Posterizing Diagrams with Top-Down Layout

Maximilian Kasperowski[a] and Reinhard von Hanxleden[b]
Department of Computer Science, Kiel University, Kiel, Germany
{mka, rvh}@informatik.uni-kiel.de

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Abstract: Diagrams serve as a communication tool and automatic graph drawing enables the creation of diagramming tools that allow seamless graph modeling and visualization. These tools typically have the goal of optimizing the produced diagrams for computer screens, which support zooming in and out of diagrams and further interaction techniques. In this paper, we consider what automatic graph drawing needs to provide to produce diagrams suitable for printing instead, where we can no longer zoom and are restricted to a fixed area. We identify key differences in the requirements between printed static diagrams and interactive on-screen diagrams, including *layout speed* and *layout area*. Our goal is to automatically draw a complex diagram to be printed on a large poster, with maximal readability. We propose a collection of refinements to the well-established Sugiyama algorithm and illustrate our approach with a large SCChart that implements a railway controller.

1 INTRODUCTION

Automatic graph drawing describes the automatic creation of node-link diagrams from a graph. In practice this graph has typically been extracted from some kind of model. Modeling tools frequently use visualizations of models, and automatic graph drawing technology allows the creation of these visualizations on-the-fly during the modeling process (Lohstroh et al., 2021; Glaser and Bork, 2021; Kasperowski et al., 2024). While such tooling typically focuses on creating diagrams that work well on a zoomable computer screen, another use case are static diagrams. In industry, it is not uncommon to create "diagram walls" that spread out over multiple square meters. These walls typically consist of numerous printouts of system components represented by large nested graphs. For example, calibration engineers use such diagram walls to explore complex engine control software. Creating such diagram walls manually is a rather time-consuming process, which motivates the work presented here.

We investigate the requirements printed diagrams have of automatic graph drawing techniques and how they differ from diagrams primarily displayed on computer screens. We perform this analysis by exemplarily creating a large printable diagram using automatic graph drawing techniques. We utilize existing techniques to optimize space usage as well as apply new techniques that are not as important or applicable for computer screens.

The diagrams included in this paper were produced using the KIELER tooling (Kasperowski et al., 2024), which uses the Eclipse Layout Kernel (Domrös et al., 2023b) to perform automatic layout. The example used throughout this paper is an excerpt of a larger poster[1] created to demonstrate the techniques discussed in this paper.

A common method to draw large nested graphs is to use a divide-and-conquer approach and work bottom-up, i. e., one first creates layouts for the bottom-most elements of the graph hierarchy and then combines those to determine size requirements of the parents, which are then laid out in turn. E. g., in Fig. 1a the layout of the subgraph in Giraffe determines the final size of the node. This is a recursive procedure terminating at the graph root.

Such bottom-up layouts produce drawings where low-level elements and labels are drawn at a uniform scale, however, for large graphs this method leads to large and hard-to-read graphs with no good overview over any given hierarchy level. This is why we instead propose to use a top-down procedure where node sizes are restricted and fixed by higher-level nodes (Kasperowski and von Hanxleden, 2023). Sublayouts are scaled down to fit within their parents. A

[a] https://orcid.org/0000-0002-7509-1678
[b] https://orcid.org/0000-0001-5691-1215

[1] https://rtsys.informatik.uni-kiel.de/~biblio/downloads/papers/ivapp25-showpiece.pdf

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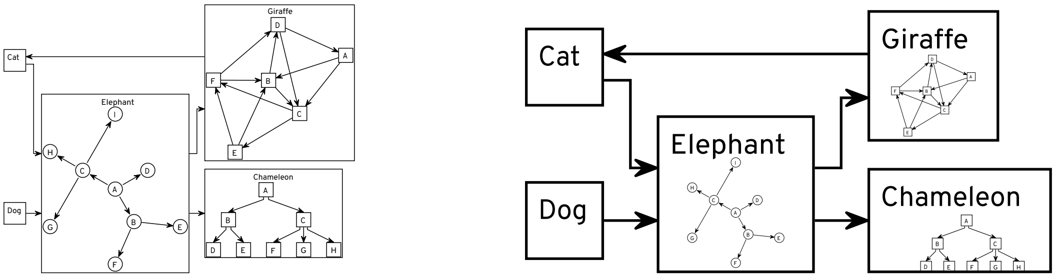

(a) Bottom-up layout.

(b) Top-down layout.

Figure 1: This simple example highlights the difference between bottom-up and top-down layout. In the bottom-up case, the children define the sizes of the parents, while in the top-down case the parents restrict the space available to their children.

comparison of the bottom-up and top-down procedure is shown in Fig. 1.

Top-down layout itself, while creating helpful overviews and structure in the drawings, also adds whitespace through its scaling. This can be seen in the nodes in Fig. 1b. This additional whitespace must be kept to a minimum for top-down layout to produce useful results. Essentially this translates to the requirement that layouts must use their provided space effectively.

This can be rephrased as stating that we want to create a good layout for a prescribed drawing area, which is itself a topic that has previously been studied extensively (Rüegg, 2018). We compare the requirements of printed diagrams with those of diagrams used on computer screens with respect to *layout speed* and *layout area*. The general layout techniques we cover in this paper are *graph wrapping*, *layer splitting*, and *label management*.

1.1 Contributions and Outline

Sec. 2 presents related work. In Sec. 3 we discuss how we apply graph drawing techniques to the problem of producing printable diagrams using existing methods as well as the following new approaches:

- We introduce the concept of *layer splitting* as a pendant to graph wrapping for producing layouts closer to a *desired aspect ratio*.
- We extend *semantic soft wrapping* with *fuzziness* to produce aesthetically pleasing and space-efficient labels.
- We propose *adaptive font sizes* to improve readability in large drawings containing many small elements.

We discuss our results and how the techniques covered in this paper help to produce a readable diagram in Sec. 4. Finally, Sec. 5 concludes this paper.

2 RELATED WORK

At first glance the task of creating a single diagram for a poster poses the question: Do we need automatic graph drawing or is a manual layout potentially better? We argue that the main advantage of a manual layout, *control*, is greatly outweighed by the many advantages of automatic layout. While users often have a very strong desire for control, manually positioning and repositioning many graph elements becomes very tedious (Petre, 1995). Automatic layout on the other provides us with consistency, we can easily adjust parameters that affect the entire diagram, and rapid prototyping is possible. Furthermore, using model order to control the automatic layout actually provides us with a large degree of control over the positioning of elements in the diagram (Domrös et al., 2023a).

To achieve minimize whitespace we apply the concept of *prescribed drawing areas* or *area-adaptive graph drawings*. In our case we are interested in techniques for layered graph drawings (Rüegg, 2018), but the problem has also been studied for other types of graph drawings such as tree drawings (Misue, 2024).

When creating large diagrams that are viewed on computer screens there are dynamic *focus and context* visualization techniques that can be used to aid with viewing large diagrams. *Fisheye* techniques encompass methods of distorting the view or the graph to highlight certain portions of the diagram (Sarkar and Brown, 1992; Formella and Keller, 1996; Tominski et al., 2006). This effect is restricted to one area of interest that is brought into focus. We could apply such an effect selectively to portions of our diagram poster, but we want to create a static view of the entire diagram to let observers explore it.

Another technique commonly used to make large diagrams readable when zoomed out is *semantic zooming*, which replaces details of the diagram with readable abstract views (Frisch et al., 2008; De Carlo et al., 2022). The detailed views are shown as the view is zoomed in. We cannot dynamically switch elements of a printed diagram, but we do want to enable observers to *zoom in* by standing closer to the poster. Therefore, we also need graphic elements that are readable from a distance and detailed elements that only become readable upon stepping closer.

3 POSTERIZING DIAGRAMS

Diagrams as a communication medium are often found printed on posters of varying sizes. For this paper we considered the challenges of automatic graph drawing specifically for the use case of producing an aesthetic and readable diagram for print. For this application we used SCCharts (von Hanxleden et al., 2014), which is a statechart (Harel, 1987) dialect and have an automatic visualization provided by the KIELER tool. Because SCCharts can be hierarchical, we can utilize top-down layout (Kasperowski and von Hanxleden, 2023) to produce drawings that provide good overviews, i. e., views of the diagram where graph elements that have relations to one another are readable and their relationships clear.

As an example for this problem we looked at a part of a model railway controller created as a student project. We chose to use only an excerpt of this rather large controller to create something that is interesting and can still be reasonably printed within a paper. The result can be seen in Fig. 2. Fig. 3 shows the same SCChart but laid out using a bottom-up procedure.

3.1 Requirements of Printed Diagrams

In this paper we are concerned with the problem of creating a diagram suitable for printing on a large poster. This use case differs from the viewing of diagrams on computer screens, and we therefore need to consider what the requirements are. The following are the core goals of large printed diagrams.

The most important elements must be clearly visible and recognizable by an observer standing in front of the poster. Further details may be smaller such that they can be read by stepping closer to the poster. Anything smaller than that can no longer be read.

A poster provides us with a larger base area than a computer screen. This means we can draw larger boxes with relatively smaller labels and still have them readable. We cannot, however, zoom in as we could on a computer. Therefore, it is important that we fill the space that we have available effectively and try to reduce the amount of elements and labels that are printed so small that they can no longer be discerned easily. With a poster we have a bit of leeway since we can move away from the poster and move closer to it to examine details, but the overall range of viable scale levels is limited.

A poster is also a communication medium. The diagram that we draw on it should be helpful and understandable. We want to clearly show "interesting" elements and relations and filter out or reduce unwanted clutter or redundant information. This will further help us in highlighting interesting features. Note that these interesting elements are domain-dependent and therefore vary between modeling languages and models.

3.2 Top-Down Layout Configuration

Using top-down layout requires setting a desired diagram size as a constraint. In our scenario these constraints are provided by the poster size.

The constraint we provide for a layout of a node is the *fixed size* of the node. This precisely defines how much space is available to the children of the node, i. e., the to-be-drawn graph, e. g., the size available to the subgraph in the Giraffe node in Fig. 1b. If the provided space is exceeded by the graph drawing procedure, a scaling is applied to fit the drawing into the prescribed area. This way top-down layout provides us with a simple mechanism to control the size elements should be drawn at.

Dynamically estimating suitable sizes is in itself a challenging problem and remains a topic for future work, however, we can manually adjust the size control to achieve an aesthetic result. For the example in Fig. 2 we set the size of the main state to roughly match the page dimensions and all other nodes were set to a size of approximately 650 px by 400 px.

There are many ways to configure layout options that affect the resulting aspect ratio of the drawing in hard-to-predict ways. A key importance in using automatic graph drawing for generating interactive diagrams is that the algorithms must be fast. In the printed case the speed of the layout computation is of secondary importance. For a given diagram to be printed it can be worthwhile to explore different layout options to determine the optimal set of layout options for a given input graph. For this we determined a small set of layout options that would have a strong effect on the area of the drawing and generated drawings for all permutations of these options.

The layout options we searched optimal settings for were the *layout direction* (down or right) and the *layer splitting*3 (see Sec. 3.3) strategy (no split or 2-layer-split). These two options have a large impact on the resulting aspect ratio of a drawing, but their effect is difficult to predict. Finally, we use the op-

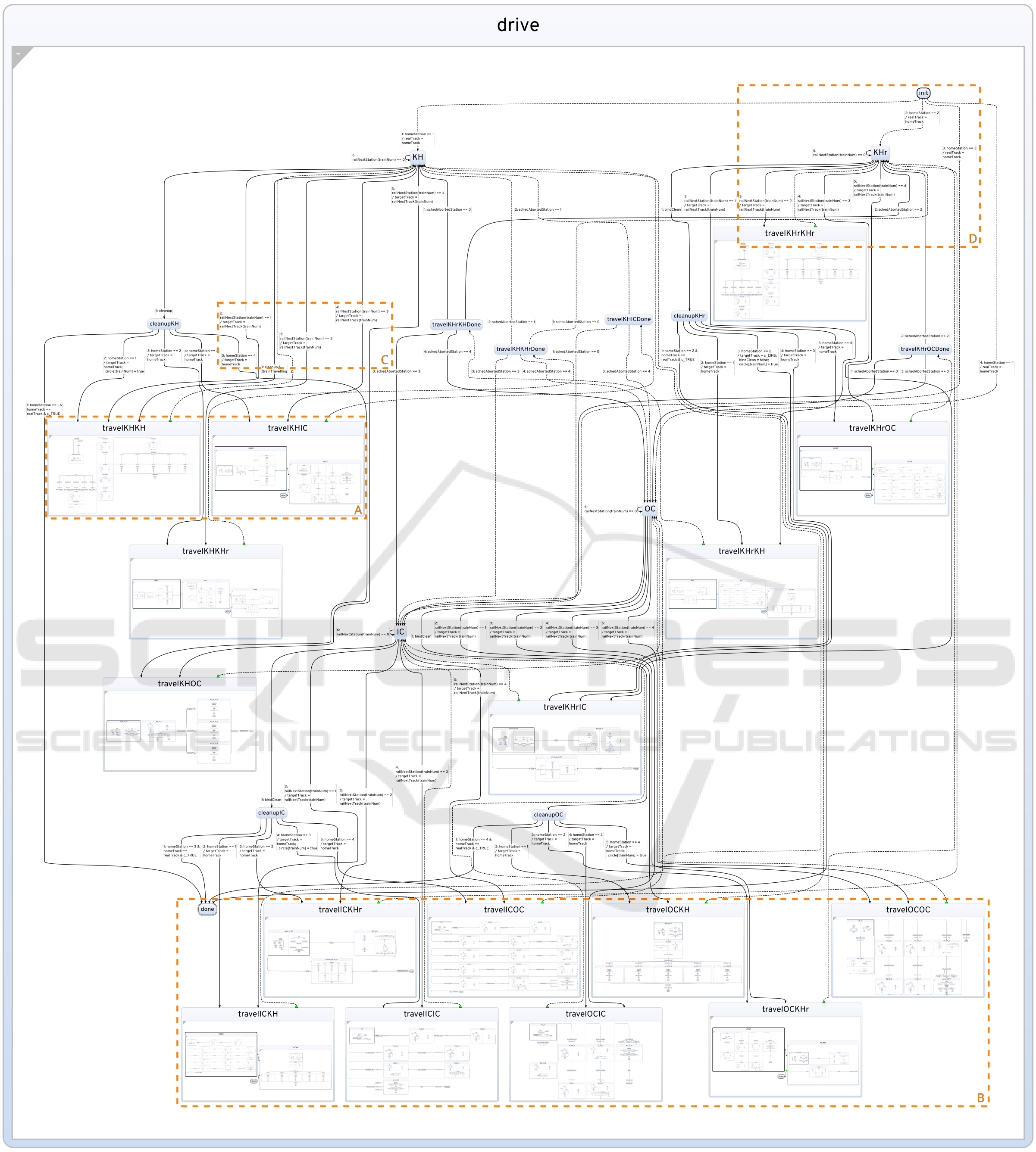

Figure 2: The drive SCChart laid out using top-down layout to neatly fit on a page or more suitably on a poster. This example demonstrates all the layout tools that are explained in the following sections. The model itself stems from a student project and is an excerpt from a larger model that controls a model railway. This drive state controls the behaviour of an individual train. There are several highlighted excerpts that are shown and discussed in later sections. Excerpt A highlights *graph wrapping* and is shown in Fig. 4. Excerpt B highlights *layer splitting* and is shown in Fig. 5. Excerpt C highlights *fuzzy soft wrapping* and is shown in Fig. 6. Excerpt D highlights *adaptive fonts* and is shown in Fig. 7.

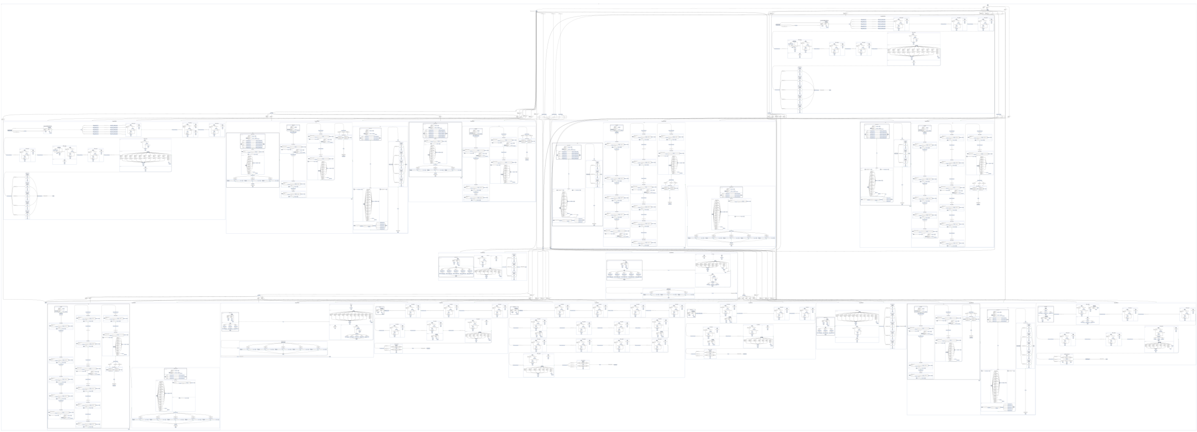

Figure 3: The drive SCChart laid out using bottom-up layout. The adaptive fonts feature is also enabled in this version. Despite this the diagram remains wholly unreadable as it would require a space of nearly fourteen meters by five meters to print fonts at their default size of 11 pt. At the current scale none of the labels are readable. Some used tools such as graph wrapping and adaptive fonts do technically help a bit, but it should be clear that this is a diagram that is too large to draw in the bottom-up manner and still produce good results. We also lose the ability to exercise direct control over the size of the root node, which in this case leads to a wide diagram that cannot effectively use the available page area.

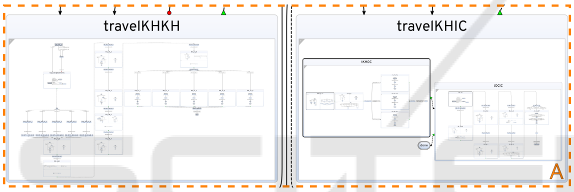

Figure 4: This state is an excerpt of Fig. 2 showing how wrapping fits long graphs into restricted spaces.

tion settings that result in an aspect ratio closest to the prescribed area's aspect ratio as it leads to minimal scaling in top-down layout. The *scale measure* introduced by Rüegg expresses this property (Rüegg, 2018).

3.3 Whitespace Management

In this section we discuss techniques to reduce the whitespace in a layered graph drawing. The topic of prescribed drawing areas for layered graph drawings has previously been studied by Rüegg and in particular the concept of *graph wrapping* is a helpful approach to control and restrict the aspect ratio required by graphs with many layers (Rüegg and von Hanxleden, 2018; Rüegg, 2018).

We utilize graph wrapping to effectively fill the space provided by our fixed sizes in situations where the drawing would normally become very long and thin. Fig. 4 demonstrates how wrapping was used for our example. One wrapped graph is contained in the travelKHKH state, and one wrapped graph is contained in the right child state of the travelKHIC state.

We propose *layer splitting* as a post-processor after the layer assignment step of the Sugiyama Algorithm (Sugiyama et al., 1981). Layer splitting addresses a problem that is orthogonal to the graph wrapping approach. While graph wrapping helps to reduce the effect of long layouts, layer splitting improves bad aspect ratios of high (in a left-to-right layout direction) layouts. The rotated case (top-to-bottom layout direction) is demonstrated in Fig. 5. Here, the travel... states are partitioned into rows.

Instead of having many thin layers as in graph wrapping, we have few layers that are very fat, i.e., they have many nodes next to each other. To decrease the width of the layer we can split up the nodes of a layer into two or more layers. In our situation with top-down layout the nodes are all of similar sizes and therefore simply staggering the nodes in a brick-like layout is sufficient to achieve a compact result.

3.4 Control and Model Order

Our use case of creating a large printed poster of a specific diagram means that we want to be able to exercise fine control over the layout of certain portions of the diagram. The diagram is merely a visualization of an underlying textual model (Kasperowski et al., 2024). The textual order in this model, i.e., the order the states are defined in, is used to infer the model order and to guide decisions during the automatic layout of the graph (Domrös et al., 2023a).

This allows us to easily adjust and control what the diagram looks like by modifying the textual model rather than being forced to fiddle with the layout al-

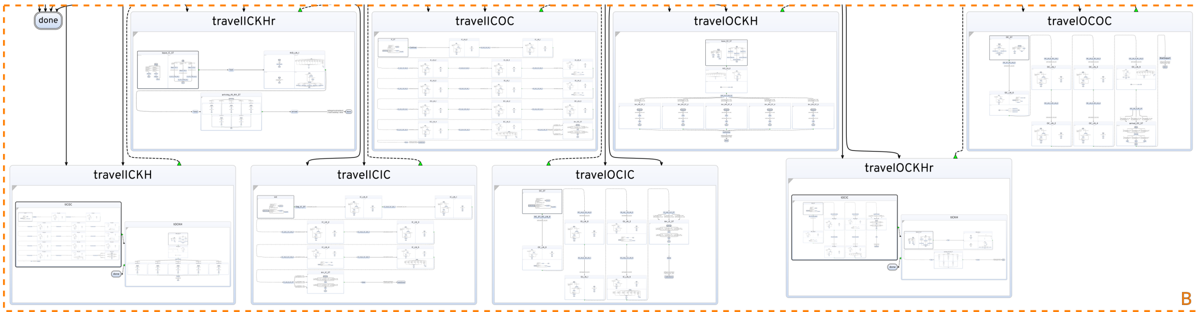

Figure 5: This state is an excerpt of Fig. 2 where layer splitting was used to decrease the width of the final layer in the main layout. This ensures that the diagram does not become too wide for the restricted page space.

gorithms themselves. This fine-granular control over the layout is invaluable when tweaking a diagram to achieve the desired appearance. Moreover, model order shows the underlying structure of a textual model even though the diagram may be cluttered. It also helps us retain stability, i. e., the general structure of diagram does not change between versions.

3.5 Label Management

In this section we discuss label management techniques that create aesthetic and space-efficient labels.

Fuzzy Label Wrapping. In realistic models there are typically many labels that also tend to be long. Labels in general and edge labels in particular can have a large effect on the overall size requirements of a graph drawing. This effect compounds in diagrams of large models and good label management is required to reduce the amount of whitespace that is introduced.

Schulze has previously studied how to perform label management for layered graph drawings (Schulze, 2019). In particular the method of *semantic soft wrapping* is of interest to us because it allows us to reduce the width and use the available vertical space. In *soft wrapping* long labels are split into multiple lines based on a maximum line length. The line break is performed on space between words if the cutoff length has been reached. Semantic soft wrapping extends this by adding additional linebreaks at semantically suitable positions. For SCCharts these are for example the slashes in the transition labels as they serve as visual separator between the trigger and action of the transition.

There are situations in which the hard linewrap cutoff creates awkward empty spaces in parts of the wrapped label. We improve the label wrapping by adding a *fuzzy cutoff* that permits a line to exceed its line length limit if the next line would be underfilled. A line is underfilled if it only covers a defined percentage of the available line space. This enhancement further compacts labels and also produces more aesthetic results. Long and mostly empty lines are greatly reduced when adding a fuzzy cutoff. In Fig. 2 a fuzzy cutoff of 30 percent is used.

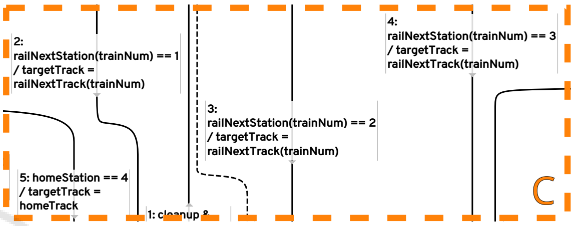

Figure 6: The edge labels in this excerpt of Fig. 2 demonstrate the result of semantic fuzzy soft wrapping.

Fig. 6 shows this in action. Soft wrapping would usually result in the segments of the form: == x, where x is some short string or number, to be placed in a new line. We instead keep these short label fragments on the previous line, which reduces the overall area occupied by the label.

Adaptive Font Sizes. When using top-down layout there can be significant scale differences between neighbouring nodes due to the contained subgraphs differing strongly in their complexity, as shown in Fig. 2. This makes larger layouts with more nodes and therefore stronger downscaling harder to read. Top-down layout is intended to maintain the overview. Situations such as this undermine the efficacy at providing readable overviews. To alleviate this problem, we introduce *adaptive font sizes* for labels, as shown in Fig. 7. The font sizes of the state labels have been increased to make them more readable, while the edge labels remain unchanged. This is a decision based on the notion that the states themselves act as landmarks and are important to obtain an overview, whereas the edge labels are details that are more relevant upon closer inspection. It is therefore a decision based on

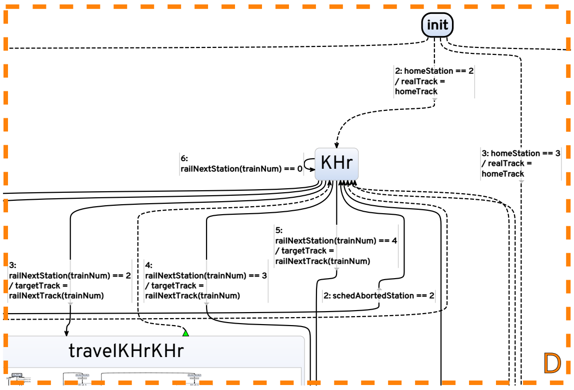

Figure 7: This excerpt of Fig. 2 demonstrates adaptive fonts.

domain knowledge for SCCharts models.

Adaptive font sizes are set automatically depending on the number of nodes in a layout. The most important elements to retain an overview over a local subdiagram are the labels of the elements. In large layouts (due to many nodes being present) the labels become small and more difficult to read. We increase the font sizes of these labels by a factor that scales linearly in the number of nodes of the layout.

In SCCharts we differentiate between simple states and macro states. Macro states contain inner behaviour and therefore these nodes often have children. Because these nodes are larger and more important, we scale their fonts up at twice the rate compared to the simple states. In Fig. 7 the init state is a simple state and its font is slightly smaller than the fonts of the two macro states in the image.

4 DISCUSSION

We have highlighted the key goal of *readability* and in summary our tools achieve this using two things. Firstly, we purposefully use size and scale to make graph elements more visible if they are important. Secondly, we exercise control over the layout to minimize whitespace. This interacts with the scaling as additional whitespace in a fixed space decreases the available space for displaying interesting things. Whitespace minimization leads to efficient utilization of the prescribed drawing area, which in turn leads less downscaling being necessary, and therefore increasing the readability of the diagram.

We identified labels in graphs to be key elements as they are readable features that provide context and detailed information about the graph elements they are attached to. Understanding a labelled graph requires being able to read the labels. Labels also have a large impact on the layout of a graph. We hence put a lot of focus on the readability of labels and on the control and display of labels.

It is evident that drawing large labelled graphs readably in their entirety is a difficult undertaking. Performing a bottom-up layout of a large graph, as seen in Fig. 3, imposes an upper limit on the graph size after which the diagrams inevitably become unreadable. Dynamic visualizations and filtering out portions of the diagrams are always viable techniques, but they are compromises as they hide or distort information. Top-down layout on the other hand aims to show the entire graph structure in a readable form. Additionally, when viewing a top-down layout on a computer screen, zooming allows the total exploration of a graph in what we would argue is an easier manner than panning and zooming in a bottom-up layout.

So far, we have only looked at node-link diagrams that are drawn using a layered approach. Some ideas transfer well to other types of graph drawing problems or other types of diagrams and others are more restricted in their general applicability. Layered graph wrapping and layer splitting are very specific strategies for optimizing the area occupied by layered layouts, but in general they are techniques to fill prescribed areas, which reduces whitespace. Whitespace minimization is a general goal in many graph drawing applications. The notion of model order to control the topology of a diagram is also more broadly applicable as long as there is an inherent ordering in the underlying model and a graph drawing algorithm that is able to leverage that ordering. Both fuzzy label wrapping and adaptive font sizes are label management tools that can be applied to any type of labelled graph.

We focused on an application where the graph comes from a model made by a developer, and we had the goal of producing a diagram that can be printed on a poster in a readable way. There are of course many other types of diagrams and graphs from a wide range of domains. In particular, graphs from the area of data visualization may come with unique challenges and requirements that are not captured by our example, because they are not manually modelled. We think the ideas presented in this paper are nonetheless helpful and can be partially applied to other applications.

5 CONCLUSION AND OUTLOOK

We showed how top-down layout can be used to produce diagrams of large models that are easier to read at a high-level than corresponding diagrams drawn using a bottom-up approach. In particular, bottom-up layouts do not allow us to easily exercise control over the total area required by a layout, and for large diagrams we obtain large and hard-to-read drawings where details and high-level elements blend together. This makes it quite unsuitable for producing large printable diagrams, whereas top-down layout can produce promising aesthetic results. We applied layered graph wrapping and semantic soft wrapping for labels for drawing graphs in prescribed areas. In addition, we introduced layer splitting, fuzzy soft wrapping, and adaptive font sizes as new techniques to further improve the results, and we leveraged the ability to sacrifice layout speed for better layout results. Searching for optimal option settings increased our layout times by a factor of four.

While this work introduces the main concepts of posterizing diagrams, we plan to evaluate the effect of the new techniques on the whitespace quantity and readability of diagrams. We also plan to develop better techniques for automatically determining good size constraints to set on nodes for top-down layout and to evaluate the usability of top-down diagrams. Especially the question of how humans who work with diagrams use them and whether top-down layouts benefit their use cases is an open question that requires further investigation.

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