ST}	0^{**}	**0.1575**	0^{***}	0.1553
N_{PT}	0^{**}	0.1132	0.0544	0.01006
N_{SPT}	0.0587^{***}	0.01575	0^{***}	0.05722

Boldface values mark the highest r^2 for models with significant terms

* Only significant in simple complexity

** Only significant in higher complexities

*** significant in all complexities

considered. Essentially, the inter-variable correlation is minimized to obtain a better model fit.

Generally, the idea is to build the model by additive composition

$$f(S) = \sum_{i=1}^{n} c_i M_i(S)$$

with S being the Statechart under observation, and c_i the coefficients that determine the influence of metrics M_i, and n the number of included metrics.

Expressed as an equation according to the example in Section 7.1, this would be

$$\begin{aligned} \text{user rating} &= \alpha + d\gamma \\ &\quad +(\beta_1 - d\delta_1) \cdot M_1 \\ &\quad +(\beta_1 - d\delta_1) \cdot M_2 \\ &\quad \vdots \\ &\quad +(\beta_{n-1} - d\delta_{n-1}) \cdot M_{n-1} \\ &\quad +(\beta_n - d\delta_n) \cdot M_n \end{aligned}$$

with d denoting the dummy variable, which is set to 0 for simple complexity Statecharts and set to 1 for Statecharts of higher complexity. α is the intercept, β the individual coefficient of simple complexity term, whereas γ and δ denote the same two for higher complexity.

To select the metrics suitable for a combined model, the correlation matrix for each dependent variable is consulted (see Figure 7.5 for an example of a correlation matrix). To find out which variables are correlated, the correlation coefficients in the upper triangular matrix are considered. In such a matrix, all variables are compared against each other, albeit bivariate (meaning that only two are compared at a time).

The correlation matrices are a good starting point to select variables for the model. However, as they only address bivariate correlation, the models generated with the information from the matrices have then to be tested for multivariate correlations.

This is done with the analysis of so called Variance Inflation Factors.

Definition 7.3.1 (Variance Inflation Factor)
The Variance Inflation Factor (VIF) *expresses the degree to which collinearity among the independent variables degrades the precision of an estimate. Its square root tells us how much the standard error is increased, compared to the standard error of uncorrelated independent variables. Typically, a VIF value greater than 10 is of concern (Myers [42]). Some authors set the critical value as low as 2.5 [2], others as high as 40 [1].*

7.3.1. Subjective User Rating (Awarded Points)

The selected metrics highlighted in Table 7.2 are evaluated to build a multilinear regression model. Significant in simple and higher complexities are the metrics TRL, log.WHR, $\mathrm{SU_A}$,$\mathrm{P_F}$, $\mathrm{NB_{MIN}}$, $\mathrm{D_M}$, $\mathrm{IF_{LL}}$, and $\mathrm{N_{ST}}$.

Table 7.3.: Variance inflation factors for complete composite subjective user rating model

Metric	VIF
TRL	52.575
log.WHR	56.018
log.WHR^2	78.725
$\mathrm{SU_A}$	355.815
$\mathrm{SU_A}^2$	181.193
$\mathrm{NB_{MIN}}$	22.73
$\mathrm{D_M}$	236.685
$\mathrm{P_F}$	6.767
$\mathrm{IF_{LL}}$	8.966
$\mathrm{N_{ST}}$	1487.907
$\mathrm{N_{ST}}^2$	3416.545
$\mathrm{TRL}_{hierarchical}$	144.623
$\mathrm{log.WHR}_{hierarchical}$	40.224
$\mathrm{log.WHR}^2_{hierarchical}$	61.867
$\mathrm{SU}_{\mathrm{A}hierarchical}$	4370.872
$\mathrm{SU}^2_{\mathrm{A}hierarchical}$	1463.381
$\mathrm{NB}_{\mathrm{MIN}hierarchical}$	8.108
$\mathrm{D}_{\mathrm{M}hierarchical}$	488.691
$\mathrm{P}_{\mathrm{F}hierarchical}$	15.851
$\mathrm{IF}_{\mathrm{LL}hierarchical}$	8.067
$\mathrm{N}_{\mathrm{ST}hierarchical}$	2391.651
$\mathrm{N}^2_{\mathrm{ST}hierarchical}$	4184.154

If all of these are put together into a linear model (with the appropriate squared terms, if applicable), the resulting adjusted r^2 value is 0.477. This is a good model fit. However, the result is too much influenced by the correlations between the independent variables (see Table 7.3 for the variance inflation factors).

Therefore, the number of variables has to be reduced. Based on the correlation matrix and the inflation factors, $\mathrm{N_{ST}}$, $\mathrm{SU_A}$ and $\mathrm{D_M}$ are removed. This does not significantly impact the adjusted r^2, as its value only decreased by 0.09.

Table 7.4 shows the coefficients of the involved metrics. The metrics used are:

- TRL (Average transition length)
- log.WHR (Logarithmized width to height ratio)
- $\mathrm{NB_{MIN}}$ (Minimum distance to the nearest node border)
- $\mathrm{P_F}$ (Placement of the final state)
- $\mathrm{IF_{LL}}$ (Number of label–label intersection faults)

The correlation matrix for simple complexity shows a rather strong correlation between the width to height ratio and the number of label–label intersections. However,

Table 7.4.: Model coefficients: Awarded points as a function of selected independent variables.

Metric	**Coefficient**
(Intercept)	-0.105
TRL	-0.013
log.WHR	1.468
log.WHR^2	4.45
$\mathrm{NB}_{\mathrm{MIN}}$	-0.056
P_{F}	0.025
$\mathrm{IF}_{\mathrm{LL}}$	-0.994
$(\mathrm{Intercept})_{hierarchical}$	1.513
$\mathrm{TRL}_{hierarchical}$	-0.074
$\mathrm{log.WHR}_{hierarchical}$	1.867
$\mathrm{log.WHR}^2_{hierarchical}$	-5.077
$\mathrm{NB}_{\mathrm{MIN}\,hierarchical}$	0.235
$\mathrm{P}_{\mathrm{F}\,hierarchical}$	0.011
$\mathrm{IF}_{\mathrm{LL}\,hierarchical}$	1.018

Table 7.5.: Variance inflation factors for composite subjective user rating model containing selected variables

Metric	**VIF**
TRL	17.495
log.WHR	7.914
log.WHR^2	7.157
$\mathrm{NB}_{\mathrm{MIN}}$	4.52
P_{F}	5.078
$\mathrm{IF}_{\mathrm{LL}}$	6.341
$\mathrm{TRL}_{hierarchical}$	30.66
$\mathrm{log.WHR}_{hierarchical}$	9.158
$\mathrm{log.WHR}^2_{hierarchical}$	9.055
$\mathrm{NB}_{\mathrm{MIN}\,hierarchical}$	2.549
$\mathrm{P}_{\mathrm{F}\,hierarchical}$	12.301
$\mathrm{IF}_{\mathrm{LL}\,hierarchical}$	6.011

if composed into the linear regression model, an analysis of the variance inflation factor shows that the multivariate correlation between these two variables is acceptable. The higher factor of P_{F} in Table 7.5 is also not of concern. This factor is the product of a non-significant term in the model. These terms are discarded when the dummy variables are set to simple or higher complexity. A more concerning issue remains with the TRL metric. The high values indicate a correlation with one of the other variables. However, even after removing the variables one by one, the VIF stays greater than 10. As the removal of the TRL metric degrades the model far more than the slightly bigger error made when keeping the variable, the VIF of 30 is accepted. All of the above metrics are displayed as an equation:

$$
\begin{aligned}
\text{points} \quad = \quad & -0.105 + 1.513 \cdot d \\
& +(-0.013 - 0.074 \cdot d) \cdot \mathrm{TRL} \\
& +(1.468 + 1.867 \cdot d) \cdot \mathrm{log.WHR} + (4.45 - 5.077 \cdot d) \cdot \mathrm{log.WHR}^2 \\
& +(-0.056 + 0.235 \cdot d) \cdot \mathrm{NB}_{\mathrm{MIN}} \\
& +(0.025 + 0.011 \cdot d) \cdot \mathrm{P}_{\mathrm{F}} \\
& +(-0.994 + 1.018 \cdot d) \cdot \mathrm{IF}_{\mathrm{LL}}
\end{aligned}
$$

The composed multilinear regression model is tested with the actual Statecharts that were subject to examination in the aforementioned experiment. The calculated response is then related with the subjective user rating. Figure 7.19 shows the data returned by the model. To put the value into context, the return value of the model and the spread of subjective user rating is shown. The average rating awarded to

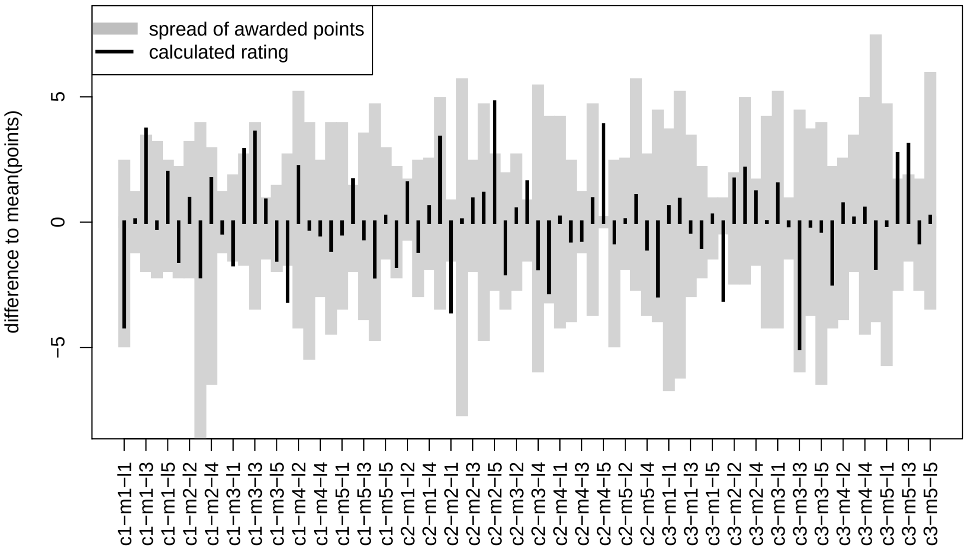


Figure 7.19.: A plot that shows the difference between points calculated by the multilinear regression model and the actual points that were awarded by participants of the experiment. The grey bars depict the spread of subjective user rating, the dashed line indicates the average rating.

each Statechart was placed on the base line. The grey bars protruding in vertical direction from the base line indicate the spread between maximum and minimum rating for each Statechart. It can be seen that the model returns ratings that are inside the range of the subjective user ratings. The divergence from the line through the origin shows that the model does not ideally approximate the average ratings given. However, the difference between calculated and average rating of a Statechart is often less than 2.5 points. The average difference between these two (calculated as the mean of the absolute difference) is 1.48 points. The results can certainly be used to indicate a preference in user rating. The maximum deviation occurred at the rating of a parallel Statechart laid out according to the ALL. Statechart “c3-m3-l3” was misjudged by 5.03 points. The reason for this could be the ambivalent ratings that the Statechart received. This is in contrast to its neighbor “c3-m3-l4”, whose rating was exceptionally well estimated and which received uniform ratings.

Another cause could be aesthetics that were excluded from the model because they were not significant in the context of all Statecharts. However, they might be relevant to the participant examining a Statechart. The Statechart “c2-m2-l5” is such a case. It received very low ratings, even though the model results describe it as an average chart. The data collected from this chart is inconspicuous, however, a visual

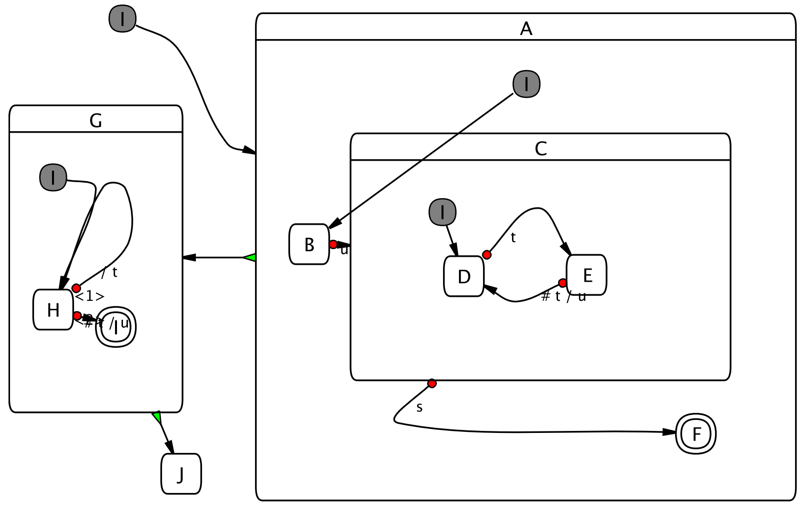


Figure 7.20.: A Statechart which was rated average by the constructed formula and which received poor subjective user ratings. Note the number of intersection faults.

examination reveals that the Statechart contains a high number of intersection faults, most notable is a transition that crosses a state. As this happened very sparsely in the complete data set, its linear model was not significant at higher complexities (see Figure 7.20 for a representation of this Statechart).

It is concluded from these observations, that the difference in rating of Statecharts that diverge from the base line is caused by Statecharts that were either not uniformly rated or that possessed negative (or even positive) traits that were not included in the final model.

7.3.2. Objective User Rating (Time)

From the data given in the correlation table for the objective user rating and all complexities, the following metrics can be chosen for the overall time model: log.WHR, $\mathrm{SU_S}$, $\mathrm{NB_{MIN}}$, $\mathrm{D_{NA}}$, $\mathrm{N_{SS}}$, IF, and $\mathrm{N_T}$ (and their squared terms, if applicable). The adjusted r^2 for a model containing all metrics is 0.4169. However, only one term is significant in this model, as the correlation between the variables influences the goodness-of-fit.

The number of metrics has to be reduced. $\mathrm{N_{SS}}$ is at least strongly correlated with three other metrics. Even though the adjusted r^2 value is rather high, the VIF analysis shows the number of simple states and the number of transitions to be strongly correlated with other factors (see Table 7.6). Relying on the VIF analysis, the metrics $\mathrm{N_T}$ and $\mathrm{N_{SS}}$ are removed from the model. This results in a decrease of the adjusted r^2, which is 0.3898 for the reduced model.

Almost all terms are now significant or nearly significant. The only insignificant

Table 7.6.: Variance inflation factors for original model

Metric	**VIF**
log.WHR	3.071
SU_S	6.074
NB_{MIN}	3.881
D_{NA}	4.652
N_{SS}	140.514
IF	2.044
N_T	120.840

term is log.WHR. The equation for these terms is

$$\begin{aligned} \text{time}_1 \;=\; & 75.977574 \\ & -18.584 \cdot \text{log.WHR} \\ & +2.316 \cdot \text{SU}_\text{S} \\ & -0.79 \cdot \text{NB}_\text{MIN} \\ & -1.008 \cdot \text{D}_\text{NA} + 0.03 \cdot {\text{D}_\text{NA}}^2 \\ & -7.192 \cdot \text{IF} + 1.272 \cdot \text{IF}^2 \end{aligned}$$

As the adjusted r^2 was lowered by the removal of the metrics N_T and N_{SS}, a possibility was found to counteract the effect by adding the metric N_{ST} (number of straight transitions) to the model. The metric was chosen because it does not correlate with the terms already in the model. This made the terms SU_S and NB_{MIN} also insignificant, but raised the adjusted r^2 to 0.4154. The significant subset of the available metrics was chosen to model the user ratings:

- D_{NA} (Distance to a normal line through all states),
- IF (Total number of intersection faults), and
- N_{ST} (Number of straight transitions).

The metrics show only a weak correlation with each other. A linear model encompassing the three (and their quadratic terms, if applicable) returns an adjusted r^2 of 0.4202.

$$\begin{aligned} \text{time}_2 \;=\; & 108.906 \\ & -0.79 \cdot \text{NB}_\text{MIN} \\ & -2.084 \cdot \text{D}_\text{NA} + 0.042 \cdot {\text{D}_\text{NA}}^2 \\ & -19.967 \cdot \text{IF} + 2.011 \cdot \text{IF}^2 \\ & +3.957 \cdot \text{N}_\text{ST} \end{aligned}$$

This is a better fitting model for the objective user rating, even though less terms are used. It seems that the high number of metrics in the first equation was still correlated with each other. Another explanation is that the addition of the good fitting N_{ST} metric compensates the removal of the other metrics.

The multilinear correlation between these variables is calculated via the variance inflation factors. As seen in Listing 7.7, the factors are over 10. As the difference to 10 is not very large, they are considered not harmful.

Table 7.7.: Variance inflation factors for adjusted model

Metric	**VIF**
D_{NA}	12.161985
${D_{NA}}^2$	12.067427
IF	13.764598
IF^2	11.532892
N_{ST}	1.847967

The composed formula is applied to the Statecharts that were used in the experiment. The results are shown in Figure 7.21. As before, the return value of the model and the spread of subjective user rating is shown. The average time needed for each Statechart is shown on the base line. The spread between maximum and minimum rating for each Statechart is shown as a grey vertical bar.

Again, differences can be seen between the objective user rating and the calculated time that an average person would need to understand one of the examined Statechart. Mostly, these differences are less than 40 seconds. The average absolute difference to the actual ratings is 27.13 seconds, which is slightly better than the difference calculated by the model that was proposed first (which has a mean difference of 27.73 seconds).

7.4. Evaluation of the Observations

The proposed models seem to fit the Statecharts used in the experiment. Almost half the calculated ratings differ less than one point from the average user rating. 80 % of the calculated ratings are within a deviation of 2.5 points (which is the median for the deviation of real awarded points, meaning that 50 % of the ratings have less and 50 % have more than this deviation from the average rating). For the needed time, a similar result can be seen. One third of the calculated ratings differ less than 10 seconds, 56 % less than 20 seconds from the average time needed. If the limit is raised to 40 seconds (the median for the deviation of the objective user rating from the average needed time), more than 81 % of the calculated ratings are included.

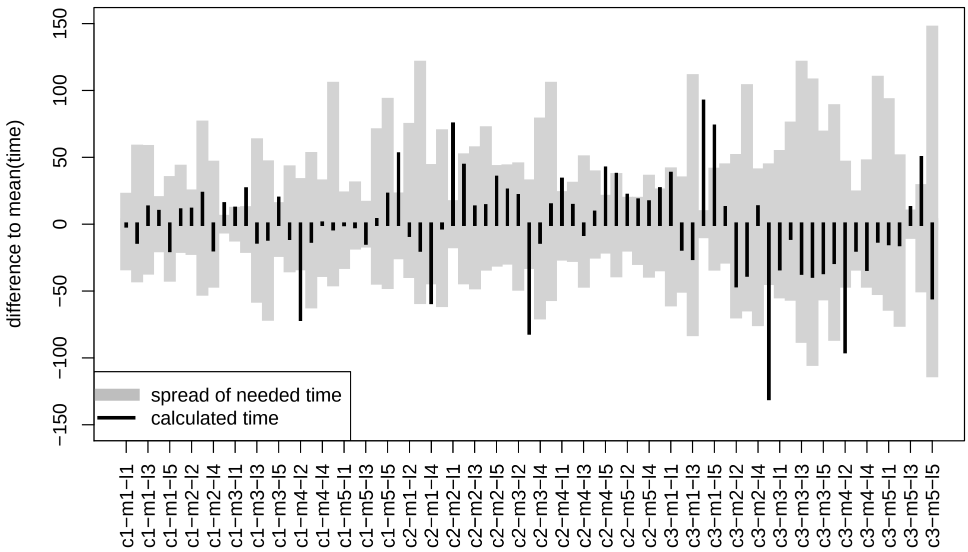


Figure 7.21.: A plot that shows the difference in time calculated by the multilinear regression model and the actual times the participants of the experiment needed to complete their assignment. The grey background depicts the spread of objective user ratings.

8. Analysis of Statechart Modeling Processes

This chapter deals with the process of creating and modifying a Statechart. The particularities of the modeling process were described in Chapter 5. The goal is to find the aspects that influence the modeling of a Statechart. Therefore, various aspects of the modeling process are researched, for instance the relation between keystrokes and mouse clicks. Another measure are the errors made while creating or modifying a Statechart.

As described in Chapter 5, three different editors were used in the experiment: A commercial What You See Is What You Get (WYSIWYG) editor, and the two editors incorporated in the KIEL framework, a macro-based editor and a text editor (see Figures 5.3, 5.4, and 5.5 for screenshots of the three tools).

The concept of WYSIWYG is known from a lot of tools, not only in editing. To achieve an objective, one has to move the mouse pointer to many locations. This requires 2D coordination of the hand and eyes. Compared to this, the text editor can be used in a sequential way. This implies a speed advantage for keystrokes. However, if the user is required to perform actions on random locations, a lot of key input is needed to reach this locations and complete the given task.

The aim of the macro-based editor was to speed up the editing process by reducing mouse movement to a minimum. Almost every command that required the user to select a function from a menu or tool bar and execute actions in the drawing space has been assigned a key macro. This leads to less time spent selecting tools, but has to be learned by the user. For the same reason the beginners were excluded in the analysis of aesthetic criteria, they were removed from the modeling dataset (learning effects and same sample size).

8.1. Mouse Clicks and Key Strokes

To get a comparable measure of the Statechart creation and modification process, the amount of actions needed to complete the given tasks was recorded. It turns out that it is not feasible to use the individual amounts of keystrokes and mouse clicks, as the user can often substitute one for the other, e.g. use four keystrokes, where it would only take two mouse clicks. Almost all participants had their own favorite approach to model the Statechart. Some preferred the keyboard, others utilized the mouse as much as possible. To find a conversion factor between the four recorded event types (mouse clicks, mouse drags, keystrokes, and key macro usage), the time needed to complete a given task was used. A statistical model was calculated to represent the time needed by the amount of individual actions.

Basically, the statistical software solves a linear system of equations

$$\begin{aligned}
\text{time needed}_{\text{real},c_1} &= x_1 \cdot \text{mc}_{c_1} + x_2 \cdot \text{md}_{c_1} + x_3 \cdot \text{ks}_{c_1} + x_4 \cdot \text{km}_{c_1} \\
\vdots \qquad &\vdots \qquad\qquad\qquad\qquad \vdots \\
\text{time needed}_{\text{real},c_n} &= x_1 \cdot \text{mc}_{c_n} + x_2 \cdot \text{md}_{c_n} + x_3 \cdot \text{ks}_{c_n} + x_4 \cdot \text{km}_{c_n}
\end{aligned}$$

to obtain the conversion factor between the four recorded events. The variables mc, md, ks, and km stand for mouse clicks, mouse drags, key strokes, and key macros, respectively. c_1 to c_n indicate the individual cases. Statistically speaking, it takes:

- 2.47 seconds for a mouse click,
- 0.72 seconds for a mouse drag,
- 0.73 seconds for a keystroke,
- 8.21 seconds for a key macro,

or, the other way around, in one second you can:

- click the mouse 0.41 times,
- perform 1.39 mouse drags,
- press a key 1.37 times,
- use a key macro 0.12 times.

The low coefficient seen for key macros might be explained by the time one needs to think of the correct macro. Another explanation might be the area of application for key macros. A copy and paste action sequence requires more planning and thought than 10 sequential keystrokes. Furthermore, a change between keyboard and mouse is particularly frequent with key macros. A key press is about four times faster than a mouse click. This is explained by the time it takes between mouse clicks. The movement from one click target to the next takes time, which is not needed between keystrokes. A special case are double clicks, as they don't need time in between to reposition the mouse. However, the time gain is lost in the statistical average for all mouse clicks.

With the coefficient from the linear equation system, a total number of actions can be calculated from the data recorded. This total number represents the time statistically needed by the participant p to execute all actions:

$$\text{time needed}_{\text{calc},p} = 2.47 \cdot \text{mc}_p + 0.72 \cdot \text{md}_p + 0.73 \cdot \text{ks}_p + 8.21 \cdot \text{km}_p$$

The linear model gives a good fit. Table 8.1 displays the mean of real time taken to complete the task (calculated as: $\text{time needed}_{\text{real},avg} = \frac{1}{n}\sum_{i=1}^{n} \text{time needed}_{\text{real},p_i}$)

Table 8.1.: Comparison of measured time to construct a specified Statechart versus time calculated by linear model

	Average Time Needed	
Tool	Real (measured)	Calculated
WYSIWYG	207.05	208.43
KIEL-macros	173.21	168.63
KIEL-KIT	159.66	159.29

Table 8.2.: Minimum actions needed to create and modify the specified chart

Editor and task	Mouseclicks	Mousedrags	Keystrokes	Macrokeys
WYSIWYG create	39	1	10	0
WYSIWYG modify	16	3	3	0
WYSIWYG total	**55**	**4**	**13**	**0**
KIEL-macros create	32	0	20	6
KIEL-macros modify	9	0	6	3
KIEL-macros total	**41**	**0**	**26**	**9**
KIEL-KIT create	11	5	46	0
KIEL-KIT modify	2	4	22	0
KIEL-KIT total	**13**	**19**	**68**	**0**

as well as the mean of the times calculated with the coefficients gained from linear regression (calculated as: $\text{time needed}_{\text{calc},avg} = \frac{1}{n}\sum_{i=1}^{n} \text{time needed}_{\text{calc},p_i}$).

This is a comparable measure between the three tools. However, not every action performed by the participants is productive. There has to be a differentiation between the actions that lead to the construction of the Statechart and the actions that were not productive, e.g. errors, unnecessary actions and actions to improve the Statechart visually.

Editor Intuitiveness Without going into the details of what constitutes an error (as this will be discussed in Section 8.2), a metric was applied to calculate the non-productive overhead of actions. The minimum number of actions (this was only empirically validated) needed to construct the Statechart specified in the experiment's handout was recorded and is displayed in Table 8.2.

With these numbers, the ratio between the amount of total actions and the minimum amount of actions needed to create a Statechart can be calculated. This gives a measure of the editor's intuitiveness of use. If a user can access the editor's full potential, the ratio would be close to one. The higher the ratio, the higher the discrepancy between the possibilities of the editor and the average user's application of them. The WYSIWYG editor has a ratio of 2.288, indicating that users made more than double the actions needed to complete the specified Statechart. This indicates a lot of potential shortcuts which could be accessed by more experienced users. A better ratio of 1.405 is found with the *KIEL-macros* editor. The experiment subjects used the potential of this editor well, which might be explained by the restricted set of commands available. The textual editor *KIEL-KIT*'s ratio of 2.292 indicates that the users did not use the full set of options available to them. Reviewing the experiment's video recordings, it was noted that the subjects avoided mouse usage. When researching the minimum amount of actions needed, it was found that more mouse usage could reduce the total actions needed. This is especially true if "copy & paste" is compared to copying elements manually by rewriting them. The longer the text to be copied, the more advantage for marking elements with the mouse and pasting them via mouse click.

8.2. Errors Made During Modeling

What is an error? Surely, a mistyped word or term has to be considered erroneous, but what about actions that lead to the same outcome, but require different actions? Is there an ideal creation process, maybe one that requires the least action to generate the wanted outcome?

As mentioned in Subsection 6.3.2, there are different categories for the user actions. The total amount of actions is composed of actions the user made in four categories:

- *productive* actions (actions that lead to the creation of the specified Statechart)
- *error* actions (actions that do not lead to the creation of the specified Statechart and need actions to undo them)
- *unnecessary* actions (actions that do not lead to the creation of the specified Statechart, but need no further actions to undo them)
- *nicefy* actions (actions which make the Statechart visually more pleasing)

The average of time needed per tool, as well as the amount of errors made, can be found in Table 8.3. The ratio of these two gives the mean time between errors. The numbers show a similarity between the WYSIWYG editor and the KIEL-macros editor, with an advantage for the KIEL-macros editor. The KIEL-KIT editor has a higher error rate and subsequently falls behind the other two. The error rate is mostly due to typing errors, as they happened frequently during the textual editing process. These errors are quickly made but also quickly corrected. If the total number of error actions is related to the total number of actions, a measure for the

Table 8.3.: Various editor characteristics

Tool	Avg. Time Needed	Avg. Amount of Errors Made	Avg. Time Between Errors	Ratio Unnecessary to Error Actions
WYSIWYG	207.05	2.18	94.8	2.63
KIEL-macros	173.21	1.55	111.6	2.87
KIEL-KIT	159.66	5.5	29.0	1.18

impact of error actions on the efficiency is gained. This measure is called *inefficiency I* and represented by Modeling Metric 6 in Chapter 4.

The amount of unnecessary actions varied between the tools. The KIEL-macros editor had the most unnecessary actions, amounting to about 31 % of all actions done. There was no difference between creating and modifying. Next, 19.5 % of the actions done in the WYSIWYG editor to create the specified Statechart were unnecessary. This increased to about 25 % during the modification of the Statechart. The least percentage of unnecessary actions were seen in the KIEL-KIT editor, where the unnecessary actions amounted to 14 % of the total actions on average during creation, increased to 17.3 % during the modification part of the experiment. The ratio between the total number of unnecessary actions and the total number of actions is measured by Metric *inefficiency II* (See Modeling Metric 7 in Chapter 4). The inefficiency ratios can be found in Table 8.4.

The high amount of unnecessary actions seen in the editing process with the KIEL-macros editor can be explained by user actions. Watching the experiment's video footage, one can conclude that the process of selecting a state is impeded by the fact that it is necessary to click very accurately on the state border. If the participant misses, he does not always realize that he has to reposition his mouse cursor. It was often seen that the user's growing frustration provoked an excessive amount of mouse clicks, which were recorded as unnecessary actions. Generally, the number of unnecessary actions was higher than the number of error actions. The ratio between both can be found in Table 8.3.

8.3. Modeling Efficiency

Efficiency is defined as the ratio of benefits to costs. Transported to the modeling process, the cost could be translated into the amount of total actions or the time needed to complete the assignment. The benefit would be the amount of productive actions that the subject took or the time taken for these actions. As the time needed for the productive actions is (theoretically) identical to the total amount of actions,

Table 8.4.: Editing efficiency by tool

	Editor		
	WYSIWYG	KIEL-macros	KIEL-KIT
Efficiency	0.64	0.58	0.72
Inefficiency I	0.08	0.11	0.13
Inefficiency II	0.21	0.31	0.15
Inefficiency III	0.07	0.00	0.00

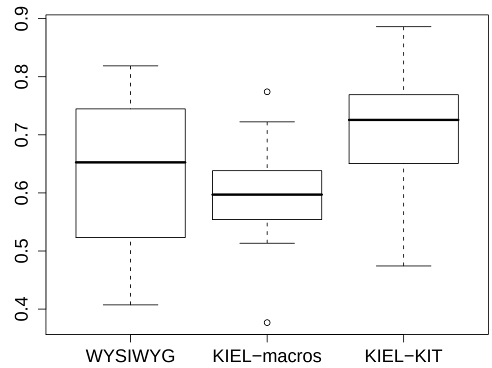


Figure 8.1.: Efficiency spread shown for each tool

either could be chosen.

$$\text{Efficiency, Tool}_i = \frac{\text{Amount of Productive Actions, Tool}_i}{\text{Total Amount of Actions, Tool}_i}$$

The average efficiency is displayed in Table 8.4, the data spread is shown in Figure 8.1. Naturally, the quotient is the same as the percentage shown in Figure 6.29 for productive actions. Together with the ratios inefficiency I and II, the percentage should amount to 100 %. The discrepancy seen with the WYSIWYG editor stems from a number of actions only seen in this kind of editors, called "nicefy" actions (see Section 8.4).

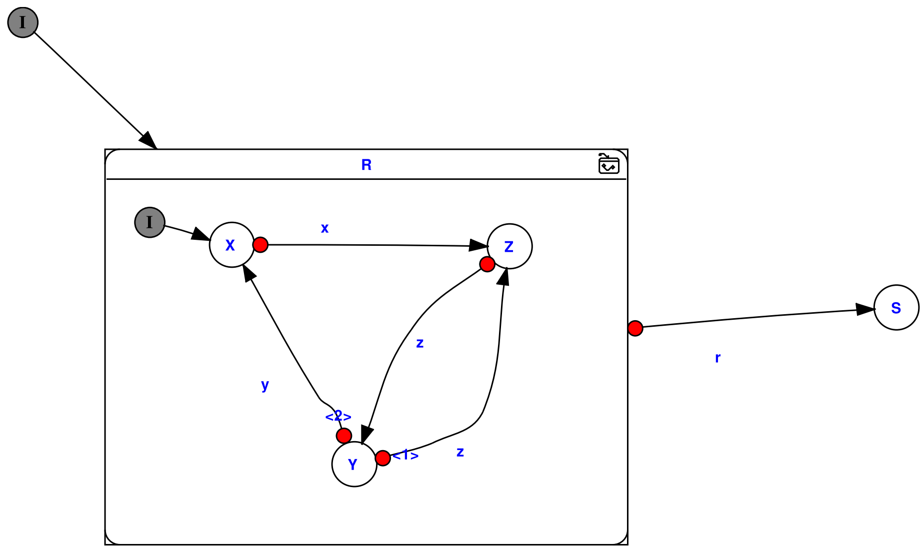
The number of error actions does not hurt the efficiency as bad as the number of unnecessary actions does. With error actions amounting from 8 % to 13 % of the total actions, the editors stay close together. However, the number of unnecessary actions takes up to 31 % of the total actions done with the KIEL-macros editor. Compared to the 15 % of the KIEL-KIT editor, this is more than double the time spent performing unproductive actions.

8.4. Modifications to Improve the Layout

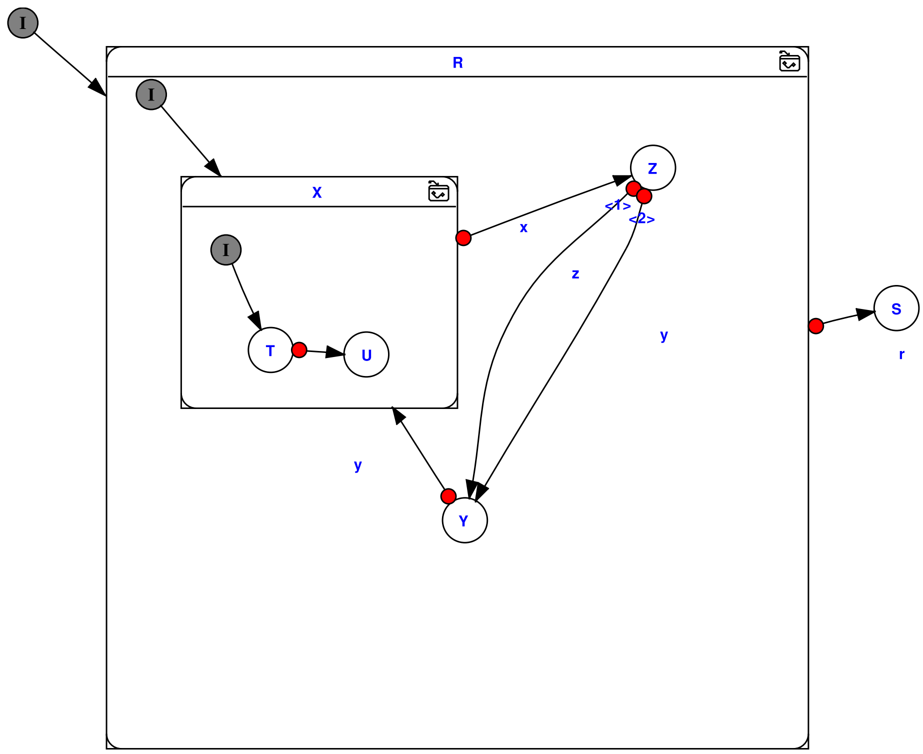
The process of creating or modifying a Statechart in the WYSIWYG editor always includes some actions—called *nicefy* actions here—where components of the Statechart are moved to different locations without changing the structure of the Statechart. This has various reasons: States might be in the way of new states to be added, labels might be unreadable because of crossing transitions, etc.

The data acquisition for this aspect was done as a side-effect of the error action recording, as it could not be decided when a movement of states and/or transition was to be considered erroneous and when it was necessary for the creation process.

An example for nicefy actions can be seen in Figure 8.2. The Statechart shown is the product of a task given to all students who participated in the second experiment.



(a) After Task *Create*



(b) After Task *Modify*

Figure 8.2.: Statechart created and modified with the WYSIWYG editor during the experiment.

In the chart shown in Subfigure (a), a hierarchical state is to be added in place of the simple state X. In order to make room for this hierarchical state, the participant had to move the initial state as well as the states Y and Z. This could have been circumvented by leaving enough space around state X during the creation of the Statechart. The participants used on average 13.2 nicefy actions while creating the Statechart and 14.6 nicefy actions while modifying it. The ratio between nicefy actions and total actions is called *inefficiency III*. Measured with Modeling Metric 8 from Chapter 4, this amounts to 5% of the total actions used to create, and almost 10 % of the actions used to modify the chart. Combined, 7 % of all actions in the WYSIWYG editor were done to improve the layout of a Statechart, as seen in Table 8.4. As explained in Section 4.2, the percentage of nicefy actions is necessary zero for the KIEL-macros editor because there are no components where the layout can be improved. Actions to improve the code layout in the KIEL-KIT editor were not recorded. The 0 % value seen in Table 8.4 for the KIEL-KIT editor is therefore an approximated value, as code improvement actions were infrequent and the total number of actions was very high.

9. Conclusion and Future Work

In this work, aesthetic criteria of Statecharts were rated and transformed into quantitative measures. Significant aesthetic criteria were identified, validated with empirical data, and combined into rating formulas. Two different models were proposed, a preference measurement and a performance measurement. The combination of several criteria allows users of these formulas to generate one overall measure for examined Statecharts. Also the user performance with three different editors was empirically related to editor characteristics. This helps to identify reasons for the user performance. Seen in the editing process using the WYSIWYG editor was that actions to improve the Statechart layout nearly double when a user has to modify an already existing Statechart. This indicates that methods which reduce the visual improvement actions are useful to reduce the total needed actions. Also seen in the results is the commonly known fact that an intuitive user interface reduces the amount of unnecessary actions.

Synthesis

The intuitiveness is not the only desired property of a Statechart editor; an efficient editing process is also wanted. The application of the modeling metrics that were defined in Section 4.2 indicated that the structural editing process has advances in efficiency over the WYSIWYG paradigm that is commonly used. However, a more intuitive interface is needed to access the full capabilities of this approach. The number of unnecessary actions outweighed the number of error actions more than two to one in both approaches with a graphical user interface, indicating a high influence on the efficiency. Other influences that were identified include the number of nicefy actions. The total number of errors should not be used as a measurement for editing performance, as the number of errors made in the textual editor was higher than the number of errors made in the other two editors. Yet, Statechart creation and modification was quicker in the textual editor, denoting a better performance. The reason for this is the nature of errors made. A more detailed look shows the difference: The kind of errors made in the textual editor are mostly typing errors, while the number of errors in the other two editors consist mainly of errors related to adding, modifying or deleting the wrong state. Further research might identify other correlations in the error data, as the collected data is very detailed and had to be condensed for this work.

The detailed data collection offered many opportunities to choose between different metrics. The selected ones fit the observations of user ratings in the original experiment. This indicates that the selection process of aesthetic criteria was conducted correctly.

The dependent variables discussed in this thesis were not correlated, i.e. none could be represented by the other. This indicted that a pleasing layout and a good comprehensibility do not necessarily go hand-in-hand. The separation led to the composition of two different models for the two dependent variables *awarded points* and *needed time*. The aesthetic criteria selected were not all used in the final models, as not all could be verified to have a significant influence on the user rating. Furthermore, there was intercorrelation between some of the significant metrics, reducing the number of usable metrics even more. However, the formulas for the calculation of awarded points and needed time fit the actual user ratings rather well. They offer a possibility to describe the influence of the analyzed Statechart layout aesthetics on the human user.

Encountered Problems

The collected data for numerous aesthetic criteria was meticulously tested and validated. However, even if the collected data is valid and withstands rigorous inspection, it has some flaws. The design of the experiment did not incorporate a strict separation of the independent variables researched in this thesis. This changing of several independent variables at the time leads to correlated data, which in turn reduces the expressiveness of the discoveries. Therefore, the composed model is less conclusive than it would be with data generated for the sole purpose of identifying single aesthetic criteria.

The usage of unspecific data also implies that there can be no null hypothesis - scientific hypothesis testing scheme for the effects of aesthetic criteria on Statechart ratings (which normally would be used for hypothesis testing), as there is no control group. The results can therefore not be gained by a statistical test for significance of difference on two groups of test subjects.

However, even if the data set is not ideal for this thesis, it was possible to extract a lot of information. One has to keep in mind the original source of the data. Furthermore, as the variables were brought together, the intercorrelation between the variables had to be tested, which led to a high number of variables that could not be considered.

It seems that the complexity of a Statechart overshadows all metrics regarding the time that was needed to understand it. Layout has less influence on the understanding of a Statechart than the number of states and transitions. If one looks at the metrics, nothing seems to be uncorrelated with complexity.

Comparing the explanatory value of the objective user rating model with the explanation for the time given by the number of states or number of transitions alone, an advantage for the single metrics can be seen. This seems to indicate that the complexity of a Statechart, as expressed by the number of states and the number of transitions, outweighs the rather special metrics, such as Statechart flow or the usage of Statechart drawing space (although the placement on a straight line was proven to be significant).

The preference of a user towards key-centered or mouse-centered input affects her or his editing speed with the different editors. The low number of participants might have a negative effect on the distribution of preferences.

Findings

This thesis led to a series of findings regarding the aesthetic criteria of Statechart layout. The following list will give a short guide to the creation of "better" Statecharts.

1. *Use Shorter Transition Lengths in Higher Complexity Statecharts*: The research done indicated that shorter transition lengths improve the subjective user rating for higher complexity Statecharts. Simple complexity Statecharts were rated independent of their transition lengths.

2. *Use Straight Transitions*: The use of straight transitions is beneficial to the rating of a Statechart, at least at higher complexity levels.

3. *Include White Space in Your Statechart*: Even if short straight transitions are beneficial to the user rating, don't forget to keep white space in your Statecharts, at least for charts of higher complexity. The results show that users actually prefer less white space in Statecharts of simple complexity, which might be because of the simplicity of design. In higher complexities, this influences the understandability and the rating of a Statechart, so a reasonable minimum distance between state borders should be kept. Too much white space is assumed to be detrimental to the understanding. However, the influence could not be shown in this research, as the data lacked higher node border distances.

4. *Prefer Oblong Statechart Design*: Users prefer oblong Statecharts and so should you. Width to height ratios close to one were shown to lessen the understandability of Statecharts. Rather than drawing square Statecharts, go wide or narrow. The next item encourages this preference even more:

5. *Place States on a Straight Line*: If states are placed on a straight line, it is easier to follow them through a sequence of actions in the Statechart. This makes the Statechart easier to understand. Even better, if they are connected with short, straight transitions! This does not affect the subjective rating of a Statechart, but the next item (also leading to straighter Statecharts) does:

6. *Keep Directional Change Between Consecutive Transitions Low*: This does not influence the understandability much, but makes the Statechart more pleasing to the eye and in turn affects the rating the Statechart receives.

7. *Keep Intersections of Statechart Elements to a Minimum*: As expected, a high number of intersection faults leads to a decline in user rating, at least in simple complexity Statecharts. The number of intersection faults does influence the

understandability of the Statecharts. The results indicate that users have no problem with a few intersection faults. However: The higher the number of intersection faults, the more time is needed to compensate for them.

The following conclusion can be drawn from the above mentioned pointers: Whenever possible, design Statecharts in a sequential way, giving users the idea of a directional flow in the chart. Don't overcrowd a Statechart with states and transitions, just to make it fit on a single page. Use abstraction, if needed, to generate the needed space.

With the identification of significant aesthetic criteria, reasons for the experiment's participants preference of the ADL could be derived. The layout algorithm behind the ADL generates short transition lengths, as it places the states in a sequential manner and avoids backwards transitions. Simple complexity Statechart of ADL design have a high width to height ratio, which was perceived as favorable by the participants. In higher complexity, Statecharts with a high ratio were awarded less points. this was no differentiating feature, as the Statecharts according to the ADL shared their width to height ratio with many other charts. The placement of final states at the right border was rewarded by the participants with a high rating, even if the placement was not always consistent. In the ADL, labels are placed in such a way that they don't intersect each other. As intersecting components degrade the Statechart's rating significantly, their absence gives the ADL an advantage in rating.

The ADL also performed excellent in the understandability testing. The following reasons can be found for its good performance: Of the significant metrics that were not related to the complexity of a Statechart, the distance to a normal line had the best explanation for the needed time. This implies that Statecharts created in a linear fashion are easier to understand. In the experiment, the Statecharts laid out according to the ALL and the LLL, to a lesser extent the ones according to the ADL and the ADBL followed this design. However, the absence of intersection faults (which were present in the LLL)and the use of straight transitions (which were not used in the ALL) favored Statecharts laid out according to the ADL and the ADBL. Although the significance of initial and final state placement could not be verified for general Statechart layout, it might be possible that the reading direction acts in favor of the "left to right" approach seen in the ADL Statecharts and rewards it with better understandability times. This, however, is not always applicable; the aesthetic criteria found may in part only apply to users from a Western culture. Developers from other cultures will need to modify them as appropriate.

The application of the developed models to Statecharts is initially limited to charts that resemble the Statecharts used in the experiment. Industrial Statecharts are usually significantly more complex than the Statecharts analyzed in this thesis. However, all relevant Statechart features, such as hierarchy and orthogonality, were applied. It is plausible that the findings apply to smaller sized hierarchical substates that denote either a hierarchy or concurrency of state machines in industrial Statecharts. As Statechart can be drawn with a high level of abstraction, it is also likely that the findings might apply to large industrial Statechart that are composed in such a way (e.g. composed of a large number of smaller Statecharts with many hierarchy levels).

Not all actions in the creation of a Statechartare productive . Errors and unnecessary actions, as well as actions to improve the visual quality of a Statechart are always part of the design process. The number of error actions does not hurt the efficiency as bad as the number of unnecessary actions does. Error actions amount from 8 % to 13 % of the total actions. The amount of unnecessary actions varied greatly between the analyzed tools. The KIEL-macros editor had the most unnecessary actions (31 %, almost a third of the total number of actions). Next was the WYSIWYG editor. The least percentage of unnecessary actions were seen in the KIEL-KIT editor (15 %). This can be accounted to the intuitiveness of the interface, see below for a proposed improvement in the KIEL-macros editor. Textual editors just don't leave much room for imagination. In graphical editors, the user is tempted to "play" with extra features which, quite simply, is time wasted that could be spent on Statechart creation. Another reason for the better performance of the structure-based editors when modifying a Statechart could be the time spent on the nicefy actions. These affected the time needed to modify a given Statechart with the WYSIWYG editor far worse than the time needed to create a Statechart.

Future Application and Improvement

Two applications for the found metrics present itself: A tool could, on request by a user, apply the metrics to a Statechart and give advice on the lowly rated Statechart layout criteria. Another possibility is the automated application of layout metrics after manual Statechart creation, following a set of rules devised from the described metrics and the analysis of user ratings in Chapter 7.

The first variant implies that the user has complete freedom to draw a Statechart, and the tool he uses could offer assistance when needed. This could be a style-checker which can be selected as a menu item, or an extra window, showing the compliance of the current Statechart with several aesthetic criteria (measured by the found metrics). The checking could be done after each movement of objects in the drawing frame, however it should be easy to turn off and on, so it would not strain the users patience with possible latency between editing actions. This checking could give the user hints on how to optimize the drawing, or even show critical regions in the Statechart, for example by highlighting them with a different color. It should be noted that the optimization of one criteria can rapidly deteriorate other aesthetic criteria, so a hint should be given to the user, which criteria he should prioritize. The other approach lets the user draw a Statechart to her or his own liking and lets an algorithm do the optimization afterwards. This would imply that the Statechart design of the user would be overruled by the algorithm in favor of a statistically "better" Statechart design. To avoid discontent, the algorithm could be implemented with user-changeable parameters, so it could be tweaked to the user's liking. In such tools, the application of structural metrics (e.g. usage of substates) as well as layout metrics could also be an option. Structural metrics have been well researched by various authors (for example Cruz-Lemus et al. [17], Appelgren and

Hvannberg [6], Genero et al. [26]) and their findings could be applied to Statechart editing tools.

Regarding editors, future implementations should be designed with more intuitiveness of interface in mind. The problem with mouse positioning mentioned in Section 8.2 could be mitigated by the enlargement of the click targets. An extension by three pixels to either side of an element's borders could ease the use of the KIEL-macros editor by reducing unnecessary clicks.

There are still factors missing (or couldn't be identified because of the data's correlation), the goodness-of-fit leaves room for more explanatory factors. However, if these could be found they would compose a statistical ideal model that might not be suitable for everyone. Personal preferences differ from developer to developer.

Further experiments could be conducted to examine the found correlations. Specifically, experiments should be planned with two subject groups (experimental and control group), and especially designed Statecharts, where only one independent variable is changed. The sample size should be larger to make a more universal statement. This would also reduce the problem of intercorrelation between the variables. Research on *feature selection* is ongoing and wide spread, so in addition to specifically generated data, one could use sophisticated selection methods for the independent variables under observation, such as described in Akay [1].

The data acquisition and validation took exceptionally long, especially for the modeling metrics. This was caused by the manual acquisition of the data. In future experiments, an automated recording of the number of user actions could save time. Furthermore, this would reduce the errors made by the person transcribing the actions.

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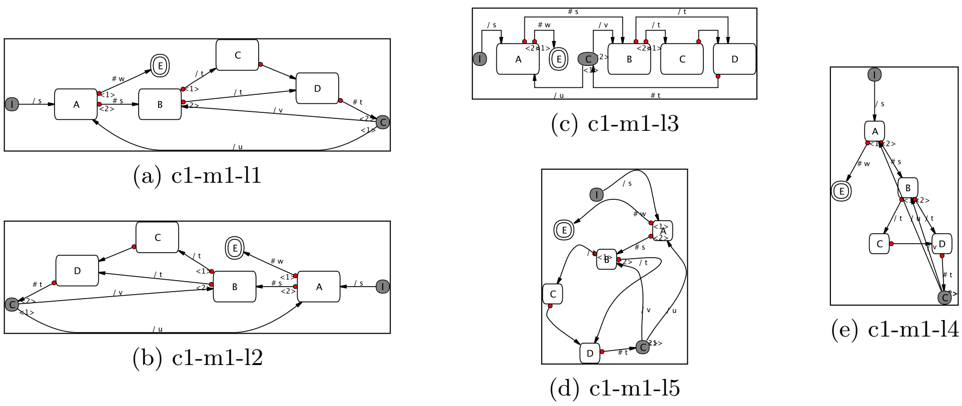
B. Statecharts Used in the Experiment

The Statecharts shown on the following pages are the basis for all data collected on aesthetic criteria. Shown are groups of five, sharing the same model m. Each group consists of five layouts l: Alternating Dot Layout (ADL) ($l1$), Alternating Dot Layout Backwards (ADBL) ($l2$), Alternating Linear Layout (ALL) ($l3$), Linear Layer Layout (LLL) ($l4$), and Arbitrary Layout (AL) ($l5$). The charts are divided into the three complexity categories simple, hierarchical, and parallel ($c1$,$c2$,$c3$).

Simple Statecharts



(a) c1-m1-l1

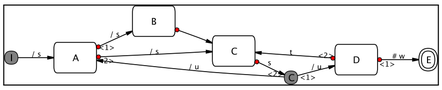
(b) c1-m1-l2

(c) c1-m1-l3

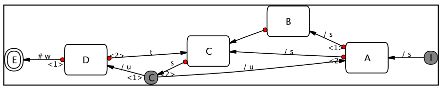
(d) c1-m1-l5

(e) c1-m1-l4

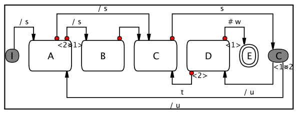
Figure B.1.: Different layouts of simple complexity Statecharts, model 1 of 5



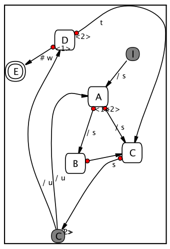
(a) c1-m2-l1



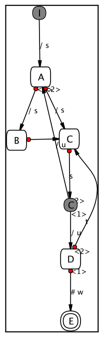
(b) c1-m2-l2



(c) c1-m2-l3

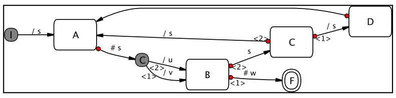


(d) c1-m2-l5

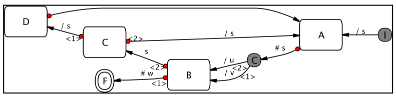


(e) c1-m2-l4

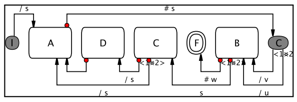
Figure B.2.: Different layouts of simple complexity Statecharts, model 2 of 5



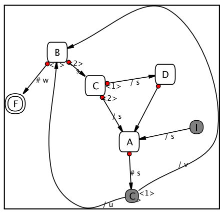
(a) c1-m3-l1



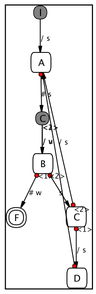
(b) c1-m3-l2



(c) c1-m3-l3

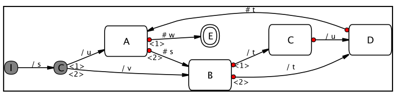


(d) c1-m3-l5

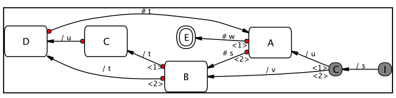


(e) c1-m3-l4

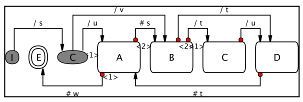
Figure B.3.: Different layouts of simple complexity Statecharts, model 3 of 5



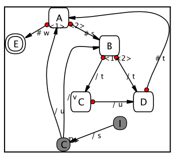
(a) c1-m4-l1



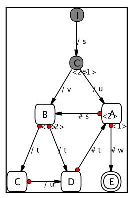
(b) c1-m4-l2



(c) c1-m4-l3

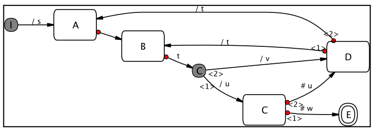


(d) c1-m4-l5

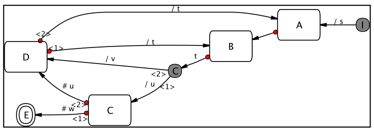


(e) c1-m4-l4

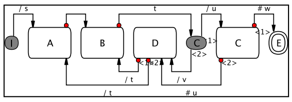
Figure B.4.: Different layouts of simple complexity Statecharts, model 4 of 5



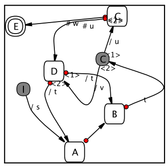
(a) c1-m5-l1



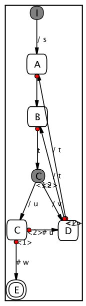
(b) c1-m5-l2



(c) c1-m5-l3



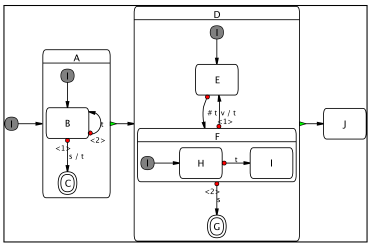
(d) c1-m5-l5



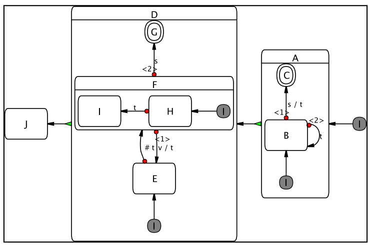
(e) c1-m5-l4

Figure B.5.: Different layouts of simple complexity Statecharts, model 5 of 5

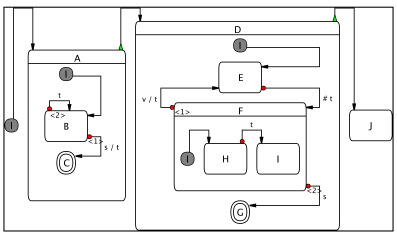
Hierarchical Statecharts



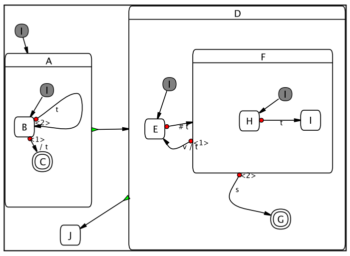
(a) c2-m2-l1



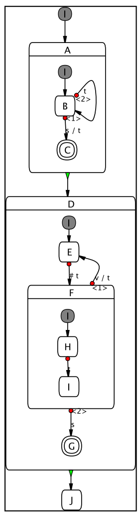
(b) c2-m1-l2



(c) c2-m1-l3

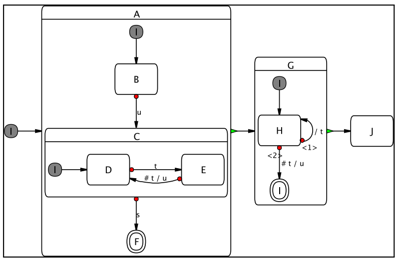


(d) c2-m1-l5

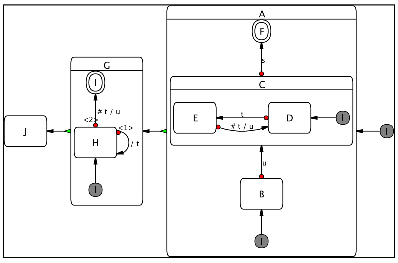


(e) c2-m1-l4

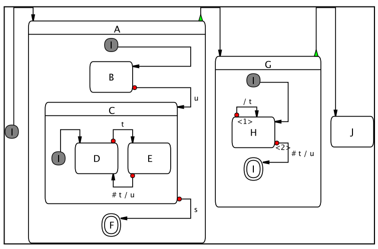
Figure B.6.: Different layouts of hierarchical complexity Statecharts, model 1 of 5



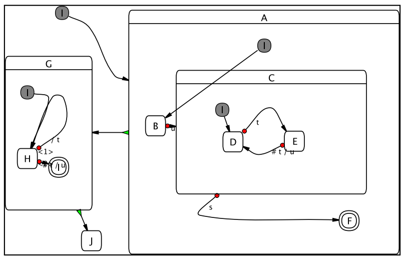
(a) c2-m2-l1



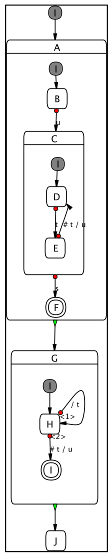
(b) c2-m2-l2



(c) c2-m2-l3

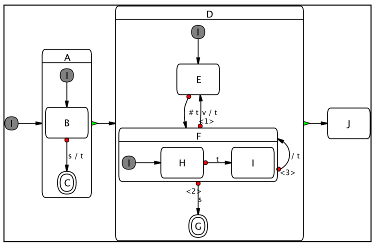


(d) c2-m2-l5

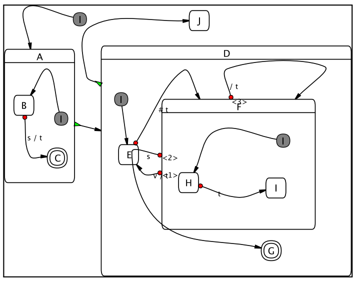


(e) c2-m2-l4

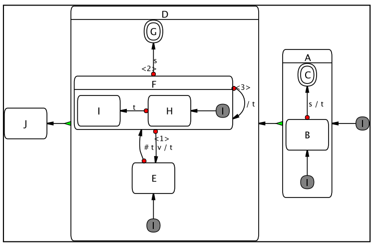
Figure B.7.: Different layouts of hierarchical complexity Statecharts, model 2 of 5



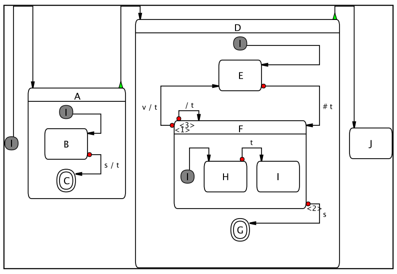
(a) c2-m2-l1



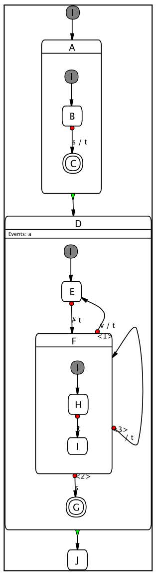
(d) c2-m3-l5



(b) c2-m3-l2

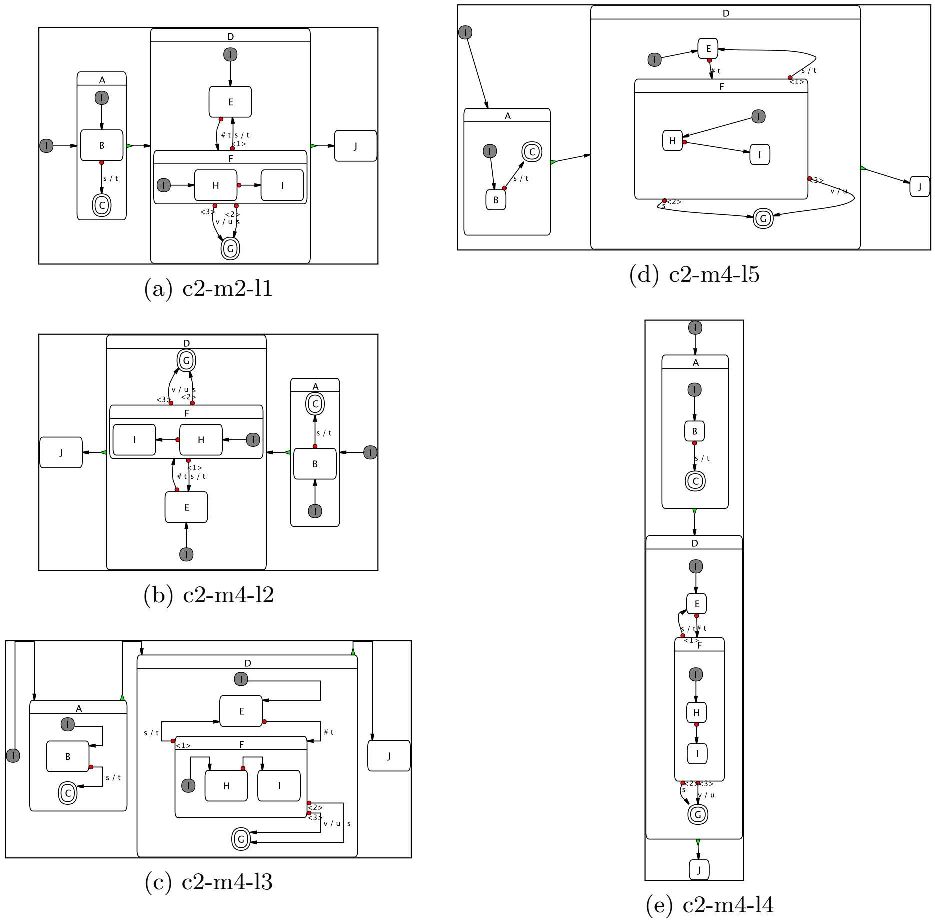


(c) c2-m3-l3



(e) c2-m3-l4

Figure B.8.: Different layouts of hierarchical complexity Statecharts, model 3 of 5



(a) c2-m2-l1

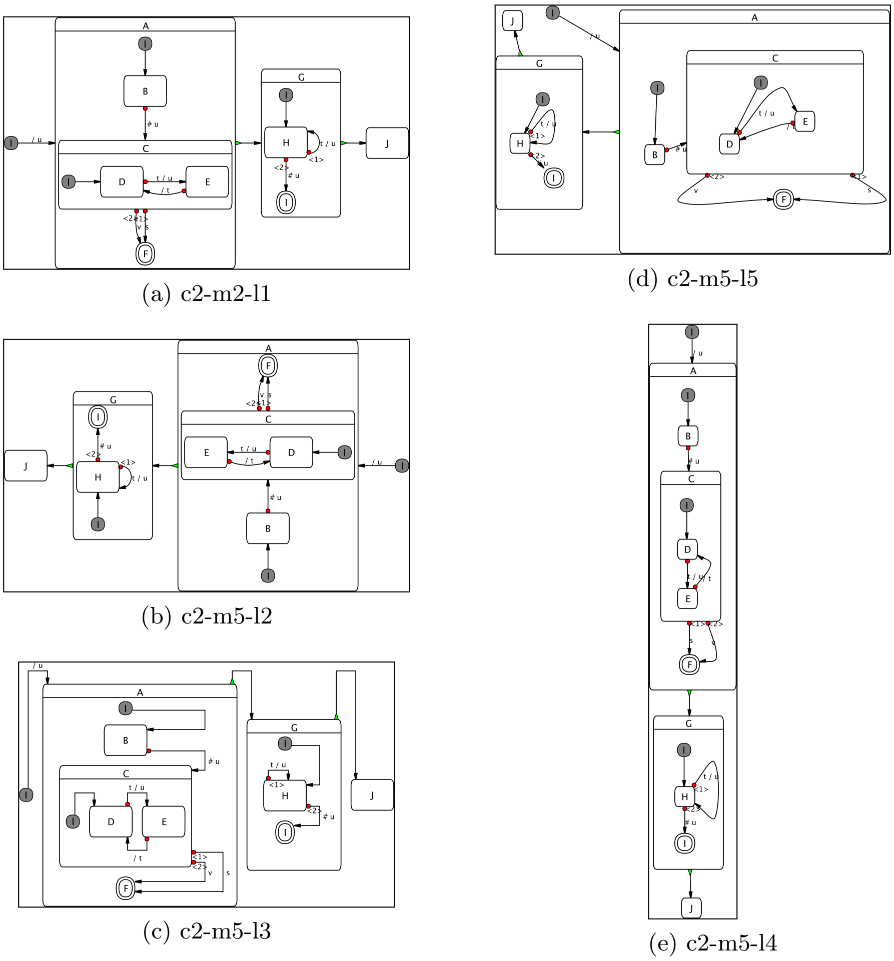
(b) c2-m4-l2

(c) c2-m4-l3

(d) c2-m4-l5

(e) c2-m4-l4

Figure B.9.: Different layouts of hierarchical complexity Statecharts, model 4 of 5



(a) c2-m2-l1

(d) c2-m5-l5

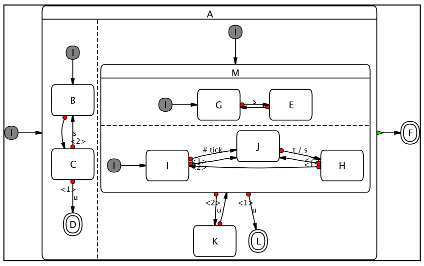
(b) c2-m5-l2

(e) c2-m5-l4

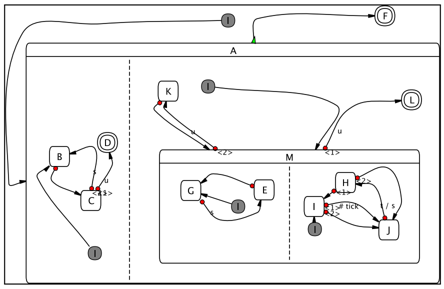
(c) c2-m5-l3

Figure B.10.: Different layouts of hierarchical complexity Statecharts, model 5 of 5

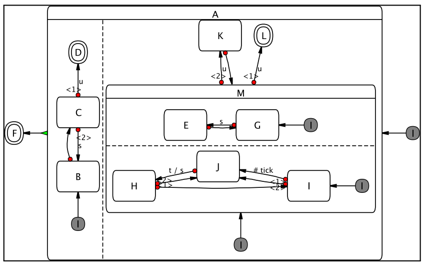
Parallel Statecharts



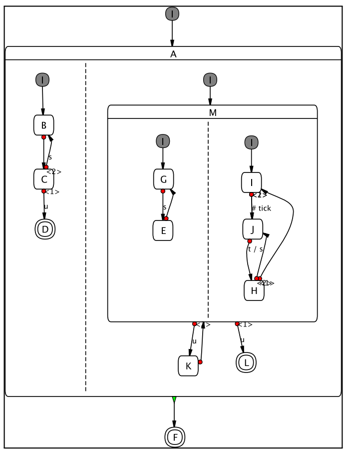
(a) c3-m3-l1



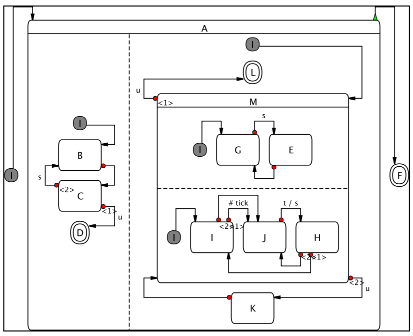
(d) c3-m1-l5



(b) c3-m1-l2

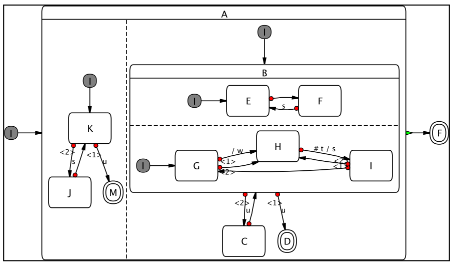


(e) c3-m1-l4

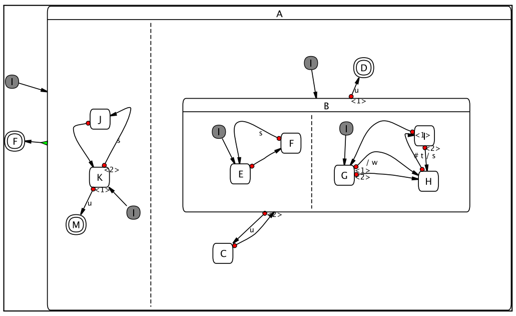


(c) c3-m1-l3

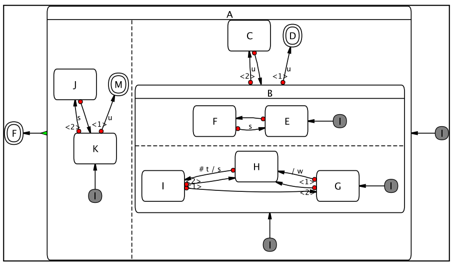
Figure B.11.: Different layouts of parallel complexity Statecharts, model 1 of 5



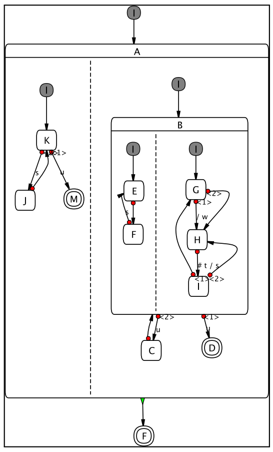
(a) c3-m3-l1



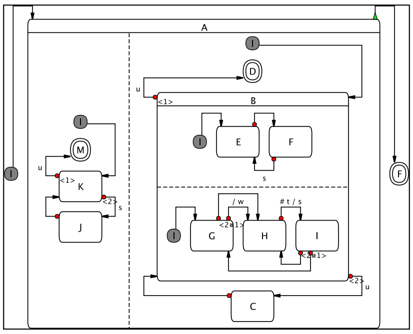
(d) c3-m2-l5



(b) c3-m2-l2

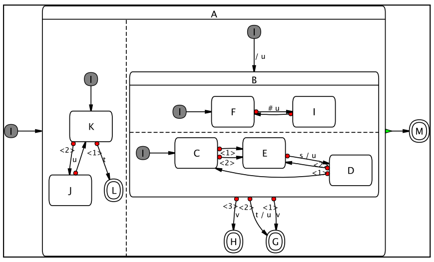


(e) c3-m2-l4

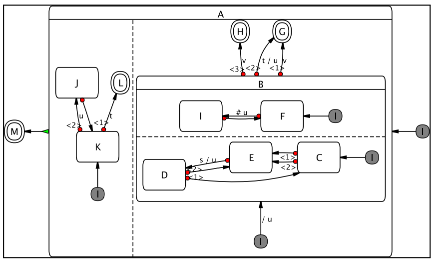


(c) c3-m2-l3

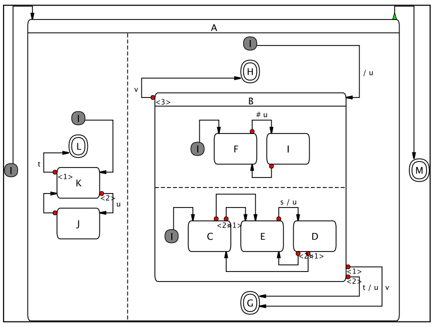
Figure B.12.: Different layouts of parallel complexity Statecharts, model 2 of 5



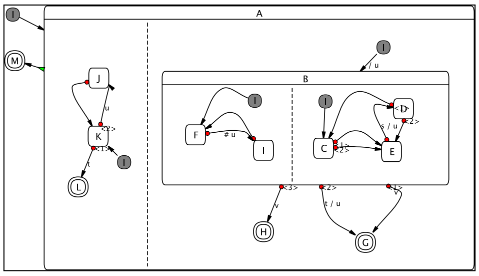
(a) c3-m3-l1



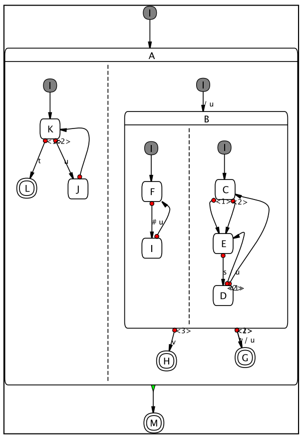
(b) c3-m3-l2



(c) c3-m3-l3

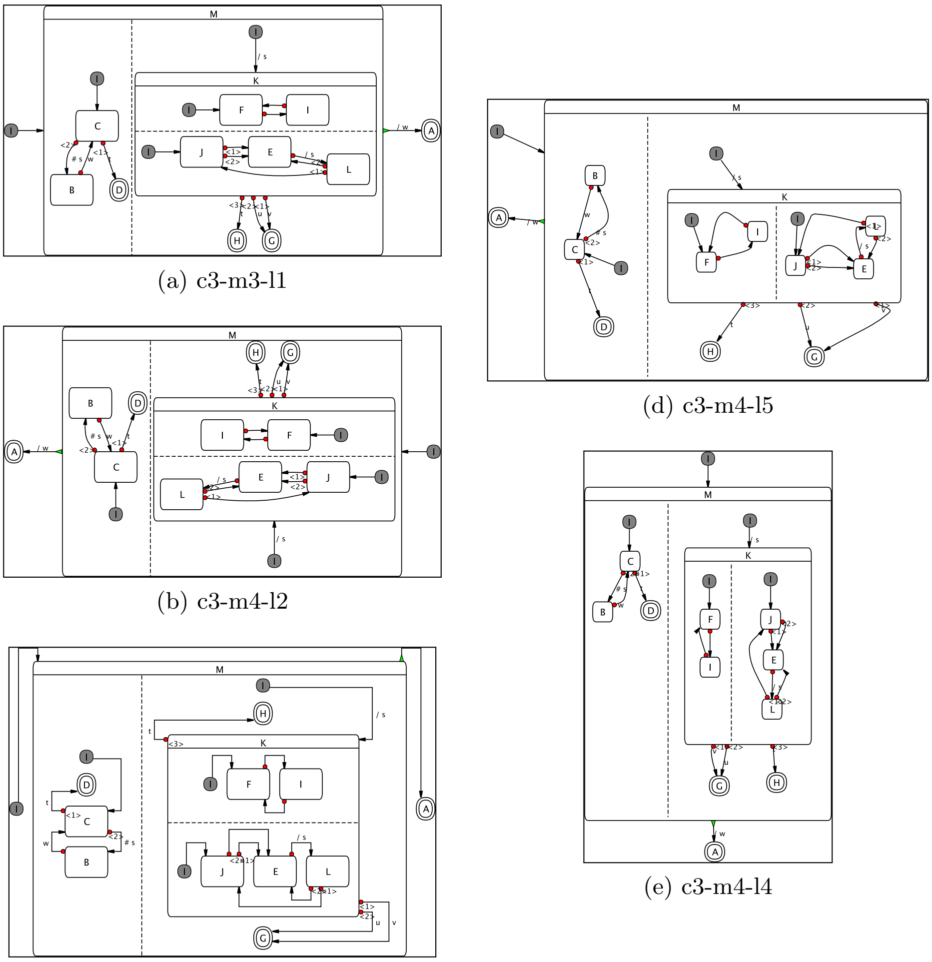


(d) c3-m3-l5



(e) c3-m3-l4

Figure B.13.: Different layouts of parallel complexity Statecharts, model 3 of 5



(a) c3-m3-l1

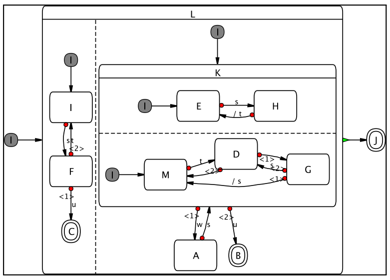
(b) c3-m4-l2

(c) c3-m4-l3

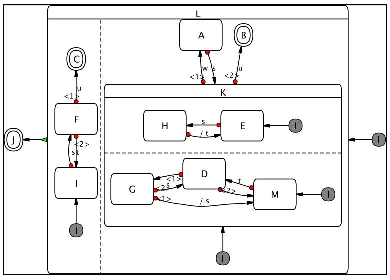
(d) c3-m4-l5

(e) c3-m4-l4

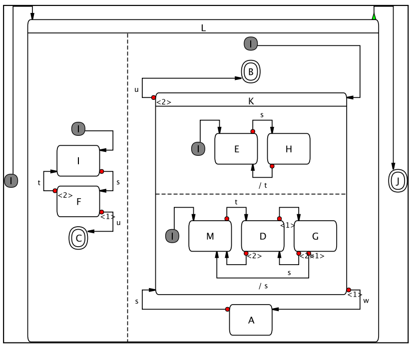
Figure B.14.: Different layouts of parallel complexity Statecharts, model 4 of 5



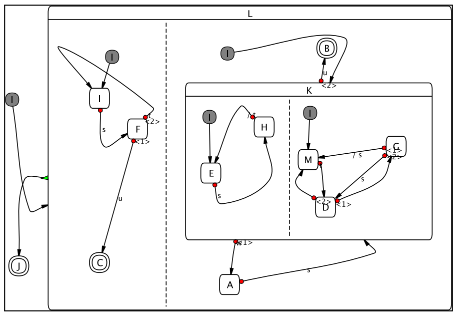
(a) c3-m3-l1



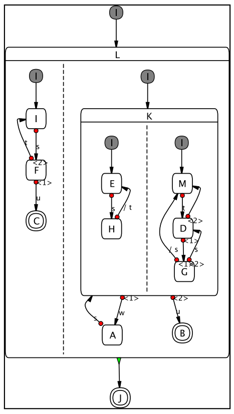
(b) c3-m5-l2



(c) c3-m5-l3



(d) c3-m5-l5



(e) c3-m5-l4

Figure B.15.: Different layouts of parallel complexity Statecharts, model 5 of 5

C. Collected Data

The following tables represent the original data that was used in the analysis of Statechart aesthetics and Statechart development methods.

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c1-m1-l1	1	1	1	1	12	-4	81	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	1	13	1	110	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	1	14	1	85	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	1	11	3	174	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	1	17	8	110	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	2	5	0	69	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	2	21	5	39	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	2	16	7	80	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	2	22	7	88	144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l1	1	1	1	2				144.93	3.46	14.04	14.04	14.04	59	57	42.49	16.43	57.05	26	28	29	29	29	7	0	7	4	0	0	4	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	1	24	1		144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	1	5	2	168	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	1	21	2	87	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	1	16	4	249	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	1	22	0	62	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	2	10	0	70	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	2	4	1	88	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	2	2	2	48	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	2	19	1	142	144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l2	1	1	2	2				144.93	3.46	14.04	14.04	14.04	160	77	42.49	16.43	57.05	26	28	29	29	29	7	0	7	3	0	0	3	0	44.11	8	0	1	9
c1-m1-l3	1	1	3	1	3	0	175	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	1	8	-8	123	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	1	10	8	103	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	1	4	6	466	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	1	2	1	64	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	2	18	-4	68	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	2	15	1	67	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	2	6	-3	45	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	2	7	-3	133	131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l3	1	1	3	2				131.89	3.15	23.93	23.93	23.93	57	87	13	13	13	0	8	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m1-l4	1	1	4	1	18	-8	90	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	1	15	-6	233	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	1	6	-8	236	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	1	7	-7	330	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	1	19	-4	136	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	2	9	-2	148	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	2	23	-7	115	91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	2	20	-6		91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	2				91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l4	1	1	4	2				91.95	0.53	7.84	7.84	7.84	33	52	60	56.63	66.75	45	47	47	47	47	7	0	7	10	1	2	5	2	65.27	9	0	0	9
c1-m1-l5	1	1	5	1	9	-7	131	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	1	23	-4	76	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	**Complexity**	**Model**	**Layout**	**Experiment**	**Participant**	**Points**	**Time**	**TRL**	**WHR**	**SU_S**	**SU_T**	**SU_A**	**P_I**	**P_F**	**NB_{AVG}**	**NB_{MIN}**	**NB_{MAX}**	**D_I**	**D_M**	**D_{NA}**	**D_{NS}**	**D_{NR}**	**N_{SS}**	**N_{HS}**	**N_S**	**IF**	**IF_{TN}**	**IF_{TT}**	**IF_{TL}**	**IF_{LL}**	**FL**	**N_{ST}**	**N_{PT}**	**N_{SPT}**	**N_T**
c1-m1-l5	1	1	5	1	20	-4		126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	1	1	-8	310	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	1				126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	2	12	-8	48	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	2	13	-5	89	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	2	14	-8	91	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	2	11	-4	118	126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m1-l5	1	1	5	2				126.42	0.75	8.39	8.39	8.39	46	38	51.4	42	65.82	44	51	45	45	45	7	0	7	7	0	1	5	1	38.77	2	0	7	9
c1-m2-l1	1	2	1	1	9	8	109	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	1	23	5	135	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	1	20	3		102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	1	1	4	104	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	1				102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	2	12	7	48	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	2	13	7	57	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	2	14	3	47	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	2	11	3	104	102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l1	1	2	1	2				102.3	5.47	17.46	17.46	17.46	69	176	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	1	12	0	55	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	1	13	-5	113	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	1	14	-6	100	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	1	11	3	60	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	1	17	2	112	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	2	5	3	85	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	2	21	-1	45	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	2	16	0	71	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	2	22	-2	53	102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l2	1	2	2	2				102.3	5.47	17.46	17.46	17.46	169	76	57.49	54	62	14	25	16	16	16	7	0	7	6	0	0	6	0	50.15	9	0	0	9
c1-m2-l3	1	2	3	1	24	7		152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	1	5	6	227	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	1	21	6	91	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	1	16	3	128	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	1	22	6	270	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	2	10	8	99	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	2	4	8	159	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	2	2	-5	37	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	2	19	6	49	152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l3	1	2	3	2				152	2.78	20.55	20.55	20.55	48	135	13	13	13	0	2	0	0	0	7	0	7	0	0	0	0	0	80	0	9	0	9
c1-m2-l4	1	2	4	1	3	2	183	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	1	8	8	140	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	1	10	-4	117	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	1	4	-3	284	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	1	2	-8	100	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	**Complexity**	**Model**	**Layout**	**Experiment**	**Participant**	**Points**	**Time**	**TRL**	**WHR**	**SU_S**	**SU_T**	**SU_A**	**P_I**	**P_F**	**NB_{AVG}**	**NB_{MIN}**	**NB_{MAX}**	**D_I**	**D_M**	**D_{NA}**	**D_{NS}**	**D_{NR}**	**N_{SS}**	**N_{HS}**	**N_S**	**IF**	**IF_{TN}**	**IF_{TT}**	**IF_{TL}**	**IF_{LL}**	**FL**	**N_{ST}**	**N_{PT}**	**N_{SPT}**	**N_T**
c1-m2-l4	1	2	4	2	18	2	76	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	2	15	-7	136	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	2	6	2	50	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	2	7	0	110	87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l4	1	2	4	2				87.95	0.28	7.93	7.93	7.93	34	177	60.02	49	71	32	28	28	28	28	7	0	7	7	0	1	6	0	56.27	8	0	1	9
c1-m2-l5	1	2	5	1	18	5	134	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	1	15	-5	139	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	1	6	2	113	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	1	7	4	85	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	1	19	3	170	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	2	9	-6	85	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	2	23	-4	80	145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	2	20	-5		145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	2				145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m2-l5	1	2	5	2				145.55	0.68	6.18	6.18	6.18	101	25	52.47	52.08	53.25	76	50	50	50	50	7	0	7	2	0	0	1	1	77.64	5	0	4	9
c1-m3-l1	1	3	1	1	18	7	208	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	1	15	4	120	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	1	6	-1	50	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	1	7	4	86	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	1	19	5	201	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	2	9	8	86	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	2	23	6	69	120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	2	20	5		120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	2				120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l1	1	3	1	2				120.66	4.47	17.91	17.91	17.91	30	175	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	1	9	0	312	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	1	23	1	98	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	1	20	1		120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	1	1	8	72	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	1				120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	2	12	1	72	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	2	13	-1	62	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	2	14	-1	46	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	2	11	3	72	120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l2	1	3	2	2				120.66	4.47	17.91	17.91	17.91	130	125	42.33	15.91	62	28	28	28	28	28	7	0	7	1	0	0	1	0	31.29	6	0	3	9
c1-m3-l3	1	3	3	1	12	8	99	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	1	13	7	123	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	1	14	5	168	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	1	11	-1	224	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	1	17	-4	144	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	2	5	-5	150	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	2	21	-2	36	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	2	16	-2	80	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c1-m3-l3	1	3	3	2	22	2	95	141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l3	1	3	3	2				141.78	3.19	23.59	23.59	23.59	39	106	13	13	13	0	12	0	0	0	7	0	7	2	0	0	2	0	100	0	9	0	9
c1-m3-l4	1	3	4	1	24	-3		104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	1	5	-4	210	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	1	21	-8	135	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	1	16	-7	171	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	1	22	-7	153	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	2	10	-6	222	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	2	4	-7	223	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	2	2	-6	162	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	2	19	-8	112	104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l4	1	3	4	2				104.36	0.3	9.67	9.67	9.67	38	77	55.74	50	62	22	25	25	25	25	7	0	7	12	2	1	5	4	46.93	9	0	0	9
c1-m3-l5	1	3	5	1	3	-4	284	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	1	8	-2	77	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	1	10	2	90	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	1	4	1	232	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	1	2	7	185	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	2	18	-3	97	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	2	15	0	65	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	2	6	-1	85	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	2	7	-1	93	142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m3-l5	1	3	5	2				142.28	1.06	5.45	5.45	5.45	153	48	55.32	36.15	77.67	59	55	56	56	56	7	0	7	6	0	0	6	0	62.11	7	0	2	9
c1-m4-l1	1	4	1	1	3	3	64	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	1	8	2	148	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	1	10	-2	168	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	1	4	-5	154	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	1	2	1	71	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	2	18	8	58	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	2	15	6	129	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	2	6	4	66	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	2	7	4	105	117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l1	1	4	1	2				117.01	4.61	18.48	18.48	18.48	77	82	58.4	17.72	130.75	20	22	23	23	23	7	0	7	2	0	0	2	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	1	18	-1	111	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	1	15	3	251	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	1	6	3	116	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	1	7	0	220	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	1	19	-2	213	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	2	9	-4	194	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	2	23	5	134	117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	2	20	-1		117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	2				117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l2	1	4	2	2				117.01	4.61	18.48	18.48	18.48	177	76	58.4	17.72	130.75	20	22	23	23	23	7	0	7	1	0	0	1	0	29.77	7	0	2	9
c1-m4-l3	1	4	3	1	9	1	144	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c1-m4-l3	1	4	3	1	23	-5	344	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	1	20	8		137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	1	1	0	75	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	1				137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	2	12	-4	63	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	2	13	4	105	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	2	14	5	171	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	2	11	0	147	137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l3	1	4	3	2				137.56	3.28	22.27	22.27	22.27	58	67	13	13	13	0	8	0	0	0	7	0	7	0	0	0	0	0	100	0	9	0	9
c1-m4-l4	1	4	4	1	12	-3	98	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	1	13	4	251	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	1	14	6	136	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	1	11	-1	53	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	1	17	2	285	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	2	5	5	111	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	2	21	4	67	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	2	16	2	103	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	2	22	0	47	67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l4	1	4	4	2				67.26	0.65	10.67	10.67	10.67	60	195	62.15	27.31	127.27	58	40	36	36	36	7	0	7	7	0	0	7	0	50.49	9	0	0	9
c1-m4-l5	1	4	5	1	24	-6		106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	1	5	-7	603	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	1	21	-2	275	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	1	16	-4	178	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	1	22	-3	149	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	2	10	-6	79	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	2	4	-2	210	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	2	2	2	77	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	2	19	-1	66	106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m4-l5	1	4	5	2				106.86	1.14	9.93	9.93	9.93	156	21	34.33	17.55	50.9	57	52	51	51	51	7	0	7	8	0	0	7	1	68.15	6	0	3	9
c1-m5-l1	1	5	1	1	24	1		131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	1	5	3	102	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	1	21	2	167	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	1	16	4	140	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	1	22	4	73	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	2	10	4	64	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	2	4	0	89	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	2	2	7	83	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	2	19	2	40	131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l1	1	5	1	2				131.17	3.03	13.61	13.61	13.61	11	197	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	1	3	-1	133	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	1	8	0	60	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	1	10	-4	316	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	1	4	1	161	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	**Complexity**	**Model**	**Layout**	**Experiment**	**Participant**	**Points**	**Time**	**TRL**	**WHR**	**SU_S**	**SU_T**	**SU_A**	**P_I**	**P_F**	**NB_{AVG}**	**NB_{MIN}**	**NB_{MAX}**	**D_I**	**D_M**	**D_{NA}**	**D_{NS}**	**D_{NR}**	**N_{SS}**	**N_{HS}**	**N_S**	**IF**	**IF_{TN}**	**IF_{TT}**	**IF_{TL}**	**IF_{LL}**	**FL**	**N_{ST}**	**N_{PT}**	**N_{SPT}**	**N_T**
c1-m5-l2	1	5	2	1	2	-1	207	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	2	18	-3	58	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	2	15	0	98	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	2	6	-2	70	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	2	7	0	56	131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l2	1	5	2	2				131.17	3.03	13.61	13.61	13.61	111	103	48.7	36.74	73.05	71	45	44	44	44	7	0	7	5	0	0	5	0	50.22	5	0	4	9
c1-m5-l3	1	5	3	1	18	-3	115	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	1	15	4	244	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	1	6	4	175	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	1	7	-1	65	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	1	19	-2	157	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	2	9	4	92	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	2	23	0	118	110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	2	20	7		110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	2				110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l3	1	5	3	2				110.22	3.15	23.93	23.93	23.93	39	138	13	13	13	0	12	0	0	0	7	0	7	1	0	0	1	0	80	0	9	0	9
c1-m5-l4	1	5	4	1	9	-2	160	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	1	23	3	109	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	1	20	-8		85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	1	1	-4	139	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	1				85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	2	12	4	36	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	2	13	-5	63	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	2	14	1	144	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	2	11	-2	64	85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l4	1	5	4	2				85.24	0.26	10.52	10.52	10.52	39	100	50.67	47	60	29	22	17	17	17	7	0	7	7	1	0	4	2	43.56	9	0	0	9
c1-m5-l5	1	5	5	1	12	-1	94	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	1	13	-7	142	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	1	14	-6	359	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	1	11	-4	55	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	1	17	-8	214	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	2	5	-3	82	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	2	21	-6	43	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	2	16	-7	177	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	2	22	-7	46	100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c1-m5-l5	1	5	5	2				100.49	1.02	9.48	9.48	9.48	61	7	45.06	23.3	85.88	68	54	52	52	52	7	0	7	9	0	1	5	3	65.73	3	0	6	9
c2-m1-l1	2	1	1	1	9	7	97	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	1	23	6	113	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	1	20	5		43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	1	1	8	170	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	1				43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	2	12	7	45	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	2	13	8	80	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c2-m1-l1	2	1	1	2	14	5	56	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	2	11	4	86	43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l1	2	1	1	2				43.47	1.54	9.51	58.99	15.63	50	150	11.01	3.2	38	53	53	55	64	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	1	3	5	177	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	1	8	6	178	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	1	10	3	162	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	1	4	-2	239	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	1	2	-1	147	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	2	18	-2	74	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	2	15	-2	81	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	2	6	-2	103	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	2	7	0	181	43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l2	2	1	2	2				43.47	1.54	9.51	58.99	15.63	150	50	10.6	0	38	46	46	47	57	0	11	3	14	3	0	0	2	1	24.39	10	0	2	12
c2-m1-l3	2	1	3	1	12	-1	132	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	1	13	-1	263	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	1	14	-5	151	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	1	11	-1	299	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	1	17	-6	202	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	2	5	0	239	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	2	21	-3	66	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	2	16	-5	103	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	2	22	-1	77	136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l3	2	1	3	2				136.83	1.74	9.38	67.97	16.06	53	153	9.24	4.43	13.38	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m1-l4	2	1	4	1	18	-4	80	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	1	15	2	231	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	1	6	-3	137	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	1	7	3	157	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	1	19	5	100	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	2	9	1	192	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	2	23	0	111	41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	2	20	4		41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	2				41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l4	2	1	4	2				41.91	0.26	5.34	70.06	11.29	45	151	18.65	6.83	33	5	4	3	3	2	11	3	14	5	0	0	5	0	22.7	10	0	2	12
c2-m1-l5	2	1	5	1	24	0		64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	1	5	0	235	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	1	21	3	239	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	1	16	-3	263	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	1	22	-5	120	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	2	10	-4	104	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	2	4	-1	169	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	2	2	4	45	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	2	19	-2	92	64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12
c2-m1-l5	2	1	5	2				64.38	1.4	4.22	79.95	11.31	11	115	21.86	12.21	36.94	144	52	51	63	43	11	3	14	4	0	0	4	0	80.83	9	0	3	12

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	**Complexity**	**Model**	**Layout**	**Experiment**	**Participant**	**Points**	**Time**	**TRL**	**WHR**	**SU_S**	**SU_T**	**SU_A**	**P_I**	**P_F**	**NB_{AVG}**	**NB_{MIN}**	**NB_{MAX}**	**D_I**	**D_M**	**D_{NA}**	**D_{NS}**	**D_{NR}**	**N_{SS}**	**N_{HS}**	**N_S**	**IF**	**IF_{TN}**	**IF_{TT}**	**IF_{TL}**	**IF_{LL}**	**FL**	**N_{ST}**	**N_{PT}**	**N_{SPT}**	**N_T**
c2-m2-l1	2	2	1	1	18	8	84	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	1	15	5	102	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	1	6	0	80	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	1	7	7	80	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	1	19	5	72	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	2	9	8	87	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	2	23	8	60	48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	2	20	6		48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	2				48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l1	2	2	1	2				48.81	1.55	8.26	60.81	14.3	50	150	11.93	3.2		38	55	56	57	67	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	1	24	6		48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	1	5	3	171	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	1	21	-1	210	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	1	16	1	112	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	1	22	-1	126	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	2	10	4	47	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	2	4	5	136	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	2	2	-3	55	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	2	19	-8	112	48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l2	2	2	2	2				48.81	1.55	8.26	60.81	14.3	150	50	11.4	0		36	48	49	50	61	0	11	3	14	1	0	0	1	0	22.5	10	0	2	12
c2-m2-l3	2	2	3	1	9	-7	365	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	1	23	-7	76	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	1	20	2		134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	1	1	0	147	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	1				134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	2	12	-4	45	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	2	13	-5	113	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	2	14	-6	56	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	2	11	-2	143	134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l3	2	2	3	2				134.58	1.56	9.31	65.03	15.65	53	153	9.2	4.55		13	46	51	46	55	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m2-l4	2	2	4	1	3	-2	92	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	1	8	-2	192	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	1	10	3	99	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	1	4	2	394	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	1	2	-4	202	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	2	18	-5	51	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	2	15	2	71	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	2	6	4	53	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	2	7	-3	150	44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l4	2	2	4	2				44.59	0.18	6.4	76.26	12.39	49	150	20.78	2.93		40	3	3	3	4	1	11	3	14	4	0	0	4	0	25.35	10	0	2	12
c2-m2-l5	2	2	5	1	12	2	107	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	1	13	-6	166	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	1	14	-4	186	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c2-m2-l5	2	2	5	1	11	-6	102	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	1	17	-6	225	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	2	5	-2	144	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	2	21	-6	93	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	2	16	-7	103	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	2	22	-3	77	98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m2-l5	2	2	5	2				98.92	1.59	3.59	81.43	11.05	13	119	25.26	14.04	59.98	179	60	59	75	50	11	3	14	9	1	2	5	1	83.17	6	0	6	12
c2-m3-l1	2	3	1	1	3	6	345	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	1	8	6	115	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	1	10	2	230	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	1	4	6	293	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	1	2	8	85	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	2	18	8	92	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	2	15	7	144	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	2	6	3	78	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	2	7	7	101	44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l1	2	3	1	2				44.14	1.56	9.4	63.64	15.53	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	1	12	-1	211	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	1	13	-3	105	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	1	14	-3	153	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	1	11	0	191	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	1	17	4	182	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	2	5	2	132	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	2	21	-3	45	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	2	16	1	131	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	2	22	-2	53	44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l2	2	3	2	2				44.14	1.56	9.4	63.64	15.53	150	50	10.58	0	38	46	46	47	53	9	11	3	14	2	0	0	1	1	25.32	10	0	2	12
c2-m3-l3	2	3	3	1	18	-7	118	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	1	15	-4	270	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	1	6	3	126	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	1	7	-4	203	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	1	19	-3	322	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	2	9	-6	158	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	2	23	-8	216	154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	2	20	-6		154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	2				154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l3	2	3	3	2				154.33	1.48	7.95	61.8	13.62	53	153	9.29	4.85	13	48	53	48	58	0	11	3	14	0	0	0	0	0	75	0	12	0	12
c2-m3-l4	2	3	4	1	24	-4		59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	1	5	3	322	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	1	21	1	170	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	1	16	4	198	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	1	22	8	404	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	2	10	8	101	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c2-m3-l4	2	3	4	2	4	1	182	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	2	2	-3	40	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	2	19	5	104	59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l4	2	3	4	2				59.37	0.26	4.15	67.07	8.69	46	150	23.25	7.86	35	4	5	4	4	2	11	3	14	6	0	0	6	0	18.28	10	0	2	12
c2-m3-l5	2	3	5	1	9	-1	181	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	1	23	-5	168	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	1	20	-4		149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	1	1	-8	287	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	1				149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	2	12	-8	70	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	2	13	-5	107	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	2	14	-6	60	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	2	11	-1	215	149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m3-l5	2	3	5	2				149.81	1.28	3.73	71.71	10.45	24	59	20.16	7.45	43.86	145	68	70	79	51	11	3	14	5	3	0	2	0	60.8	2	0	10	12
c2-m4-l1	2	4	1	1	24	4		43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	1	5	2	243	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	1	21	-1	179	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	1	16	6	106	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	1	22	3	140	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	2	10	0	94	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	2	4	3	102	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	2	2	8	59	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	2	19	5	72	43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l1	2	4	1	2				43.31	1.44	10.18	60.65	16.26	50	150	11.01	3.2	38	53	53	55	60	8	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	1	9	-4	158	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	1	23	5	93	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	1	20	5		43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	1	1	4	115	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	1				43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	2	12	1	69	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	2	13	3	111	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	2	14	2	60	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	2	11	-3	95	43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l2	2	4	2	2				43.31	1.44	10.18	60.65	16.26	150	50	10.6	0	38	46	46	47	53	9	11	3	14	3	0	0	1	2	18.51	9	0	3	12
c2-m4-l3	2	4	3	1	3	-8	143	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	1	8	-6	100	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	1	10	-7	331	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	1	4	-8	157	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	1	2	4	195	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	2	18	-5	73	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	2	15	-3	150	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	2	6	-4	60	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l3	2	4	3	2	7	-4	129	153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	**Complexity**	**Model**	**Layout**	**Experiment**	**Participant**	**Points**	**Time**	**TRL**	**WHR**	$\mathbf{SU_S}$	$\mathbf{SU_T}$	$\mathbf{SU_A}$	$\mathbf{P_I}$	$\mathbf{P_F}$	$\mathbf{NB_{AVG}}$	$\mathbf{NB_{MIN}}$	$\mathbf{NB_{MAX}}$	$\mathbf{D_I}$	$\mathbf{D_M}$	$\mathbf{D_{NA}}$	$\mathbf{D_{NS}}$	$\mathbf{D_{NR}}$	$\mathbf{N_{SS}}$	$\mathbf{N_{HS}}$	$\mathbf{N_S}$	**IF**	$\mathbf{IF_{TN}}$	$\mathbf{IF_{TT}}$	$\mathbf{IF_{TL}}$	$\mathbf{IF_{LL}}$	**FL**	$\mathbf{N_{ST}}$	$\mathbf{N_{PT}}$	$\mathbf{N_{SPT}}$	$\mathbf{N_T}$
c2-m4-l3	2	4	3	2				153.83	1.87	9.27	65.02	16.13	53	153	8.94	4.85	13	41	46	42	50	0	11	3	14	0	0	0	0	0	90	0	12	0	12
c2-m4-l4	2	4	4	1	12	-4	151	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	1	13	4	124	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	1	14	7	80	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	1	11	3	275	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	1	17	4	185	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	2	5	0	124	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	2	21	7	67	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	2	16	4	84	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	2	22	-1	78	36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l4	2	4	4	2				36.83	0.17	6.45	73.7	11.67	51	157	21.9	13.75	32.48	2	4	2	2	1	11	3	14	6	0	0	5	1	15.67	10	0	2	12
c2-m4-l5	2	4	5	1	18	0	96	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	1	15	0	109	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	1	6	1	92	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	1	7	-6	368	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	1	19	-1	137	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	2	9	-2	73	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	2	23	-2	108	101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	2	20	-2		101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	2				101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m4-l5	2	4	5	2				101.09	1.93	3.05	67.08	9.18	9	176	32.15	11.17	103.4	155	66	63	75	42	11	3	14	4	0	0	4	0	61.58	9	0	3	12
c2-m5-l1	2	5	1	1	12	4	107	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	1	13	6	113	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	1	14	5	145	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	1	11	4	90	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	1	17	4	144	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	2	5	0	131	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	2	21	5	62	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	2	16	7	98	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	2	22	7	98	47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l1	2	5	1	2				47.42	1.61	7.96	57.37	13.64	50	150	13.38	3.2	56	55	56	57	67	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	1	18	3	146	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	1	15	-3	120	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	1	6	-1	103	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	1	7	0	173	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	1	19	-6	176	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	2	9	-1	80	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	2	23	2	112	47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	2	20	-2		47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	2				47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l2	2	5	2	2				47.42	1.61	7.96	57.37	13.64	150	50	12.97	0	56	48	49	50	61	0	11	3	14	2	0	0	2	0	20.31	10	0	3	13
c2-m5-l3	2	5	3	1	24	-6		148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	1	5	-8	285	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c2-m5-l3	2	5	3	1	21	-2	157	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	1	16	-8	146	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	1	22	-5	115	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	2	10	-8	96	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	2	4	-8	100	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	2	2	-6	58	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	2	19	0	82	148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l3	2	5	3	2				148.67	1.54	8.86	64.23	14.99	54	155	9.29	4.85	13	46	54	46	55	0	11	3	14	0	0	0	0	0	83.08	0	13	0	13
c2-m5-l4	2	5	4	1	9	5	136	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	1	23	1	168	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	1	20	-8		56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	1	1	-4	105	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	1				56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	2	12	4	41	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	2	13	-1	81	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	2	14	5	109	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	2	11	2	75	56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l4	2	5	4	2				56.17	0.15	6.78	76.46	12.35	49	148	24.87	15.31	42.2	6	6	3	3	1	11	3	14	5	0	0	5	0	18.99	10	0	3	13
c2-m5-l5	2	5	5	1	3	-1	179	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	1	8	-4	155	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	1	10	-1	126	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	1	4	2	163	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	1	2	-7	90	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	2	18	4	92	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	2	15	-4	102	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	2	6	-1	62	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	2	7	0	115	95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c2-m5-l5	2	5	5	2				95.68	1.59	3.59	81.43	10.87	13	4	29.35	16.38	57.5	155	59	60	71	49	11	3	14	4	0	0	4	0	79.48	8	0	5	13
c3-m1-l1	3	1	1	1	12	-3	163	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	1	13	4	222	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	1	14	6	136	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	1	11	4	156	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	1	17	6	331	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	2	5	-4	188	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	2	21	3	93	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	2	16	6	160	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	2	22	5	159	57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l1	3	1	1	2				57.51	1.64	11.97	80.94	19.6	50	150	12.23	3.2	36	63	63	64	70	48	16	4	20	8	0	0	7	1	43.22	18	0	1	19
c3-m1-l2	3	1	2	1	24	-4		57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	1	5	-1	318	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	1	21	-1	174	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	1	16	-1	192	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	1	22	-4	190	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m1-l2	3	1	2	2	10	-2	189	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	2	4	3	228	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	2	2	-1	150	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	2	19	-8	220	57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l2	3	1	2	2				57.51	1.64	11.97	80.94	19.6	150	50	11.83	0	36	64	64	66	72	48	16	4	20	6	0	0	6	0	43.22	18	0	1	19
c3-m1-l3	3	1	3	1	3	0	389	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	1	8	-8	231	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	1	10	-7	160	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	1	4	-7	258	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	1	2	-7	161	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	2	18	-6	168	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	2	15	0	172	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	2	6	-3	105	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	2	7	-4	292	133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l3	3	1	3	2				133.32	1.25	9.65	83.68	15.19	52	152	9.74	4.11	13	71	73	72	80	54	16	4	20	1	0	0	1	0	20	0	19	0	19
c3-m1-l4	3	1	4	1	18	0	153	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	1	15	1	385	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	1	6	-1	131	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	1	7	3	295	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	1	19	7	318	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	2	9	4	174	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	2	23	6	162	55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	2	20	8		55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	2				55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l4	3	1	4	2				55.14	0.77	3.56	79.66	8.46	50	151	32.17	18.14	46	86	86	87	94	65	16	4	20	7	0	0	4	3	42.98	14	0	5	19
c3-m1-l5	3	1	5	1	9	-5	204	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	1	23	-5	233	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	1	20	0		139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	1	1	-8	183	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	1				139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	2	12	-7	122	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	2	13	-5	167	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	2	14	-6	130	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	2	11	-5	190	139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m1-l5	3	1	5	2				139.49	1.56	4.38	82.57	11.81	54	89	22.41	7.61	41.25	132	91	84	90	64	16	4	20	9	0	0	7	2	73.56	3	0	16	19
c3-m2-l1	3	2	1	1	9	7	317	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	1	23	2	238	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	1	20	-4		58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	1	1	6	191	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	1				58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	2	12	6	120	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	2	13	7	137	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	2	14	6	137	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m2-l1	3	2	1	2	11	6	186	58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l1	3	2	1	2				58.37	1.75	11.21	82.18	18.68	50	150	14.25	3.2	38	59	59	60	66	46	16	4	20	7	0	0	5	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	1	12	-2	166	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	1	13	-3	213	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	1	14	-5	397	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	1	11	0	240	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	1	17	6	283	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	2	5	-1	215	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	2	21	-5	134	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	2	16	-2	248	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	2	22	-3	203	58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l2	3	2	2	2				58.37	1.75	11.21	82.18	18.68	150	50	13.33	0	38	60	60	61	67	46	16	4	20	6	0	0	4	2	41.68	16	0	3	19
c3-m2-l3	3	2	3	1	24	-6		133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	1	5	-8	353	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	1	21	-5	226	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	1	16	-7	273	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	1	22	2	249	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	2	10	-8	221	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	2	4	-8	301	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	2	2	-6	141	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	2	19	-1	140	133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l3	3	2	3	2				133.24	1.25	9.67	83.68	15.21	52	152	11.75	4.25	13	72	74	73	80	53	16	4	20	1	0	0	1	0	10	0	19	0	19
c3-m2-l4	3	2	4	1	3	-2	328	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	1	8	4	185	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	1	10	2	160	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	1	4	3	295	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	1	2	6	268	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	2	18	1	169	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	2	15	2	177	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	2	6	3	84	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	2	7	0	193	57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l4	3	2	4	2				57.17	0.6	4.55	80.6	9.14	49	153	25.91	8.28	44.89	66	66	66	70	50	16	4	20	7	0	0	6	1	42.72	14	0	5	19
c3-m2-l5	3	2	5	1	18	3	185	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	1	15	2	292	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	1	6	-2	214	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	1	7	-3	423	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	1	19	3	311	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	2	9	-4	303	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	2	23	0	221	70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	2	20	4		70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	2				70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m2-l5	3	2	5	2				70.86	1.67	3.43	91.62	9.93	24	44	29	13.46	55.88	110	59	58	64	54	16	4	20	7	0	0	5	2	74.87	11	0	8	19
c3-m3-l1	3	3	1	1	18	7	167	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19

Continued on next page

Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m3-l1	3	3	1	1	15	1	270	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	1	6	-3	138	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	1	7	8	409	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	1	19	0	243	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	2	9	7	233	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	2	23	1	131	56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	2	20	-2		56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	2				56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l1	3	3	1	2				56.01	1.69	10.99	80.97	18.37	50	150	13.3	4.4	37.36	55	55	57	62	42	16	4	20	7	0	0	5	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	1	9	0	198	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	1	23	2	208	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	1	20	-5		56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	1	1	6	269	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	1				56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	2	12	0	127	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	2	13	0	220	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	2	14	-1	95	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	2	11	-2	149	56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l2	3	3	2	2				56.01	1.69	10.99	80.97	18.37	150	50	12.06	0	38	55	55	55	62	42	16	4	20	6	0	0	4	2	32.43	16	0	3	19
c3-m3-l3	3	3	3	1	12	-1	267	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	1	13	1	214	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	1	14	-2	157	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	1	11	-1	333	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	1	17	-4	351	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	2	5	4	331	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	2	21	-1	129	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	2	16	-5	198	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	2	22	5	195	142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l3	3	3	3	2				142.37	1.35	8.76	83.92	14.35	52	152	11.78	4.33	13	70	73	72	79	53	16	4	20	0	0	0	0	0	30	0	19	0	19
c3-m3-l4	3	3	4	1	24	8		62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	1	5	7	425	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	1	21	3	223	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	1	16	5	412	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	1	22	4	464	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	2	10	4	438	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	2	4	3	342	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	2	2	0	322	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	2	19	7	232	62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l4	3	3	4	2				62.25	0.69	4.21	79.06	9.06	50	151	27.42	13.17	43	77	76	76	80	57	16	4	20	12	0	0	8	4	38.47	13	0	6	19
c3-m3-l5	3	3	5	1	3	3	254	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	1	8	-2	224	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	1	10	5	417	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	1	4	-1	341	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m3-l5	3	3	5	1	2	-3	176	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	2	18	3	164	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	2	15	-7	178	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	2	6	0	125	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	2	7	1	243	71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m3-l5	3	3	5	2				71.1	1.78	4.26	91.72	11.96	1	18	27.06	12.29	55.01	171	65	65	73	60	16	4	20	7	0	0	6	1	79.92	8	0	11	19
c3-m4-l1	3	4	1	1	3	-1	292	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	1	8	4	153	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	1	10	1	165	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	1	4	3	270	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	1	2	4	190	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	2	18	8	132	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	2	15	7	207	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	2	6	2	88	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	2	7	7	256	52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l1	3	4	1	2				52.91	1.75	10.75	78.05	17.85	50	150	13.67	3.04	58	55	55	57	62	42	16	4	20	4	0	0	4	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	1	18	-2	116	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	1	15	-8	205	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	1	6	0	281	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	1	7	-3	270	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	1	19	-4	157	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	2	9	0	190	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	2	23	1	276	52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	2	20	-5		52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	2				52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l2	3	4	2	2				52.91	1.75	10.75	78.05	17.85	150	50	13.5	0	58	55	55	56	62	42	16	4	20	5	0	0	5	0	33.56	16	0	3	19
c3-m4-l3	3	4	3	1	9	-6	213	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	1	23	-5	290	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	1	20	1		140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	1	1	0	222	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	1				140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	2	12	-5	188	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	2	13	-6	191	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	2	14	-5	162	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	2	11	-1	140	140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l3	3	4	3	2				140.89	1.38	8.93	84.12	14.65	52	152	11.77	4.48	13	69	71	70	77	52	16	4	20	1	0	0	1	0	30	0	19	0	19
c3-m4-l4	3	4	4	1	12	3	206	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	1	13	5	222	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	1	14	6	411	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	1	11	3	270	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	1	17	0		46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	2	5	-1	226	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	2	21	8	139	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m4-l4	3	4	4	2	16	6	196	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	2	22	0	167	46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l4	3	4	4	2				46.47	0.6	5.21	81.52	10.11	50	153	23.07	9.22	40.14	62	63	61	65	46	16	4	20	7	0	0	6	1	36.57	13	0	6	19
c3-m4-l5	3	4	5	1	24	4		76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	1	5	-1	292	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	1	21	4	171	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	1	16	-4	300	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	1	22	-1	365	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	2	10	8	198	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	2	4	-1	315	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	2	2	-1	160	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	2	19	-3	161	76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m4-l5	3	4	5	2				76.11	1.57	4.28	87.38	10.94	9	41	29.73	11.12	59.58	170	65	65	73	62	16	4	20	10	0	0	9	1	64.67	11	0	8	19
c3-m5-l1	3	5	1	1	24	-2		51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	1	5	3	277	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	1	21	-1	130	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	1	16	7	240	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	1	22	-1	209	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	2	10	-2	278	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	2	4	3	181	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	2	2	8	128	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	2	19	5	166	51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l1	3	5	1	2				51.53	1.42	12.3	79.1	19.29	50	150	14.06	3.03	36	66	66	67	74	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	1	3	0	440	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	1	8	2	283	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	1	10	-1	359	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	1	4	2	291	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	1	2	0	462	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	2	18	-6	124	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	2	15	-2	244	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	2	6	-2	195	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	2	7	-4	222	51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l2	3	5	2	2				51.53	1.42	12.3	79.1	19.29	150	50	13.89	0	36	68	68	69	76	51	16	4	20	6	0	0	6	0	51.24	16	0	3	19
c3-m5-l3	3	5	3	1	18	-8	190	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	1	15	4	193	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	1	6	6	197	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	1	7	-5	324	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	1	19	-6	369	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	2	9	-7	153	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	2	23	-8	140	132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	2	20	-5		132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	2				132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19
c3-m5-l3	3	5	3	2				132.53	1.2	9.28	83.79	14.6	52	152	11.8	4.41	13	72	74	72	80	55	16	4	20	1	0	0	1	0	18.95	0	19	0	19

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Table C.1.: Data used in the analysis of Statechart aesthetics

Chart	Complexity	Model	Layout	Experiment	Participant	Points	Time	TRL	WHR	SU_S	SU_T	SU_A	P_I	P_F	NB_{AVG}	NB_{MIN}	NB_{MAX}	D_I	D_M	D_{NA}	D_{NS}	D_{NR}	N_{SS}	N_{HS}	N_S	IF	IF_{TN}	IF_{TT}	IF_{TL}	IF_{LL}	FL	N_{ST}	N_{PT}	N_{SPT}	N_T
c3-m5-l4	3	5	4	1	9	4	332	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	1	23	6	223	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	1	20	8		50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	1	1	-4	162	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	1				50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	2	12	6	98	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	2	13	4	153	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	2	14	6	157	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	2	11	2	170	50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l4	3	5	4	2				50.9	0.56	5.87	77.53	11.2	50	152	24.58	11.7	43.3	62	62	62	66	46	16	4	20	10	0	0	10	0	46.34	13	0	6	19
c3-m5-l5	3	5	5	1	12	3	460	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	1	13	-7	215	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	1	14	-5	319	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	1	11	-6	412	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	1	17	-8	499	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	2	5	2	260	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	2	21	-5	145	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	2	16	-5	399	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	2	22	-7	216	123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19
c3-m5-l5	3	5	5	2				123.46	1.47	3.89	90.53	10.28	30	89	27.65	11.41	54.13	96	83	81	89	81	16	4	20	6	0	2	4	0	68.7	8	0	11	19

Table C.2.: Data used in the analysis of Statechart development methods

Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
1	1	1	1	455	145	21	17	0	21	41	1	10	0	52	2	0	0
1	1	1	2	231	116	20	22	0	17	32	3	11	0	25	1	4	0
1	1	1	3	438	127	38	18	0	2	7	0	2	0	22	2	1	0
1	1	1	4	668	91	18	9	0	4	9	1	0	0	20	1	0	0
1	1	1	5	240	91	21	14	0	2	3	1	1	0	17	2	2	0
1	1	1	6	170	76	10	15	0	0	0	0	0	0	14	0	3	0
1	1	1	7	303	86	26	12	0	2	4	0	2	0	18	2	2	0
1	1	1	8	256	92	15	14	0	0	0	0	0	0	22	1	4	0
1	1	1	9	233	77	26	13	0	0	0	0	0	0	10	1	1	0
1	1	1	10	640	122	25	15	0	0	0	0	0	0	48	1	4	0
1	1	1	11	372	104	30	19	0	8	13	1	6	0	23	1	4	0
1	1	1	12	485	148	31	22	0	11	20	1	10	0	55	1	2	0
1	1	1	13	425	98	32	12	0	4	4	0	2	0	19	1	0	0
1	1	1	14	363	98	21	14	0	2	1	0	2	0	20	0	2	0
1	1	1	15	345	92	14	20	0	3	9	0	4	0	23	1	6	0
1	1	1	16	377	117	21	9	0	4	20	0	0	0	17	1	0	0
1	1	1	17	412	104	29	12	0	2	4	0	2	0	16	4	0	0
1	1	1	18	243	70	13	12	0	0	0	0	0	0	2	0	1	0
1	1	1	19	415	131	27	23	0	6	14	0	1	0	60	4	6	0
1	1	1	20	305	81	17	16	0	4	8	1	3	0	7	0	3	0
1	1	1	21	173	97	11	17	0	3	3	0	2	0	18	0	4	0
1	1	1	22	318	85	27	14	0	4	9	2	6	0	11	2	0	0
1	1	1	23	186	37	18	21	0	0	0	0	0	0	3	0	0	0
1	1	1	24	241	43	13	23	0	2	0	0	6	0	14	2	0	0
1	1	2	1	309	78	27	4	0	0	0	0	0	0	51	5	1	0
1	1	2	2	131	59	22	8	1	6	0	0	3	1	21	0	1	0
1	1	2	3	163	47	21	3	0	0	0	0	0	0	11	3	0	0
1	1	2	4	247	39	18	5	0	0	0	0	0	0	5	1	2	0
1	1	2	5	108	49	14	7	0	2	5	0	1	0	18	2	2	0
1	1	2	6	86	31	9	1	0	0	0	0	0	0	6	0	0	0
1	1	2	7	247	36	38	4	0	0	0	0	0	0	9	11	0	0
1	1	2	8	165	52	19	6	0	2	3	0	1	0	12	0	1	0
1	1	2	9	131	49	14	2	0	0	0	0	0	0	19	0	0	0
1	1	2	10	223	49	16	8	0	4	7	0	3	0	11	3	0	0
1	1	2	11	140	54	14	5	0	0	0	0	0	0	25	2	0	0
1	1	2	12	98	59	8	13	0	6	9	2	5	0	21	1	0	0
1	1	2	13	216	68	20	14	0	5	17	0	12	0	17	0	1	0
1	1	2	14	165	44	13	4	0	0	0	0	0	0	11	0	0	0
1	1	2	15	150	41	12	4	0	0	0	0	0	0	8	0	1	0
1	1	2	16	124	44	9	5	0	1	3	0	0	0	4	3	2	0
1	1	2	17	194	58	16	3	0	0	0	0	0	0	23	0	0	0
1	1	2	18	195	49	18	3	0	0	0	0	0	0	12	5	0	0
1	1	2	19	317	83	18	12	0	7	15	0	4	0	36	3	3	0

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Table C.2.: Data used in the analysis of Statechart development methods

Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
1	1	2	20	236	52	17	9	6	10	8	0	3	6	8	0	2	0
1	1	2	21	94	33	10	4	0	0	0	0	0	0	9	0	1	0
1	1	2	22	150	42	15	4	0	0	0	0	0	0	9	2	1	0
1	1	2	23	128	40	18	7	0	0	0	0	0	0	22	3	0	0
1	1	2	24	155	29	14	6	0	0	0	0	0	0	9	0	0	0
2	1	1	1	221	42	1	21	7	0	0	0	0	0	16	1	2	0
2	1	1	2	374	47	8	20	10	5	4	0	3	3	22	3	0	1
2	1	1	3	120	50	4	33	7	3	1	0	4	0	25	2	3	0
2	1	1	4	457	53	0	36	9	3	0	0	2	1	29	0	1	1
2	1	1	5	584	67	2	23	8	2	4	0	0	1	31	2	0	0
2	1	1	6	609	46	5	27	9	6	5	0	7	3	16	0	0	1
2	1	1	7	820	77	5	27	5	4	0	1	8	0	37	2	0	0
2	1	1	8	285	55	1	32	6	2	1	0	4	0	28	0	0	0
2	1	1	9	370	70	7	31	11	8	14	0	13	3	21	0	1	1
2	1	1	10	370	59	4	17	11	6	5	0	0	4	23	4	0	0
2	1	1	11	520	75	0	36	11	1	0	0	0	1	48	0	1	3
2	1	1	12	472	87	5	20	13	4	4	0	0	4	66	0	0	2
2	1	1	13	245	34	0	41	8	2	3	0	5	0	4	0	0	2
2	1	1	14	651	94	8	29	7	3	0	1	3	1	65	1	1	1
2	1	1	15	270	69	0	29	8	0	0	0	0	0	22	0	1	0
2	1	1	16	324	56	3	24	8	1	0	0	0	1	28	0	0	0
2	1	1	17	443	33	5	20	8	2	0	0	0	2	7	0	0	0
2	1	1	18	228	29	8	23	10	9	4	3	7	4	4	0	2	0
2	1	1	19	623	113	2	58	11	10	9	0	20	3	73	1	6	1
2	1	1	20	415	70	6	21	9	4	1	0	0	4	45	1	0	0
2	1	1	21	314	64	7	29	8	9	4	2	5	7	36	1	0	1
2	1	1	22	249	50	6	25	9	4	2	0	3	2	21	0	2	0
2	1	1	23	345	65	6	22	11	5	3	1	2	4	30	0	0	0
2	1	1	24	908	82	0	50	12	5	5	0	9	2	37	0	6	2
2	1	2	1	62	16	0	6	3	0	0	0	0	0	6	0	0	0
2	1	2	2	86	15	3	7	3	0	0	0	0	0	9	0	0	0
2	1	2	3	74	21	0	11	3	0	0	0	0	0	17	0	0	0
2	1	2	4	100	13	0	10	3	0	0	0	0	0	6	0	0	0
2	1	2	5	165	17	2	6	3	0	0	0	0	0	5	2	0	0
2	1	2	6	110	24	3	8	5	4	6	0	2	2	9	0	0	0
2	1	2	7	213	35	2	6	3	0	0	0	0	0	21	0	0	0
2	1	2	8	91	18	0	10	3	0	0	0	0	0	9	0	0	0
2	1	2	9	68	11	2	8	3	0	0	0	0	0	4	1	0	0
2	1	2	10	90	23	0	9	3	2	1	0	4	0	11	0	0	0
2	1	2	11	112	23	0	6	5	2	1	0	0	2	13	0	0	0
2	1	2	12	73	18	2	6	3	0	0	0	0	0	8	0	0	0
2	1	2	13	79	13	0	10	3	0	0	0	0	0	8	0	0	0
2	1	2	14	142	15	2	6	3	0	0	0	0	0	8	0	0	0
2	1	2	15	44	14	0	10	3	0	0	0	0	0	6	0	0	0

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Table C.2.: Data used in the analysis of Statechart development methods

Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
2	1	2	16	106	13	0	10	3	0	0	0	0	0	6	0	0	0
2	1	2	17	89	10	2	6	3	0	0	0	0	0	4	0	0	0
2	1	2	18	80	12	1	8	3	0	0	0	0	0	4	1	0	0
2	1	2	19	106	33	0	12	3	0	0	0	0	0	28	0	3	0
2	1	2	20	106	14	2	6	5	2	0	0	0	2	8	0	0	0
2	1	2	21	64	9	3	6	3	0	0	0	0	0	5	1	0	0
2	1	2	22	55	12	2	6	2	0	0	0	0	0	7	0	0	0
2	1	2	23	65	7	3	5	3	0	0	0	0	0	3	1	0	0
2	1	2	24	110	11	0	11	3	0	0	0	0	0	5	0	0	1
3	1	1	1	367	11	6	177	1	14	5	2	58	0	2	0	6	0
3	1	1	2	270	18	13	168	1	10	0	0	28	0	6	5	25	0
3	1	1	3	597	3	4	306	1	21	0	0	77	0	1	0	40	0
3	1	1	4	444	1	2	253	7	13	0	0	52	0	0	0	41	0
3	1	1	5	234	3	1	166	10	6	0	0	22	0	0	0	25	0
3	1	1	6	303	5	3	242	2	8	0	0	19	0	0	0	44	0
3	1	1	7	211	1	1	179	11	1	0	0	4	0	0	0	48	0
3	1	1	8	461	12	5	114	4	14	3	0	32	0	3	0	2	0
3	1	1	9	413	5	0	282	6	18	0	0	62	1	0	0	53	0
3	1	1	10	337	1	0	334	1	21	0	0	72	0	0	0	56	0
3	1	1	11	272	2	0	233	9	9	0	0	36	0	0	0	19	0
3	1	1	12	363	29	7	226	3	12	4	1	47	1	14	0	26	0
3	1	1	13	215	5	2	154	6	3	0	0	10	0	1	0	25	0
3	1	1	14	355	17	6	161	4	15	3	0	27	1	8	2	33	0
3	1	1	15	213	6	0	174	2	13	2	0	13	0	1	0	4	0
3	1	1	16	571	4	3	136	7	6	0	0	10	0	2	2	7	0
3	1	1	17	553	1	2	174	9	6	0	1	24	2	0	1	14	0
3	1	1	18	262	2	0	177	8	5	0	0	13	0	0	0	34	3
3	1	1	19	257	22	0	119	6	9	2	0	13	0	9	0	23	0
3	1	1	20	292	11	5	112	6	3	1	0	7	0	0	2	13	1
3	1	1	21	592	1	0	188	9	4	0	0	9	0	0	0	50	0
3	1	1	22	391	6	4	266	1	10	1	0	22	0	1	1	50	0
3	1	1	23	289	1	0	123	8	10	0	0	14	0	0	0	15	1
3	1	1	24	623	11	0	334	1	20	1	0	90	0	4	0	25	0
3	1	2	1	77	2	4	37	1	3	1	1	7	0	0	0	0	0
3	1	2	2	72	4	2	62	0	5	0	0	7	0	1	1	5	0
3	1	2	3	116	0	0	102	1	5	0	0	33	1	0	0	2	0
3	1	2	4	144	2	0	79	0	4	0	0	12	0	0	0	7	0
3	1	2	5	76	0	0	72	0	2	0	0	19	0	0	0	11	0
3	1	2	6	50	0	0	77	0	2	0	0	6	0	0	0	15	0
3	1	2	7	90	1	0	90	0	2	0	0	13	0	0	0	10	0
3	1	2	8	121	2	0	39	0	2	1	0	11	0	0	0	2	0
3	1	2	9	121	4	0	71	1	6	1	0	17	1	0	0	2	0
3	1	2	10	58	1	0	83	0	6	0	0	21	0	0	0	15	0
3	1	2	11	54	1	0	64	0	3	0	0	12	0	0	0	4	0

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Table C.2.: Data used in the analysis of Statechart development methods

Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
3	1	2	12	97	9	0	68	0	4	0	0	17	0	3	0	0	0
3	1	2	13	70	5	2	46	1	0	0	0	0	0	1	1	0	0
3	1	2	14	92	2	2	79	0	4	0	0	18	0	0	0	12	0
3	1	2	15	61	2	0	67	0	0	0	0	0	0	0	0	17	0
3	1	2	16	341	1	0	52	4	6	0	0	8	1	1	0	2	0
3	1	2	17	147	3	0	76	10	4	3	0	12	0	0	0	20	0
3	1	2	18	72	0	0	67	0	0	0	0	0	0	0	0	5	0
3	1	2	19	69	6	0	67	0	1	1	0	1	0	0	0	23	0
3	1	2	20	79	4	2	47	1	0	0	0	0	0	0	0	5	0
3	1	2	21	212	0	0	160	10	20	0	0	123	9	0	0	23	0
3	1	2	22	132	3	1	76	0	0	0	0	0	0	0	0	31	0
3	1	2	23	77	0	0	38	3	1	0	0	7	0	0	0	0	0
3	1	2	24	116	4	0	63	0	4	0	0	14	0	1	0	5	0
1	2	1	2	158	61	11	29	1	4	4	0	6	0	13	0	0	1
1	2	1	4	200	99	13	17	0	0	0	0	0	0	20	1	3	0
1	2	1	5	445	135	16	30	0	4	13	0	10	0	34	0	4	0
1	2	1	6	321	80	15	9	0	0	0	0	0	0	16	0	0	0
1	2	1	7	313	80	17	11	0	0	0	0	0	0	13	0	2	0
1	2	1	9	313	75	15	16	0	2	4	1	2	0	10	3	0	0
1	2	1	10	197	106	28	13	0	2	2	0	0	0	29	5	1	0
1	2	1	11	325	87	17	14	0	4	7	0	3	0	7	0	0	0
1	2	1	12	236	112	25	29	1	6	13	0	10	0	52	0	3	0
1	2	1	13	178	80	28	10	0	0	0	0	0	0	12	0	0	0
1	2	1	14	467	115	27	16	0	6	8	0	3	0	39	1	2	0
1	2	1	15	133	64	19	21	0	0	0	0	0	0	12	0	0	0
1	2	1	16	252	83	17	15	0	0	0	0	0	0	14	3	0	0
1	2	1	18	150	76	11	11	1	2	3	0	0	1	3	1	1	0
1	2	1	19	170	98	21	19	3	6	9	0	4	0	17	1	5	0
1	2	1	20	155	52	24	23	0	4	4	2	5	0	4	4	0	0
1	2	1	21	280	87	24	14	0	3	6	1	3	0	18	1	4	0
1	2	1	22	193	70	18	14	0	2	4	0	2	0	7	0	2	0
1	2	1	23	322	54	29	24	6	4	1	1	2	2	17	0	0	0
1	2	2	2	101	38	8	12	0	8	17	0	7	0	4	0	0	0
1	2	2	4	140	47	12	10	0	2	4	0	1	0	9	0	1	0
1	2	2	5	244	67	27	8	0	4	6	0	2	0	28	4	2	0
1	2	2	6	182	39	11	6	0	2	2	0	2	0	5	1	0	0
1	2	2	7	172	48	16	4	0	0	0	0	0	0	9	2	0	0
1	2	2	9	223	51	27	4	0	0	0	0	0	0	21	2	0	0
1	2	2	10	207	80	35	8	0	0	0	0	0	0	44	8	4	0
1	2	2	11	247	53	31	8	0	3	7	0	2	0	18	9	2	0
1	2	2	12	121	39	21	8	0	2	5	0	3	0	4	1	0	0
1	2	2	13	86	38	12	3	0	0	0	0	0	0	5	0	0	0
1	2	2	14	241	50	18	4	3	4	3	0	2	3	11	0	0	0
1	2	2	15	110	31	29	7	0	0	0	0	0	0	10	2	0	0

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Table C.2.: Data used in the analysis of Statechart development methods

Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
1	2	2	16	142	36	20	5	0	0	0	0	0	0	2	1	0	0
1	2	2	18	117	43	15	5	0	0	0	0	0	0	8	2	1	0
1	2	2	19	196	56	13	9	2	6	16	0	3	0	13	0	2	0
1	2	2	20	105	36	15	4	0	1	2	0	0	0	14	1	0	0
1	2	2	21	143	45	17	6	0	0	0	0	0	0	8	3	2	0
1	2	2	22	118	51	14	5	0	2	3	1	2	0	17	1	0	0
1	2	2	23	165	32	22	7	2	0	0	0	0	0	13	4	0	0
2	2	1	2	158	47	5	23	6	2	3	0	3	0	27	0	0	1
2	2	1	4	427	82	1	44	9	3	2	1	2	2	43	0	0	0
2	2	1	5	204	49	6	34	6	2	1	0	4	0	24	0	3	0
2	2	1	6	146	48	4	20	6	0	0	0	0	0	28	0	0	0
2	2	1	7	288	38	3	53	10	7	5	0	4	5	14	0	14	0
2	2	1	9	236	57	7	38	7	1	1	1	9	0	28	0	4	1
2	2	1	10	486	55	0	25	8	4	8	0	5	1	14	0	1	0
2	2	1	11	298	97	9	49	12	12	19	0	16	6	46	4	5	1
2	2	1	12	136	39	5	21	8	2	0	0	0	2	19	0	0	1
2	2	1	13	287	49	6	22	9	4	4	0	0	4	21	0	1	0
2	2	1	14	231	55	9	30	6	6	3	2	9	0	34	0	1	0
2	2	1	15	150	53	5	25	5	0	0	0	0	0	25	0	2	0
2	2	1	16	552	51	5	22	10	3	4	0	3	2	24	0	0	1
2	2	1	18	213	36	7	26	14	6	5	2	4	4	7	1	0	2
2	2	1	19	165	61	0	30	10	0	0	0	0	0	32	0	4	0
2	2	1	20	346	64	2	34	8	3	2	1	2	2	32	0	0	0
2	2	1	21	119	53	0	22	6	0	0	0	0	0	19	0	0	0
2	2	1	22	300	53	6	22	6	2	1	1	3	0	26	0	0	0
2	2	1	23	145	55	6	20	6	0	0	0	0	0	29	0	0	0
2	2	2	2	52	17	1	8	3	0	0	0	0	0	13	0	0	0
2	2	2	4	151	21	0	10	4	0	0	0	0	0	10	0	0	1
2	2	2	5	68	26	0	6	3	0	0	0	0	0	14	0	0	0
2	2	2	6	67	12	2	6	3	0	0	0	0	0	5	0	0	0
2	2	2	7	74	13	0	16	3	0	0	0	0	0	5	0	2	0
2	2	2	9	82	13	2	6	6	2	0	0	0	2	5	0	0	1
2	2	2	10	187	17	0	6	3	0	0	0	0	0	8	0	0	0
2	2	2	11	42	11	1	10	3	0	0	0	0	0	5	0	0	0
2	2	2	12	100	21	2	6	5	0	0	0	0	0	11	0	0	2
2	2	2	13	49	14	2	6	3	0	0	0	0	0	10	0	0	0
2	2	2	14	83	15	3	6	3	0	0	0	0	0	8	0	0	0
2	2	2	15	73	15	2	6	3	0	0	0	0	0	8	0	0	0
2	2	2	16	224	12	1	8	5	0	0	0	0	0	5	0	0	2
2	2	2	18	59	15	2	6	3	0	0	0	0	0	9	0	0	0
2	2	2	19	35	13	0	10	3	0	0	0	0	0	6	0	0	0
2	2	2	20	169	20	1	8	3	0	0	0	0	0	14	0	0	0
2	2	2	21	43	14	0	6	3	0	0	0	0	0	7	0	0	0
2	2	2	22	94	11	3	8	3	0	0	0	0	0	2	0	0	0

Continued on next page

Table C.2.: Data used in the analysis of Statechart development methods

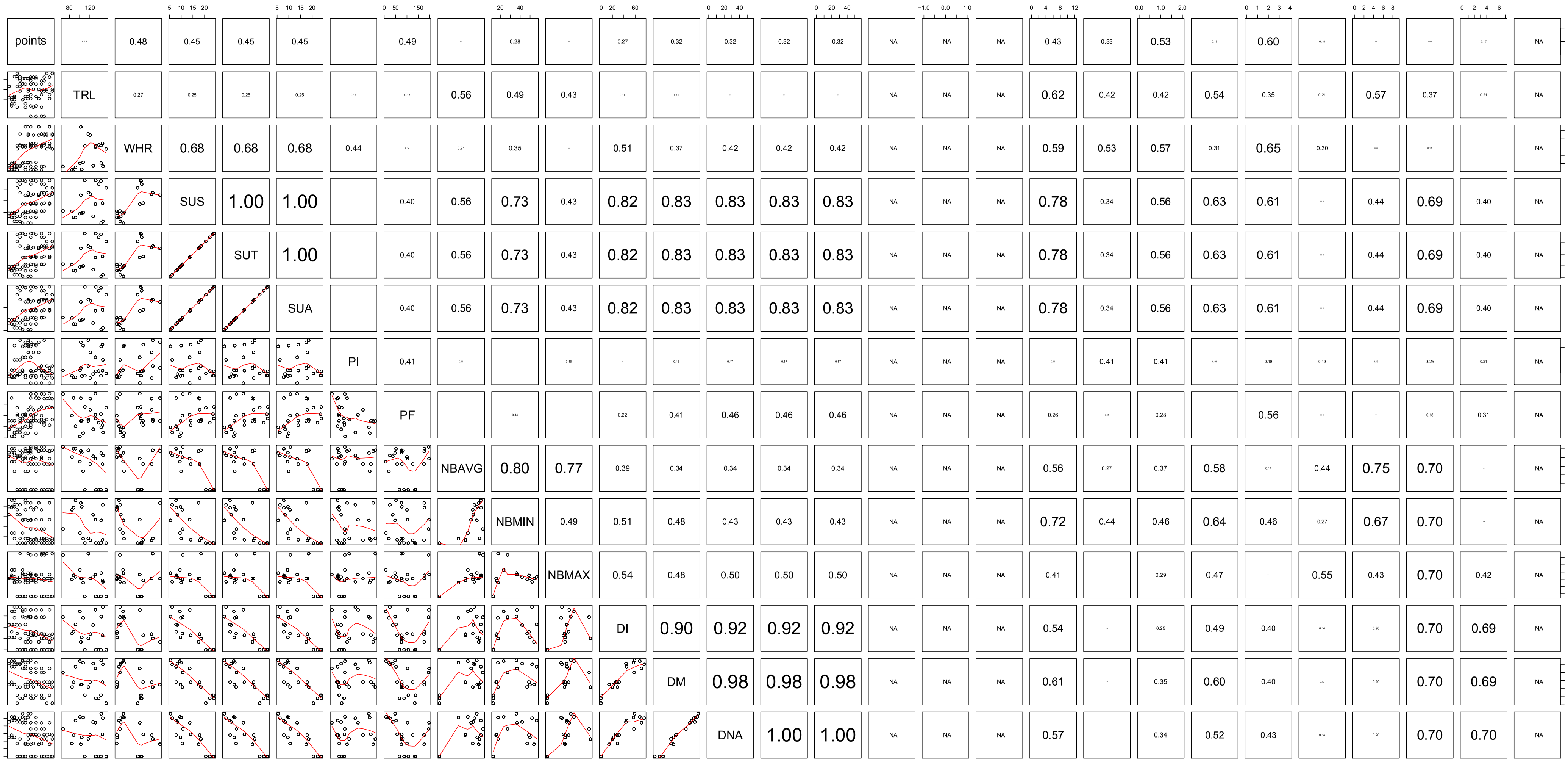
Tool	Create/ Modify	Experiment	Participant	Time	Mouseclicks	Mousedrags	Keystrokes	Macrokeys	Error Mouseclicks	Error Mousedrags	Error Keystrokes	Error Macrokeys	Unnecessary Mouseclicks	Unnecessary Mousedrags	Unnecessary Keystrokes	Unnecessary Macrokeys	Nicefy Mousedrags
2	2	2	23	43	12	2	6	3	0	0	0	0	0	7	0	0	0
3	2	1	2	360	5	4	134	5	3	1	0	5	0	2	2	15	1
3	2	1	4	222	1	0	195	4	2	0	0	2	0	0	0	11	0
3	2	1	5	165	1	0	155	12	5	0	0	10	0	0	0	36	2
3	2	1	6	150	1	0	209	7	6	1	0	19	0	0	0	37	0
3	2	1	7	190	3	0	198	10	10	0	0	25	0	0	0	30	0
3	2	1	9	174	8	1	154	9	6	0	0	23	0	4	1	25	0
3	2	1	10	149	12	3	139	1	9	0	0	9	0	4	0	12	0
3	2	1	11	178	1	0	215	7	4	0	0	24	0	0	0	39	1
3	2	1	12	358	4	2	239	5	11	2	0	55	0	0	0	39	0
3	2	1	13	338	14	7	218	7	14	0	0	64	1	7	0	42	0
3	2	1	14	183	5	1	196	6	7	0	0	16	0	1	0	34	0
3	2	1	15	207	6	1	157	9	7	1	0	17	0	0	0	32	2
3	2	1	16	195	3	0	180	5	6	0	0	12	0	0	0	6	0
3	2	1	18	378	1	0	227	6	22	0	0	60	0	0	0	12	0
3	2	1	19	378	15	0	188	6	15	3	0	41	0	2	0	6	0
3	2	1	20	304	9	2	146	20	5	1	1	12	0	2	0	24	2
3	2	1	21	138	4	0	195	10	9	0	0	28	0	0	0	23	0
3	2	1	22	259	11	5	232	1	7	1	0	23	0	4	3	45	0
3	2	1	23	147	1	0	139	12	2	0	0	5	0	0	0	21	0
3	2	2	2	191	5	1	52	3	4	0	0	11	2	0	0	6	1
3	2	2	4	66	0	0	63	0	0	0	0	0	0	0	0	2	0
3	2	2	5	49	0	0	64	1	0	0	0	0	0	0	0	13	0
3	2	2	6	31	0	0	68	0	0	0	0	0	0	0	0	8	0
3	2	2	7	103	0	0	161	4	7	0	0	17	1	0	0	24	1
3	2	2	9	61	1	0	65	1	2	0	0	4	0	0	0	4	0
3	2	2	10	49	4	0	56	0	2	0	0	8	0	2	0	12	0
3	2	2	11	37	1	0	80	0	6	0	0	15	0	0	0	12	0
3	2	2	12	156	3	2	50	2	2	0	0	2	0	0	0	0	0
3	2	2	13	86	4	1	50	1	0	0	0	0	0	2	0	4	0
3	2	2	14	71	7	3	85	1	3	0	0	3	1	1	1	11	0
3	2	2	15	84	1	0	63	0	0	0	0	0	0	0	0	13	0
3	2	2	16	109	4	1	102	2	8	4	1	21	2	0	0	11	0
3	2	2	18	144	1	0	77	0	3	0	0	5	0	0	0	2	0
3	2	2	19	107	2	0	71	0	8	0	0	15	0	0	0	6	0
3	2	2	20	51	3	1	43	2	2	0	0	2	0	0	0	3	0
3	2	2	21	80	0	0	108	0	10	0	0	28	0	0	0	9	0
3	2	2	22	72	0	0	90	0	2	0	0	2	0	0	0	24	0
3	2	2	23	47	0	0	94	2	0	0	0	0	0	0	0	23	0

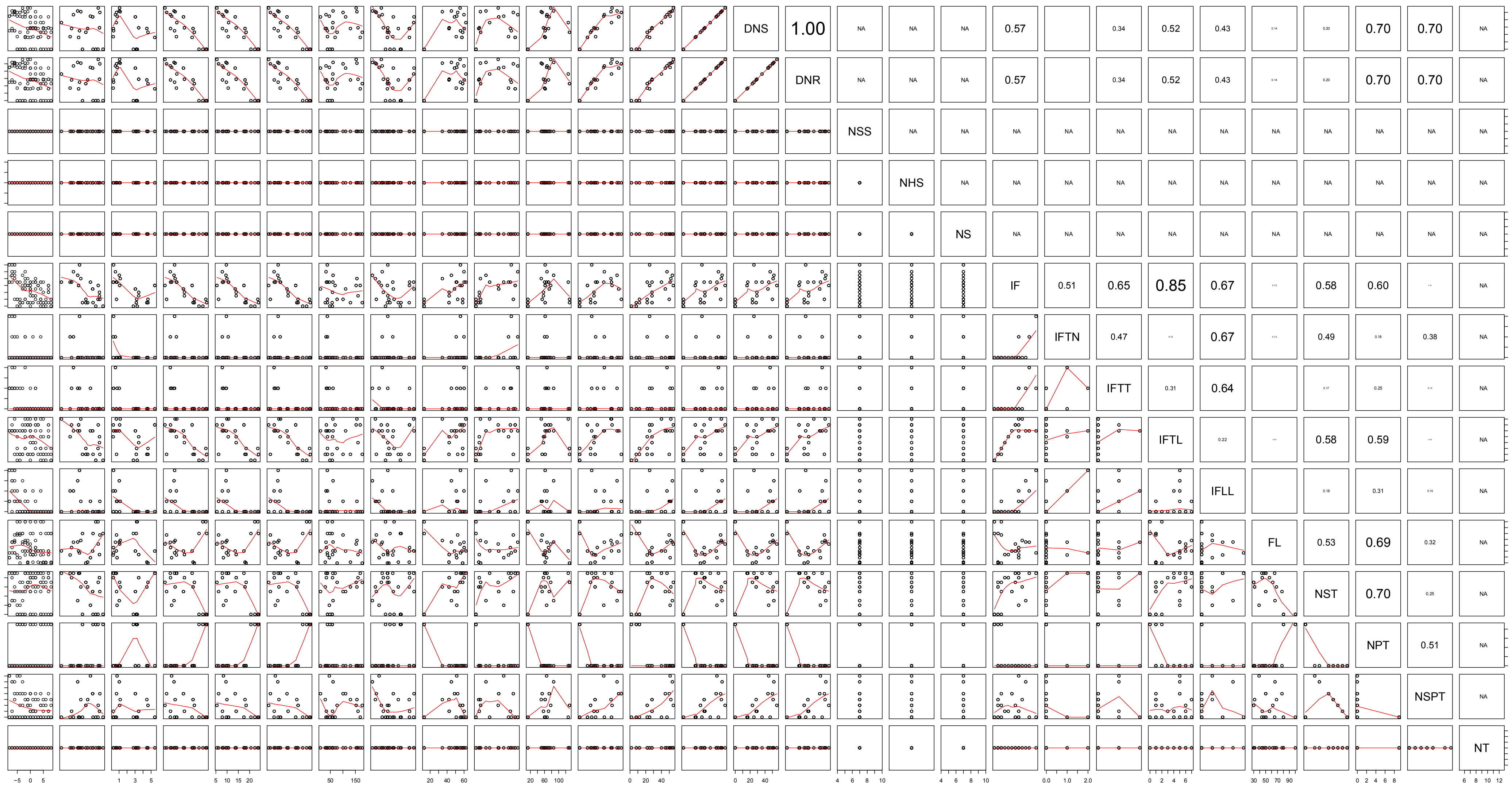
D. Correlation Matrices

The following pages contain the correlation matrices used to decide which metrics to include in the composite model. For a detailed description see Figure 7.5 containing a smaller example. The variables are labeled with the abbreviations designated in Table 4.1.

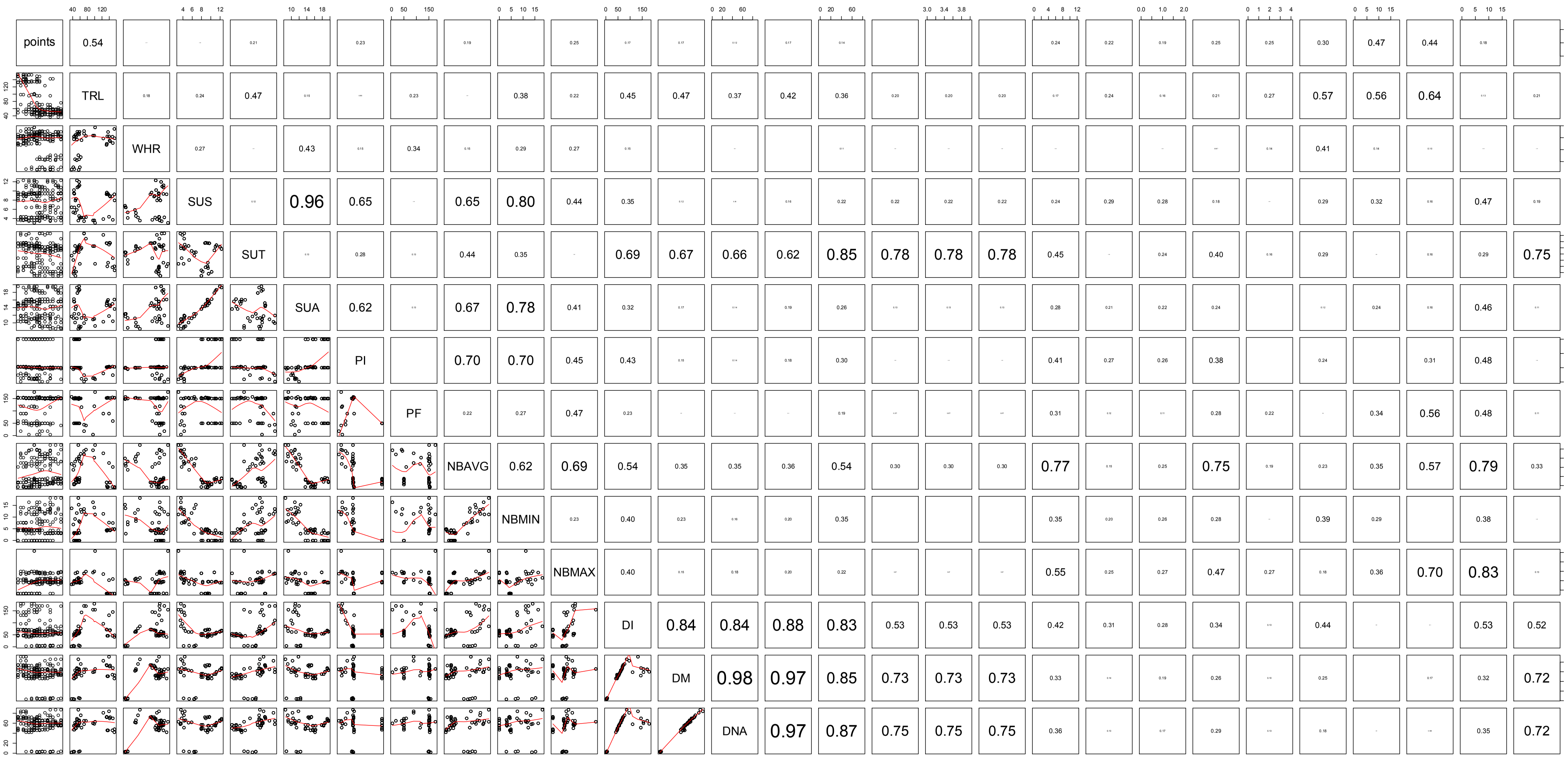
The matrices contain Spearman's correlation coefficients and scatterplots for every combination of two variables. The small numbers seen around the frame design the values for the plotted data and are not meaningful for the correlation coefficients.

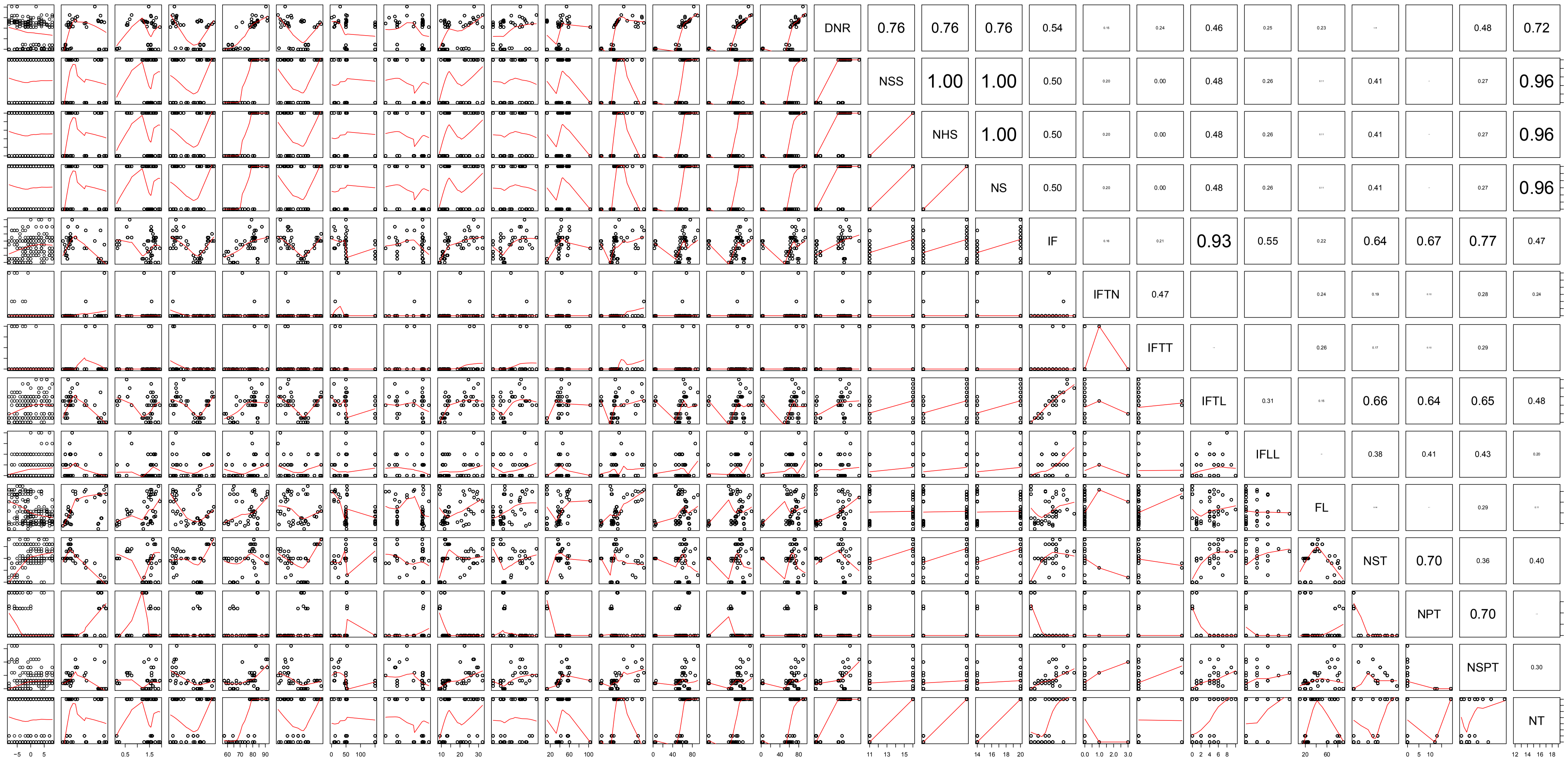
Correlation Matrix for Dependent Variable Points, Statecharts of Simple Complexity



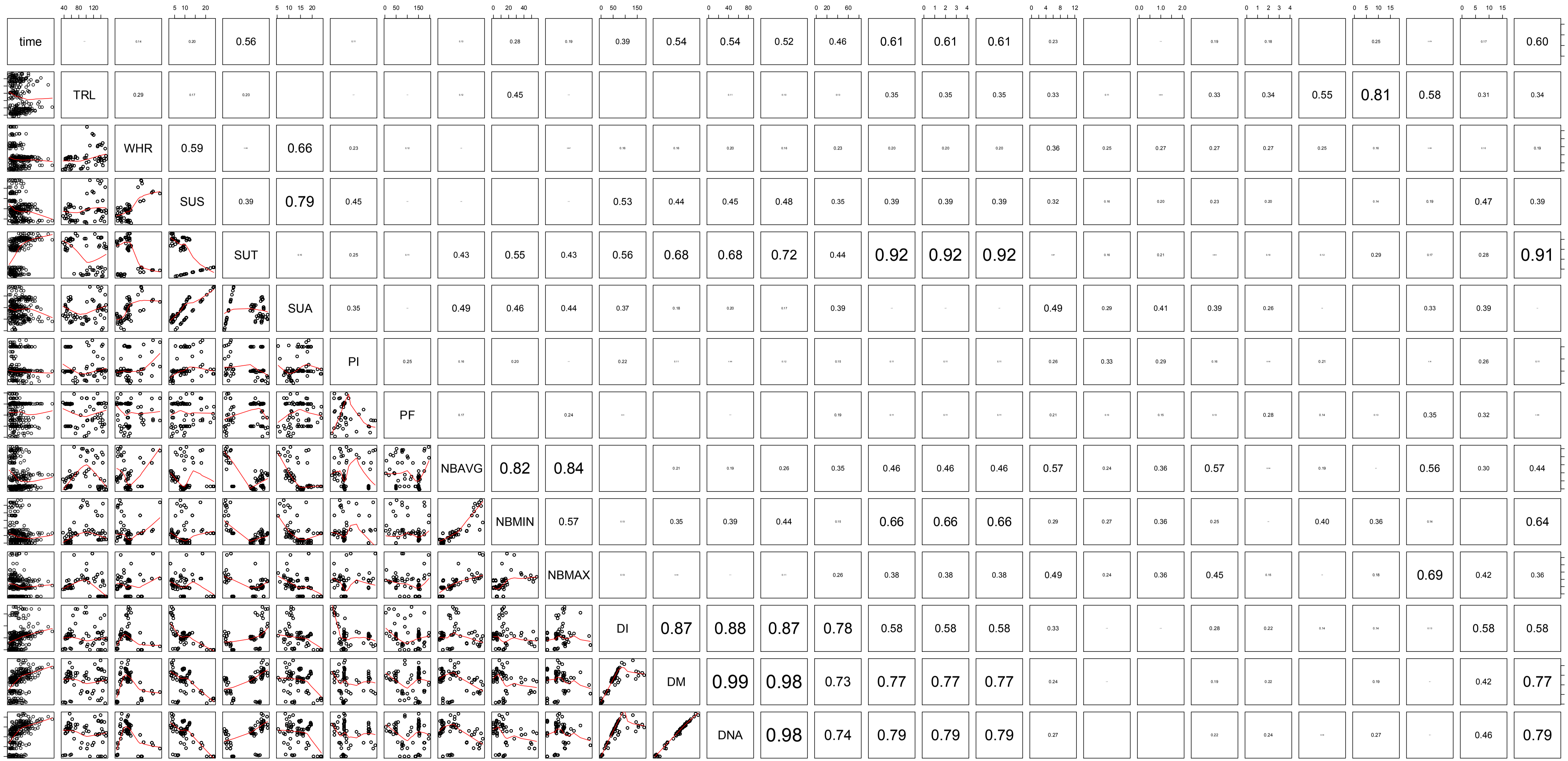

DNS
DNR
NSS
NHS
NS
IF
IFTN
IFTT
IFTL
IFLL
FL
NST
NPT
NSPT
NT

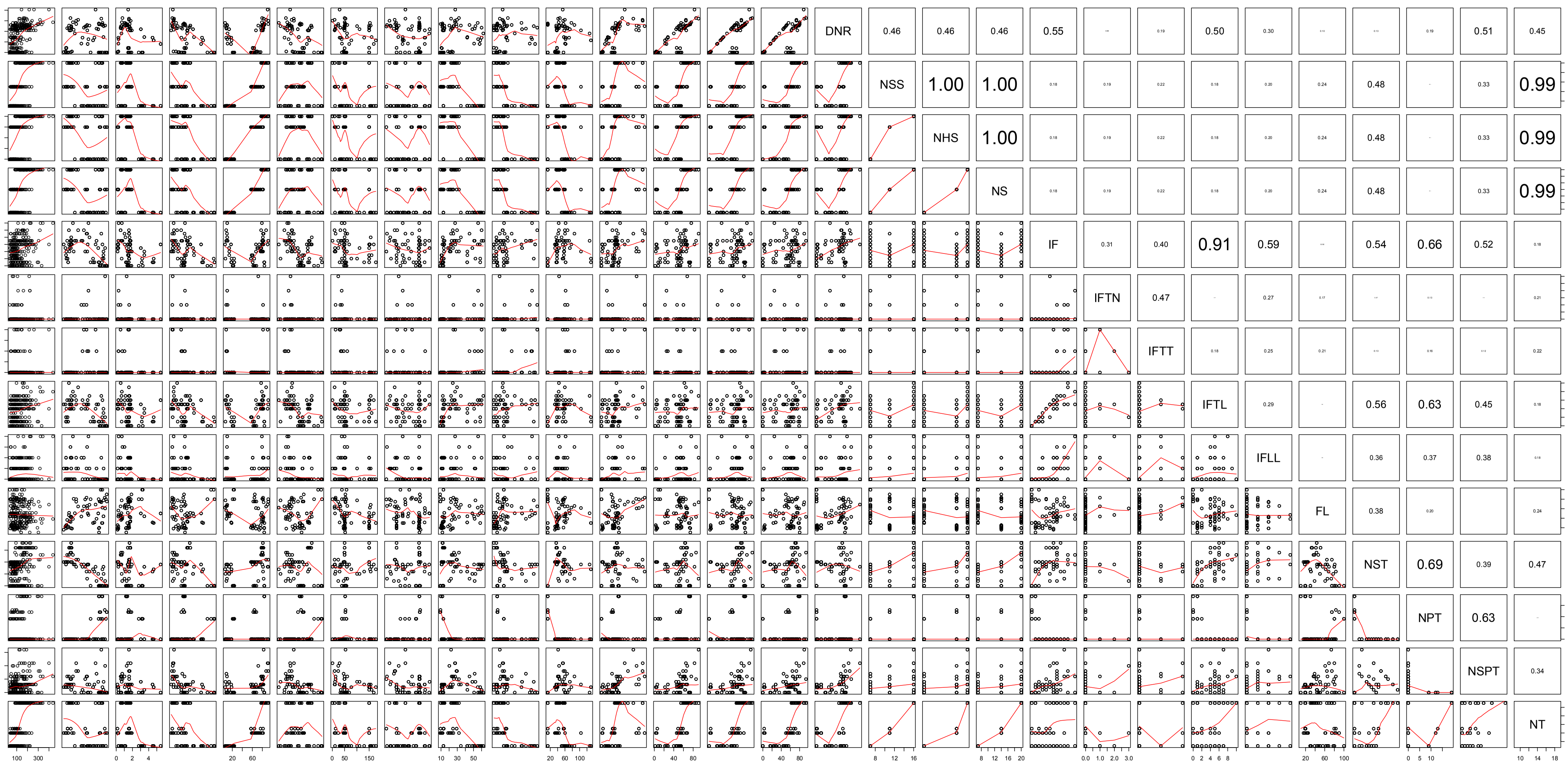
Correlation Matrix for Dependent Variable Points, Statecharts of Higher Complexity




DNR
NSS
NHS
NS
IF
IFTN
IFTT
IFTL
IFLL
FL
NST
NPT
NSPT
NT

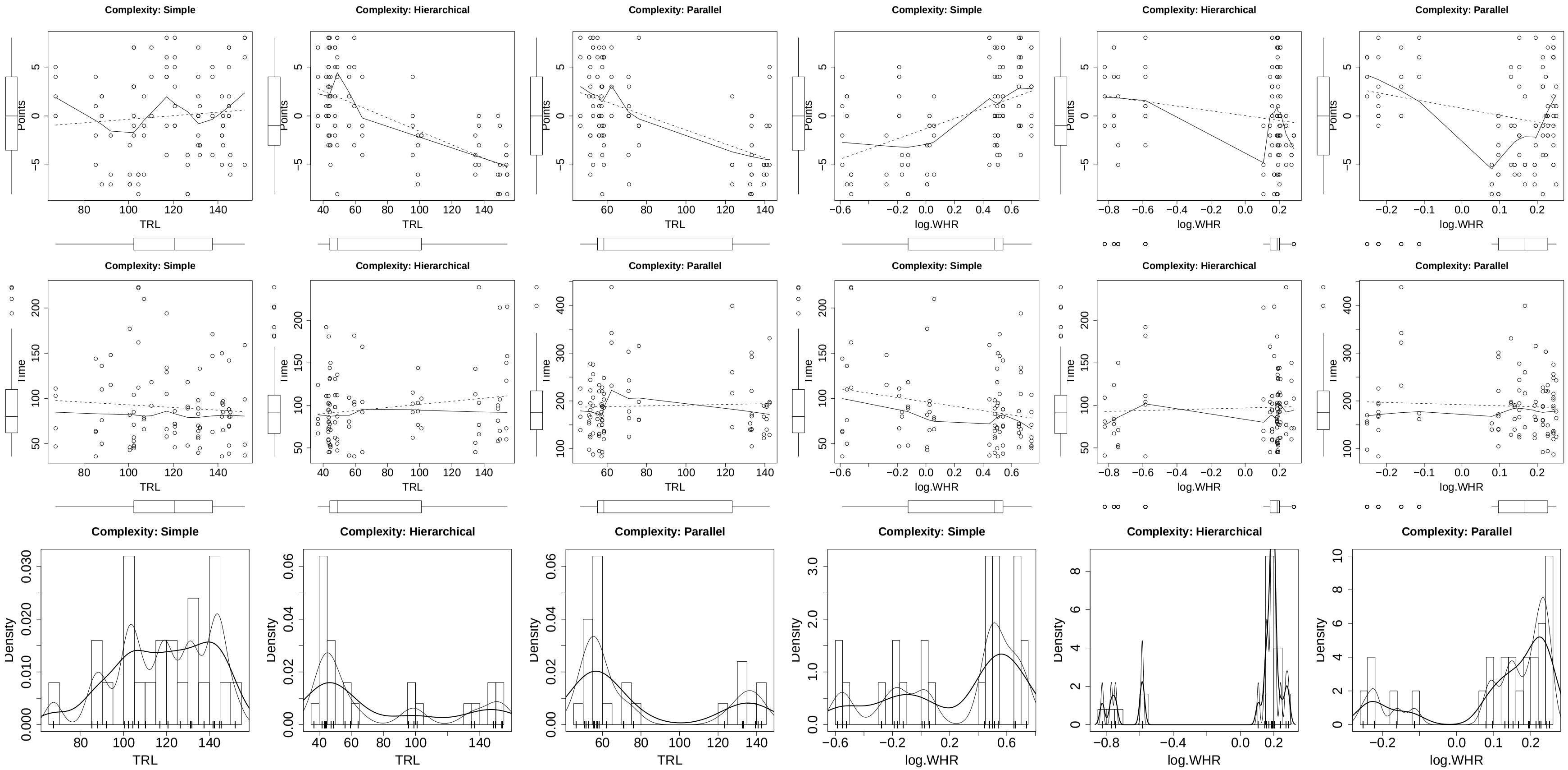
Correlation Matrix for Dependent Variable Time, Statecharts of All Complexities



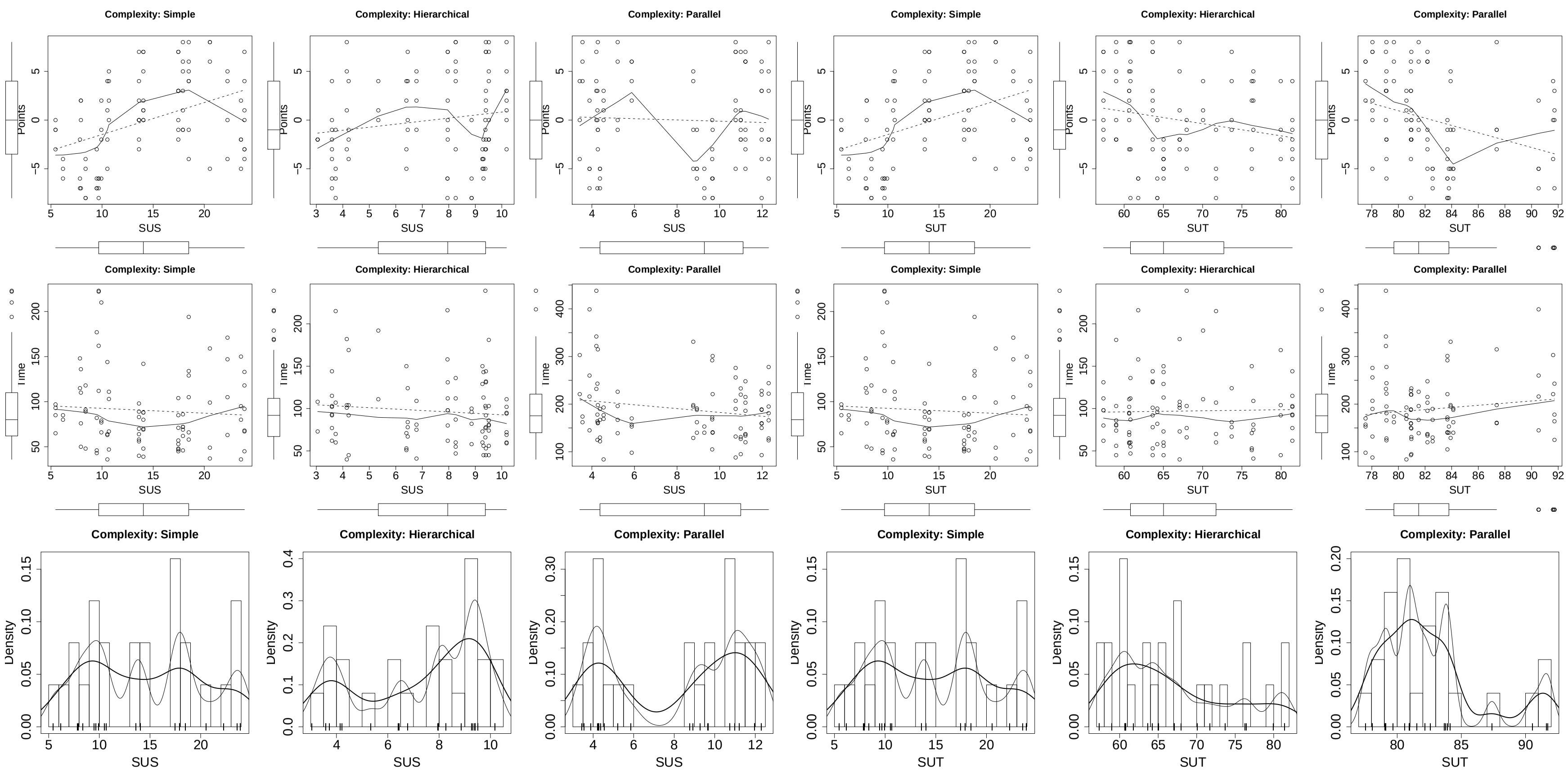

DNR
NSS
NHS
NS
IF
IFTN
IFTT
IFTL
IFLL
FL
NST
NPT
NSPT
NT

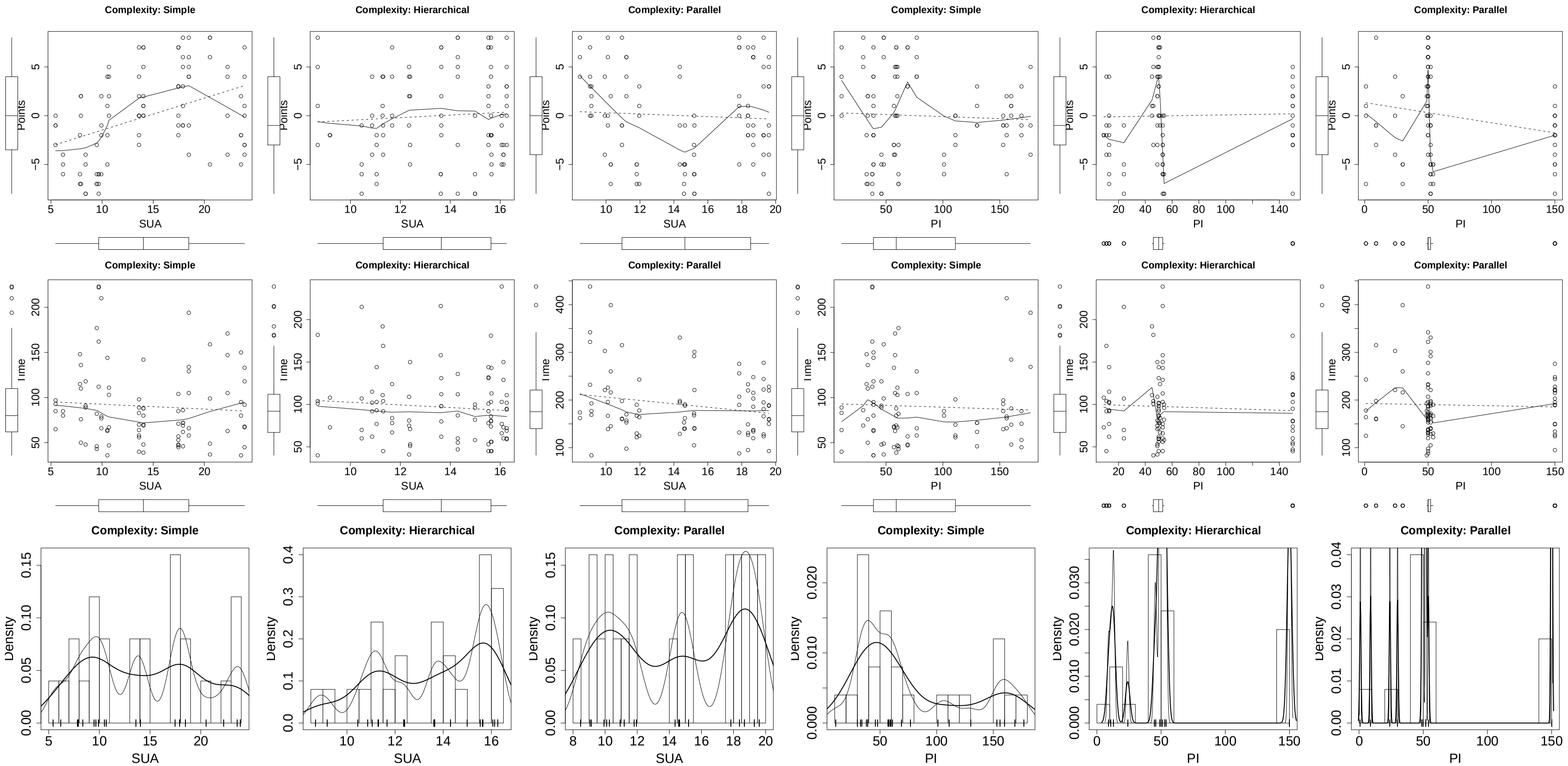
E. Data Scatterplots

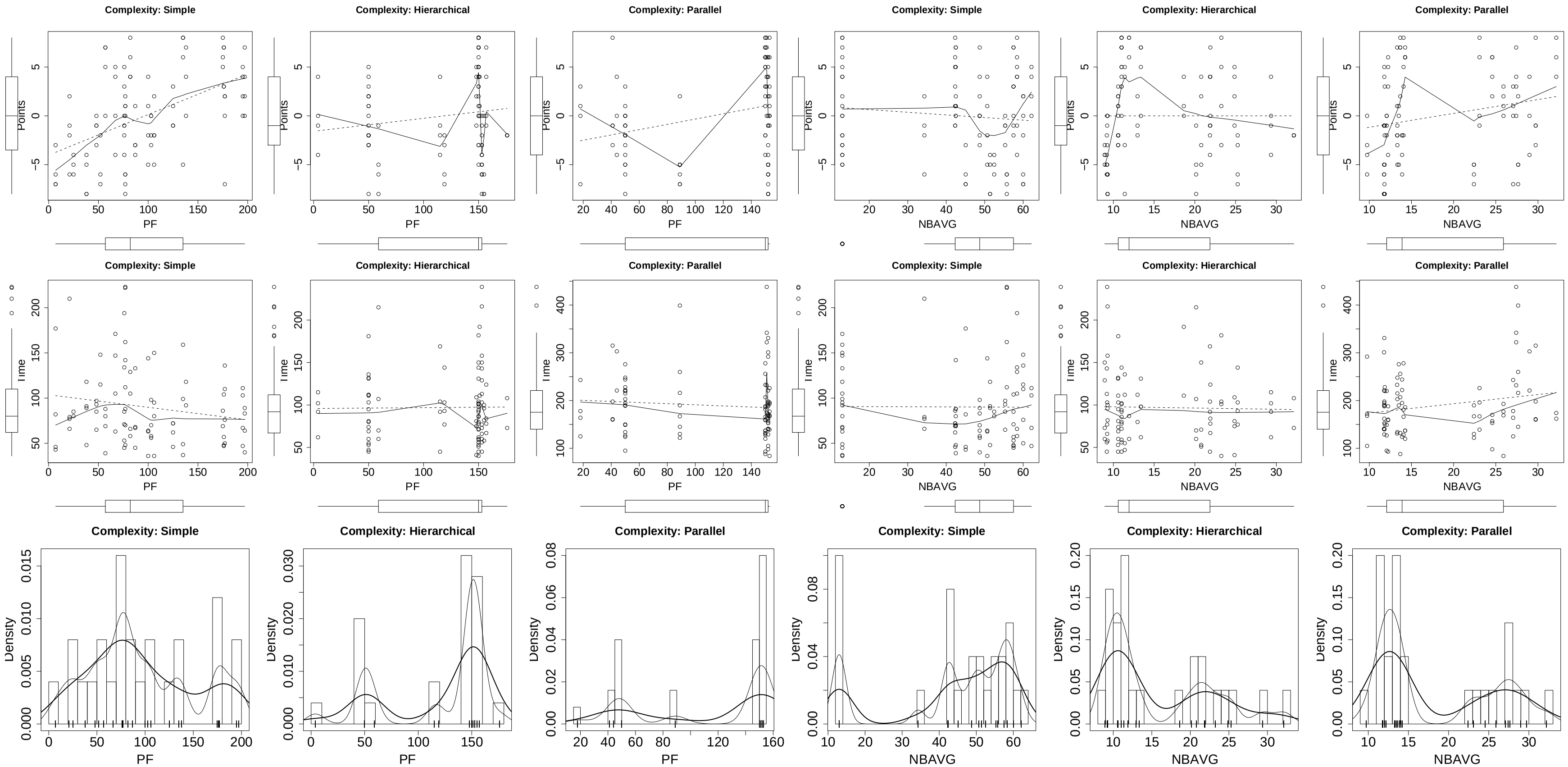
The collected data was displayed in a set of scatterplots to identify linear and non-linear correlations between the dependent and the independent variables. The plots on the following pages show the dataset used in the composition of the multivariate regression formula for both, awarded points and needed time. The variables are labeled with the abbreviations designated in Table 4.1.



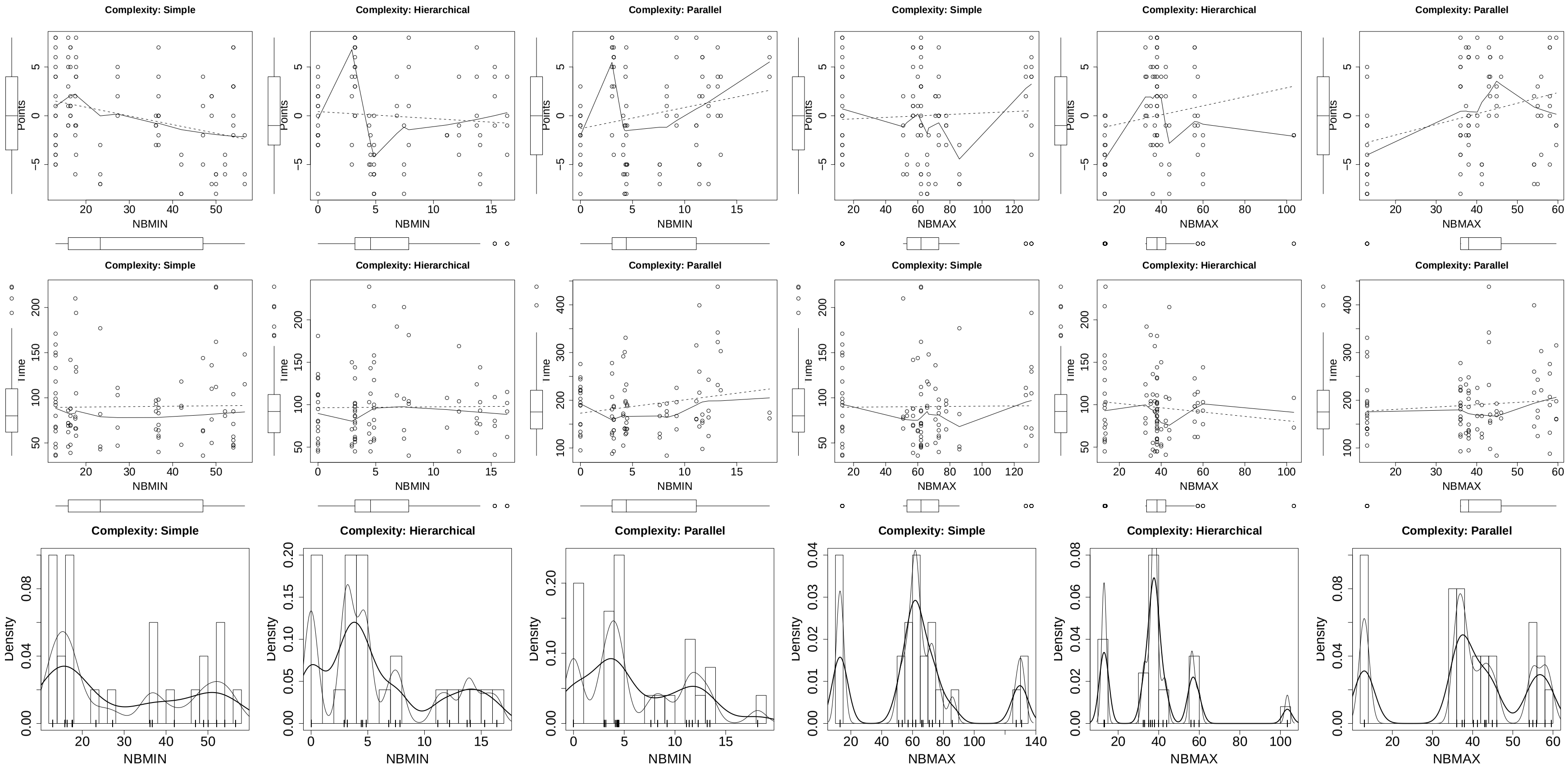
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
TRL
log.WHR


Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
SUS
SUT
Time
Density

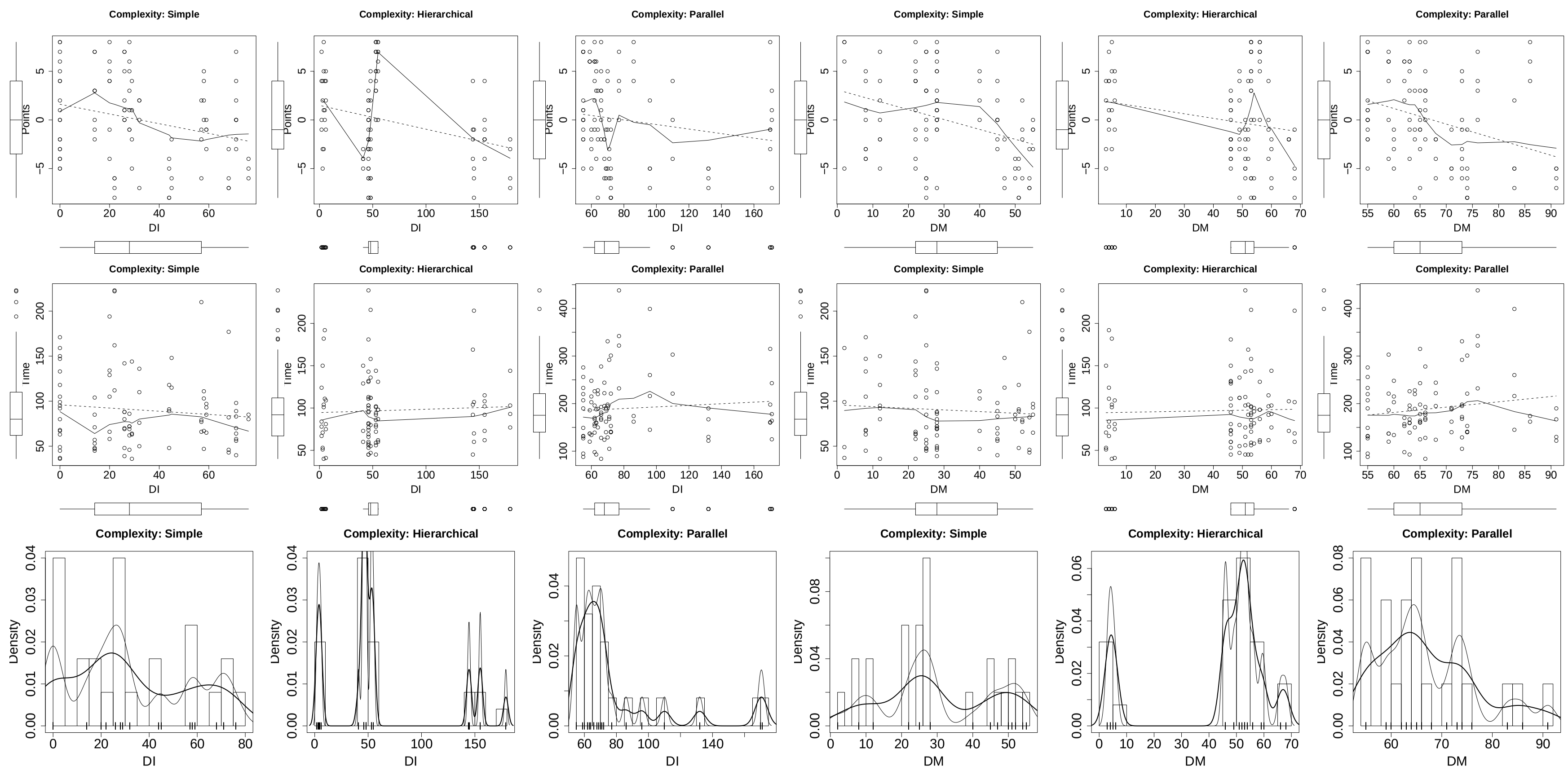

Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
SUA
PI



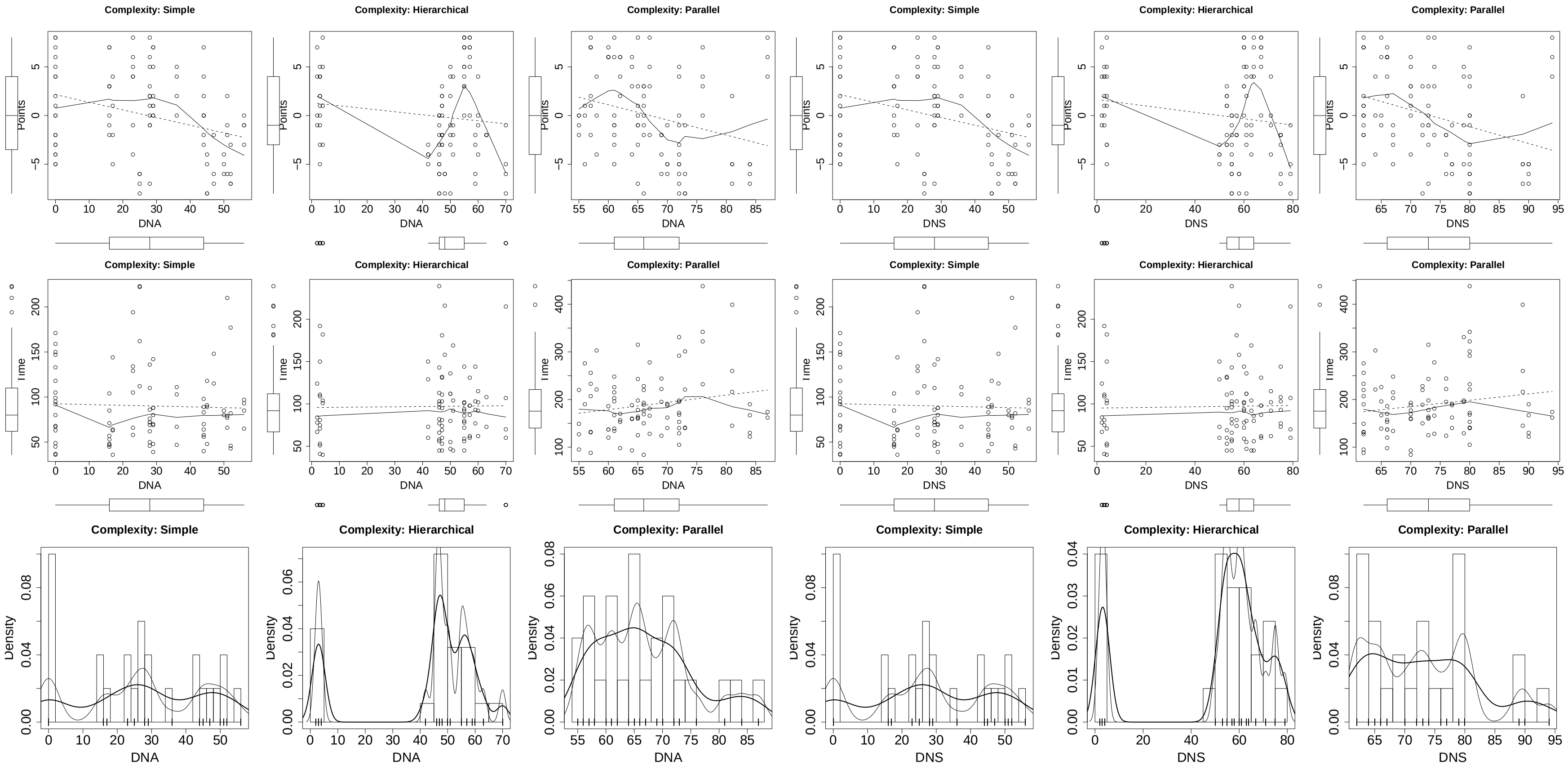
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
PF
NBAVG
Time
Density



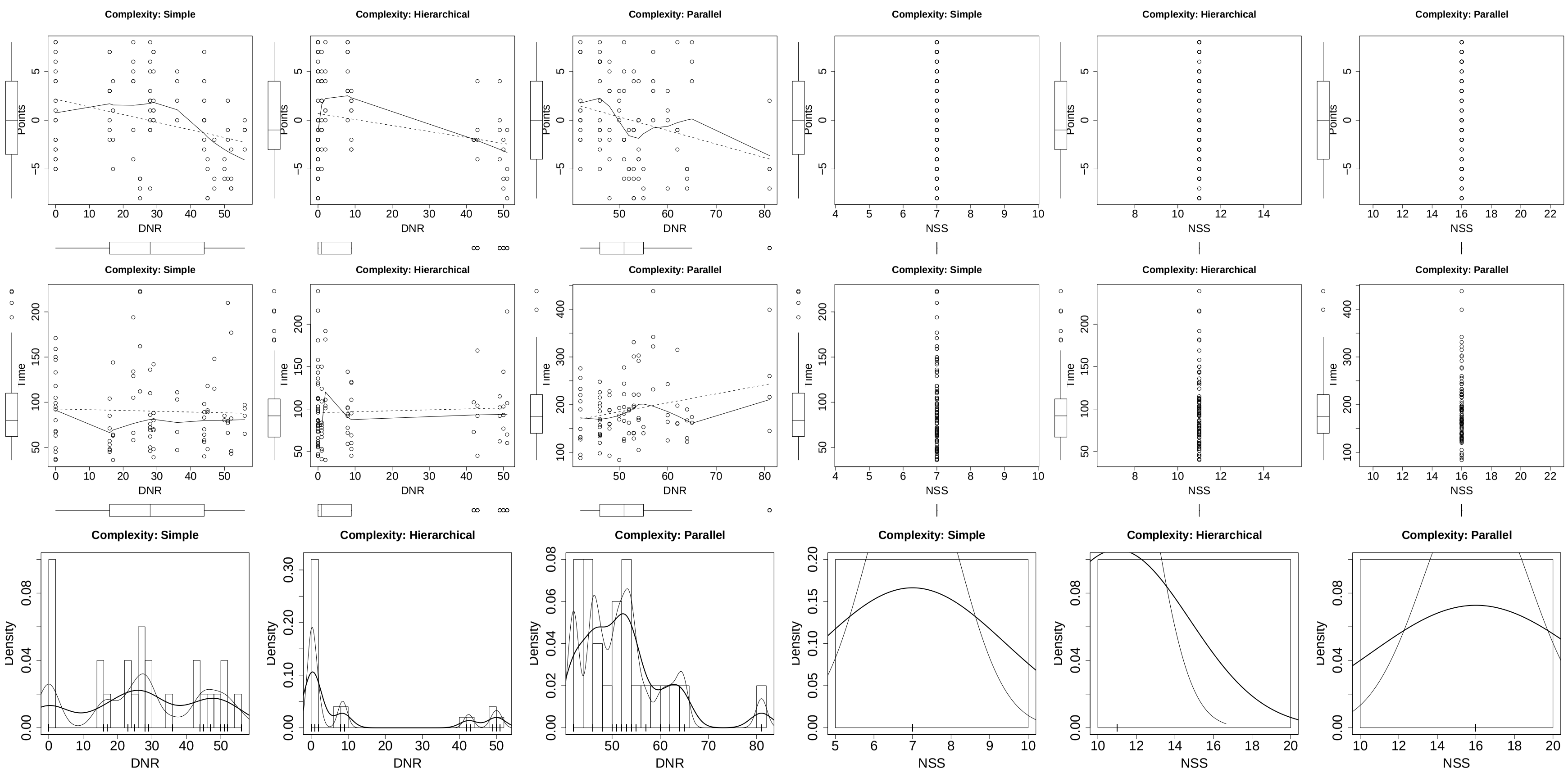
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
NBMIN
NBMAX
Time
Density



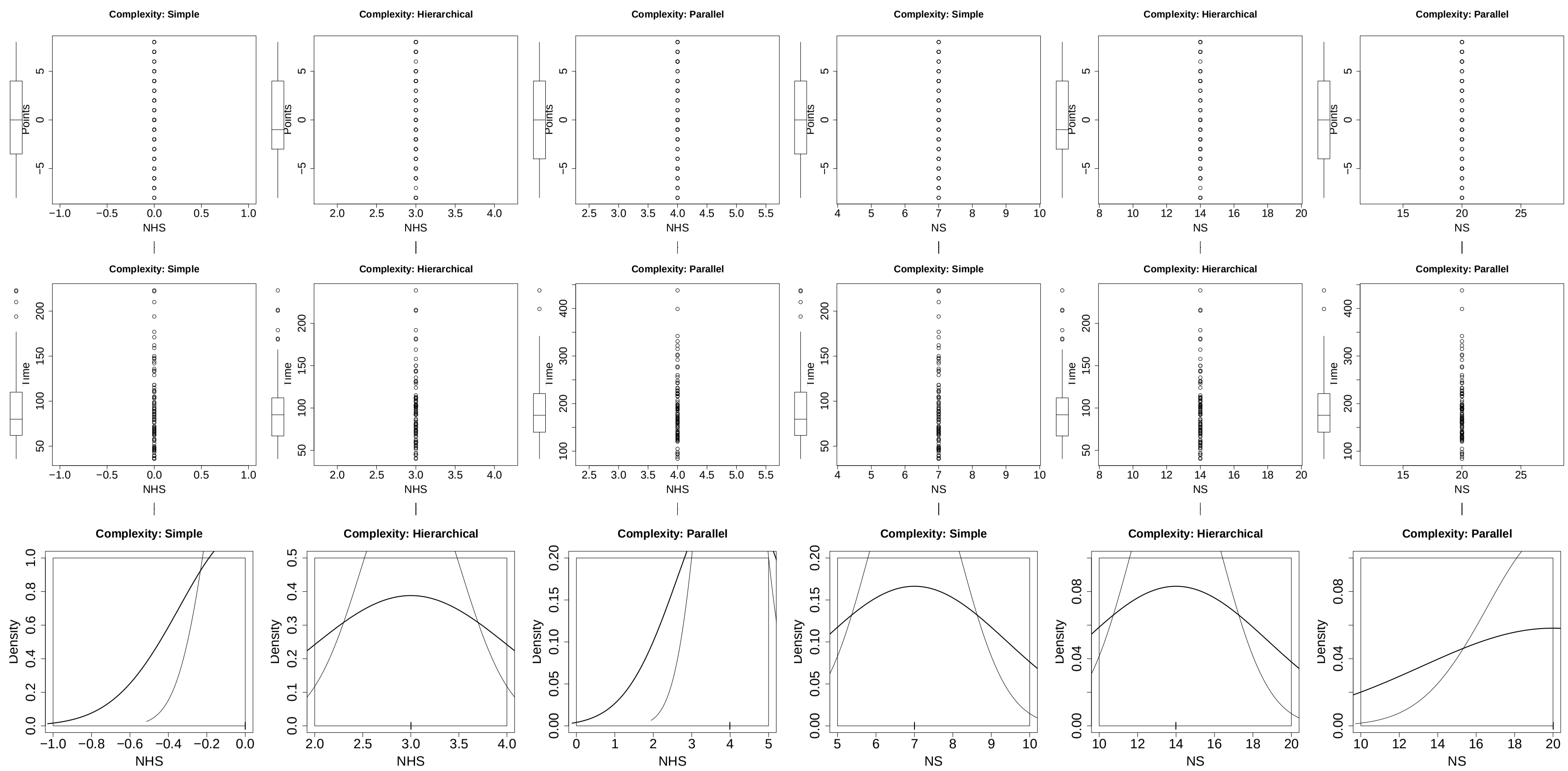
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
DI
DM
Time
Density

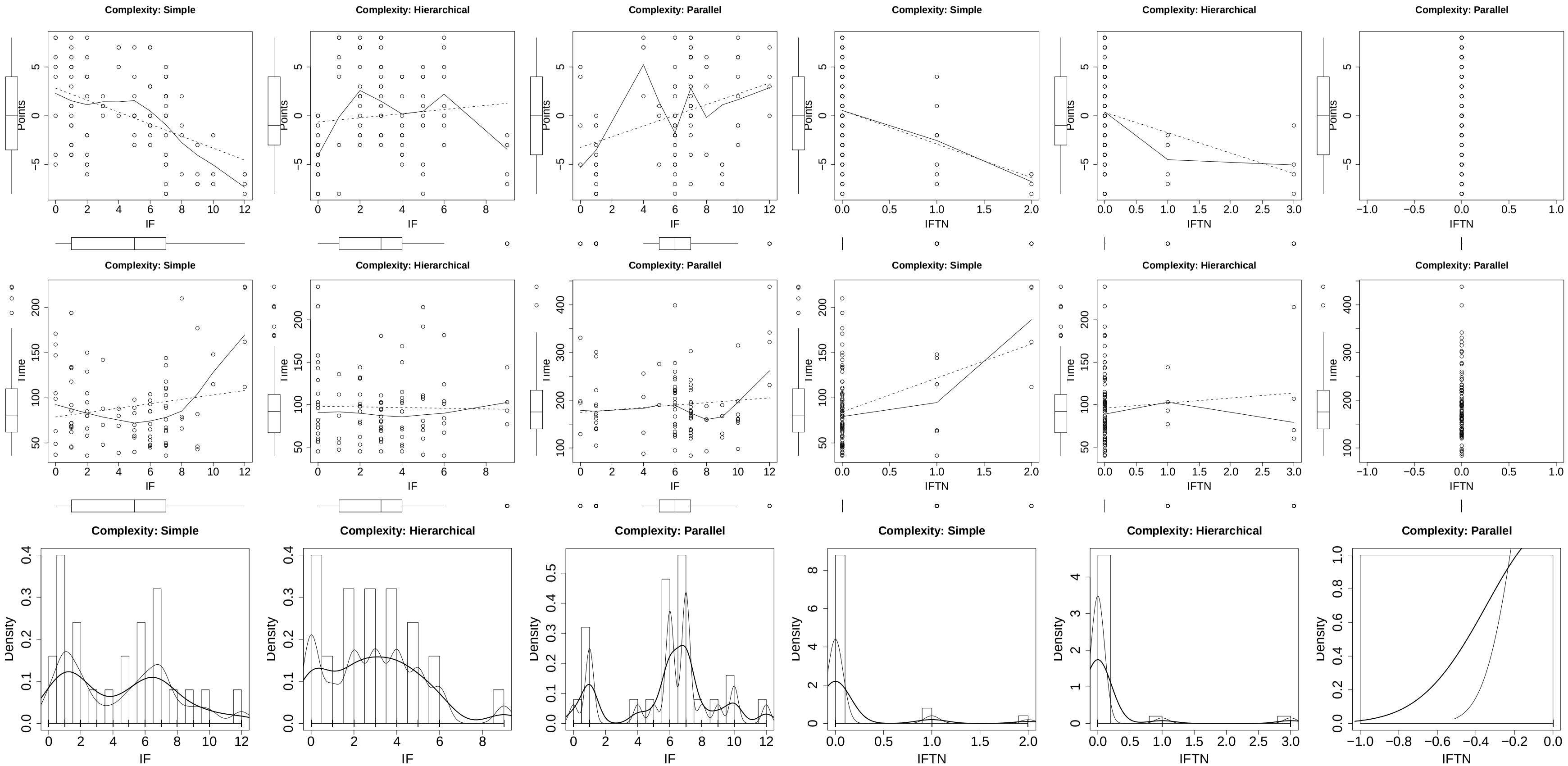


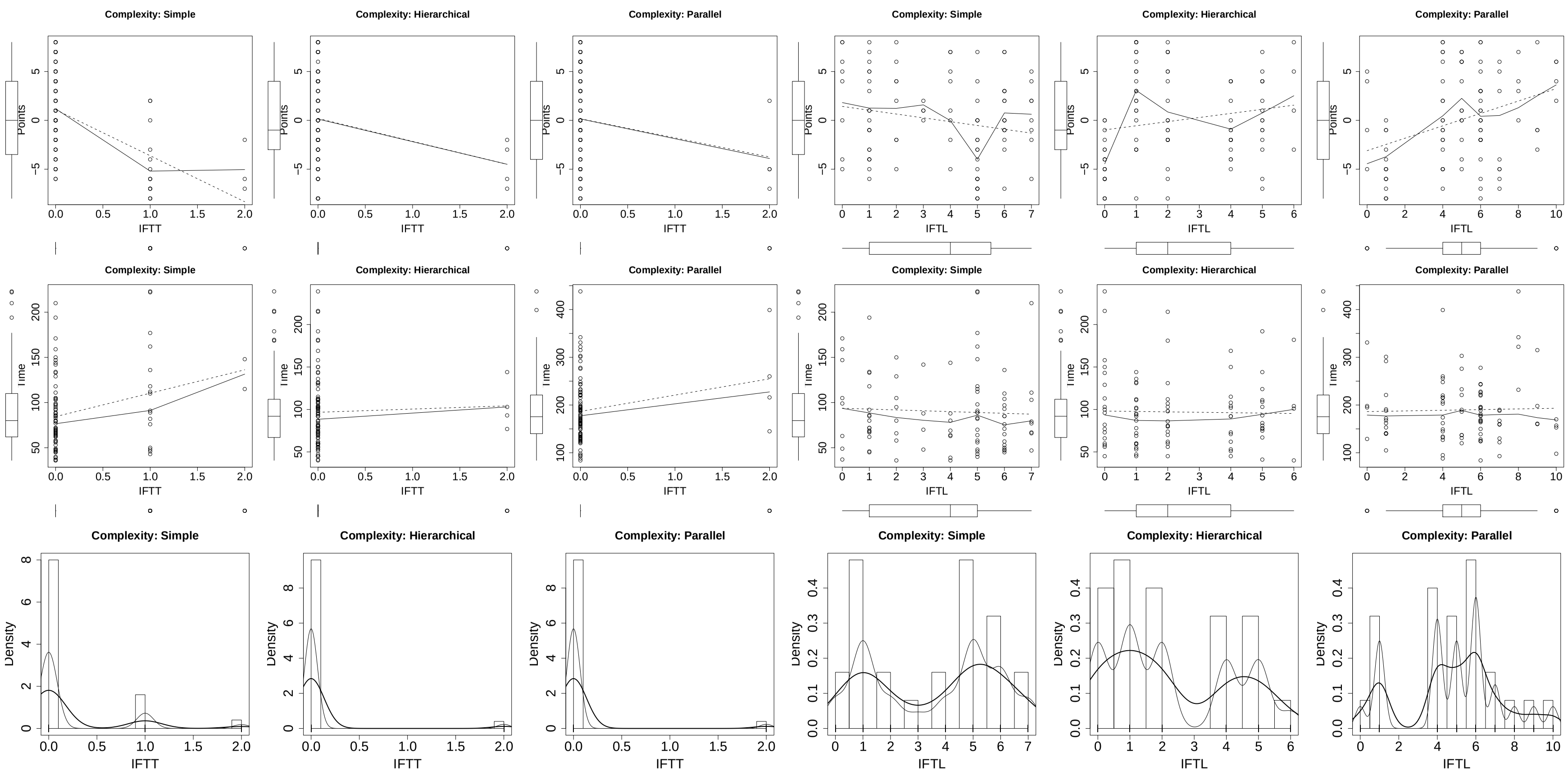
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
DNA
DNS



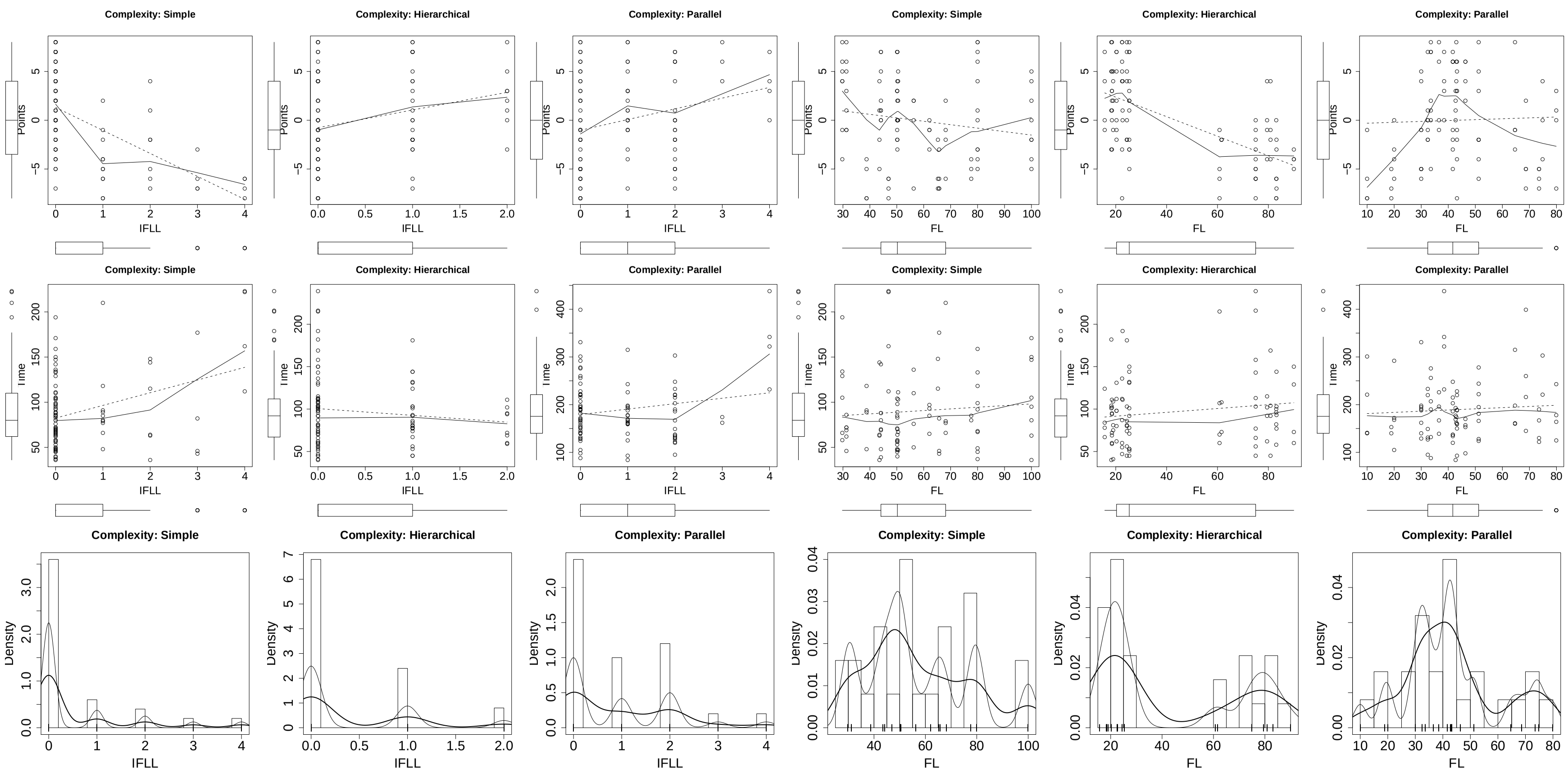
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
DNR
NSS

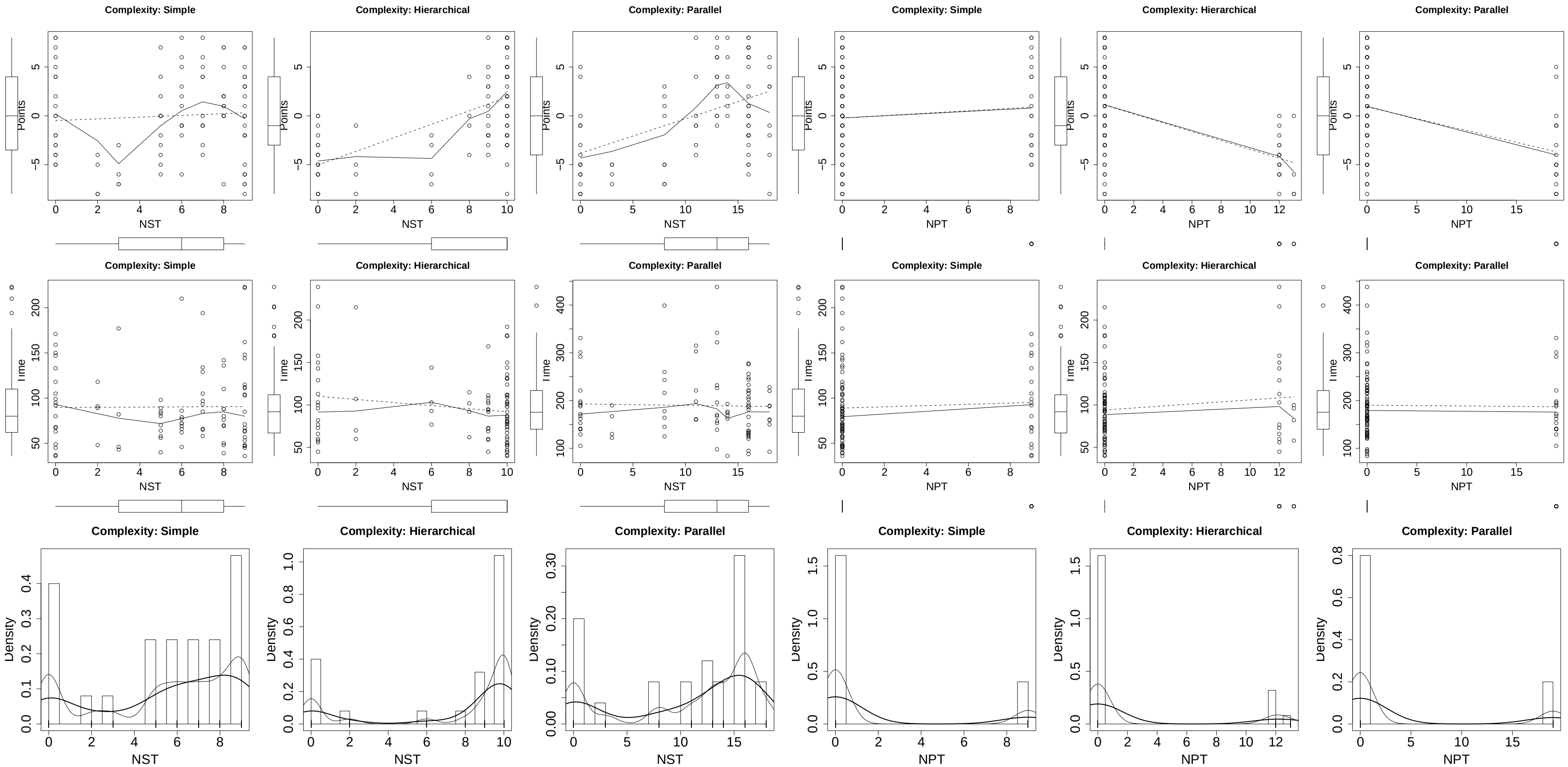

Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
NHS
NS


Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
IF
IFTN

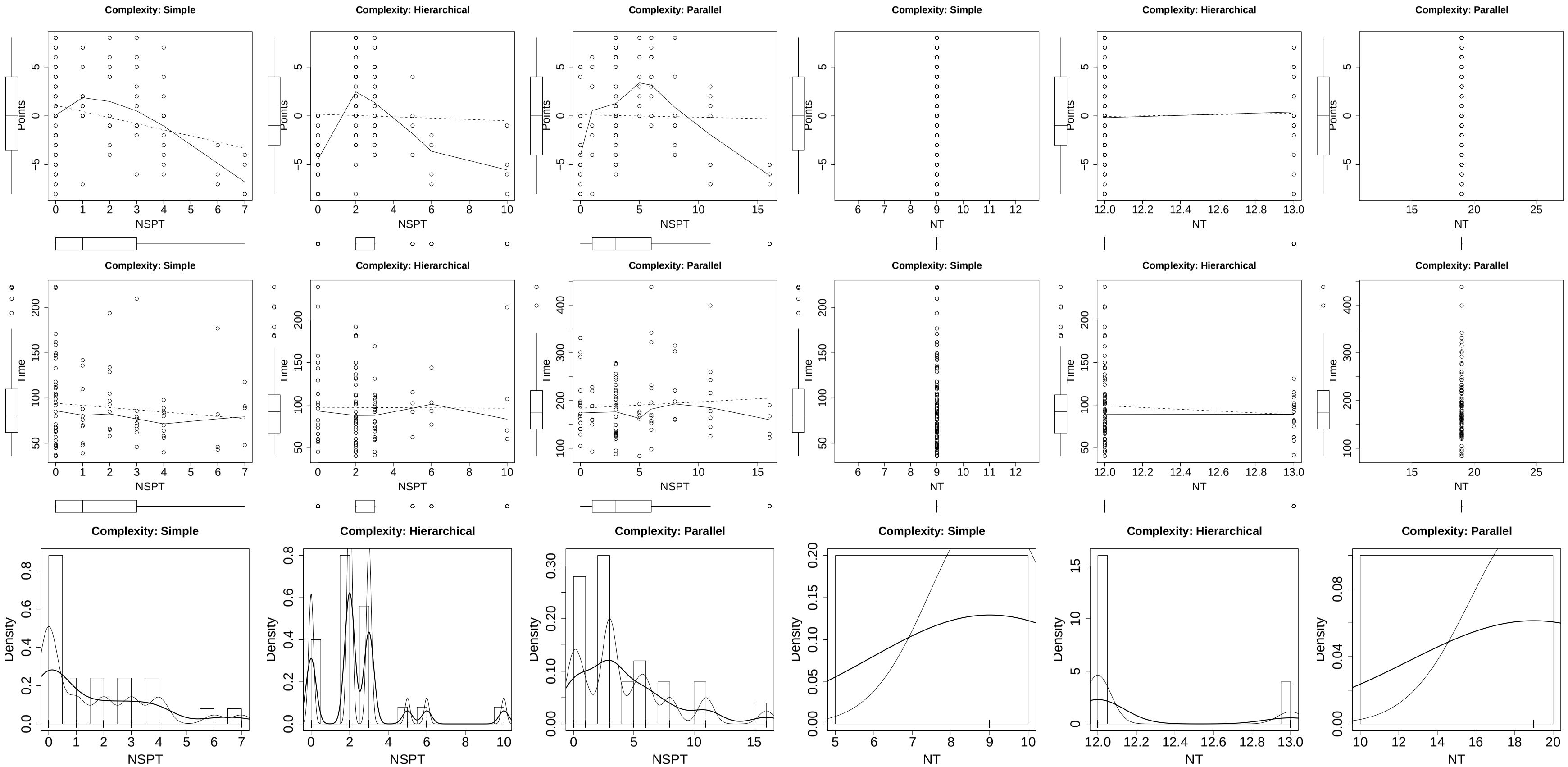


Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
IFTT
IFTL


Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
IFLL
FL



Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
Time
Density
NST
NPT


Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Complexity: Simple
Complexity: Hierarchical
Complexity: Parallel
Points
NSPT
NT
Time
Density

F. Written Code

F.1. Files written in R

The following pages contain all R files that were used in the creation of this thesis.

F.1.1. validate-data.R

```
source("read-data.R")
library("car")
source("validate-data-functions.R")

#####

# pretest function, does a histogram, density line and boxplot of the given data

# plot(data.placement$initial.y~ data.placement$initial.x, main="Positions of
      initial states")
# plot(data.placement$final.y~ data.placement$final.x, main="Positions of final
      states")

#####
# testing the validity of the data
#####

source("validate-data-consistency.R")

#####
# Plausibility:
#####

pdf("datavalidation.pdf")
source("validate-data-plausibility.R")
dev.off()


#####

pdf("sampleboxplot.pdf")
par(mai=c(1,2.5,0.5,2.5))
boxplot(Aesthetics2$time[complexity==3&experiment==2], ylab="time needed (avanced
       users)", cex.axis=1.3, cex.lab=1.3)
dev.off()

pdf("samplescatterplots.pdf")
scatterplot(Aesthetics2$points[complexity==2],Aesthetics2$trlenavg[complexity
      ==2], smooth=F,reg.line=F, boxplots="",col=c("black", "black", "black"),
      ylab="points (advanced)", xlab="average transition length", main="
      complexity: hierarchical", cex.axis=1.5, cex.lab=1.5, cex.main=1.5)
scatterplot(Aesthetics2$points[complexity==2],Aesthetics2$trlenavg[complexity
      ==2],col=c("black", "black", "black"), ylab="points (advanced)", xlab="
      average transition length", main="complexity: hierarchical", cex.axis=1.5,
      cex.lab=1.5, cex.main=1.5)
dev.off()

y <- rt(200, df = 5)
pdf("sampleqqplot.pdf")
qqnorm(y); qqline(y)
dev.off()


library("geneplotter")  ## from BioConductor
require("RColorBrewer") ## from CRAN


pdf("smoothPI.pdf")
smoothScatter(data.placement[,1],data.placement[,2],ylim=c(0,100),nrpoints=Inf,
      colramp=colorRampPalette(brewer.pal(9,"Greys")[1:8]), bandwidth=13, xlab="x
       position (%)", ylab="y position (%)", cex.axis=1.5, cex.lab=1.5)
points(data.placement[,1],data.placement[,2],ylim=c(0,100),pch=20)
dev.off()

pdf("smoothPF.pdf")
smoothScatter(data.placement[,3],data.placement[,4],ylim=c(0,100),nrpoints=Inf,
      colramp=colorRampPalette(brewer.pal(9,"Greys")[1:8]), bandwidth=11, xlab="x
       position (%)", ylab="y position (%)", cex.axis=1.5, cex.lab=1.5)
points(data.placement[,3],data.placement[,4],ylim=c(0,100),pch=20)
dev.off()


library("scatterplot3d")

test <- array(NA, c(75,5))
test[,1] <- data.placement[,1]
test[,2] <- data.placement[,2]
test[,3] <- data.pointsadv[,1]
test[,4] <- data.placement[,3]
test[,5] <- data.placement[,4]


templmis <- lm(test[,3]~test[,1]+test[,2])
templmfs <- lm(test[,3]~test[,4]+test[,5])

pdf("scatterplot3d-pos.pdf", width=6.1, height=6)
tempscat3dis <- scatterplot3d(test[,1], test[,2], test[,3], xlab="Statechart x
      axis (%)", ylab="", zlab="points", angle=55, highlight.3d=FALSE, pch=20, y.
      margin.add=0.5)
tempscat3dis$plane3d(templmis)
text(6,-2,"Statechart y axis (%)", pos=4, srt=55)
tempscat3dfs <- scatterplot3d(test[,4], test[,5], test[,3], xlab="Statechart x
      axis (%)", ylab="", zlab="points", angle=55, highlight.3d=FALSE, pch=20, y.
      margin.add=0.5)
tempscat3dfs$plane3d(templmfs)
text(6,-2,"Statechart y axis (%)", pos=4, srt=55)
dev.off()
```

F.1.2. validate-data-functions.R

```
pretest = function(input, name, shortname=name, xla="all complexities", yla=name
      ,...){
  boxplot(input, ylab=yla, xlab=xla, main="",...)
  IQR <- diff(summary(input[c(5, 2)]))
  dest <- density(input)  # or some smaller width, maybe,
  hist(input, xlim = range(dest$x),xlab=name, main = "", ylab = "density",
       probability = TRUE,...)    # <<<--- this is the vital argument
  #par(new = TRUE)
  #hist(input, axes=FALSE)
    lines(dest, lty = 2)
  #par(mar = c(5, 4, 4, 4) + 0.3)  # Leave space for z axis
  #axis(4, at = pretty(range(input)))
  #mtext("value", 4, 3)
  #hist(input, main=name, freq=F)


  #axis(4)
  #par(new=TRUE)
  #lines(density(input))
}

pretestc = function(input, name, shortname=name, axlbl=c("complexity 1","
      complexity 2","complexity 3"),xl="", yl=name , axs=1,...){
  boxplot(input[1:25], input[26:50], input[51:75], main="", xlab=xl, ylab=yl, cex
      .axis=1.3, cex.lab=1.3, ...)
  axis(axs, c(1:3), axlbl, cex.axis=1.3)
  oldpar <- par(no.readonly=TRUE)
  par(mfrow=c(1,3),mai=c(2,0.8,2,0.2), mgp=c(4.3,1,0))
  for (i in 1:3){
    IQR <- diff(summary(input[(1+(25*(i-1))):(25*i)])[c(5, 2)])
    dest <- density(input[(1+(25*(i-1))):(25*i)])  # or some smaller width, maybe
      ,
    hist(input[(1+(25*(i-1))):(25*i)], xlim = range(dest$x), xlab=paste(shortname
      ,"\ncomplexity ",i,sep=""), main = "", ylab = "density", probability = TRUE
      , cex.axis=1.9, cex.lab=1.9)    # <<<--- this is the vital argument
  #par(new = TRUE)
  #hist(input, axes=FALSE)
    lines(dest, lty = 2)
  #par(mar = c(5, 4, 4, 4) + 0.3)  # Leave space for z axis
  #axis(4, at = pretty(range(input)))
  #mtext("value", 4, 3)
  #hist(input, main=name, freq=F)


  #axis(4)
  #par(new=TRUE)
  #lines(density(input))
  }
  #par(mfrow=c(1,1))
  par(oldpar)
}

histogram= function(input, name){
  IQR <- diff(summary(input)[c(5, 2)])
  dest <- density(input)  # or some smaller width, maybe,
  hist(input, xlim = range(dest$x),main=name, xlab = "value", ylab = "density",
       probability = TRUE)    # <<<--- this is the vital argument
  lines(dest, lty = 2)
}

layoutboxplot=function(input, name, ...){
  oldpar <- par(no.readonly=TRUE)
  par(mfrow=c(1,3),mai=c(2,0.7,2,0.2))
  boxplot(input[c(1,6,11,16,21),1], input[c(2,7,12,17,22),1],input[c
      (3,8,13,18,23),1], input[c(4,9,14,19,24),1], input[c(5,10,15,20,25),1],
      ylab=paste(name, ", c1", sep=""), cex.axis=1.9, cex.lab=1.9, ...)
  axis(1, c(1:5), c("ADL","ADBL","ALL","LLL","AL"),las = 2, cex.axis=1.9)
  boxplot(input[c(26,31,36,41,46),1], input[c(27,32,37,42,47),1],input[c
      (28,33,38,43, 48),1], input[c(29,34,39,44, 49),1], input[c(30,35,40,45,50)
      ,1], ylab=paste(name, ", c2", sep=""), cex.axis=1.9, cex.lab=1.9, ...)
  axis(1, c(1:5), c("ADL","ADBL","ALL","LLL","AL"),las = 2, cex.axis=1.9)
  boxplot(input[c(51,56,61,66,71),1], input[c(52,57,62,67,72),1],input[c
      (53,58,63,68,73),1], input[c(54,59,64,69,74),1], input[c(55,60,65,70,75)
      ,1], ylab=paste(name, ", c3", sep=""), cex.axis=1.9, cex.lab=1.9, ...)
  axis(1, c(1:5), c("ADL","ADBL","ALL","LLL","AL"),las = 2, cex.axis=1.9)
  par(oldpar)
  #par(mfrow=c(1,1))

}

crossingplot=function(row, text, ...){
oldpar <- par(no.readonly=TRUE)
par(mfrow=c(3,5))
for (j in 1:3){
for (i in 1:5){
plot(data.crossing.detail[c(i+(j-1)*25,i+5+(j-1)*25,i+10+(j-1)*25,i+15+(j-1)*25,i
      +20+(j-1)*25),row], main=paste("c",j," l",i,sep=""),ylim=range(data.
      crossing.detail[,row]) , axes=FALSE, xlab="model", ylab=text, ...)
axis(1)
axis(2, c(0:max(data.crossing.detail[,row])), c(0:max(data.crossing.detail[,row])
      ))
box()
}
}
par(oldpar)
}
```

F.1.3. validate-data-consistency.R

```
###
# Consistency:
###

if(
length(union(data.pointsbeg[data.pointsbeg<(-8)], data.pointsbeg[data.pointsbeg
     >(8)])) == 0 &&
   length(data.timebeg[data.timebeg<0]) == 0 &&
   length(union(data.pointsadv[data.pointsadv<(-8)], data.pointsadv[data.
     pointsadv>(8)])) == 0 &&
   length(data.timeadv[data.timeadv<0]) == 0 &&
   length(data.pointsbeg[,1]) == 75 &&
   length(data.timebeg[,1]) == 75 &&
   length(data.pointsadv[,1]) == 75 &&
   length(data.timeadv[,1]) == 75 &&
   length(data.pointstimebeg[is.na(data.pointstimebeg)]) == 0 &&
   length(data.pointstimeadv[is.na(data.pointstimeadv)]) == 0
   ) print("Consistency: No values above +8 or below -8 for points, no time below
      0, all data present")

if(
length(data.trlenavg[data.trlenavg<0]) == 0 &&
length(data.trlenmin[data.trlenmin<0]) == 0 &&
length(data.trlenmax[data.trlenmax<0]) == 0 &&
length(data.trlenavg[,1]) == 75 &&
length(data.trlenmin[,1]) == 75 &&
length(data.trlenmax[,1]) == 75 &&
length(data.trlensummary[is.na(data.trlensummary)]) == 0
) print("Consistency: No transition length below 0, all data present")

if(
length(data.xyratio[data.xyratio<=0]) == 0 &&
length(data.xyratio[,1]) == 75 &&
length(data.xyratio[is.na(data.xyratio)]) == 0
) print("Consistency: No x-y-ratio below or equal 0, all data present")


if(
length(union(data.width[data.width<32], data.height[data.height<32])) == 0 &&
length(data.width) == 75 &&
length(data.width[is.na(data.width)]) == 0 &&
length(data.height) == 75 &&
length(data.height[is.na(data.height)]) == 0
) print("Consistency: No width or height below 32 (size of a small simple state),
      all data present")


if(
length(union(data.spaceusage[data.spaceusage>100], data.spaceusage[data.
     spaceusage<0])) == 0 &&
length(data.spaceusage[,1]) == 75 &&
length(data.spaceusage[is.na(data.spaceusage)]) == 0
) print("Consistency: Space usage cannot be below 0% or exceed 100%, all data
     present")


if(
length(union(data.placement[data.placement>100], data.placement[data.placement
     <0])) == 0 &&
length(data.placement[,1]) == 75 &&
length(data.placement[,2]) == 75 &&
length(data.placement[,3]) == 75 &&
length(data.placement[,4]) == 75 &&
length(data.placement[is.na(data.placement)]) == 0
) print("Consistency: Placement of initial and final state cannot be below 0% or
     exceed 100%, all data present")

if(
length(data.spaceavg[data.spaceavg<0]) == 0 &&
length(data.spacemin[data.spacemin<0]) == 0 &&
length(data.spacemax[data.spacemax<0]) == 0 &&
length(data.spaceavg[,1]) == 75 &&
length(data.spacemin[,1]) == 75 &&
length(data.spacemax[,1]) == 75 &&
length(data.spaceavg[is.na(data.spaceavg)]) == 0 &&
length(data.spacemin[is.na(data.spacemin)]) == 0 &&
length(data.spacemax[is.na(data.spacemax)]) == 0
) print("Consistency: Distance to nearest Neigbor cannot be negative, all data
     present")

if(
length(data.distance.all[data.distance.all<0]) == 0 &&
length(data.distance.simple[data.distance.simple<0]) == 0 &&
length(data.distance.bottom[data.distance.bottom<0]) == 0 &&
length(data.distance.all[,1]) == 75 &&
length(data.distance.simple[,1]) == 75 &&
length(data.distance.bottom[,1]) == 75 &&
length(data.distance.all[is.na(data.distance.all)]) == 0 &&
length(data.distance.simple[is.na(data.distance.simple)]) == 0 &&
length(data.distance.bottom[is.na(data.distance.bottom)]) == 0
) print("Consistency: Distance from line cannot be negative, all data present")

# missing: state levels
# validierung durch draufgucken...
print("Consistency: State levels - no checking done")

# missing: size relations
print("Consistency: Size relations - no checking done")

if(
length(union(data.crossing.detail[data.crossing.detail>100], data.crossing.detail
     [data.crossing.detail<0])) == 0 &&
length(data.crossing.detail[,1]) == 75 &&
length(data.crossing.detail[,2]) == 75 &&
length(data.crossing.detail[,3]) == 75 &&
```

```
length(data.crossing.detail[,4]) == 75 &&
length(data.crossing.detail[is.na(data.crossing.detail)]) == 0
) print("Consistency: Intersections cannot be negative, all data present")

# missing: flow
print("Consistency: Flow - no checking done, no data present")

if(
length(data.transbends[data.transbends<0]) == 0 &&
length(data.transbends[,1]) == 75 &&
length(data.transbends[,2]) == 75 &&
length(data.transbends[,3]) == 75 &&
length(data.transbends[is.na(data.transbends)]) == 0
) print("Consistency: Transition bends cannot be negative, all data present")


###
# Editing
###

if(
length(data.mousekey.beginner[data.mousekey.beginner<0]) == 0 &&
length(data.mousekey.advanced[data.mousekey.advanced<0]) == 0 &&
length(data.mousekey.beginner[is.na(data.mousekey.beginner)]) == 0 &&
length(data.mousekey.advanced[is.na(data.mousekey.advanced)]) == 0
) print("Consistency: amount of editing actions cannot be negative")

if(
length(data.mk.errors.beginner.graph[data.mk.errors.beginner.graph<0]) == 0 &&
length(data.mk.errors.beginner.struct[data.mk.errors.beginner.struct<0]) == 0 &&
length(data.mk.errors.beginner.text[data.mk.errors.beginner.text<0]) == 0 &&
length(data.mk.errors.beginner.graph[is.na(data.mk.errors.beginner.graph)]) == 0
      &&
length(data.mk.errors.beginner.struct[is.na(data.mk.errors.beginner.struct)]) ==
      0 &&
length(data.mk.errors.beginner.text[is.na(data.mk.errors.beginner.text)]) == 0 &&
length(data.mk.errors.advanced.graph[data.mk.errors.advanced.graph<0]) == 0 &&
length(data.mk.errors.advanced.struct[data.mk.errors.advanced.struct<0]) == 0 &&
length(data.mk.errors.advanced.text[data.mk.errors.advanced.text<0]) == 0 &&
length(data.mk.errors.advanced.graph[is.na(data.mk.errors.advanced.graph)]) == 0
      &&
length(data.mk.errors.advanced.struct[is.na(data.mk.errors.advanced.struct)]) ==
      0 &&
length(data.mk.errors.advanced.text[is.na(data.mk.errors.advanced.text)]) == 0 &&
length(data.mk.erroractions.beginner.graph[data.mk.erroractions.beginner.graph
      <0]) == 0 &&
length(data.mk.erroractions.beginner.struct[data.mk.erroractions.beginner.struct
      <0]) == 0 &&
length(data.mk.erroractions.beginner.text[data.mk.erroractions.beginner.text<0])
      == 0 &&
length(data.mk.erroractions.beginner.graph[is.na(data.mk.erroractions.beginner.
      graph)]) == 0 &&
length(data.mk.erroractions.beginner.struct[is.na(data.mk.erroractions.beginner.
      struct)]) == 0 &&
length(data.mk.erroractions.beginner.text[is.na(data.mk.erroractions.beginner.
      text)]) == 0 &&
length(data.mk.erroractions.advanced.graph[data.mk.erroractions.advanced.graph
      <0]) == 0 &&
length(data.mk.erroractions.advanced.struct[data.mk.erroractions.advanced.struct
      <0]) == 0 &&
length(data.mk.erroractions.advanced.text[data.mk.erroractions.advanced.text<0])
      == 0 &&
length(data.mk.erroractions.advanced.graph[is.na(data.mk.erroractions.advanced.
      graph)]) == 0 &&
length(data.mk.erroractions.advanced.struct[is.na(data.mk.erroractions.advanced.
      struct)]) == 0 &&
length(data.mk.erroractions.advanced.text[is.na(data.mk.erroractions.advanced.
      text)]) == 0
) print("Consistency: amount of errors and error actions cannot be negative")
      else (print("!!! Failed check: amount of errors and error actions !!!"))
```

F.1.4. validate-data-plausibility.R

```
pretestc(data.pointsbeg[,1], "points (beginners)")
layoutboxplot(data.pointsbeg, "points (beginners)")
pretestc(data.timebeg[,1], "time (beginners)")
layoutboxplot(data.timebeg, "time (beginners)")
pretestc(data.pointsadv[,1], "points (adv. users)")
layoutboxplot(data.pointsadv, "points (adv. users)")
pretestc(data.timeadv[,1], "time (adv. users)")
layoutboxplot(data.timeadv, "time (adv. users)")

oldpar <- par(no.readonly=TRUE)
par(mai=c(2,1,2,0.2))
boxplot(data.trlenavg[1:25,1], data.trlenavg[26:50,1], data.trlenavg[51:75,1],
      ylab="average transition length", main="", cex.axis=1.3, cex.lab=1.3)
axis(1, c(1:3), c("complexity 1","complexity 2","complexity 3"), cex.axis=1.3,
      cex.lab=1.3)
par(oldpar)
par(mfrow=c(3,3))

boxplot(as.data.frame(data.trlenavg[1:25,]), main="avg trans length, c1", ylab="
      pixel")
boxplot(as.data.frame(data.trlenavg[26:50,]), main="avg trans length, c2", ylab="
      pixel")
boxplot(as.data.frame(data.trlenavg[51:75,]), main="avg trans length, c3", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmin[1:25,]), main="min trans length, c1", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmin[26:50,]), main="min trans length, c2", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmin[51:75,]), main="min trans length, c3", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmax[1:25,]), main="max trans length, c1", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmax[26:50,]), main="max trans length, c2", ylab="
      pixel")
boxplot(as.data.frame(data.trlenmax[51:75,]), main="max trans length, c3", ylab="
      pixel")


histogram(data.trlenavg[1:25,1], "avg trans length, c1")
histogram(data.trlenavg[26:50,1], "avg trans length, c2")
histogram(data.trlenavg[51:75,1], "avg trans length, c3")
histogram(data.trlenmin[1:25,1], "min trans length, c1")
histogram(data.trlenmin[26:50,1], "min trans length, c2")
histogram(data.trlenmin[51:75,1], "min trans length, c3")
histogram(data.trlenmax[1:25,1], "max trans length, c1")
histogram(data.trlenmax[26:50,1], "max trans length, c2")
histogram(data.trlenmax[51:75,1], "max trans length, c3")
#pretest(data.trlenmin[,1], "minimum transition length")
#pretest(data.trlenmax[,1], "maximum transition length")
par(mfrow=c(1,1))
# boxplot the different layouts against each other, average trans. length
layoutboxplot(data.trlenavg, name="avg. transition length")


#pretest(data.xyratio[,1], "xy ratio")

oldpar <- par(no.readonly=TRUE)
par(mai=c(2,1,2,0.2))
plot(data.xyratio[,1], ylab="statechart width to height ratio", log="y", xlab="
      Statechart", main="", axes=FALSE)
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"))
axis(2)
box()
boxplot(data.xyratio[1:25,1],data.xyratio[26:50,1],data.xyratio[51:75,1], ylab="
      statechart width to height ratio", log="y")
axis(1, c(1:3), c("complexity 1","complexity 2","complexity 3"))
par(oldpar)

pretest(data.width, "statechart width, overall")
pretestc(data.width, "statechart width")
pretest(data.height, "statechart height, overall")
pretestc(data.height, "statechart height")

#pretest(data.spaceusage[,1], "percentage of chart area used by states")
pretestc(data.spaceusage.simple[,1], "% of chart area used by simple states", "SU
       (Simple)")
layoutboxplot(data.spaceusage.simple, "space usage (simple)")

pretestc(data.spaceusage.top[,1], "% of chart area used by top-level states", "SU
       (Top)")
layoutboxplot(data.spaceusage.top, "space usage (toplevel)")

pretestc(data.spaceusage.macrobar[,1], "% of chart area used by states (incl.
      state attr. space)", "SU (Attr.)")
layoutboxplot(data.spaceusage.macrobar, "space usage (state attr. space)")

pretest(data.placement[,1], "hor. pos. of initial state (%)", cex.axis=2, cex.lab
      =2)
pretest(data.placement[,2], "vert. pos. of initial state (%)", cex.axis=2, cex.
      lab=2)
pretest(data.placement[,3], "hor. pos. of final state (in %)", cex.axis=2, cex.
      lab=2)
pretest(data.placement[,4], "vert. pos. of final state (in %)", cex.axis=2, cex.
      lab=2)

plot(data.placement[,2]~ data.placement[,1], main="Positions of initial states",
      xlab="Horizontal Position (in %)", ylab="Vertical Position (in %)", ylim =
      c(0,100))
plot(data.placement[,4]~ data.placement[,3], main="Positions of final states",
      xlab="Horizontal Position (in %)", ylab="Vertical Position (in %)", ylim =
      c(0,100))


pretestc(data.spaceavg[,1], "avg. node dist.")
```

```r
layoutboxplot(data.spaceavg, "avg. node dist.")
pretestc(data.spacemin[,1], "min. node dist.")
layoutboxplot(data.spacemin, "min. node dist.")
pretestc(data.spacemax[,1], "max. node dist.")
layoutboxplot(data.spacemax, "max. node dist.")

oldpar <- par(no.readonly=TRUE)
par(mfrow=c(1,1),mai=c(2,0.8,2,0.2))
pretest(data.distance.initial2[,1], "distance to initial line", cex.axis=1.3, cex
      .lab=1.3, horizontal=TRUE, yla="all complexities", xla="distance to initial
       line")

pretestc(data.distance.initial2[,1], "distance to initial line", "dist. initial
      line", horizontal=TRUE, yl="complexity", axs=2, axlbl=c(1:3), xl="distance
      to initial line")

layoutboxplot(data.distance.initial2, "dist. to initial line")
pretest(data.distance.middle2[,1], "distance to middle line", cex.axis=1.3, cex.
      lab=1.3, horizontal=TRUE, yla="all complexities", xla="distance to middle
      line")
pretestc(data.distance.middle2[,1], "distance to middle line", "dist. middle line
      ", horizontal=TRUE, yl="complexity", axs=2, axlbl=c(1:3), xl="distance to
      middle line")
layoutboxplot(data.distance.middle2, "dist. to middle line")
pretest(data.distance.all2[,1], "distance to a normal line (all)", cex.axis=1.3,
      cex.lab=1.3, horizontal=TRUE, yla="all complexities", xla="distance to a
      normal line (all)")
pretestc(data.distance.all2[,1], "distance to a normal line (all)", "dist. NL (
      all)", horizontal=TRUE, yl="complexity", axs=2, axlbl=c(1:3), xl="distance
      to a normal line (all)")
layoutboxplot(data.distance.all2, "dist. normal line (all)")
pretest(data.distance.simple2[,1], "distance to a normal line (simple)", cex.axis
      =1.3, cex.lab=1.3, horizontal=TRUE, yla="all complexities", xla="distance
      to a normal line (simple)")
pretestc(data.distance.simple2[,1], "distance to a normal line (simple)","dist.NL
       (simple)", horizontal=TRUE, yl="complexity", axs=2, axlbl=c(1:3), xl="
      distance to a normal line (simple)")
layoutboxplot(data.distance.simple2, "dist. normal line (simple)")
pretest(data.distance.bottom[,1], "distance to a normal line (recursive)", cex.
      axis=1.3, cex.lab=1.3, horizontal=TRUE, yla="all complexities", xla="
      distance to a normal line (recursive)")
pretestc(data.distance.bottom[,1], "distance to a normal line (recursive)", "dist
      . NL (rec.)", horizontal=TRUE, yl="complexity", axs=2, axlbl=c(1:3), xl="
      distance to a normal line (recursive)")
#layoutboxplot(data.distance.simple2, "dist. normal line (simple)")
layoutboxplot(data.distance.bottom, "dist. normal line (rec.)")
par(oldpar)
# number of states. Was: State levels
# validierung durch draufgucken...

# missing: size relations
#

plot(data.crossing.detail[,1], main="number of trans-node crossings", axes=FALSE)
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"))
axis(2)
box()
plot(data.crossing.detail[,2], main="number of trans-trans crossings", axes=FALSE
      )
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"))
axis(2)
box()
plot(data.crossing.detail[,3], main="number of trans-label crossings", axes=FALSE
      )
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"))
axis(2)
box()
plot(data.crossing.detail[,4], main="number of label-label crossings", axes=FALSE
      )
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"))
axis(2)
box()

data.crossing.detail[,5] <- data.crossing.detail[,1]+data.crossing.detail[,2]+
      data.crossing.detail[,3]+data.crossing.detail[,4]

plot(data.crossing.detail[,5], ylab="total number of distance problems", axes=
      FALSE, type="h", xlab="")
axis(1, c(1:75), c("c1m1l1","","","","","c1m2l1","","","","","c1m3l1
      ","","","","","c1m4l1","","","","","c1m5l1","","","","","c2m1l1
      ","","","","","c2m2l1","","","","","c2m3l1","","","","","c2m4l1
      ","","","","","c2m5l1","","","","","c3m1l1","","","","","c3m2l1
      ","","","","","c3m3l1","","","","","c3m4l1","","","","","c3m5l1","","","","
      c3m5l5"), las=2)
axis(2)
box()

histogram(data.crossing.detail[,5], "total number of distance problems")

crossingplot(1, "number of transition - node crossings")
crossingplot(2, "number of transition - transition crossings")
crossingplot(3, "number of transition - label crossings")
crossingplot(4, "number of label - label crossings")
crossingplot(5, "total number of distance problems")

par(mfrow=c(1,1))

pretest(data.flow[,1], "Statechart flow (overall)")
pretestc(data.flow[,1], "Statechart flow")
layoutboxplot(data.flow, "Statechart flow")

oldpar <- par(no.readonly=TRUE)
par(mai=c(1,0.8,0.2,0.5), mfrow=c(3,1))
plot(data.transbends[,1], xlab="", ylab="straight trans.", axes=FALSE, cex=1.3,
      cex.lab=1.6, type="h", lwd=2)
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"), cex.axis=2)
axis(2,cex.axis=1.6)
box()
plot(data.transbends[,2], xlab="", ylab="polyline trans.", axes=FALSE, cex=1.3,
      cex.lab=1.6, type="h", lwd=2)
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"), cex.axis=2)
axis(2, cex.axis=1.6)
```

```
box()
plot(data.transbends[,3], xlab="", ylab="spline trans.", axes=FALSE, cex=1.3, cex
      .lab=1.6, type="h", lwd=2)
axis(1, c(1,26,51,75), c("c1m1l1","c2m1l1","c3m1l1","c3m5l5"), cex.axis=2)
axis(2, cex.axis=1.6)
box()
par(oldpar)
par(mfrow=c(1,1))

###
# Editing
###
oldpar <- par(no.readonly=TRUE)
par(mai=c(2,4,0.5,0.5))
#boxplot(data.mousekey.beginner, main="Actions, Beginner", xlab="Action", ylab="
      Number Of Actions")
#boxplot(data.mousekey.advanced, main="Actions, Advanced", xlab="Action", ylab="
      Number Of Actions")
names(data.mousekey.beginner) <- c("mouse clicks, beg.","mouse drags, beg.","
      keystrokes, beg.","key macros, beg")
names(data.mousekey.advanced) <- c("mouse clicks, adv.","mouse drags, adv.","
      keystrokes, adv.","key macros, adv")
data.mousekey <- data.mousekey.beginner
data.mousekey.advanced[20:24,] <- NA
data.mousekey[,5:8] <- data.mousekey.advanced[,1:4]
boxplot(data.mousekey, main="input actions, all editors", xlab="", ylab="number
      of input actions", las=2)
#boxplot(data.mousekey.beginner.graph, main="Actions, Beginner, WYSIWYG-Editor",
      xlab="Action", ylab="Number Of Actions")
#boxplot(data.mousekey.advanced.graph, main="Actions, Advanced, WYSIWYG-Editor",
      xlab="Action", ylab="Number Of Actions")

names(data.mousekey.beginner.graph) <- c("mouse clicks, beg.","mouse drags, beg
      .","keystrokes, beg.","key macros, beg")
names(data.mousekey.advanced.graph) <- c("mouse clicks, adv.","mouse drags, adv
      .","keystrokes, adv.","key macros, adv")
data.mousekey.graph <- data.mousekey.beginner.graph
data.mousekey.advanced.graph[20:24,] <- NA
data.mousekey.graph[,5:8] <- data.mousekey.advanced.graph[,1:4]
boxplot(data.mousekey.graph,  xlab="", ylab="number of actions", las=2)

#boxplot(data.mousekey.beginner.struct, main="Actions, Beginner, KIEL-macros",
      xlab="Action", ylab="Number Of Actions")
#boxplot(data.mousekey.advanced.struct, main="Actions, Advanced, KIEL-macros",
      xlab="Action", ylab="Number Of Actions")

names(data.mousekey.beginner.struct) <- c("mouse clicks, beg.","mouse drags, beg
      .","keystrokes, beg.","key macros, beg")
names(data.mousekey.advanced.struct) <- c("mouse clicks, adv.","mouse drags, adv
      .","keystrokes, adv.","key macros, adv")
data.mousekey.struct <- data.mousekey.beginner.struct
data.mousekey.advanced.struct[20:24,] <- NA
data.mousekey.struct[,5:8] <- data.mousekey.advanced.struct[,1:4]
boxplot(data.mousekey.struct,  xlab="", ylab="number Of actions", las=2)
#boxplot(data.mousekey.beginner.text, main="Actions, Beginner, KIEL-KIT", xlab="
      Action", ylab="Number Of Actions")
#boxplot(data.mousekey.advanced.text, main="Actions, Advanced, KIEL-KIT", xlab="
      Action", ylab="Number Of Actions")

names(data.mousekey.beginner.text) <- c("mouse clicks, beg.","mouse drags, beg
      .","keystrokes, beg.","key macros, beg")
names(data.mousekey.advanced.text) <- c("mouse clicks, adv.","mouse drags, adv
      .","keystrokes, adv.","key macros, adv")
data.mousekey.text <- data.mousekey.beginner.text
data.mousekey.advanced.text[20:24,] <- NA
data.mousekey.text[,5:8] <- data.mousekey.advanced.text[,1:4]
boxplot(data.mousekey.text,  xlab="", ylab="number Of actions", las=2)

#boxplot(data.mousekey.errors.beginner[c(2,14),], main="Number Of Actions of
      Errors, Beginner", xlab="User", ylab="Number Of Actions")
#boxplot(data.mousekey.errors.advanced[c(2,14),], main="Number Of Actions of
      Errors, Advanced", xlab="User", ylab="Number Of Actions")
#boxplot(data.mousekey.errors.beginner[c(1,3,15),], main="Number Of Actions of
      Error Actions, Beginner", xlab="User", ylab="Number Of Actions")
#boxplot(data.mousekey.errors.advanced[c(1,3,15),], main="Number Of Actions of
      Error Actions, Advanced", xlab="User", ylab="Number Of Actions")


#boxplot(data.mk.errors.beginner.actions.by.user.graph, main="Error Actions,
      Beginner, WYSIWYG Editor", xlab="Action", ylab="Number Of Actions")
#boxplot(data.mk.errors.advanced.actions.by.user.graph, main="Error Actions,
      Advanced, WYSIWYG Editor", xlab="Action", ylab="Number Of Actions")

names(data.mk.errors.beginner.actions.by.user.graph) <- c("mouse clicks, beg.","
      mouse drags, beg.","keystrokes, beg.","key macros, beg")
names(data.mk.errors.advanced.actions.by.user.graph) <- c("mouse clicks, adv.","
      mouse drags, adv.","keystrokes, adv.","key macros, adv")
data.mk.errors.graph <- data.mk.errors.beginner.actions.by.user.graph
data.mk.errors.advanced.actions.by.user.graph[20:24,] <- NA
data.mk.errors.graph[,5:8] <- data.mk.errors.advanced.actions.by.user.graph[,1:4]
boxplot(data.mk.errors.graph,  xlab="", ylab="number Of actions", las=2)

#boxplot(data.mk.errors.beginner.actions.by.user.struct, main="Error Actions,
      Beginner, KIEL-macros Editor", xlab="Action", ylab="Number Of Actions")
#boxplot(data.mk.errors.advanced.actions.by.user.struct, main="Error Actions,
      Advanced, KIEL-macros Editor", xlab="Action", ylab="Number Of Actions")

names(data.mk.errors.beginner.actions.by.user.struct) <- c("mouse clicks, beg.","
      mouse drags, beg.","keystrokes, beg.","key macros, beg")
names(data.mk.errors.advanced.actions.by.user.struct) <- c("mouse clicks, adv.","
      mouse drags, adv.","keystrokes, adv.","key macros, adv")
data.mk.errors.struct <- data.mk.errors.beginner.actions.by.user.struct
data.mk.errors.advanced.actions.by.user.struct[20:24,] <- NA
data.mk.errors.struct[,5:8] <- data.mk.errors.advanced.actions.by.user.struct
      [,1:4]
boxplot(data.mk.errors.struct, xlab="", ylab="number Of actions", las=2)
```

```
#boxplot(data.mk.errors.beginner.actions.by.user.text, main="Error Actions,
      Beginner, KIEL-KIT Editor", xlab="Action", ylab="Number Of Actions")
#boxplot(data.mk.errors.advanced.actions.by.user.text, main="Error Actions,
      Advanced, KIEL-KIT Editor", xlab="Action", ylab="Number Of Actions")

names(data.mk.errors.beginner.actions.by.user.text) <- c("mouse clicks, beg.","
      mouse drags, beg.","keystrokes, beg.","key macros, beg")
names(data.mk.errors.advanced.actions.by.user.text) <- c("mouse clicks, adv.","
      mouse drags, adv.","keystrokes, adv.","key macros, adv")
data.mk.errors.text <- data.mk.errors.beginner.actions.by.user.text
data.mk.errors.advanced.actions.by.user.text[20:24,] <- NA
data.mk.errors.text[,5:8] <- data.mk.errors.advanced.actions.by.user.text[,1:4]
boxplot(data.mk.errors.text,  xlab="", ylab="number Of actions", las=2)

boxplot(data.mk.errors.graph+data.mk.errors.struct+data.mk.errors.text, main="
      error actions, all editors", xlab="", ylab="number Of actions", las=2)

names(data.mk.errors.beginner.graph) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")
names(data.mk.errors.advanced.graph) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")

names(data.mk.errors.beginner.struct) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")
names(data.mk.errors.advanced.struct) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")

names(data.mk.errors.beginner.text) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")
names(data.mk.errors.advanced.text) <- c("cat.0", "cat.1.1", "cat.1.2", "cat
      .1.3", "cat.1.4", "cat.1.5", "cat.2.1", "cat.2.2", "cat.2.3", "cat.2.4", "
      cat.2.5", "cat.3.1", "cat.3.2")

boxplot(data.mk.errors.beginner.graph[,c(2,3,4,5,7,8,9)], las=2, ylab="number of
      errors")
boxplot(data.mk.errors.advanced.graph[,c(2,3,4,5,7,8,9)],  las=2, ylab="number of
       errors")

boxplot(data.mk.errors.beginner.struct[,c(2,3,4,5,7,8,9)],  las=2, ylab="number
      of errors")
boxplot(data.mk.errors.advanced.struct[,c(2,3,4,5,7,8,9)],  las=2, ylab="number
      of errors")

boxplot(data.mk.errors.beginner.text[,c(2,3,4,5,7,8,9)],  las=2, ylab="number of
      errors")
boxplot(data.mk.errors.advanced.text[,c(2,3,4,5,7,8,9)],  las=2, ylab="number of
      errors")


par(oldpar)
```

F.1.5. read-data.R

```
###
# points given and time used
###

# beginners

data.pointstimebeg <- read.csv("../data/data-points-time-beginner.csv", header=
     TRUE,row.names=1)
data.pointsbeg <- data.pointstimebeg[1]
data.timebeg <- data.pointstimebeg[2]

# advanced users

data.pointstimeadv <- read.csv("../data/data-points-time-advanced.csv", header=
     TRUE,row.names=1)
data.pointsadv <- data.pointstimeadv[1]
data.timeadv <- data.pointstimeadv[2]




###
# transition length of each statechart
###

# min, max, avg

data.trlensummary<-read.csv("../data/data-transition-length-summary.csv", header=
     TRUE,row.names=1)
data.trlenmin <- data.trlensummary[1]
data.trlenmax <- data.trlensummary[2]
data.trlenavg <- data.trlensummary[3]
data.trlendetail <- read.csv("../data/data-transition-length2.csv")
###
# x-y-ratio of statecharts
###

data.xyratio<-read.csv("../data/data-xyratio.csv", header=TRUE,row.names=1)

###
# usage of available space
###

# first, read width and height of each chart
data.widthheight<-read.csv("../data/data-width-height.csv", header=TRUE,row.names
     =1)

data.width <- data.widthheight[,1]
data.height <- data.widthheight[,2]

# area
data.area <- data.width * data.height

# read used space for each chart

data.spaceusage <- read.csv("../data/data-space-usage.csv", header=TRUE,row.names
     =1)
data.spaceusage.simple <- read.csv("../data/data-spaceusage-simple.csv", header=
     TRUE,row.names=1)
data.spaceusage.top <- read.csv("../data/data-spaceusage-top.csv", header=TRUE,
     row.names=1)
data.spaceusage.macrobar <- read.csv("../data/data-spaceusage-macrobar.csv",
     header=TRUE,row.names=1)

###
# placement of initial and final state in %
###

data.placement<-read.csv("../data/data-placement-initial-final-state-normalized.
     csv", header=TRUE,row.names=1)



###
# distance between state border and nearest neighbor
###

data.spaceavg<-read.csv("../data/data-state-distance-avg.csv", header=TRUE,row.
     names=1)
data.spacemin<-read.csv("../data/data-state-distance-min.csv", header=TRUE,row.
     names=1)
data.spacemax<-read.csv("../data/data-state-distance-max.csv", header=TRUE,row.
     names=1)

###
# distance from a line through the initial state
###

data.distance.initial <- read.csv("../data/data-distance-initial.csv", header=
     TRUE,row.names=1)

###
# distance from a middle line
###

data.distance.middle <- read.csv("../data/data-distance-middle.csv", header=TRUE,
     row.names=1)

###
# distance from a normal line
###

data.distance.all<-read.csv("../data/data-distance-normal-all.csv", header=TRUE,
     row.names=1)
data.distance.simple<-read.csv("../data/data-distance-normal-simple.csv", header=
     TRUE,row.names=1)
```

```
data.distance.bottom<-read.csv("../data/data-distance-normal-bottom.csv", header=
      TRUE,row.names=1)
data.distance.top<-read.csv("../data/data-distance-normal-top.csv", header=TRUE,
      row.names=1)

data.distance.initial2 <- data.distance.initial[1]
data.distance.middle2 <- data.distance.middle[1]
data.distance.all2 <- data.distance.all[1]
data.distance.simple2 <- data.distance.simple[1]

for (i in 1:75){
  if (data.distance.initial[i,1] > data.distance.initial[i,2]){
    data.distance.initial2[i,1] <- data.distance.initial[i,2]
  }
  if (data.distance.middle[i,1] > data.distance.middle[i,2]){
    data.distance.middle2[i,1] <- data.distance.middle[i,2]
  }
  if (data.distance.all[i,1] > data.distance.all[i,2]){
    data.distance.all2[i,1] <- data.distance.all[i,2]
  }
  if (data.distance.simple[i,1] > data.distance.simple[i,2]){
    data.distance.simple2[i,1] <- data.distance.simple[i,2]
  }
}

###
# state levels
###
data.numberofstates <- read.csv("../data/data-number-of-states.csv", header=TRUE,
      row.names=1)

###
# size relations
###

data.occupiedspace <- read.csv("../data/data-space-occupied.csv", header=TRUE,row
      .names=1)

#data.sizerel <-read.csv("data-sizerel.csv", header=TRUE,row.names=1)
#(no csv generated yet)


###
# intersections
###
data.crossing<-read.csv("../data/data-intersection-summary.csv", header=TRUE,row.
      names=1)
data.crossing.detail<-read.csv("../data/data-intersection-summary-detail.csv",
      header=TRUE,row.names=1)


###
# flow
###

data.flow<-read.csv("../data/data-flow.csv", header=TRUE,row.names=1)


###
# transition bends
###

data.transbends <- read.csv("../data/data-transition-bends.csv", header=TRUE,row.
      names=1)
data.transbends.straight <- read.csv("../data/data-transition-bends-straight.csv
      ", header=TRUE,row.names=1)
data.transbends.polyline <- read.csv("../data/data-transition-bends-polyline.csv
      ", header=TRUE,row.names=1)
data.transbends.spline <- read.csv("../data/data-transition-bends-spline.csv",
      header=TRUE,row.names=1)


#####
# Editing
#####

data.mousekey.beginner <- read.csv("../data/mousekey/beginner-summary.csv",
      header=TRUE,row.names=1)
data.mousekey.beginner.create <- read.csv("../data/mousekey/beginner-summary-
      create.csv", header=TRUE,row.names=1)
data.mousekey.beginner.modify <- read.csv("../data/mousekey/beginner-summary-
      modify.csv", header=TRUE,row.names=1)

data.mousekey.beginner.create.graph <- read.csv("../data/mousekey/beginner-
      summary-create-graph.csv", header=TRUE,row.names=1)
data.mousekey.beginner.create.struct <- read.csv("../data/mousekey/beginner-
      summary-create-struct.csv", header=TRUE,row.names=1)
data.mousekey.beginner.create.text <- read.csv("../data/mousekey/beginner-summary
      -create-text.csv", header=TRUE,row.names=1)

data.mousekey.beginner.modify.graph <- read.csv("../data/mousekey/beginner-
      summary-modify-graph.csv", header=TRUE,row.names=1)
data.mousekey.beginner.modify.struct <- read.csv("../data/mousekey/beginner-
      summary-modify-struct.csv", header=TRUE,row.names=1)
data.mousekey.beginner.modify.text <- read.csv("../data/mousekey/beginner-summary
      -modify-text.csv", header=TRUE,row.names=1)

data.mousekey.beginner.graph <- data.mousekey.beginner.create.graph + data.
      mousekey.beginner.modify.graph
data.mousekey.beginner.struct <- data.mousekey.beginner.create.struct + data.
      mousekey.beginner.modify.struct
data.mousekey.beginner.text <- data.mousekey.beginner.create.text + data.mousekey
      .beginner.modify.text

###

data.mousekey.advanced <- read.csv("../data/mousekey/advanced-summary.csv",
      header=TRUE,row.names=1)
data.mousekey.advanced.create <- read.csv("../data/mousekey/advanced-summary-
      create.csv", header=TRUE,row.names=1)
```

```
data.mousekey.advanced.modify <- read.csv("../data/mousekey/advanced-summary-modify.csv", header=TRUE,row.names=1)

data.mousekey.advanced.create.graph <- read.csv("../data/mousekey/advanced-summary-create-graph.csv", header=TRUE,row.names=1)
data.mousekey.advanced.create.struct <- read.csv("../data/mousekey/advanced-summary-create-struct.csv", header=TRUE,row.names=1)
data.mousekey.advanced.create.text <- read.csv("../data/mousekey/advanced-summary-create-text.csv", header=TRUE,row.names=1)

data.mousekey.advanced.modify.graph <- read.csv("../data/mousekey/advanced-summary-modify-graph.csv", header=TRUE,row.names=1)
data.mousekey.advanced.modify.struct <- read.csv("../data/mousekey/advanced-summary-modify-struct.csv", header=TRUE,row.names=1)
data.mousekey.advanced.modify.text <- read.csv("../data/mousekey/advanced-summary-modify-text.csv", header=TRUE,row.names=1)

data.mousekey.advanced.graph <- data.mousekey.advanced.create.graph + data.mousekey.advanced.modify.graph
data.mousekey.advanced.struct <- data.mousekey.advanced.create.struct + data.mousekey.advanced.modify.struct
data.mousekey.advanced.text <- data.mousekey.advanced.create.text + data.mousekey.advanced.modify.text

#write.csv(data.mousekey.beginner.graph, file = "../data/mousekey/beginner-summary-graph.csv")
#write.csv(data.mousekey.beginner.struct, file = "../data/mousekey/beginner-summary-struct.csv")
#write.csv(data.mousekey.beginner.text, file = "../data/mousekey/beginner-summary-text.csv")
#write.csv(data.mousekey.advanced.graph, file = "../data/mousekey/advanced-summary-graph.csv")
#write.csv(data.mousekey.advanced.struct, file = "../data/mousekey/advanced-summary-struct.csv")
#write.csv(data.mousekey.advanced.text, file = "../data/mousekey/advanced-summary-text.csv")

##########
# Errors #
##########

# Summary of errors/actions made, sorted by category and students

data.mk.errors.beginner.graph <- read.csv("../data/mousekey-errors/beginner-errors-by-category-graph.csv", header=TRUE,row.names=1)
data.mk.errors.beginner.struct <- read.csv("../data/mousekey-errors/beginner-errors-by-category-struct.csv", header=TRUE,row.names=1)
data.mk.errors.beginner.text <- read.csv("../data/mousekey-errors/beginner-errors-by-category-text.csv", header=TRUE,row.names=1)

data.mk.errors.advanced.graph <- read.csv("../data/mousekey-errors/advanced-errors-by-category-graph.csv", header=TRUE,row.names=1)
data.mk.errors.advanced.struct <- read.csv("../data/mousekey-errors/advanced-errors-by-category-struct.csv", header=TRUE,row.names=1)
data.mk.errors.advanced.text <- read.csv("../data/mousekey-errors/advanced-errors-by-category-text.csv", header=TRUE,row.names=1)

data.mk.erroractions.beginner.graph <- read.csv("../data/mousekey-errors/beginner-actions-by-category-graph.csv", header=TRUE,row.names=1)
data.mk.erroractions.beginner.struct <- read.csv("../data/mousekey-errors/beginner-actions-by-category-struct.csv", header=TRUE,row.names=1)
data.mk.erroractions.beginner.text <- read.csv("../data/mousekey-errors/beginner-actions-by-category-text.csv", header=TRUE,row.names=1)

data.mk.erroractions.advanced.graph <- read.csv("../data/mousekey-errors/advanced-actions-by-category-graph.csv", header=TRUE,row.names=1)
data.mk.erroractions.advanced.struct <- read.csv("../data/mousekey-errors/advanced-actions-by-category-struct.csv", header=TRUE,row.names=1)
data.mk.erroractions.advanced.text <- read.csv("../data/mousekey-errors/advanced-actions-by-category-text.csv", header=TRUE,row.names=1)

# these were read to create the above summaries. Now commented out and the summaries are read instead.
# if separate data is needed for creation and editing, un-comment the lines below

#data.mk.errors.beginner.create.graph <- read.csv("../data/mousekey-errors/beginner-errors-by-category-create-graph.csv", header=TRUE,row.names=1)
#data.mk.errors.beginner.modify.graph <- read.csv("../data/mousekey-errors/beginner-errors-by-category-modify-graph.csv", header=TRUE,row.names=1)
#data.mk.errors.beginner.create.struct <- read.csv("../data/mousekey-errors/beginner-errors-by-category-create-struct.csv", header=TRUE,row.names=1)
#data.mk.errors.beginner.modify.struct <- read.csv("../data/mousekey-errors/beginner-errors-by-category-modify-struct.csv", header=TRUE,row.names=1)
#data.mk.errors.beginner.create.text <- read.csv("../data/mousekey-errors/beginner-errors-by-category-create-text.csv", header=TRUE,row.names=1)
#data.mk.errors.beginner.modify.text <- read.csv("../data/mousekey-errors/beginner-errors-by-category-modify-text.csv", header=TRUE,row.names=1)

#data.mk.errors.advanced.create.graph <- read.csv("../data/mousekey-errors/advanced-errors-by-category-create-graph.csv", header=TRUE,row.names=1)
#data.mk.errors.advanced.modify.graph <- read.csv("../data/mousekey-errors/advanced-errors-by-category-modify-graph.csv", header=TRUE,row.names=1)
#data.mk.errors.advanced.create.struct <- read.csv("../data/mousekey-errors/advanced-errors-by-category-create-struct.csv", header=TRUE,row.names=1)
#data.mk.errors.advanced.modify.struct <- read.csv("../data/mousekey-errors/advanced-errors-by-category-modify-struct.csv", header=TRUE,row.names=1)
#data.mk.errors.advanced.create.text <- read.csv("../data/mousekey-errors/advanced-errors-by-category-create-text.csv", header=TRUE,row.names=1)
#data.mk.errors.advanced.modify.text <- read.csv("../data/mousekey-errors/advanced-errors-by-category-modify-text.csv", header=TRUE,row.names=1)

#data.mk.erroractions.beginner.create.graph <- read.csv("../data/mousekey-errors/beginner-actions-by-category-create-graph.csv", header=TRUE,row.names=1)
#data.mk.erroractions.beginner.modify.graph <- read.csv("../data/mousekey-errors/beginner-actions-by-category-modify-graph.csv", header=TRUE,row.names=1)
#data.mk.erroractions.beginner.create.struct <- read.csv("../data/mousekey-errors/beginner-actions-by-category-create-struct.csv", header=TRUE,row.names=1)
#data.mk.erroractions.beginner.modify.struct <- read.csv("../data/mousekey-errors/beginner-actions-by-category-modify-struct.csv", header=TRUE,row.names=1)
#data.mk.erroractions.beginner.create.text <- read.csv("../data/mousekey-errors/beginner-actions-by-category-create-text.csv", header=TRUE,row.names=1)
```

```
#data.mk.erroractions.beginner.modify.text <- read.csv("../data/mousekey-errors/
      beginner-actions-by-category-modify-text.csv", header=TRUE,row.names=1)

#data.mk.erroractions.advanced.create.graph <- read.csv("../data/mousekey-errors/
      advanced-actions-by-category-create-graph.csv", header=TRUE,row.names=1)
#data.mk.erroractions.advanced.modify.graph <- read.csv("../data/mousekey-errors/
      advanced-actions-by-category-modify-graph.csv", header=TRUE,row.names=1)
#data.mk.erroractions.advanced.create.struct <- read.csv("../data/mousekey-errors
      /advanced-actions-by-category-create-struct.csv", header=TRUE,row.names=1)
#data.mk.erroractions.advanced.modify.struct <- read.csv("../data/mousekey-errors
      /advanced-actions-by-category-modify-struct.csv", header=TRUE,row.names=1)
#data.mk.erroractions.advanced.create.text <- read.csv("../data/mousekey-errors/
      advanced-actions-by-category-create-text.csv", header=TRUE,row.names=1)
#data.mk.erroractions.advanced.modify.text <- read.csv("../data/mousekey-errors/
      advanced-actions-by-category-modify-text.csv", header=TRUE,row.names=1)

data.mk.errors.beginner.tools <- read.csv("../data/mousekey-errors/beginner-by-
      tool.csv", header=TRUE,row.names=1)
data.mk.errors.advanced.tools <- read.csv("../data/mousekey-errors/advanced-by-
      tool.csv", header=TRUE,row.names=1)

####

# mouseclick, mousedrag, keypress and keymacro by user

data.mk.errors.beginner.actions.by.user.graph <- read.csv("../data/mousekey-
      errors/beginner-actions-by-user-graph.csv", header=TRUE,row.names=1)
data.mk.errors.beginner.actions.by.user.struct <- read.csv("../data/mousekey-
      errors/beginner-actions-by-user-struct.csv", header=TRUE,row.names=1)
data.mk.errors.beginner.actions.by.user.text <- read.csv("../data/mousekey-errors
      /beginner-actions-by-user-text.csv", header=TRUE,row.names=1)

data.mk.errors.advanced.actions.by.user.graph <- read.csv("../data/mousekey-
      errors/advanced-actions-by-user-graph.csv", header=TRUE,row.names=1)
data.mk.errors.advanced.actions.by.user.struct <- read.csv("../data/mousekey-
      errors/advanced-actions-by-user-struct.csv", header=TRUE,row.names=1)
data.mk.errors.advanced.actions.by.user.text <- read.csv("../data/mousekey-errors
      /advanced-actions-by-user-text.csv", header=TRUE,row.names=1)

#####

data.editors.beginner.time <- t(read.csv("../../../../usability/experiment-1/3-
      resultcreateanalyse.csv", header=TRUE,row.names=1))

data.editors.advanced.time <- t(read.csv("../../../../usability/experiment-2/3-
      resultcreateanalyse.csv", header=TRUE,row.names=1))
```

F.1.6. generate-plots.R

```
library("car")
library("corrgram")


source("dataset-functions.R")


Aesthetics <- read.csv("../data/aesthetics.csv", header=TRUE)
Aesthetics$chart <- as.factor(Aesthetics$chart)
Aesthetics$complexity <- as.factor(Aesthetics$complexity)
Aesthetics$model <- as.factor(Aesthetics$model)
Aesthetics$layout <- as.factor(Aesthetics$layout)
Aesthetics$experiment <- as.factor(Aesthetics$experiment)
Aesthetics$WHR <- log10(Aesthetics$WHR)
tempnames <- names(Aesthetics)
tempnames[7] <- "log.WHR"
names(Aesthetics) <- tempnames

Aesthetics$d0 <- 0
Aesthetics$d1 <- 0
Aesthetics$d2 <- 0


Aesthetics$d0[Aesthetics$complexity==1] <- 1
Aesthetics$d1[Aesthetics$complexity==2] <- 1
Aesthetics$d2[Aesthetics$complexity==3] <- 1

Aesthetics2 <- Aesthetics[Aesthetics$experiment==2,]

# add dummy variable to distinguish between c1 and c2+c3
Aesthetics2$complexity2 <- 0
Aesthetics2$complexity2 <- ((Aesthetics2$complexity==2)|(Aesthetics2$complexity
      ==3))*1
Aesthetics2$complexity2 <- as.factor(Aesthetics2$complexity2)


attach(Aesthetics2)



#############
# Editing
#############

Editing <- read.csv("../data/editing.csv", header=TRUE, row.names=1)





# draw scatterplots and histograms
pdf("plots-adv-combined.pdf")
for (i in c(6:33)){
sp3points4(i, cex.lab=1.6, cex.axis=1.6, cex=1.3, cex.main=1.6)
sp3time4(i, cex.lab=1.6, cex.axis=1.6, cex=1.3, cex.main=1.6)
histnew2(i, Aesthetics2[i][Aesthetics2[2]==1], "Complexity: Simple", cex.lab=1.6,
       cex.axis=1.6, cex=1.3, cex.main=1.6)
histnew2(i, Aesthetics2[i][Aesthetics2[2]==2|Aesthetics2[2]==3],"Complexity:
      Hierarchical and Parallel", cex.lab=1.6, cex.axis=1.6, cex=1.3, cex.main
      =1.6)
histnew2(i, Aesthetics2[,i], "Complexity: All", cex.lab=1.6, cex.axis=1.6, cex
      =1.3, cex.main=1.6)
}

dev.off()

pdf("plots-adv.pdf")
for (i in c(6:33)){
sp3points3(i, cex.lab=1.6, cex.axis=1.6, cex=1.3, cex.main=1.6)
sp3time3(i, cex.lab=1.6, cex.axis=1.6, cex=1.3, cex.main=1.6)
#histnew(i,1,1, "Complexity: Simple", names(Aesthetics[i]))
#histnew(i,2,1, "Complexity: Hierarchical", names(Aesthetics[i]))
#histnew(i,3,1, "Complexity: Parallel", names(Aesthetics[i]))
}
dev.off()


# draw an empty sheet
pdf("plots-empty.pdf")
plot(1:10, 1:10, type="n", axes=FALSE, xlab="", ylab="", frame.plot=FALSE)
dev.off()




# draw correlation matrices
pdf("plots-corrtable-complexity1-adv.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==1&experiment==2),c(34:35, 6:20, 24:33)], lower.
      panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("plots-corrtable-complexity2-adv.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==2&experiment==2),c(34:35, 6:20, 24:33)], lower.
      panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("plots-corrtable-complexity3-adv.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==3&experiment==2),c(34:35, 6:20, 24:33)], lower.
      panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("plots-corrtable-complexity1-adv-points.pdf", width=30, height=30)
pairs(Aesthetics2[complexity==1,c(34, 6:20, 24:33)], lower.panel=panel.smooth,
      upper.panel=panel.cor)
dev.off()
```

```
pdf("plots-corrtable-complexity23-adv-points.pdf", width=30, height=30)
pairs(Aesthetics2[(complexity==3|complexity==2),c(34, 6:20, 24:33)], lower.panel=
      panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("plots-corrtable-complexity123-adv-time.pdf", width=30, height=30)
pairs(Aesthetics2[,c(35, 6:20, 24:33)], lower.panel=panel.smooth, upper.panel=
      panel.cor)
dev.off()

pdf("corrtable-c1e2-points-spearman.pdf", width=30, height=30)
pairs(Aesthetics2[complexity==1,c(34, 6:33)], lower.panel=panel.smooth, upper.
      panel=panel.cor3, main="Correlation Matrix for Dependent Variable Points,
      Statecharts of Simple Complexity", cex.main=2)
dev.off()
pdf("corrtable-c23e2-points-spearman.pdf", width=30, height=30)
pairs(Aesthetics2[(complexity==3|complexity==2),c(34, 6:33)], lower.panel=panel.
      smooth, upper.panel=panel.cor3, main="Correlation Matrix for Dependent
      Variable Points, Statecharts of Higher Complexity", cex.main=2)
dev.off()

pdf("corrtable-c123e2-time-spearman.pdf", width=30, height=30)
pairs(Aesthetics2[,c(35, 6:33)], lower.panel=panel.smooth, upper.panel=panel.cor3
      , main="Correlation Matrix for Dependent Variable Time, Statecharts of All
      Complexities", cex.main=2)
dev.off()

pdf("corrtable-example2.pdf")
pairs(Aesthetics2[,c(6,15,30)], lower.panel=panel.smooth, upper.panel=panel.cor3)
dev.off()
```

F.1.7. dataset-functions.R

```
lowess.na <- function(x, y = NULL, f = 2/3,...) {  #do lowess with missing data

  x1 <- subset(x,(!is.na(x)) &(!is.na(y)))
  y1 <- subset(y, (!is.na(x)) &(!is.na(y)))
  lowess.na <- lowess(x1,y1,f, ...)
}

sp3points <- function(i){
scatterplot(Aesthetics[i][(Aesthetics[2]==1 & Aesthetics[5]==1)],
      Aesthetics$points[(Aesthetics[2]==1 & Aesthetics[5]==1)],  xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Simple, Level: Beginner")
histnew(i,1,1,"Complexity: Simple, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==1 & Aesthetics[5]==2)],
      Aesthetics$points[(Aesthetics[2]==1 & Aesthetics[5]==2)], xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Simple, Level: Advanced")
histnew(i,1,2,"Complexity: Simple, Level: Advanced", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==2 & Aesthetics[5]==1)],
      Aesthetics$points[(Aesthetics[2]==2 & Aesthetics[5]==1)], xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Hierarchical, Level:
      Beginner")
histnew(i,2,1,"Complexity: Hierarchical, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==2 & Aesthetics[5]==2)],
      Aesthetics$points[(Aesthetics[2]==2 & Aesthetics[5]==2)],xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Hierarchical, Level:
      Advanced")
histnew(i,2,2,"Complexity: Hierarchical, Level: Advanced", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==3 & Aesthetics[5]==1)],
      Aesthetics$points[(Aesthetics[2]==3 & Aesthetics[5]==1)],  xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Parallel, Level: Beginner
      ")
histnew(i,3,2,"Complexity: Parallel, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==3 & Aesthetics[5]==2)],
      Aesthetics$points[(Aesthetics[2]==3 & Aesthetics[5]==2)],  xlab=names(
      Aesthetics)[i], ylab="Points", main="Complexity: Parallel, Level: Advanced
      ")
histnew(i,3,2,"Complexity: Parallel, Level: Advanced", names(Aesthetics)[i])
}

sp3points2 <- function(i){
scatterplot(Aesthetics[i][Aesthetics[2]==1],Aesthetics$points[Aesthetics[2]==1],
      groups=experiment[Aesthetics$complexity==1],  xlab=names(Aesthetics)[i],
      ylab="Points", main="Complexity: Simple", col=c("black","black", "darkgray
      "), legend.title="Experiment")
histnew(i,1,1,"Complexity: Simple", names(Aesthetics)[i])
scatterplot(Aesthetics[i][Aesthetics[2]==2],Aesthetics$points[Aesthetics[2]==2],
      groups=experiment[Aesthetics$complexity==2],  xlab=names(Aesthetics)[i],
      ylab="Points", main="Complexity: Hierarchical", col=c("black","black", "
      darkgray"), legend.title="Experiment")
histnew(i,2,1,"Complexity: Hierarchical", names(Aesthetics)[i])
scatterplot(Aesthetics[i][Aesthetics[2]==3],Aesthetics$points[Aesthetics[2]==3],
      groups=experiment[Aesthetics$complexity==3],  xlab=names(Aesthetics)[i],
      ylab="Points", main="Complexity: Parallel", col=c("black","black", "
      darkgray"), legend.title="Experiment")
histnew(i,3,1,"Complexity: Parallel", names(Aesthetics)[i])
}

sp3points3 <- function(i, ...){
scatterplot(Aesthetics2[i][Aesthetics2[2]==1],Aesthetics2$points[Aesthetics2
      [2]==1], groups=experiment[Aesthetics2$complexity==1],  xlab=names(
      Aesthetics2)[i], ylab="Points", main="Complexity: Simple", col=c("black","
      black", "darkgray"), legend.title="Experiment", ...)

scatterplot(Aesthetics2[i][Aesthetics2[2]==2],Aesthetics2$points[Aesthetics2
      [2]==2], groups=experiment[Aesthetics2$complexity==2],  xlab=names(
      Aesthetics2)[i], ylab="Points", main="Complexity: Hierarchical", col=c("
      black","black", "darkgray"), legend.title="Experiment", ...)

scatterplot(Aesthetics2[i][Aesthetics2[2]==3],Aesthetics2$points[Aesthetics2
      [2]==3], groups=experiment[Aesthetics2$complexity==3],  xlab=names(
      Aesthetics2)[i], ylab="Points", main="Complexity: Parallel", col=c("black
      ","black", "darkgray"), legend.title="Experiment", ...)

}



sp3points4 <- function(i,...){
scatterplot(Aesthetics2[i][Aesthetics2[2]==1],Aesthetics2$points[Aesthetics2
      [2]==1],  xlab=names(Aesthetics2)[i], ylab="Points", main="Points,
      Complexity: Simple", col=c("black","black", "darkgray"),...)

scatterplot(Aesthetics2[i][Aesthetics2[2]==2 | Aesthetics2[2]==3],
      Aesthetics2$points[Aesthetics2[2]==2 | Aesthetics2[2]==3],  xlab=names(
      Aesthetics2)[i], ylab="Points", main="Points, Complexity: Hierarchical and
      Parallel", col=c("black","black", "darkgray"),...)
}

histnew <- function(i,j,k, main, xlab,...){
hist(Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)], nclass=n.bins(
      Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)], "simple"),
      probability=T, ylab="Density", main=main, xlab=xlab, cex=.75,...)
lines(density(Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)], na.rm=TRUE),
      lwd=2)
points(Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)], rep(0, length(
      Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)])), pch="|")
box()
lines(density(Aesthetics[i][(Aesthetics[2]==j & Aesthetics[5]==k)], adjust=.5, na
      .rm=TRUE), lwd=1)

}

# data: Aesthetics2[i][Aesthetics2[2]==2|3]
histnew2 <- function(i, data, main,...){
  hist(data, nclass=n.bins(data, "simple"), probability=T, ylab="Density", main=
      main, xlab=names(Aesthetics2[i]), cex=.75,...)
lines(density(data, na.rm=TRUE), lwd=2)
```

```r
points(data, rep(0, length(data)), pch="|")
box()
lines(density(data, adjust=.5, na.rm=TRUE), lwd=1)


}


sp3time <- function(i){
scatterplot(Aesthetics[i][(Aesthetics[2]==1 & Aesthetics[5]==1)],Aesthetics$time
      [(Aesthetics[2]==1 & Aesthetics[5]==1)],  xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Simple, Level: Beginner")
histnew(i,1,1,"Complexity: Simple, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==1 & Aesthetics[5]==2)], Aesthetics$time
      [(Aesthetics[2]==1 & Aesthetics[5]==2)], xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Simple, Level: Advanced")
histnew(i,1,2,"Complexity: Simple, Level: Advanced", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==2 & Aesthetics[5]==1)], Aesthetics$time
      [(Aesthetics[2]==2 & Aesthetics[5]==1)], xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Hierarchical, Level: Beginner")
histnew(i,2,1,"Complexity: Hierarchical, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==2 & Aesthetics[5]==2)], Aesthetics$time
      [(Aesthetics[2]==2 & Aesthetics[5]==2)],xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Hierarchical, Level: Advanced")
histnew(i,2,2,"Complexity: Hierarchical, Level: Advanced", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==3 & Aesthetics[5]==1)],Aesthetics$time
      [(Aesthetics[2]==3 & Aesthetics[5]==1)],  xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Parallel, Level: Beginner")
histnew(i,3,2,"Complexity: Parallel, Level: Beginner", names(Aesthetics)[i])
scatterplot(Aesthetics[i][(Aesthetics[2]==3 & Aesthetics[5]==2)],Aesthetics$time
      [(Aesthetics[2]==3 & Aesthetics[5]==2)],  xlab=names(Aesthetics)[i], ylab="
      Time", main="Complexity: Parallel, Level: Advanced")
histnew(i,3,2,"Complexity: Parallel, Level: Advanced", names(Aesthetics)[i])
}

sp3time2 <- function(i){
#par(mfrow=c(3,2))
scatterplot(Aesthetics[i][Aesthetics[2]==1],Aesthetics$time[Aesthetics[2]==1],
      groups=experiment[Aesthetics$complexity==1],  xlab=names(Aesthetics)[i],
      ylab="Time", main="Complexity: Simple", col=c("black","black", "darkgray"),
       legend.title="Experiment")
histnew(i,1,1,"Complexity: Simple", names(Aesthetics)[i])
scatterplot(Aesthetics[i][Aesthetics[2]==2],Aesthetics$time[Aesthetics[2]==2],
      groups=experiment[Aesthetics$complexity==2],  xlab=names(Aesthetics)[i],
      ylab="Time", main="Complexity: Hierarchical", col=c("black","black", "
      darkgray"), legend.title="Experiment")
histnew(i,2,1,"Complexity: Hierarchical", names(Aesthetics)[i])
scatterplot(Aesthetics[i][Aesthetics[2]==3],Aesthetics$time[Aesthetics[2]==3],
      groups=experiment[Aesthetics$complexity==3],  xlab=names(Aesthetics)[i],
      ylab="Time", main="Complexity: Parallel", col=c("black","black", "darkgray
      "), legend.title="Experiment")
histnew(i,3,1,"Complexity: Parallel", names(Aesthetics)[i])
}


sp3time3 <- function(i, ...){
#par(mfrow=c(3,2))
scatterplot(Aesthetics2[i][Aesthetics2[2]==1],Aesthetics2$time[Aesthetics2
      [2]==1],  xlab=names(Aesthetics2)[i], ylab="Time", main="Complexity: Simple
      ", col=c("black","black", "darkgray"), ...)

scatterplot(Aesthetics2[i][Aesthetics2[2]==2],Aesthetics2$time[Aesthetics2
      [2]==2],  xlab=names(Aesthetics2)[i], ylab="Time", main="Complexity:
      Hierarchical", col=c("black","black", "darkgray"), ...)

scatterplot(Aesthetics2[i][Aesthetics2[2]==3],Aesthetics2$time[Aesthetics2
      [2]==3],  xlab=names(Aesthetics2)[i], ylab="Time", main="Complexity:
      Parallel", col=c("black","black", "darkgray"), ...)
histnew(i,1,1,"Complexity: Simple", names(Aesthetics2)[i], ...)
histnew(i,2,1,"Complexity: Hierarchical", names(Aesthetics2)[i], ...)
histnew(i,3,1,"Complexity: Parallel", names(Aesthetics2)[i], ...)
}

sp3time4 <- function(i,...){

scatterplot(Aesthetics2[,i],Aesthetics2$time,  xlab=names(Aesthetics2)[i], ylab="
      Time", main="Time, Complexity: All", col=c("black","black", "darkgray")
      ,...)


}

panel.cor <- function(x, y, digits=2, prefix="", cex.cor)
{
    usr <- par("usr"); on.exit(par(usr))
    par(usr = c(0, 1, 0, 1))
    r <- abs(cor(x, y, use="pairwise.complete.obs"))
    txt <- format(c(r, 0.123456789), digits=digits)[1]
    txt <- paste(prefix, txt, sep="")
    if(missing(cex.cor)) cex <- 0.8/strwidth(txt)

    test <- cor.test(x,y)
    # borrowed from printCoefmat
    Signif <- symnum(test$p.value, corr = FALSE, na = FALSE,
                  cutpoints = c(0, 0.001, 0.01, 0.05, 0.1, 1),
                  symbols = c("***", "**", "*", ".", " "))

    text(0.5, 0.5, txt, cex = cex * r)
    text(.8, .8, Signif, cex=cex, col=2)
}

panel.cor2 <- function(x, y, digits=2, prefix="", cex.cor)
{
    usr <- par("usr"); on.exit(par(usr))
    par(usr = c(0, 1, 0, 1))
    r <- abs(cor(x, y, use="pairwise.complete.obs", method="spearman"))
    txt <- format(c(r, 0.123456789), digits=digits)[1]
    txt <- paste(prefix, txt, sep="")
    if(missing(cex.cor)) cex <- 0.8/strwidth(txt)

    test <- cor.test(x,y, method="spearman")
    # borrowed from printCoefmat
```

```
    Signif <- symnum(test$p.value, corr = FALSE, na = FALSE,
                  cutpoints = c(0, 0.001, 0.01, 0.05, 0.1, 1),
                  symbols = c("***", "**", "*", ".", " "))

    text(0.5, 0.5, txt, cex = cex * r)
    text(0.8, 0.8, Signif, cex=cex, col=2)
}

panel.cor3 <- function(x, y, digits=2, prefix="", cex.cor)
{
    usr <- par("usr"); on.exit(par(usr))
    par(usr = c(0, 1, 0, 1))
    r <- abs(cor(x, y, use="pairwise.complete.obs", method="spearman"))
    txt <- format(c(r, 0.123456789), digits=digits)[1]
    txt <- paste(prefix, txt, sep="")
    if(missing(cex.cor)) cex <- 0.8/strwidth(txt)

    test <- cor.test(x,y, method="spearman")
    # borrowed from printCoefmat
    Signif <- symnum(test$p.value, corr = FALSE, na = FALSE,
                  cutpoints = c(0, 0.001, 0.01, 0.05, 0.1, 1),
                  symbols = c("***", "**", "*", ".", " "))

    text(0.5, 0.5, txt, cex = cex * r)
    #text(0.8, 0.8, Signif, cex=cex, col=2)
}

highcorrelation <- function(corrmatrix){
  r <- corrmatrix
y <- which(lower.tri(r), TRUE)
z <- data.frame(row = rownames(r)[y[, 1]],
                col = colnames(r)[y[, 2]],
                cor = r[y])
subset(z, abs(cor) > 0.5)

}
```

F.1.8. dataset.R

```
# these libraries are obligatory
library("car")
library("corrgram")

# functions were stored externally
source("dataset-functions.R")

#read aesthetics data
Aesthetics <- read.csv("../data/aesthetics.csv", header=TRUE)
Aesthetics$chart <- as.factor(Aesthetics$chart)
Aesthetics$complexity <- as.factor(Aesthetics$complexity)
Aesthetics$model <- as.factor(Aesthetics$model)
Aesthetics$layout <- as.factor(Aesthetics$layout)
Aesthetics$experiment <- as.factor(Aesthetics$experiment)
Aesthetics$log.WHR <- log10(Aesthetics$WHR)

Aesthetics$d0 <- 0
Aesthetics$d1 <- 0
Aesthetics$d2 <- 0

Aesthetics$TR2 <- Aesthetics$TRL ^2

Aesthetics$d0[Aesthetics$complexity==1] <- 1
Aesthetics$d1[Aesthetics$complexity==2] <- 1
Aesthetics$d2[Aesthetics$complexity==3] <- 1

Aesthetics2 <- Aesthetics[Aesthetics$experiment==2,]

# add dummy variable to distinguish between c1 and c2+c3
Aesthetics2$complexity2 <- 0
Aesthetics2$complexity2 <- ((Aesthetics2$complexity==2)|(Aesthetics2$complexity
      ==3))*1
Aesthetics2$complexity2 <- as.factor(Aesthetics2$complexity2)

# test for differences between beginner and advanced users
summary(lm(Aesthetics$points ~ Aesthetics$d1
           + Aesthetics$d2 + Aesthetics$TRL + Aesthetics$experiment))
summary(lm(Aesthetics$time ~ Aesthetics$d1
           + Aesthetics$d2 + Aesthetics$TRL + Aesthetics$experiment))

# attach data frame
attach(Aesthetics2)

contrasts(complexity)

# test for differences in complexity
summary(lm(points ~ d0 + TRL))
summary(lm(points ~ d0 + TRL + TR2))
summary(lm(points ~ d1 + d2 + TRL))
summary(lm(points ~ TRL + complexity))
summary(lm(points ~ TRL + TR2 + complexity))

summary(lm(time ~ TRL + TR2))
summary(lm(time ~ d0 + TRL + TR2))
summary(lm(time ~ d1+d2 + TRL + TR2))
summary(lm(time ~ TRL + TR2 + complexity))

# generate squared terms
log.WHR2 <- log.WHR^2
SUS2 <- SUS^2
SUT2 <- SUT^2
SUA2 <- SUA^2

PI2 <- PI^2
PF2 <- PF^2

NBAVG2 <- NBAVG^2
NBMIN2 <- NBMIN^2
NBMAX2 <- NBMAX^2

DI2 <- DI^2
DM2 <- DM^2
DNA2 <- DNA^2
DNS2 <- DNS^2
DNR2 <- DNR^2

NS2 <- NSS^2
NSS2 <- NSS^2
NHS2 <- NHS^2

IF2 <- IF^2

FL2 <- FL^2

NST2 <- NST^2
NT2 <- NT^2


#######
# test



########
# points / time ~ variable

###
# TRL
###

# points
summary(lm(points ~ TRL*complexity2))
summary(lm(points ~ (TRL+TR2)*complexity2))

# time
```

```
summary(lm(time ~ TRL ))
summary(lm(time ~ TRL + TR2 ))

pdf("TRLmodel.pdf")
lm.TRLp <- lm(points~TRL*complexity2)
plot(TRL[complexity==1], points[complexity==1],
     col="black", xlab="TRL", ylab="points", pch=20,
     cex.axis=1.2, cex.lab=1.2, xlim=c(min(TRL),
     max(TRL)), ylim=c(-8,12))
points(TRL[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
abline(lm.TRLp$coef[1] + lm.TRLp$coef[3],
       lm.TRLp$coef[2] + lm.TRLp$coef[4], col="black", lty=2)
abline(lm.TRLp$coef[1], lm.TRLp$coef[2], col="black")
legend("topleft", c("simple", "hierarchical"),
       pch=c(20,21), col=c("black", "black"),inset = .025,
       cex=1.2, lty=c(1,2))
lm.TRLt <- lm(time~TRL)
plot(TRL, time, col="black", pch=19, xlab="TRL",
     ylab="time", cex.axis=1.2, cex.lab=1.2, ylim=c(0,500))
abline(lm.TRLt$coef[1], lm.TRLt$coef[2], col="black")
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()



###
# x-y-ratio
###

# points
summary(lm(points ~ log.WHR*complexity2))

summary(lm(points ~ (log.WHR + log.WHR2)*complexity2))
# guter Zusammenhang mit quadratischem Term

# time
summary(lm(time ~ log.WHR ))

summary(lm(time ~ log.WHR + log.WHR2 ))
# signifikantes Ergebnis mit quadratischem Term

lm.WHR <- lm(points~log.WHR*complexity2)
lm.WHR2 <- lm(points~(log.WHR+log.WHR2)*complexity2)


testsimplep=function(whr){
  return(-2.5570 + 3.8692*whr + 6.4531*(whr^2))
}
testhierarchicalp=function(whr){
  return(-2.5570+3.1977 + (3.8692-8.796)*whr
         + (6.4531-10.4169)*(whr^2))
}
testt=function(whr){
  return(147.5 + -24.73*whr - 134.68*(whr^2))
}

test <- as.data.frame(log.WHR)
test[,2] <- as.data.frame(testsimplep(log.WHR))
test[,3] <- as.data.frame(testhierarchicalp(log.WHR))
test[,4] <- as.data.frame(testt(log.WHR))
test2 <- test[order(test[,1]),]

pdf("WHRmodel.pdf")
plot(log.WHR[complexity==1], points[complexity==1],
     xlab="log(WHR)", ylab="points", pch=20, cex.axis=1.2,
     cex.lab=1.2, xlim=c(min(log.WHR),max(log.WHR)),
     ylim=c(-8,12))
points(log.WHR[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(test2[,1], test2[,2])
lines(test2[,1], test2[,3], col="black", lty=2)
legend("topleft", c("simple", "hierarchical"), pch=c(20,21),
       col=c("black", "black"),inset = .025, cex=1.2, lty=c(1,2))

plot(log.WHR, time, ylim=c(0,550),pch=19, xlab="log(WHR)",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(test2[,1], test2[,4])
legend("topleft", "all complexities", pch=19, col="black",
       inset = .025, cex=1.2, lty=c(1,2))
dev.off()



###
# usage of available space
###

# points
summary(lm(points ~ SUS*complexity2))
summary(lm(points ~ SUT*complexity2))
summary(lm(points ~ SUA*complexity2))


summary(lm(points ~ (SUS + SUS2)*complexity2))
summary(lm(points ~ (SUT + SUT2)*complexity2))
summary(lm(points ~ (SUA + SUA2)*complexity2))

# time
summary(lm(time ~ SUS ))
summary(lm(time ~ SUT ))
summary(lm(time ~ SUA ))

summary(lm(time ~ SUS + SUS2 ))
summary(lm(time ~ SUT + SUT2 ))
summary(lm(time ~ SUA + SUA2 ))

SUAsimplep=function(data){return(-15.15038 + 1.94026*data
  + -0.05371*(data^2))}
SUAhierarchicalp=function(data){return(-15.15038+31.39426
```

```
  + (1.94026-4.34843)*data + (0.13834-0.05371)*(data^2))}
SUSt=function(data){return(160.301 - 3.451*data)}

SUAdata <- as.data.frame(SUA)
SUAdata[,2] <- as.data.frame(SUAsimplep(SUA))
SUAdata[,3] <- as.data.frame(SUAhierarchicalp(SUA))
SUSdata <- as.data.frame(SUS)
SUSdata[,2] <- as.data.frame(SUSt(SUS))
SUAdata2 <- SUAdata[order(SUAdata[,1]),]
SUSdata2 <- SUSdata[order(SUSdata[,1]),]


pdf("SUmodel.pdf")
plot(SUA[complexity==1], points[complexity==1],
     xlab="SUA", ylab="points", pch=20, cex.axis=1.2,
     cex.lab=1.2, xlim=c(min(SUA),max(SUA)),ylim=c(-8,12))
points(SUA[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(SUAdata2[,1], SUAdata2[,2])
lines(SUAdata2[,1], SUAdata2[,3], col="black", lty=2)
legend("topleft", c("simple", "hierarchical"), pch=c(20,21), col=c("black", "
      black"),inset = .025, cex=1.2, lty=c(1,2))

plot(SUS, time, ylim=c(0,550),pch=19, xlab="SUS",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(SUSdata2[,1], SUSdata2[,2])
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()


###
# placement of initial and final state
###
PI <- PI/2
PF <- PF/2

# points
summary(lm(points ~ PI*complexity2))
summary(lm(points ~ PF*complexity2))

summary(lm(points ~ PI + PI2+complexity2))
summary(lm(points ~ PF + +PF2+complexity2))

# time
summary(lm(time ~ PI ))
summary(lm(time ~ PF ))

summary(lm(time ~ PI + PI2))
summary(lm(time ~ PF + PF2))


PFsimplep=function(data){
  return(-4.02802 + 0.08317*data)
}
PFhierarchicalp=function(data){
  return(-4.02802+1.69265 + (0.08317-0.04276)*data)
}


PFdata <- as.data.frame(PF)
PFdata[,2] <- as.data.frame(PFsimplep(PF))
PFdata[,3] <- as.data.frame(PFhierarchicalp(PF))
PFdata2 <- PFdata[order(PFdata[,1]),]


pdf("PFmodel.pdf")
plot(PF[complexity==1], points[complexity==1],
     xlab="PF", ylab="points", pch=20, cex.axis=1.2,
     cex.lab=1.2, xlim=c(min(PF),max(PF)), ylim=c(-8,12))
points(PF[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(PFdata2[,1], PFdata2[,2])
lines(PFdata2[,1], PFdata2[,3], col="black", lty=2)
legend("topleft", c("simple", "hierarchical"),
       pch=c(20,21), col=c("black", "black"),
       inset = .025, cex=1.2, lty=c(1,2))

dev.off()


###
# distance of nodes
###

# points
summary(lm(points ~ NBAVG*complexity2))
summary(lm(points ~ NBMIN*complexity2))
summary(lm(points ~ NBMAX*complexity2))
summary(lm(points[NBMAX<120] ~
           NBMAX[NBMAX<120]*complexity2[NBMAX<120]))

summary(lm(points ~ (NBAVG + NBAVG2) * complexity2))
summary(lm(points ~ (NBMIN + NBMIN2) * complexity2))
summary(lm(points[NBMAX<120] ~
           (NBMAX[NBMAX<120] + NBMAX2[NBMAX<120])
           * complexity2[NBMAX<120]))

#time
summary(lm(time ~ NBAVG ))
summary(lm(time ~ NBMIN ))
summary(lm(time[NBMAX<120] ~ NBMAX[NBMAX<120] ))

summary(lm(time ~ NBAVG + NBAVG2 ))
summary(lm(time ~ NBMIN + NBMIN2 ))
summary(lm(time[NBMAX<120] ~
           NBMAX[NBMAX<120] + NBMAX2[NBMAX<120] ))

NBMINsimplep=function(data){
  return(2.65923 -0.08911*data)
}
NBMINhierarchicalp=function(data){
```

```
  return(2.65923 -3.06339 +(0.15630-0.08911)*data)
}
NBMINt=function(data){
  return(141.542 - 1.143*data)
}

NBMINdata <- as.data.frame(NBMIN)
NBMINdata[,2] <- as.data.frame(NBMINsimplep(NBMIN))
NBMINdata[,3] <- as.data.frame(NBMINhierarchicalp(NBMIN))
NBMINdata[,4] <- as.data.frame(NBMINt(NBMIN))
NBMINdata2 <- NBMINdata[order(NBMINdata[,1]),]


pdf("NBmodel.pdf")
plot(NBMIN[complexity==1], points[complexity==1],
     xlab="NBMIN", ylab="points", pch=20, cex.axis=1.2,
     cex.lab=1.2, xlim=c(min(NBMIN),max(NBMIN)),
     ylim=c(-8,12))
points(NBMIN[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(NBMINdata2[,1], NBMINdata2[,2])
lines(0:20, NBMINhierarchicalp(c(0:20)), col="black", lty=2)
lines(20:60, NBMINhierarchicalp(c(20:60)), col="black",
      lty=2)
legend("topleft", c("simple", "hierarchical"), pch=c(20,21),
       col=c("black", "black"),inset = .025, cex=1.2,
       lty=c(1,2))

plot(NBMIN, time, ylim=c(0,550),pch=19, xlab="NBMIN",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(NBMINdata2[,1], NBMINdata2[,4])
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()


###
# distance to a straight line
###

# points
summary(lm(points ~ DI * complexity2))
summary(lm(points ~ DM * complexity2))
summary(lm(points ~ DNA * complexity2))
summary(lm(points ~ DNS * complexity2))
summary(lm(points ~ DNR * complexity2))

summary(lm(points ~ (DI + DI2) * complexity2))
summary(lm(points ~ (DM + DM2) * complexity2))
summary(lm(points ~ (DNA + DNA2) * complexity2))
summary(lm(points ~ (DNS + DNS2) * complexity2))
summary(lm(points ~ (DNR + DNR2) * complexity2))

# time
summary(lm(time ~ DI ))
summary(lm(time ~ DM ))
summary(lm(time ~ DNA ))
summary(lm(time ~ DNS ))
summary(lm(time ~ DNR ))

summary(lm(time ~ DI + DI2 ))
summary(lm(time ~ DM + DM2 ))
summary(lm(time ~ DNA + DNA2 ))
summary(lm(time ~ DNS + DNS2 ))
summary(lm(time ~ DNR + DNR2 ))


DMsimplep=function(data){
  return(3.08961 - 0.10160*data)
}
DNAt=function(data){
  return(98.664757 - 1.763106*data + 0.040971*(data^2))
}

DMdata <- as.data.frame(DM[complexity==1])
DMdata[,2] <- as.data.frame(DMsimplep(DM[complexity==1]))
DMdata2 <- DMdata[order(DMdata[,1]),]
DNAdata <- as.data.frame(DNA)
DNAdata[,2] <- as.data.frame(DNAt(DNA))
DNAdata2 <- DNAdata[order(DNAdata[,1]),]


pdf("DSLmodel.pdf")
plot(DM[complexity==1], points[complexity==1], xlab="DM",
     ylab="points", pch=20, cex.axis=1.2, cex.lab=1.2)
lines(DMdata2[,1], DMdata2[,2])

plot(DNA, time, ylim=c(0,550),pch=19, xlab="DNA",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(DNAdata2[,1], DNAdata2[,2])
legend("topleft", "all complexities", pch=19, col="black",
       inset = .025, cex=1.2, lty=c(1,2))
dev.off()





###
# number of states
###

#points
summary(lm(points ~ NSS * complexity2))

# time
summary(lm(time ~ NS ))
summary(lm(time ~ NSS ))
summary(lm(time ~ NHS ))
```

```
summary(lm(time ~ NS + NS2))
summary(lm(time ~ NSS + NSS2))
summary(lm(time ~ NHS + NHS2))

NSSt=function(data){
  return(222.3486 -31.9711*data + 1.8706*(data^2))
}

NSSdata <- as.data.frame(NSS)
NSSdata[,2] <- as.data.frame(NSSt(NSS))
NSSdata2 <- NSSdata[order(NSSdata[,1]),]


pdf("NSplot.pdf")
scatterplot(NS, points, jitter=list(x=0.25, y=0),
            xlab="jitter(NS)",
            col=c("black","black","black"),
            smooth=FALSE, cex.axis=1.5, cex.lab=1.5)
plot(NSS, time, ylim=c(0,550),pch=19, xlab="NSS",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
#lines(NSSdata2[,1], NSSdata2[,2])
lines(7:16,NSSt(c(7:16)), lty=2)
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()



###
# intersection faults
###

# points
summary(lm(points ~ IF * complexity2))
summary(lm(points ~ IF + IF2 + complexity2))
summary(lm(points ~ IFTN * complexity2))
summary(lm(points ~ IFTT * complexity2))
summary(lm(points ~ IFTL * complexity2))
summary(lm(points ~ IFLL * complexity2))

# time
summary(lm(time ~ IF ))
summary(lm(time ~ IF + IF2 ))

summary(lm(time ~ IFTN ))
summary(lm(time ~ IFTT ))
summary(lm(time ~ IFTL ))
summary(lm(time ~ IFLL ))



IFsimplep=function(data){
  return(2.8289 - 0.6150*data)
}
IFhierarchicalp=function(data){
  return(2.8289-4.3064 + (0.9472-0.6150)*data )
}
IFt=function(data){
  return(121.2902 - 9.4383*data + 1.5483*(data^2))
}

IFdata <- as.data.frame(IF)
IFdata[,2] <- as.data.frame(IFsimplep(IF))
IFdata[,3] <- as.data.frame(IFhierarchicalp(IF))
IFdata[,4] <- as.data.frame(IFt(IF))
IFdata2 <- IFdata[order(IFdata[,1]),]


pdf("IFmodel.pdf")
plot(IF[complexity==1], points[complexity==1],
     xlab="IF", ylab="points", pch=20, cex.axis=1.2,
     cex.lab=1.2, xlim=c(min(IF),max(IF)),  ylim=c(-8,12))
points(IF[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(IFdata2[,1], IFdata2[,2])
lines(IFdata2[,1], IFdata2[,3], col="black", lty=2)
legend("topleft", c("simple", "hierarchical"),
       pch=c(20,21), col=c("black", "black"),
       inset = .025, cex=1.2, lty=c(1,2))

plot(IF, time, ylim=c(0,550),pch=19, xlab="IF",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(IFdata2[,1], IFdata2[,4])
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()



###
# statechart Flow
###

# points
summary(lm(points ~ FL * complexity2))
summary(lm(points ~ (FL + FL2) * complexity2))

# time
summary(lm(time ~ FL ))
summary(lm(time ~ FL + FL2 ))


FLsimplep=function(data){
  return(9.606450 -0.303616*data+0.002114*(data^2))
}
FLhierarchicalp=function(data){
  return(9.606450-11.162693 + (0.474564-0.303616)*data
         + (0.002114-0.004536)*(data^2))
}
```

```
FLt=function(data){return(93.210995 + 1.656922*data
         - 0.016628*(data^2))
}

FLdata <- as.data.frame(FL)
FLdata[,2] <- as.data.frame(FLsimplep(FL))
FLdata[,3] <- as.data.frame(FLhierarchicalp(FL))
FLdata[,4] <- as.data.frame(FLt(FL))
FLdata2 <- FLdata[order(FLdata[,1]),]


pdf("FLmodel.pdf")
plot(FL[complexity==1], points[complexity==1], xlab="FL",
     ylab="points", pch=20, cex.axis=1.2, cex.lab=1.2,
     xlim=c(min(FL),max(FL)),  ylim=c(-8,12))
points(FL[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="black")
lines(FLdata2[,1], FLdata2[,2])
lines(FLdata2[,1], FLdata2[,3], col="black", lty=2)
legend("topleft", c("simple", "hierarchical"),
       pch=c(20,21), col=c("black", "black"),
       inset = .025, cex=1.2, lty=c(1,2))

plot(FL, time, ylim=c(0,550),pch=19, xlab="FL",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(FLdata2[,1], FLdata2[,4])
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()



###
# Number of Transitions
###

# points
summary(lm(points ~ NST * complexity2))
summary(lm(points ~ NPT * complexity2))
summary(lm(points ~ NSPT * complexity2))
summary(lm(points ~ NT * complexity2))
summary(lm(points ~ (NST + NST2) * complexity2))

# time
summary(lm(time ~ NST ))
summary(lm(time ~ NPT ))
summary(lm(time ~ NSPT ))
summary(lm(time ~ NT ))
summary(lm(time ~ NST + NST2))
summary(lm(time ~ NT + NT2))

NSThierarchicalp=function(data){
  return(-3.16697 + 0.31483*data)
}
NTt=function(data){
  return(205.4068 + -23.4566*data + 1.1906*(data^2))
}

NSTdata <- as.data.frame(NST)
NSTdata[,2] <- as.data.frame(NSThierarchicalp(NST))
NSTdata2 <- NSTdata[order(NSTdata[,1]),]
NTdata <- as.data.frame(NT)
NTdata[,2] <- as.data.frame(NTt(NT))
NTdata2 <- NTdata[order(NTdata[,1]),]

pdf("NTmodel.pdf")
plot(NST[complexity==2|complexity==3],
     points[complexity==2|complexity==3], xlab="NST",
     ylab="points", cex.axis=1.2, cex.lab=1.2, col="black")
lines(NSTdata2[,1], NSTdata2[,2], col="black", lty=2)
plot(NT, time, ylim=c(0,550),pch=19, xlab="NT",
     ylab="time", cex.axis=1.2, cex.lab=1.2)
lines(9:19, NTt(9:19))
legend("topleft", "all complexities", pch=19,
       col="black",inset = .025, cex=1.2, lty=c(1,2))
dev.off()



#####
# Versuch
#####

summary(lm(points ~ TRL + TR2 + log.WHR + log.WHR2 + SUT
          + SUT2 + DM +  NST + IF + IF2 + FL + complexity2))
vif(lm(points ~ TRL + TR2 + log.WHR + log.WHR2 + SUT + SUT2
       + DM +  NST + IF + IF2 + FL + complexity2))
summary(lm(points ~ log.WHR + DM +  IF + FL + complexity2))
vif(lm(points ~ log.WHR + DM +  IF + FL + complexity2))
test2=function(logxy,distmid,intfault,FL){
  return(3.45 + 4.9*logxy - 0.08*distmid + 0.37*intfault
         - 0.066*FL + 2.24)
}
plot(fitted.values((lm(points ~ log.WHR + DM +  IF + FL
                       + complexity2))))
points(test2(log.WHR, DM, IF, FL), col="red")
#####
summary(lm(points ~ TRL + TR2 + log.WHR + log.WHR2
           + complexity2))
vif(lm(points ~ TRL + TR2 + log.WHR + log.WHR2
       + complexity2))
summary(lm(points ~ TRL + TR2 + SUT + sut2
           + complexity2))
vif(lm(points ~ TRL + TR2 + SUT + sut2
       + complexity2))
# anderes Modell, vif schlecht

# alle signifikanten metriken drin
summary(lm(points~(TRL+log.WHR+log.WHR2+SUA+SUA2
                  +NBMIN+DM+PF+IFLL+NST+NST2)*complexity2))
vif(lm(points~(TRL+log.WHR+log.WHR2+SUA+SUA2
              +NBMIN+DM+PF+IFLL+NST+NST2)*complexity2))
```

```
summary(lm(points~(TRL+log.WHR+log.WHR2+IF)*complexity2))
vif(lm(points~(TRL+log.WHR+log.WHR2+IF)*complexity2))

summary(lm(points~(TRL+log.WHR+log.WHR2+IFLL )*complexity2))
vif(lm(points~(TRL+log.WHR+log.WHR2+IFLL )*complexity2))

summary(lm(points~(TRL+log.WHR+PF+IFLL)*complexity2))
vif(lm(points~(TRL+log.WHR+PF+IFLL)*complexity2))

summary(lm(points~(TRL+log.WHR+log.WHR2+NBMIN+PF+IFLL)
           *complexity2))
vif(lm(points~(TRL+log.WHR+log.WHR2+NBMIN+PF+IFLL)
       *complexity2))

summary(lm(points~(TRL+NBMIN+PF+IFLL)*complexity2))
vif(lm(points~(TRL+NBMIN+PF+IFLL)*complexity2))

summary(lm(points~(TRL+log.WHR+NBMIN+PF+IFLL)*complexity2))
vif(lm(points~(TRL+log.WHR+NBMIN+PF+IFLL)*complexity2))

TRLnorm <- (TRL-min(TRL))/(max(TRL)-min(TRL))
log.WHRnorm <- (log.WHR-min(log.WHR))/(max(log.WHR)
                                       -min(log.WHR))
#log.WHRnorm <- log10(WHRnorm)
log.WHRnorm2 <- (log.WHRnorm)^2
NBMINnorm <- (NBMIN-min(NBMIN))/(max(NBMIN)-min(NBMIN))
PFnorm <- (PF-min(PF))/(max(PF)-min(PF))
IFLLnorm <- (IFLL-min(IFLL))/(max(IFLL)-min(IFLL))

summary(lm(points~(TRLnorm+log.WHRnorm+NBMINnorm
                   +PFnorm+IFLLnorm)*complexity2))
vif(lm(points~(TRLnorm+log.WHRnorm+NBMINnorm
               +PFnorm+IFLLnorm)*complexity2))


#####
# Versuch
#####

summary(lm(time ~ log.WHR + log.WHR2 + SUT + SUT2
           + NBMIN + DNA + DNA2 + IF + IF2  + FL + FL2
           + NST + NST2))
vif(lm(time ~ log.WHR + log.WHR2 + SUT + SUT2
       + NBMIN + DNA + DNA2 + IF + IF2  + FL + FL2
       + NST + NST2))
# 7 significant terms

summary(lm(time ~ SUT + SUT2 + DNA + DNA2 + IF + IF2
           + NST + NSS))
vif(lm(time ~ SUT + SUT2 + DNA + DNA2 + IF + IF2
       + NST + NSS))
# 9 significant

summary(lm(time~log.WHR+SUS+NBMIN+DNA+NSS+IF+NT))
vif(lm(time~log.WHR+SUS+NBMIN+DNA+NSS+IF+NT))

summary(lm(time~log.WHR+SUS+NBMIN+DNA+ DNA2 +IF+ IF2 ))
vif(lm(time~log.WHR+SUS+NBMIN+DNA+ DNA2 +IF+ IF2 ))

summary(lm(time~log.WHR+SUS+NBMIN+DNA+IF))
vif(lm(time~log.WHR+SUS+NBMIN+DNA+IF+ IF2 ))

summary(lm(time~NSS+NT+IF))

summary(lm(time ~ DNA + DNA2 + IF + IF2  + NST))
vif(lm(time ~ DNA + DNA2 + IF + IF2  + NST))

####
# test
####

pointsformula = function(d){
return(-0.105003 + 1.513129*d + (-0.013148-0.073788*d)*TRL
       + (1.467586+1.867131*d)*log.WHR
       + (4.449800-5.077132*d)*(log.WHR^2)
       + (-0.056037+0.235263*d)*NBMIN
       + (0.025074+0.011027*d)*PF
       + (-0.994217+1.017972*d)*IFLL)
}


test <- Aesthetics2[,c(6,7,14,12,28)]
num <- seq(1,375, by=5)
test2 <- Aesthetics2[,c(6,7,14,12,28)][num,]

pointsformula(0)
pointsformula(1)
simplepoints <- pointsformula(0)
hierarchicalpoints <- pointsformula(1)
simplepoints <- as.data.frame(simplepoints)[num,]
hierarchicalpoints <- as.data.frame(hierarchicalpoints)[num,]



pointsframe <- as.data.frame(matrix(Aesthetics2$points,
                                    ncol=5, byrow=TRUE))
realpoints <- apply(pointsframe, 1, mean, na.rm=TRUE)
realpointsmin <- apply(pointsframe, 1, min, na.rm=TRUE)
realpointsmax <- apply(pointsframe, 1, max, na.rm=TRUE)

fullnames <- Aesthetics2$chart[num]
names <- Aesthetics2$chart[num]
names[seq(2,75, by=2)] <- NA


mean(abs(c(simplepoints[1:25],hierarchicalpoints[26:75])
         -realpoints))
differencep <- as.data.frame(c(simplepoints[1:25],
                               hierarchicalpoints[26:75])
```

```
                              -realpoints)
differencep[2] <- fullnames

calculatedp <- as.data.frame(fullnames)
calculatedp[2] <- as.data.frame(c(simplepoints[1:25],
                                  hierarchicalpoints[26:75]))
calculatedp[3] <- realpoints
names(calculatedp) <- c("chart","calc.points",
                        "mean.real.points")
## select only 11 statecharts
calculatedp[seq(1,75,by=5),]
abs(calculatedp[2]-calculatedp[3])

mean(abs(calculatedp[2][seq(1,75,by=5),]
         -calculatedp[3][seq(1,75,by=5),]))
mean(abs(calculatedp[2][seq(1,75,by=5),]
         -calculatedp[3][seq(2,75,by=5),]))
mean(abs(calculatedp[2][seq(3,75,by=5),]
         -calculatedp[3][seq(3,75,by=5),]))
mean(abs(calculatedp[2][seq(1,75,by=5),]
         -calculatedp[3][seq(4,75,by=5),]))
mean(abs(calculatedp[2][seq(1,75,by=5),]
         -calculatedp[3][seq(5,75,by=5),]))



#par(mfrow=c(2,1))


pdf("appliance-formula-points.pdf", width=9, height=6)
par(mar=c(7, 5, 4, 2) + 0.1, lend=2)
plot(rep(0,75), ylim=c(-8,8), axes=FALSE, xlab="",
     ylab="difference to mean(points)", cex.lab=1, type="n")
axis(2, cex.axis=1)
axis(1, labels=names[seq(1,75,by=2)], at=seq(1,75,by=2),
     las=2, cex.axis=1)
points(realpointsmin-realpoints, type="h", col="lightgrey",
       lwd=10,lend=2)
points(realpointsmax-realpoints, type="h", col="lightgrey",
       lwd=10,lend=2)

points(c(simplepoints[1:25]-realpoints[1:25],
         hierarchicalpoints[26:75]-realpoints[26:75]),
       col="black", pch=20, type="h", lwd=3)
legend("topleft", c("spread of awarded points",
                    "calculated rating"), pch=c(NA,NA),
       lty=c(1,1), lwd=c(10,3),col = c("grey", "black") )
box()
dev.off()


# with charts ordered by the deviation
test <- as.data.frame(c(simplepoints[1:25]
                        -realpoints[1:25],
                        hierarchicalpoints[26:75]
                        -realpoints[26:75]))
names(test) <- "deviation"
test[,2] <- as.data.frame(fullnames)
test[,3] <- as.data.frame(realpointsmin-realpoints)
test[,4] <- as.data.frame(realpointsmax-realpoints)
test2 <- test[order(test[,1]),]

#pdf("appliance-formula-points.pdf", width=9, height=6)
par(mar=c(7, 5, 4, 2) + 0.1, lend=2)
plot(rep(0,75), ylim=c(-8,8), axes=FALSE, xlab="",
     ylab="difference to mean(points)", cex.lab=1, type="n")
axis(2, cex.axis=1)
axis(1, labels=test2[,2], at=1:75, las=2, cex.axis=1)
box()
points(test2[,3], type="h", col="lightgrey",lwd=10,lend=2)
points(test2[,4], type="h", col="lightgrey",lwd=10,lend=2)
points(test2[,1], col="black", pch=20, type="h", lwd=5)
lines(rep(0,75), ylim=c(-8,8), pch=20, lty=2, lwd=5)
legend("topleft", c("limits of actual awarded points",
                    "calculated rating"), pch=c(NA,20),
       lty=c(1,1), lwd=c(10,1),col = c("grey", "black") )
#dev.off()


pdf("appliance-formula-points-v2.pdf", width=9, height=6)
par(mar=c(7, 5, 4, 2) + 0.1, lend=2)
plot(rep(0,75), ylim=c(-8,8), axes=FALSE, xlab="",
     ylab="difference to mean(points)", cex.lab=1, type="n")
axis(2, cex.axis=1)
axis(1, labels=names[seq(1,75,by=2)], at=seq(1,75,by=2),
     las=2, cex.axis=1)
box()
points(realpointsmin-realpoints, type="h", col="lightgrey",
       lwd=20,lend=2)
points(realpointsmax-realpoints, type="h", col="lightgrey",
       lwd=20,lend=2)
points(c(simplepoints[1:25]-realpoints[1:25],
         hierarchicalpoints[26:75]-realpoints[26:75]),
       col="black", pch=20, type="o")
lines(rep(0,75), ylim=c(-8,8), pch=20, lty=2)
legend("bottomleft", c("limits of actual awarded points",
                       "calculated rating"), pch=c(NA,20),
       lty=c(2,1), lwd=c(10,1),col = c("grey", "black") )
dev.off()


distancepointssimple <- realpoints-simplepoints
distancepointshierarchical <- realpoints-hierarchicalpoints
maxdistancepoints <- realpointsmax-realpoints
mindistancepoints <- realpointsmin-realpoints

distancerealpoints <- maxdistancepoints
distancerealpoints <- as.data.frame(distancerealpoints)
distancerealpoints[2] <- abs(mindistancepoints)

absdist <- apply(distancerealpoints, 1, max)
```

```r
barplot(absdist)
barplot(c(abs(distancepointssimple[1:25]),
          abs(distancepointshierarchical[26:75])),
        ylim=c(0,10), names.arg=names, las = 2,
        axes=FALSE, add=TRUE, col="red")

#names.arg=Aesthetics2$chart[num]
plot(c(distancepointssimple[1:25],
       distancepointshierarchical[26:75]))
lines(maxdistancepoints, type="S")
lines(mindistancepoints, type="S")

barplot(c(distancepointssimple[1:25],
          distancepointshierarchical[26:75]))
lines(max(maxdistancepoints, mindistancepoints))



#############
# time
#############

timeformula = function(){
return(108.905526
       - 2.084012*DNA
       + 0.042023*(DNA^2)
       - 19.966945*IF
       + 2.011368*(IF^2)
       + 3.957036*NST)
}

timeformula2 = function(){
return(75.977574
       - 18.583526*log.WHR
       + 2.316132*SUS
       - 0.789542*NBMIN
       - 1.008281*DNA
       + 0.030332*(DNA^2)
       - 7.191888*IF
       + 1.272297*(IF^2))
}


#timeformula()
timeneeded <- timeformula()
timeneeded <- as.data.frame(timeneeded)[num,]

timeneeded2 <- timeformula2()
timeneeded2 <- as.data.frame(timeneeded2)[num,]

mean(abs(timeneeded-realtime))
mean(abs(timeneeded2-realtime))
timeframe <- as.data.frame(matrix(Aesthetics2$time,
                                  ncol=5, byrow=TRUE))


realtime <- apply(timeframe, 1, mean, na.rm=TRUE)
realtimemin <- apply(timeframe, 1, min, na.rm=TRUE)
realtimemax <- apply(timeframe, 1, max, na.rm=TRUE)



distancetime <- realtime-timeneeded
maxdistancetime <- realtimemax-realtime
mindistancetime <- realtimemin-realtime


pdf("appliance-formula-time.pdf", width=9, height=6)
par(mar=c(7, 5, 4, 2) + 0.1, lend=2)
plot(rep(0,75), ylim=c(-150,150), axes=FALSE, xlab="",
     ylab="difference to mean(time)", cex.lab=1, type="n")
axis(2, cex.axis=1)
axis(1, labels=names[seq(1,75,by=2)], at=seq(1,75,by=2),
     las=2, cex.axis=1)
points(realtimemin-realtime, type="h", col="lightgrey",
       lwd=10,lend=2)
points(realtimemax-realtime, type="h", col="lightgrey",
       lwd=10,lend=2)
points(timeneeded-realtime, col="black", pch=20, type="h",
       lwd=3)
legend("bottomleft", c("spread of needed time",
                       "calculated time"), pch=c(NA,NA),
       lty=c(1,1), lwd=c(10,3),col = c("grey", "black") )
box()
dev.off()

pdf("appliance-formula-time-v2.pdf", width=9, height=6)
par(mar=c(7, 5, 4, 2) + 0.1, lend=2)
plot(rep(0,75), ylim=c(-150,150), axes=FALSE, xlab="",
     ylab="difference to mean(time)", cex.lab=1, type="n")
axis(2, cex.axis=1)
axis(1, labels=names[seq(1,75,by=2)], at=seq(1,75,by=2),
     las=2, cex.axis=1)
points(realtimemin-realtime, type="h", col="lightgrey",
       lwd=20,lend=2)
points(realtimemax-realtime, type="h", col="lightgrey",
       lwd=20,lend=2)
points(timeneeded-realtime, col="black", pch=20, type="o")
lines(rep(0,75), ylim=c(-8,8), pch=20, lty=2)
legend("bottomleft", c("limits of actual needed time",
                       "calculated time"), pch=c(NA,20),
       lty=c(2,1), lwd=c(10,1),col = c("grey", "black") )
box()
dev.off()
```

```
#############
# Editing
#############

# detach aesthetics data frame
detach(Aesthetics2)

# read editing data frame
Editing <- read.csv("../data/editing2.csv", header=TRUE,
                    row.names=1)

Editing$tool <- as.factor(Editing$tool)
Editing$create.modify <- as.factor(Editing$create.modify)
Editing$beginner.advanced <-
  as.factor(Editing$beginner.advanced)
attach(Editing2)
Editing2 <- Editing[Editing$beginner.advanced==2,]
model <- lm(Editing2$time ~ Editing2$keypresses
            + Editing2$macrokeys + Editing2$mouseclicks
            + Editing2$mousedrags)
summary(model)
model.1 <- lm(Editing2$time[tool==1]
              ~ Editing2$keypresses[tool==1]
              + Editing2$macrokeys[tool==1]
              + Editing2$mouseclicks[tool==1]
              + Editing2$mousedrags[tool==1])
model.2 <- lm(Editing2$time[tool==2]
              ~ Editing2$keypresses[tool==2]
              + Editing2$macrokeys[tool==2]
              + Editing2$mouseclicks[tool==2]
              + Editing2$mousedrags[tool==2])
model.3 <- lm(Editing2$time[tool==3]
              ~ Editing2$keypresses[tool==3]
              + Editing2$macrokeys[tool==3]
              + Editing2$mouseclicks[tool==3]
              + Editing2$mousedrags[tool==3])
summary(model.1)
summary(model.2)
summary(model.3)

Editing2$total.actions <- (19.43+Editing2$keypresses*0.73
                           + 8.21*Editing2$macrokeys
                           + Editing2$mouseclicks*2.47
                           + 0.72*Editing2$mousedrags)
Editing2$total.actions2 <- round(Editing2$total.actions)


mean(Editing2$time[tool==1&Editing2$create.modify==1])
mean(Editing2$total.actions[tool==1&Editing2$create.modify==1])
mean(Editing2$time[tool==2&Editing2$create.modify==1])
mean(Editing2$total.actions[tool==2&Editing2$create.modify==1])
mean(Editing2$time[tool==3&Editing2$create.modify==1])
mean(Editing2$total.actions[tool==3&Editing2$create.modify==1])


Editing2$minimum.mouseclicks <- c(rep(39,19),rep(16,19),
                                  rep(32,19),rep(9,19),
                                  rep(11,19),rep(2,19))
Editing2$minimum.mousedrags <- c(rep(1,19),rep(3,19),
                                 rep(0,19),rep(0,19),
                                 rep(15,19),rep(4,19))
Editing2$minimum.keypresses <- c(rep(10,19),rep(3,19),
                                 rep(20,19),rep(6,19),
                                 rep(46,19),rep(22,19))
Editing2$minimum.macrokeys <- c(rep(0,19),rep(0,19),
                                rep(6,19),rep(3,19),
                                rep(0,19),rep(0,19))

Editing2$minimum.actions <- (19.43
                        +Editing2$minimum.keypresses*0.73
                        + 8.21*Editing2$minimum.macrokeys
                        + Editing2$minimum.mouseclicks*2.47
                        + 0.72*Editing2$minimum.mousedrags)



detach(Editing2)
attach(Editing2)

Editing2$total.erroractions[tool==1] <- (4.8575
                           +error.mouseclicks[tool==1]*2.47
                           + error.mousedrags[tool==1]*0.72
                           + error.keypresses[tool==1]*0.73
                           + error.macrokeys[tool==1]*8.21)
Editing2$total.erroractions[tool==2|tool==3] <-
  (6.476667+error.mouseclicks[tool==2|tool==3]*2.47
   + error.mousedrags[tool==2|tool==3]*0.72
   + error.keypresses[tool==2|tool==3]*0.73
   + error.macrokeys[tool==2|tool==3]*8.21)

Editing2$total.unnecessary[tool==1] <-
  (4.8575+unnecessary.mouseclicks[tool==1]*2.47
   + unnecessary.mousedrags[tool==1]*0.72
   + unnecessary.keypresses[tool==1]*0.73
   + unnecessary.macrokeys[tool==1]*8.21)
Editing2$total.unnecessary[tool==2|tool==3] <-
  (6.476667+unnecessary.mouseclicks[tool==2|tool==3]*2.47
   + unnecessary.mousedrags[tool==2|tool==3]*0.72
   + unnecessary.keypresses[tool==2|tool==3]*0.73
   + unnecessary.macrokeys[tool==2|tool==3]*8.21)

Editing2$total.nicefy[tool==1] <-
  (4.8575 + nicefy.mousedrags[tool==1]*0.72)
Editing2$total.nicefy[tool==2|tool==3] <-
  nicefy.mousedrags[tool==2|tool==3]*0.72
```

```
productive.actions2 <-
  (Editing2$total.actions - (Editing2$total.erroractions
                           + Editing2$total.unnecessary
                           + Editing2$total.nicefy))

Editing2$productive.actions[tool==1] <-
  (4.8575+productive.mouseclicks[tool==1]*2.47
   + productive.mousedrags[tool==1]*0.72
   + productive.keypresses[tool==1]*0.73
   + productive.macrokeys[tool==1]*8.21)
Editing2$productive.actions[tool==2|tool==3] <-
  (6.476667 +productive.mouseclicks[tool==2|tool==3]*2.47
   + productive.mousedrags[tool==2|tool==3]*0.72
   + productive.keypresses[tool==2|tool==3]*0.73
   + productive.macrokeys[tool==2|tool==3]*8.21)

# attach newly created columns
detach(Editing2)
attach(Editing2)

# pie charts
slices1 <- c(mean(Editing2$productive.actions[tool==1]),
             mean(Editing2$total.erroractions[tool==1]),
             mean(Editing2$total.unnecessary[tool==1]),
             mean(Editing2$total.nicefy[tool==1]))
slices2 <- c(mean(Editing2$productive.actions[tool==2]),
             mean(Editing2$total.erroractions[tool==2]),
             mean(Editing2$total.unnecessary[tool==2]),
             mean(Editing2$total.nicefy[tool==2]))
slices3 <- c(mean(Editing2$productive.actions[tool==3]),
             mean(Editing2$total.erroractions[tool==3]),
             mean(Editing2$total.unnecessary[tool==3]),
             mean(Editing2$total.nicefy[tool==3]))
# neccessary \n for newlines
lbls <- c("productive\nactions", "\nerror actions\n",
          "\n\nunnecessary\nactions", "  nicefy actions\n  ")
pct1 <- round(slices1/sum(slices1)*100)
pct2 <- round(slices2/sum(slices2)*100)
pct3 <- round(slices3/sum(slices3)*100)
lbls1 <- paste(lbls, pct1) # add percents to labels
lbls1 <- paste(lbls1,"%",sep="") # ad % to labels
lbls1[1] <- paste(lbls1[1],"\n\n",sep="") # ad % to labels
lbls2 <- paste(lbls, pct2) # add percents to labels
lbls2 <- paste(lbls2,"%",sep="") # ad % to labels
lbls2[1] <- paste(lbls2[1],"\n\n",sep="") # ad % to labels
lbls3 <- paste(lbls, pct3) # add percents to labels
lbls3 <- paste(lbls3,"%",sep="") # ad % to labels
lbls3[1] <- paste(lbls3[1],"\n\n",sep="") # ad % to labels
#pdf("actions-piecharts.pdf", width=7)
pie(slices1, labels = lbls1,cex=2, init.angle=310)
pie(slices2, labels = lbls2,cex=2, init.angle=310)
pie(slices3, labels = lbls3,cex=2, init.angle=310)
#dev.off()
library(plotrix)
# not so nice 3D-Piecharts
pie3D(slices1, labels = lbls1,explode=0.1,
      col=rainbow(length(lbls1)),
      main="percentage of action categories, tool 1")
pie3D(slices2, labels = lbls2,explode=0.1,
      col=rainbow(length(lbls2)),
      main="percentage of action categories, tool 2")
pie3D(slices3, labels = lbls3,explode=0.1,
      col=rainbow(length(lbls3)),
      main="percentage of action categories, tool 3")


mean(Editing2$productive.actions[tool==1])
#[1] 128.0074
mean(Editing2$productive.actions[tool==2])
#[1] 91.60026
mean(Editing2$productive.actions[tool==3])
#[1] 108.8661
mean(Editing2$total.actions[tool==1])
#[1] 188.9966
mean(Editing2$total.actions[tool==2])
#[1] 148.8826
mean(Editing2$total.actions[tool==3])
#[1] 139.8584
mean(time[tool==1])
#[1] 207.0526
mean(time[tool==2])
#[1] 173.2105
mean(time[tool==3])
#[1] 159.6579


Editing2$efficiency <- Editing2$productive.actions/Editing2$total.actions

efficiency1 <- mean(Editing2$productive.actions[tool==1])/
  mean(Editing2$total.actions[tool==1])
efficiency2 <- mean(Editing2$productive.actions[tool==2])/
  mean(Editing2$total.actions[tool==2])
efficiency3 <- mean(Editing2$productive.actions[tool==3])/
  mean(Editing2$total.actions[tool==3])

efficiency1
efficiency2
efficiency3

mean(round((Editing2$total.actions[tool==1]/
            Editing2$minimum.actions[tool==1]), 2)*100)
mean(round((Editing2$total.actions[tool==2]/
            Editing2$minimum.actions[tool==2]), 2)*100)
mean(round((Editing2$total.actions[tool==3]/
            Editing2$minimum.actions[tool==3]), 2)*100)


mean(round((Editing2$total.actions[tool==1]-
            Editing2$minimum.actions[tool==1])/
```

```
           Editing2$total.actions[tool==1], 2)*100)
mean(round((Editing2$total.actions[tool==2]-
            Editing2$minimum.actions[tool==2])/
           Editing2$total.actions[tool==2], 2)*100)
mean(round((Editing2$total.actions[tool==3]-
            Editing2$minimum.actions[tool==3])/
           Editing2$total.actions[tool==3], 2)*100)

pdf("boxplot-efficiency.pdf", width=7)
boxplot(Editing2$efficiency[tool==1],
        Editing2$efficiency[tool==2],
        Editing2$efficiency[tool==3],
        names=c("WYSIWYG","KIEL-macros","KIEL-KIT"),
        cex.lab=1.4, cex.axis=1.4)
dev.off()



# average amount of errors made
mean(Editing2$errors[tool==1])
#[1] 2.184211
mean(Editing2$errors[tool==2])
#[1] 1.552632
mean(Editing2$errors[tool==3])
#[1] 5.5

#average time between errors
sum(Editing2$time[tool==1])/sum(Editing2$errors[tool==1])
sum(Editing2$time[tool==2])/sum(Editing2$errors[tool==2])
sum(Editing2$time[tool==3])/sum(Editing2$errors[tool==3])


# sinnvoll? eher nicht.
mean(errors[tool==1]/Editing2$productive.actions[tool==1])
#[1] 0.0203794
mean(errors[tool==2]/Editing2$productive.actions[tool==2])
#[1] 0.01244871
mean(errors[tool==3]/Editing2$productive.actions[tool==3])
#[1] 0.05528222

mean(Editing2$total.erroractions[tool==1]/
     Editing2$productive.actions[tool==1])
#[1] 0.1150057
mean(Editing2$total.erroractions[tool==2]/
     Editing2$productive.actions[tool==2])
#[1] 0.09232886
mean(Editing2$total.erroractions[tool==3]/
     Editing2$productive.actions[tool==3])
#[1] 0.1408364

Editing2$total.erroractions[tool==1]/
  Editing2$errors[tool==1]
Editing2$total.erroractions[tool==2]/
  Editing2$errors[tool==2]
Editing2$total.erroractions[tool==3]/
  Editing2$errors[tool==3]

#Editing2$efficiency[Editing2$efficiency<0.4] <- NA

sum(Editing2$total.unnecessary[tool==1])/
  sum(Editing2$total.erroractions[tool==1])
sum(Editing2$total.unnecessary[tool==2])/
  sum(Editing2$total.erroractions[tool==2])
sum(Editing2$total.unnecessary[tool==3])/
  sum(Editing2$total.erroractions[tool==3])


mean(total.unnecessary[tool==1&create.modify==1])/
  mean(total.actions[tool==1&create.modify==1])
mean(total.unnecessary[tool==1&create.modify==2])/
  mean(total.actions[tool==1&create.modify==2])
mean(total.unnecessary[tool==2&create.modify==1])/
  mean(total.actions[tool==2&create.modify==1])
mean(total.unnecessary[tool==2&create.modify==2])/
  mean(total.actions[tool==2&create.modify==2])
mean(total.unnecessary[tool==3&create.modify==1])/
  mean(total.actions[tool==3&create.modify==1])
mean(total.unnecessary[tool==3&create.modify==2])/
  mean(total.actions[tool==3&create.modify==2])




################################
#      Ausgabe von Plots       #
#    Please use the Makefile   #
#(only acutely used plots here)#
################################



# draw scatterplots and histograms
pdf("dataset.pdf")

for (i in c(6:33)){
sp3points4(i)
sp3time4(i)
histnew2(i, Aesthetics2[i][Aesthetics2[2]==1],
         "Complexity: Simple")
histnew2(i, Aesthetics2[i][Aesthetics2[2]==2|
                           Aesthetics2[2]==3],
         "Complexity: Hierarchical and Parallel")
histnew2(i, Aesthetics2[,i], "Complexity: All")
}

dev.off()

pdf("dataset-only-advanced.pdf")
for (i in c(6:33)){
sp3points3(i)
sp3time3(i)
```

```
}
dev.off()


# draw an empty sheet
pdf("test.pdf")
plot(1:10, 1:10, type="n", axes=FALSE, xlab="", ylab="",
     frame.plot=FALSE)
dev.off()



# draw correlation matrices for complexity 1-3 and beginner-advanced
pdf("corrtable-c1e1.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==1&experiment==1),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c1e2.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==1&experiment==2),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c2e1.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==2&experiment==1),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c2e2.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==2&experiment==2),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c3e1.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==3&experiment==1),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c3e2.pdf", width=30, height=30)
pairs(Aesthetics[(complexity==3&experiment==2),
                 c(34:35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("corrtable-c1e2-points.pdf", width=30, height=30)
pairs(Aesthetics2[complexity==1,c(34, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c23e2-points.pdf", width=30, height=30)
pairs(Aesthetics2[(complexity==3|complexity==2),
                  c(34, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()
pdf("corrtable-c123e2-time.pdf", width=30, height=30)
pairs(Aesthetics2[,c(35, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("corrtable-c123e2-time-reduced.pdf", width=30,
    height=30)
pairs(Aesthetics2[,c(35, 6,7,9,14,18,24,27:30)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("corrtable-c123e2-points.pdf", width=30, height=30)
pairs(Aesthetics2[,c(34, 6:20, 24:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("corrtable-c123e2-points-reduced.pdf", width=30,
    height=30)
pairs(Aesthetics2[,c(34, 6,7,9,15,17,24,29,30)],
      lower.panel=panel.smooth, upper.panel=panel.cor)
dev.off()

pdf("corrtable-example.pdf")
pairs(Aesthetics2[,c(7,9,17)], lower.panel=panel.smooth,
      upper.panel=panel.cor)
dev.off()

pdf("corrtable-example2.pdf")
pairs(Aesthetics2[,c(6,15,30)], lower.panel=panel.smooth,
      upper.panel=panel.cor3)
dev.off()

corrgram(Aesthetics)

# correlations
cm11 <- cor(Aesthetics[complexity==1&experiment==1,6:35],
            use="pairwise.complete.obs")
symnum(cm11)
cm21 <- cor(Aesthetics[complexity==2&experiment==1,6:35],
            use="pairwise.complete.obs")
symnum(cm21)
cm31 <- cor(Aesthetics[complexity==3&experiment==1,6:35],
            use="pairwise.complete.obs")
symnum(cm31)
cm12 <- cor(Aesthetics[complexity==1&experiment==2,6:35],
            use="pairwise.complete.obs")
symnum(cm12)
cm22 <- cor(Aesthetics[complexity==2&experiment==2,6:35],
            use="pairwise.complete.obs")
symnum(cm22)
cm32 <- cor(Aesthetics[complexity==3&experiment==2,6:35],
            use="pairwise.complete.obs")
symnum(cm32)


highcorrelation(cm11)
```

```
highcorrelation(cm21)
highcorrelation(cm31)
highcorrelation(cm12)
highcorrelation(cm22)
highcorrelation(cm32)

# correlation tables with spearman method
pdf("corrtable-c1e2-points-spearman.pdf", width=30,
    height=30)
pairs(Aesthetics2[complexity==1,c(34, 6:33)],
      lower.panel=panel.smooth, upper.panel=panel.cor2)
dev.off()
pdf("corrtable-c23e2-points-spearman.pdf", width=30,
    height=30)
pairs(Aesthetics2[(complexity==3|complexity==2),
                  c(34, 6:33)], lower.panel=panel.smooth,
      upper.panel=panel.cor2)
dev.off()

pdf("corrtable-c123e2-time-spearman.pdf", width=30,
    height=30)
pairs(Aesthetics2[,c(35, 6:33)], lower.panel=panel.smooth,
      upper.panel=panel.cor2)
dev.off()


for (i in 6:33){
  cor <- cor.test(Aesthetics2[,i][complexity==1],
                  points[complexity==1], method="spearman")
  print(paste(names(Aesthetics2[i]), round(cor$estimate,4)))
}

for (i in 6:33){
  cor <- cor.test(Aesthetics2[,i][complexity==2|complexity==3],
                  points[complexity==2|complexity==3],
                  method="spearman")
  print(paste(names(Aesthetics2[i]), round(cor$estimate,4)))
}

for (i in 6:33){
  cor <- cor.test(Aesthetics2[,i], time, method="spearman")
  print(paste(names(Aesthetics2[i]), round(cor$estimate,4)))
}

###
# exemplary correlation tables for the significant metrics
###

pdf("corrtable-select-points1-spearman.pdf", width=9,
    height=9)
pairs(Aesthetics2[complexity==1,
                  c(34,6,37,10,12,14,17,28,30)],
      lower.panel=panel.smooth, upper.panel=panel.cor2)
dev.off()
```

```
pdf("corrtable-select-points23-spearman.pdf", width=9,
    height=9)
pairs(Aesthetics2[(complexity==3|complexity==2),
                  c(34,6,37,10,12,14,17,28,30 )],
      lower.panel=panel.smooth, upper.panel=panel.cor2)
dev.off()


pdf("corrtable-select-time-spearman.pdf", width=9,
    height=9)
pairs(Aesthetics2[,c(35, 37,8,14,18,21,24,30)],
      lower.panel=panel.smooth, upper.panel=panel.cor2)
dev.off()



###
# visualization of the correlation between label-label intersections and points[
     complexity==1]
scatterplot(points[complexity==1]~IFLL[complexity==1],
            ylab="points awarded, c1",
            xlab="# of label-label intersections",
            col=c("black","black","black"), cex.lab=1.9,
            cex.axis=1.9)


# on dummy-variable regression
jane <- read.table("jane.txt", header=TRUE)
y <- jane[,3]
x <- jane[,1]
color <- jane[,2]
out <- lm(y ~ x + color)
summary(out)
coef <- coefficients(out)
pdf("dummyregr-example.pdf")
plot(x, y, col = as.character(color),
     pch=rep(c(15,16,17), 50), cex.lab=1, cex.axis=1)
abline(coef["(Intercept)"] + coef["colorred"],
    coef["x"], col = "red")
abline(coef["(Intercept)"] + coef["colorgreen"],
    coef["x"], col = "green", lty=2)
abline(coef["(Intercept)"], coef["x"], col = "blue", lty=3)
legend("topleft", c("square", "circle", "triangle"),
       pch=c(15,16,17), col=c("red", "blue", "green"),
       inset = .025, cex=1.2, lty=c(1,2,3))
dev.off()
summary(out)

out <- lm(y ~ x + color + 0)
summary(out)
coef <- coefficients(out)
plot(x, y, col = as.character(color))
for (col in levels(color)) {
    k <- color == col
    predname <- paste("color", col, sep="")
    abline(coef[predname], coef["x"], col = col)
```

```
}


# dummy-variable regression with different slopes!
library(car)
data(Duncan)
attach(Duncan)

lm.out <- lm(prestige ~ education*type)

## Plot the data and regresssion surface for each occupation type
plot(Duncan$prestige[Duncan$type=="prof"]
     ~ Duncan$education[Duncan$type=="prof"],
     xlim=c(0,105), ylim=c(0,105), xlab="education",
     ylab="prestige")
points(Duncan$prestige[Duncan$type=="wc"]
       ~ Duncan$education[Duncan$type=="wc"],
       col="red")
points(Duncan$prestige[Duncan$type=="bc"]
       ~ Duncan$education[Duncan$type=="bc"],
       col="blue")

abline(lm.out$coef[1] + lm.out$coef[3], lm.out$coef[2] +
       lm.out$coef[5]) ## prof
abline(lm.out$coef[1]+lm.out$coef[4],
       lm.out$coef[2]+lm.out$coef[6],
       col="red", lty=3) ## wc
abline(lm.out$coef[1], lm.out$coef[2], col="blue") ## bc
```

```
# angewand auf TRL
lm.out <- lm(points~TRL*complexity2)
plot(TRL[complexity==1], points[complexity==1], col="green")
points(TRL[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="red")
abline(lm.out$coef[1] + lm.out$coef[3], lm.out$coef[2]
       + lm.out$coef[4], col="red")
abline(lm.out$coef[1], lm.out$coef[2], col="green")

lm.out <- lm(points~log.WHR*complexity2)
plot(log.WHR[complexity==1], points[complexity==1],
     col="green")
points(log.WHR[complexity==2|complexity==3],
       points[complexity==2|complexity==3], col="red")
abline(lm.out$coef[1] + lm.out$coef[3], lm.out$coef[2]
       + lm.out$coef[4], col="red")
abline(lm.out$coef[1], lm.out$coef[2], col="green")


# plot points vs. time

pdf("pointsVtime.pdf")
scatterplot(points, time, xlab="awarded points",
            ylab="time needed",
            col=c("black","black","black"),
            cex.axis=1.5, cex.lab=1.5)
dev.off()
```

F.2. Files written in JAVA

The following pages contain all java files that were used in the creation of this thesis.

F.2.1. XMLAnalyzer.java

F.2.2. XML.java

F.2.3. CSVWriter.java

F.2.4. SVGPathParser.java

F.2.5. SVGPathHandler.java

F.2.6. Sink3.java