Taming Graphical Modeling

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Abstract. Visual models help to understand complex systems. However, with the user interaction paradigms established today, activities such as creating, maintaining or browsing visual models can be very tedious. Valuable engineering time is wasted with archaic activities such as manual placement and routing of nodes and edges. This paper presents an approach to enhance productivity by focusing on the *pragmatics* of model-based design.
Our contribution is twofold: First, the concept of *meta layout* enables the synthesis of different diagrammatic views on graphical models. This modularly employs sophisticated layout algorithms, closing the gap between MDE and graph drawing theory. Second, a *view management* logic harnesses this auto-layout to present customized views on models.
These concepts have been implemented in the open source Kiel Integrated Environment for Layout Eclipse Rich Client (KIELER). Two applications—editing and simulation—illustrate how view management helps to increase developer productivity and tame model complexity.

1 Introduction

Simply put, the main task of a programmer is to command the computer to do the right thing. The programming mechanics of computers has undergone quite an evolution: From manually stamping programs on punch cards over non-reversible type writers to the main method still used today—text editor and keyboard. While different IDEs might offer various support levels for large software artifacts, the basic mechanics of writing or changing a line of code is rather standard and efficient. Hence, editing text has been established for many decades.

The introduction of graphical models has added the second dimension to one-dimensional text. However, this new freedom comes at a heavy price: We are back to the early times of mechanical typewriters with rather archaic user interactions. Graphical layout has to be manually defined by placing and routing of nodes and edges. Deleting graphical objects, like using white-out on a typewriter, creates new white-space that might not be large enough to insert new expressions, i. e. new graphical constructs. Manually creating more space in a complex diagram is like using scissors and glue. In fact, in large industrial projects it is not uncommon that highly-paid engineers use scissors and glue

to create large hand-crafted posters from print-outs to help navigate through complex models.

Graphical views on models are manually defined and hence static like a typewritten piece of paper. Creating multiple different views, e. g., for different levels of abstraction, onto the same model requires much manual editing work. Often one ends up working with one single abstraction level or changing syntax from graphical to structural to get more detailed or more abstract representations. Although abstraction might play an important role for MDE, so far, graphical aspects of models certainly do not. Instead of unfolding their potential as a vivid means of communication they remain no more than syntactic sugar. When trying to communicate with the computer through graphical models, the computer will not answer in the same language. For example, model transformations typically lose the graphical information and result in a model without a graphical view, which is like typing in text and getting a punch card as an answer. Even graphical means like graph grammars do not produce proper layouts for newly introduced items. If one believes that a diagram communicates the meaning of a model better than another representation, and if one wants this to be widely accepted by domain users that are not necessarily computer scientists, then one has to teach computers to truly master this language.

This paper presents an approach to bridge the gap between MDE and graph drawing theory to enable the automatic processing of graphical models and fundamentally enhance the user interaction mechanisms—also for rich diagram notations. After the related work in Sec. 2, Sec. 3 gives the required terminology and defines the focus of our approach—*pragmatics*. Sec. 4 introduces the central contributions: First, Sec. 4.1 explicates how *meta layout* enables the synthesis of different diagrammatic views on graphical models. Meta layout offers interfaces to plug in sophisticated layout algorithms and to utilize them according to higher-level optimization criteria. Second, Sec. 4.2 presents how *view management* logic employs this auto-layout to dynamically and interactively present custom views on models. Sec. 5 illustrates these concepts with the open source Kiel Integrated Environment for Layout Eclipse Rich Client (KIELER). Sec. 5.2 discusses two fields of application—model editing and simulation. Sec. 6 presents an experimental evaluation, the paper concludes in Sec. 7.

For a more detailed presentation than space permits here, we refer to another report [1] that includes a further discussion of the layout parametrization (Sec. 4.1) and structure-based editing (Sec. 5.2).

2 Related Work

This work is an interdisciplinary task and hence there is a large body of related work emerging from related communities.

The MDE community employs means of user experience enhancements orthogonal to ours [2]. There are multiple recent approaches on creating model-to-model transformations not by complex transformation languages, but *from examples* [3] or *by demonstration* [4]. It would be interesting to combine such

approaches with the structure-based editing framework presented in Sec. 5.2 to give the user very natural ways to define custom editing operations him- or herself. Also, transformation languages based on triple graph grammars [5] could augment structure-based editing by graphical views on the transformations themselves.

The field of *Human Centred Software Engineering* [6] also addresses usability and productivity. However, these approaches mainly focus on the question of how to make the best user experience with a given product. In contrast, we try to enhance the development process itself with novel tool support.

Another related community focuses on software visualization [7], which mainly presents what we call *effects* on graphical views (cf. Sec. 4.2). We also employ the notion of *focus & context* by Card et al. [8], see Sec. 5.2. Musiel and Jacobs [9] apply this technique to UML class diagrams, using notions of *level of detail* and a rudimentary specialized automatic layout algorithm. In our approach to view management we try to generalize such ideas by orchestration of software visualization concepts (effects) with the context (triggers) in which they should be applied to dynamically synthesize graphical views on models.

Automatic layout problems for arbitrary diagrams are often NP-complete, and diagram quality is difficult to measure [10]. However, the graph drawing theory community emerged with sophisticated algorithms that solve single layout problems efficiently with appealing results [11,12]. There exist open layout library projects with multiple sophisticated algorithms such as the Open Graph Drawing Framework (OGDF) [13], Graphviz [14] and Zest[1]. There are also commercial tools such as yFiles (yWorks GmbH) and ILOG JViews [15]. Demirezen et al. use automatic layout in Eclipse with the GraphViz tool as an example of reusing tools employing model transformations [16].

The KIEL project [17] evaluated the usage of automatic layout and structure-based editing in the context of *Statecharts*. It provided a platform for exploring layout alternatives and has been used for cognitive experiments evaluating established and novel modeling paradigms. However, it was rather limited in its scope and applicability, hence it has been succeeded by the KIELER project, which is the context of the work presented here.

3 Pragmatics

In linguistics the study of how the meaning of languages is constructed and understood is referred to as *semiotics*. It divides into the disciplines of syntax, semantics and pragmatics [18]. These categories can be applied both to natural as well as artificial languages, for programming or modeling. In the context of artificial languages, *syntax* is determined by formal rules defining expressions of the language and *semantics* determines the meaning of syntactic constructs [19]. "Linguistic *pragmatics* can, very roughly and rather broadly, be described as *the science of language use*" [20]. This also holds for MDE with its artificial

[1] `http://www.eclipse.org/gef/zest/`

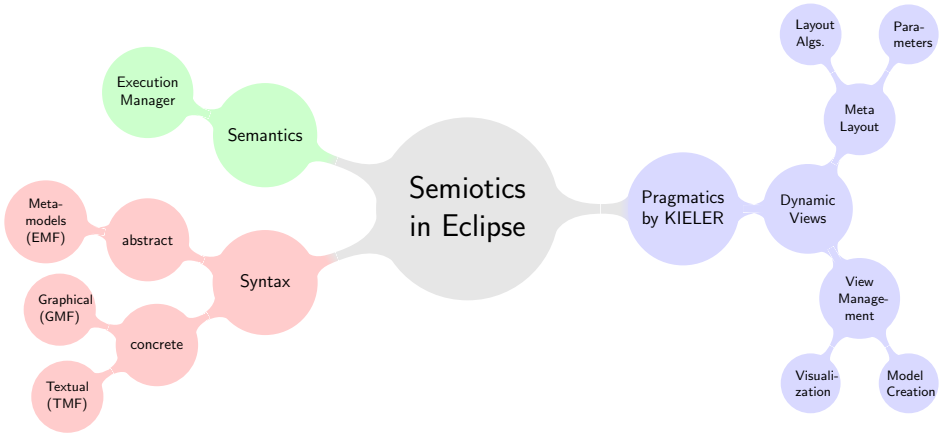


Fig. 1. KIELER! focuses on *pragmatics* and enhances the use of syntax and semantics of models which are defined by modeling platforms such as Eclipse

languages, as discussed in the following. However, first we clarify some more terminology specific to MDE according to the modeling linguists Atkinson and Kühne [21].

The main artifacts in MDE are *models* with two main concepts: A model *represents* some software artifact or real-world domain and *conforms* to a *metamodel*, defining its *abstract syntax*. Additionally, the *concrete syntax* is the concrete rendering of the abstract concepts. Concrete syntax can be textual or displayed in a structured way, for example a tree view. To be comprehensible, also a graphical syntax is very often used, the Unified Modeling Language (UML) is one example.

A *graphical model* is a model that *can* have a graphical representation, e. g., a UML class model. A *view* onto the model is a concrete drawing of the model, sometimes also *diagram* or *notation model*, e. g., a class diagram. The abstract structure of the model leaving all graphical information behind is the *semantical* or *domain model*, or just *model* in short. Hence, the *model* conforms to the abstract syntax, while the *view* conforms to the concrete syntax. A view can represent any subset of the model, which in some frameworks is used to break up complex models into multiple manageable views. Hence, there is no fixed one-to-one relationship between model and view.

State-of-the-practice approaches still lack generic answers on how to specify *semantics* [22], but handle *syntax* of models very well, both abstract and concrete. They provide code generators to easily provide model implementations, syntax parsers and textual and graphical editors with common features like the Eclipse Graphical Modeling Framework (GMF)[2].

[2] `http://www.eclipse.org/modeling/gmf/`

The third field of linguistics, *pragmatics*, traditionally refers to how elements of a language should be used, e. g., for what purposes a certain statement should be used, or under what circumstances a level of hierarchy should be introduced in a model. We slightly extend this traditional interpretation of pragmatics to all practical aspects of handling a model in its design process [23]. This includes practical design activities themselves such as editing and browsing of graphical models in order to construct, analyze and effectively communicate a model's meaning.

4 Taming Complex Models

The main problem with pragmatics in state-of-the-practice modeling IDEs is the widely accepted way of user interaction with diagrams: What-You-See-Is-What-You-Get (WYSIWYG) Drag-and-Drop (DND) editing. DND here encompasses all manual layout activities that a modeler has to perform, such as positioning—like dragging new objects from a palette or toolbar to the canvas—or setting sizes of graphical objects (nodes) or setting bend points of connections (edges). We do not distinguish whether such actions are real drag-and-drop operations with the mouse or are performed by keyboard, e.g. when moving objects around with arrow keys.

When working with graphical models, it is useful to have an immediate graphical feedback on editing operations, hence, WYSIWYG is not the problem. However, DND adds a lot of extra mechanical effort on editing diagrams. To quote a professional developer [24]: "I quite often spend an hour or two just moving boxes and wires around, with no change in functionality, to make it that much more comprehensible when I come back to it."

With such a standard editing paradigm one often ends up with exactly one static view for a subset of a model where the developer once has decided the abstraction level—e. g., level of detail or subset of displayed nodes. To get a different view requires to start the editing process all-over.

4.1 Meta Layout

The idea of *meta layout* is to synthesize views automatically, thus freeing the user to focus on the model itself. As discussed further in Sec. 4.2, this not only saves time formerly spent on manual drawing activities, but yields completely new possibilities for user interaction. The meta layout framework consists of two main parts: (1) A bridge between layout algorithm libraries and diagram editors and (2) parametrization possibilities to get the desired layout result of available algorithms, see also Fig. 2.

The layout bridge connects a range of layout algorithms with established graphical model diagram editors. Fig. 3, with a class diagram of the KGraph, shows an example layout/editor combination.

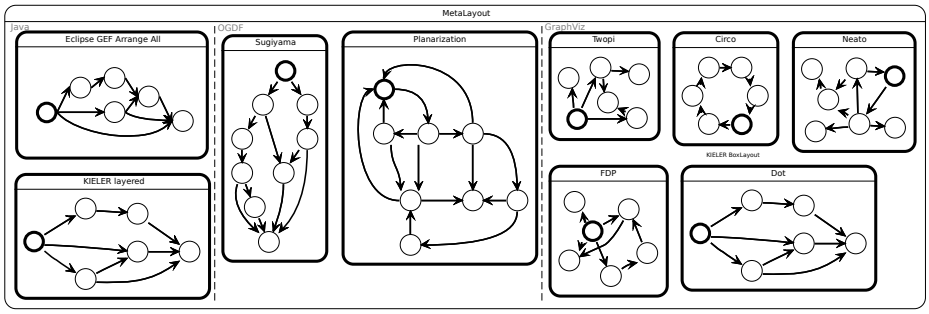


Fig. 2. Meta layout in KIELER: Employ different layout algorithms in one diagram.

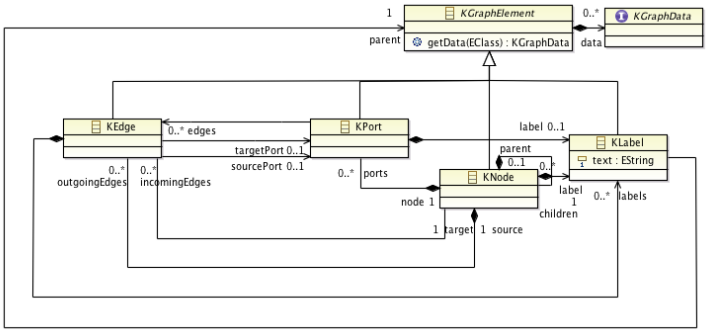


Fig. 3. The KGraph: An Ecore class diagram with mixed upward planarization.

As illustrated in Fig. 4, the meta layout framework contains a basic graph data structure, the *KGraph*, for exchanging data between a concrete diagram editor and a layout algorithm. To achieve genericity, this does not assume any specific format of either of the two worlds. Glue code that translates between used data structures in both domains allows to use any diagram editor with any layout algorithm. The KGraph is used as an intermediate format to (1) formulate the layout problem and to (2) store the layout result, i. e. the concrete coordinates and sizes. The KGraph follows the ideas of GraphML[3] but is simplified to the needs in this context.

Meta layout not only bridges between diagrams and layouters, it also tries to do this in a smart customizable way. It provides an extensible layout option system with priorities to specify which layouter types fit best to which diagram kinds. Parameters provided by the algorithms can be made available in the framework. Additionally, layouters get called recursively if the algorithms

[3] `http://graphml.graphdrawing.org/`

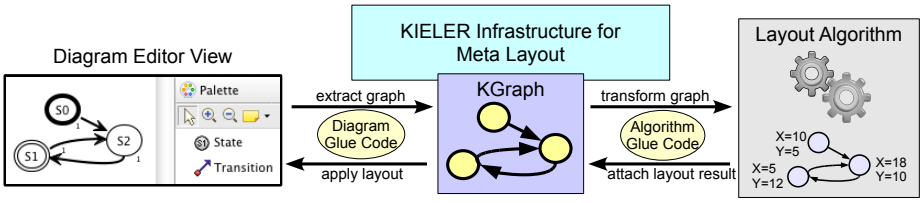


Fig. 4. Overview of the Kieler Infrastructure for Meta Layout (KIML).

themselves do not handle nested graphs. Furthermore, meta layout allows to use multiple different layout algorithms for different parts of one and the same view as shown in Fig. 2, which is well suited for nested models. More details on these features are given elsewhere [1].

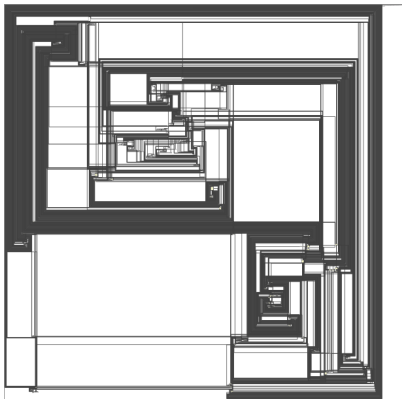
In summary, meta layout bundles a set of layout algorithms and matches them with concrete diagram syntaxes. It lets the user mix parameters and layouters to find the optimal layout result for custom model views.

However, there are limits of automatic layout of views when models become too complex. Consider for example the current UML2 Metamodel, which consists of 263 types with no nested structuring and thousands of relations and inheritances between the classes. This metamodel is available as an EMF Ecore model in the Eclipse Model Development Tools (MDT)[4], as a semantical model augmented with some very small manually placed views, but due to the model's complexity, there is no complete view available [25]. With meta layout, it is possible to synthesize such a view; Fig. 5a shows the layout generated by KIML using the Mixed-Upward-Planarization algorithm [26], which is optimized for class diagrams and respects the different types of edges. However, the result looks more like a VLSI integrated-circuit die and is hardly usable. Especially the numerous relations make the diagram unreadable. Standard navigation techniques like manual zooming and panning come to their limits; see also Fig. 5b. This limitation of plain layout application prompts the need for *view management*, discussed next.

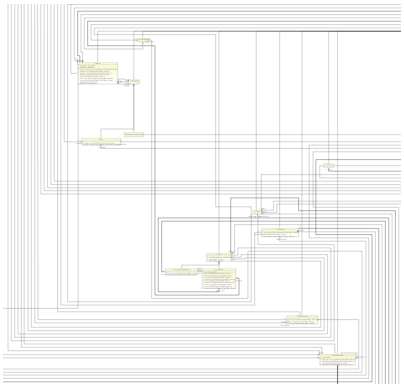
4.2 View Management

When models and their corresponding views become too complex, it is time for abstraction. *View management* is inter alia a means to automate the choice of right abstraction levels. For a given model, view management chooses the subset of the model that should be presented in a view. It decides the *level of detail* [9] for all graphical elements and adds other graphical effects to views. This automatic synthesis of views is only possible due to the automatic layout service offered by meta layout. Hence, in different words, meta layout provides model

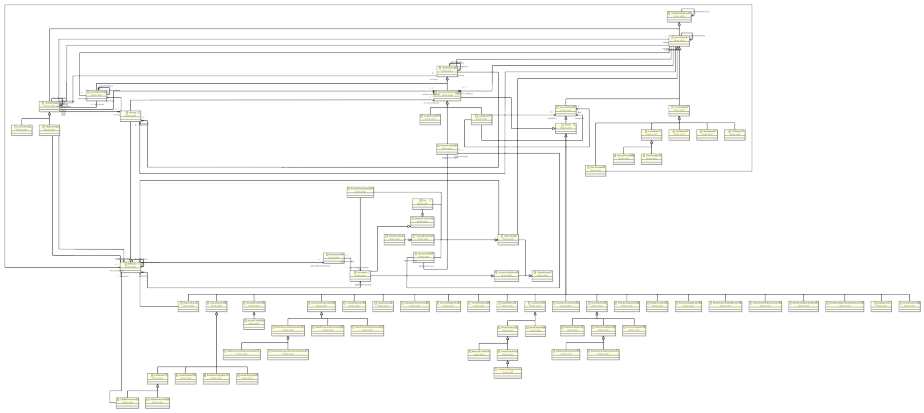
[4] `http://www.eclipse.org/modeling/mdt`



(a) Complete model.



(b) Cutout with 20x zoom.

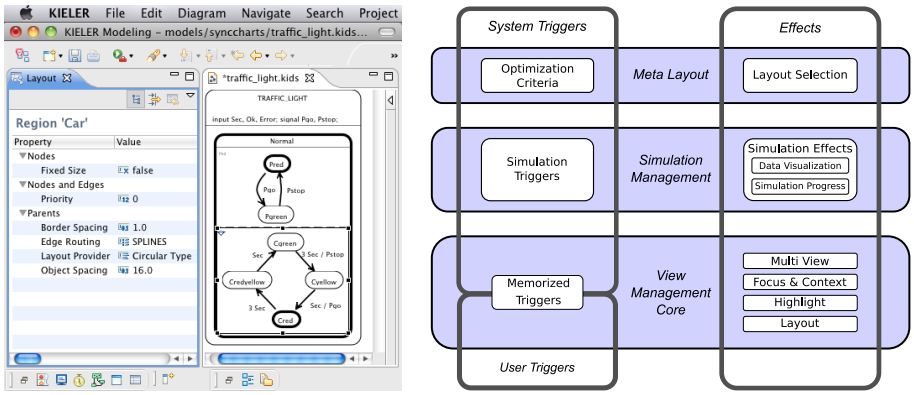


(c) A filtered view to the same model showing only Activity model parts.

Fig. 5. Class diagram of the UML 2.1 metamodel in Eclipse. Standard navigation techniques come to their limits. Views become unusable. Filtering in view management can synthesize a feasible view.

views as a service which view management uses. The idea of view management is to focus automatically to the parts of the model that are "currently interesting."

Obviously the context in which the user employs the model is important for this task. For example, to learn only about a smaller subset of the UML, e. g., Activity models, one may create a customized view on the UML metamodel that only contains elements immediately relevant to Activity models. Fig. 5c shows such a view that is again automatically synthesized with meta layout. However, this limited set of only 79 classes with much less edges presents a view that actually can be used very well to browse Activity models.



(a) KIELER specifying layout options. (b) Aspects of view management [23].

Fig. 6. Meta layout and view management.

To make view management context sensitive requires a generic architecture that allows to define conditions under which certain views shall be synthesized. View management listens to *triggers* or *events* under which certain graphical *effects* should be executed on the view. The orchestration of a set of triggers and effects forms a *view management scheme* (VMS), see also Fig. 6b. Triggers are categorized in user triggers—e. g., manual selection of elements—and system triggers—e. g., an event during a simulation run. Effects range from highlighting elements, configuring levels of details, filtering graphical objects to visualizing simulation data. An important effect uses the meta layout to rearrange the view that might have been changed by other effects like filters. As space here is limited, our following examples concentrate on the filtering mechanism. The next section presents an implementation of view management and discusses two applications.

5 Kiel Integrated Environment for Layout Eclipse Rich Client (KIELER)

The approaches presented in this paper are implemented and evaluated in the project KIELER, the Kiel Integrated Environment for Layout Eclipse Rich Client.[5] In the spirit of genericity, KIELER builds on the plug-in concept provided by Eclipse and especially its modeling projects.[6] As illustrated in Fig. 1, KIELER provides enhancements for pragmatics, to be combined with syntax and semantics defined by other projects.

[5] `http://www.informatik.uni-kiel.de/rtsys/kieler`
[6] `http://www.eclipse.org/modeling/`

5.1 Kieler Infrastructure for Meta Layout (KIML)

KIML uses the Eclipse Modeling Framework (EMF) to specify abstract syntax. For concrete syntax KIML supports graphical editors generated with the Graphical Editing Framework (GEF), a framework to implement graphical DSL editors. The Graphical Modeling Framework (GMF) is a generative approach to GEF editors that has a standard persistence handling of models and their views (the *notation model* in GMF terminology). KIML provides a generic implementation of the diagram glue code (Fig. 4) for GEF/GMF.

Hence, for most GMF editors KIELER's automatic layout can be used out-of-the-box. Optionally, the Eclipse extension point *layoutInfo* is used to specify default values for layout options, e. g., diagram types to setup default layout types. This has been done, for example, for the MDT/Papyrus UML suite [27]. For other concrete syntax frameworks based on GEF, like the Generic Eclipse Modeling System (GEMS)[7], Marama [28] or Graphiti[8], the glue code would have to be extended accordingly.

For layout algorithm integration KIELER provides the *layoutProvider* extension point. It is used to specify the layout options that the corresponding algorithm accepts and priorities for diagram types that it supports. The algorithm itself has to be implemented following a simple abstract class.

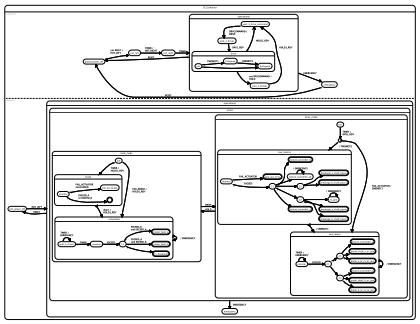
How rich a diagram notation may be is determined by the diagram editor and the supported features of the concrete layout algorithm. Currently it supports many rich notations like nesting, hyperedges, multiple edge types, unconnected boxes (e. g., orthogonal regions, swimlanes), port constraints, flow direction, which can be extended in order not to limit the concrete syntax of models and gets elaborated in [1]. It explicitly focuses not only on popular current Eclipse-based editors, but also on widely accepted notations like Matlab/Simulink or Labview.

5.2 Applications for View Management

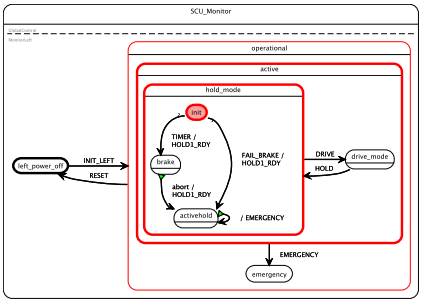
As an example, the following illustrates how view management in KIELER augments the editing and simulation of *SyncCharts* [29].

Simulation with Focus & Context One means to learn about the behavior of a SyncChart is to execute it stepwise while the simulation browser highlights active states. This paradigm is used by most state machine based tools like Matlab/Simulink/Stateflow or Rhapsody. The usual means for navigation are panning, zooming and opening different parts of the model in different windows or canvases. However, for complex models it becomes difficult and effort prone to manually navigate through a model. Figs. 7a/b demonstrate this with an avionics application [30].

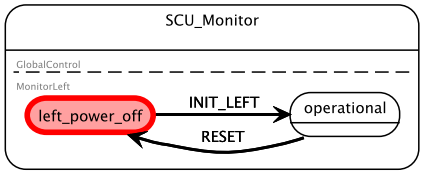
[7] `http://www.eclipse.org/gmt/gems/`
[8] `http://www.eclipse.org/modeling/gmp`



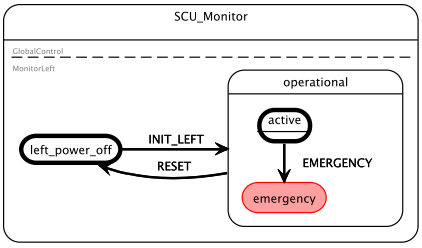
(a) The whole SyncCharts model.



(b) Even in deep hierarchy usually the full complexity of the model is hidden.



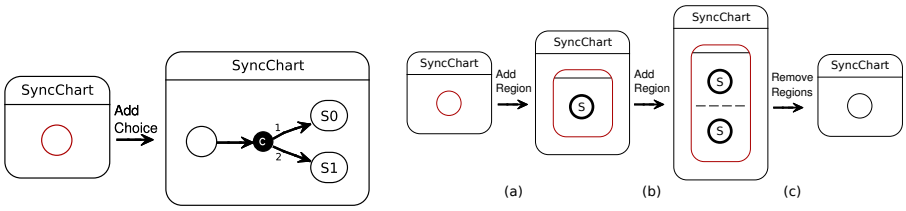
(c) Focus & Context (1): Starting a simulation collapses all inactive states and manually collapsed regions.



(d) Focus & Context (2): Advancing a simulation will always expand only active states with their full hierarchy.

Fig. 7. Focus & Context in a SyncChart

To alleviate this problem, the view management service can synthesize a new view on the model dynamically. The idea is to use *focus and context* methods to present only the "interesting" parts of the model [17]. For SyncCharts, a natural definition of "interesting" considers the currently *active* states, as illustrated in Figs. 7c/d. In KIELER, a specific trigger for the simulation notifies the view management about changes in state activity. A simple effect then highlights active states. An additional effect changes the level of detail at which the model objects get displayed in the view. In KIELER this is implemented by using GEF's methods to collapse or expand compartments, which comprise the contents of states and parallel regions. Afterwards view management uses KIML to rearrange all elements and zooms-to-fit to make best use of the given space. This unfolds the potentials of focus & context, as it presents all required details in the *focus* while still showing the direct neighbor inactive states collapsed with reduced detail level as the *context*. An animated morphing between the different views is provided to match the mental map of the user. For an impression of this, the reader is referred to example videos on-line (or the KIELER tool itself).



(a) Adding a choice construct.

(b) Adding a region to simple and a complex state, followed by removal of all regions.

Fig. 8. Example transformations for SyncCharts

Structure-Based Editing Another task in an MDE design process is to create or modify models. One approach to harness view management is to go back to textual editing. A textual editing framework like Xtext[9] can be enriched with graphical views synthesized on-the-fly to get full round-trip engineering.

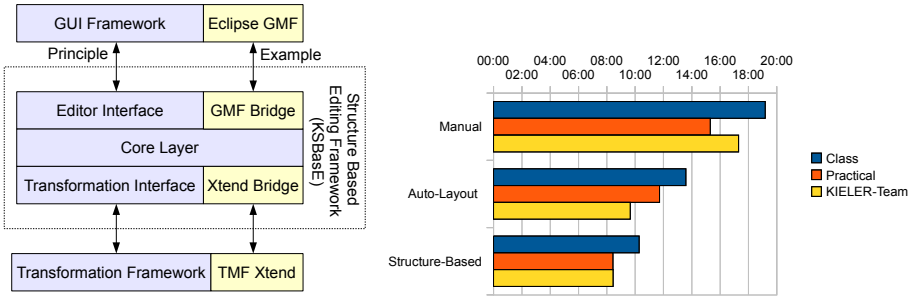
An alternative approach that stays in the graphical domain and keeps the direct visual feedback like WYSIWYG is *structure-based editing*. It employs model-to-model (M2M) transformations on the semantic model—its structure. It is an interactive approach where the user can work on the model view. The workflow for editing a model reduces to the following steps: (1) Focus a graphical model object for modification and (2) apply an editing transformation operation. View management with KIML applies the transformation, creates new graphical elements, and rearranges the resulting view.

The general implementation scope is shown in Fig. 9a. Again, to be generic, it allows any M2M transformation framework to be used with KIELER Structure-Based Editing (KSBasE). To integrate with the user interface, KIELER connects to the Eclipse Textual Modeling Framework (TMF) Xtend transformation system and all graphical GMF editors.

6 Evaluation

To assess the benefits of view management for model editing, we have conducted a study using KIELER. The hypothesis to be evaluated was that structure-based editing reduces the development times for creation and modification of graphical models significantly compared to usual WYSIWYG Drag-and-Drop (DND) editing. The 30 subjects divided into three different categories: The *class* group was familiar with the syntax of SyncCharts but not with modeling editors. The *practical* group took part in a practical course and had some experience already with Eclipse GMF editors. The last group comprised developers of the *KIELER team*, combining experiences with SyncCharts and the Eclipse SyncCharts editor.

[9] `http://www.eclipse.org/Xtext/`



(a) Scope of KSBasE (b) Evaluation of different editing methods.

Fig. 9. KIELER Structure-Based Editing (KSBasE)

The task was to create three different SyncCharts, using a different input method in random order for each: (1) standard Drag-and-Drop editing, (2) DND editing with manually triggered automatic layout and (3) structure-based editing as presented above. The models were provided in a comprehensible but formal textual notation. The experiment and its outcome are described in detail elsewhere [31], but Fig. 9b summarizes the results.

Editing with automatic layout decreased the necessary modeling times in average by nearly 33%. Full KSBasE reduced the times by another 15% compared to DND. From auto-layout to KSBasE the difference was mainly influenced by the earlier experience, e. g., how well keyboard shortcuts could be employed.

The SyncCharts in the tasks were of rather simple structure, and only creation was required, no modifications. Hence, only rather plain transformations in KSBasE were necessary to complete the tasks. More complex transformations might result in even greater speedups.

7 Conclusions

Visual models help to understand complex systems. However, with current interaction paradigms, activities such as creating or browsing visual models can be very tedious. We presented an approach on enhancing the *pragmatics* of model-based design—the way a user interacts with models. The concept of *meta layout* enables the dynamic synthesis of different diagrammatic views on graphical models. *View management* builds upon automatic layout to configure views on models given a certain context in which the model is examined. An experimental evaluation supports the claim that view management with auto-layout helps to tame complexity in graphical modeling.

Additional modeling languages under investigation are the UML and actor-oriented dataflow languages. Ongoing work is integration and development of more layout algorithms to support more specialized graphical syntaxes and to enhance the aesthetics of layout results. Optimal layout parameters should be

determined automatically by measuring aesthetics with metrics and evolutionary algorithms/machine learning. Another current goal is the adoption of a view management language for formulating view management use cases and to establish view management as a "first-class citizen" in modeling.

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