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Data Visualization in ProB

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Bachelorarbeit

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Erklärung

Hiermit versichere ich, dass ich diese Bachelorarbeit selbstständig verfasst habe. Ich habe dazu keine anderen als die angegebenen Quellen und Hilfsmittel verwendet.

Düsseldorf, den 14. Juni 2013

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Abstract

Hier kommt eine ca. einseitige Zusammenfassung der Arbeit rein.

Contents

1 Introduction

During the course of this paper, the different tools and concepts that were necessary in the scope of this work will be introduced. Then the motivation and the requirements for the desired visualizations will be described in detail. The actual visualizations that were created will then be presented, followed by further ideas for implementations and related work.

2 Background

2.1 B-Method

The B-Method is a method of specifying and designing software systems that was originally created by J.R. Abrial [AAH05]. Central to the B-Method are the concepts of *abstract machines* that specify how a system should function [Sch01].

An *abstract machine* describes how a particular component should work. In order to do this, the machine specifies *operations* which describe how the machine should work. An *operation* can change the *state* of the machine. A *state* is a set of *variables* that are constrained by an *invariant*. In order for the model to be valid, the *invariant* must evaluate to true for every state in the model.

Two specification languages used within the scope of the B-Method are Classical B and Event-B. There are several tools available to check and verify these specification languages [LIST TOOLS].

2.2 ProB

ProB is a tool created to verify formal specifications [LB03]. In addition to verifying Classical B and Event-B specifications, ProB also verifies models written in the CSP-M, TLA+, and Z specification languages. ProB differs from other tools dealing with model verification in that it is fully automated. Several tools have also been written to extend ProB and add functionality.

ProB verifies models through consistency checking and animation. Conistency checking is the systematic check of all states within a particular specification. In order to do this, ProB checks the state space of the specification in question. The state space is a graph with *states* saved as vertices and *operations* saved as edges.

ProB is a model checker and animator for specifications written in the Classical B, Event-B, CSP-M, TLA+, and Z specification languages [LB03]. There is a standalone version of the ProB software available with the graphical user interface written in Tcl/Tk. A binary command-line interface is also available for the software.

In 2006, a project began to develop a ProB plug-in for the Rodin software suite so that ProB could be used in conjunction with Rodin.

In the fall of 2011, planning for the ProB 2.0 API began. The main goal of the ProB 2.0

API was to adapt and optimize the existing Java API to build a user interface on top of a programmatic API. Functional programming techniques were used in the development of the software as much as possible. To meet these ends, the Groovy scripting language was heavily integrated into to the ProB 2.0 core. The ProB 2.0 API includes a fully functional webserver with servlets that allow the extension of the Java core into JavaScript and HTML. The fully functional webconsole available in the API makes use of this technology.

2.3 D3 and JavaScript

Since a web server was already available in the ProB 2.0 application, it was plausible to create visualizations using javascript and HTML. The ProB 2.0 application is an Eclipse application, so it also would have been possible to create visualizations using a native Java or Eclipse library. I carried out an experiment at the beginning of this work to determine the feasibility of the different graph libraries. JUNG was considered because it is the software framework that is the ProB 2.0 API currently uses, but it was discarded because of the difficulty of embedding Swing visualizations into Eclipse applications. The ZEST graph library was a feasible option, but in the end, I chose to use the D3 library.

D3 (Data-Driven Documents) is an open source JavaScript library that was developed by Bostock, Ogievetsky, and Heer for the visualization of different types of data [BOH11]. The output of the D3 functions is a pure SVG and HTML document object model that implements the W3C Selectors API. Because of this, the entire docmument can be styled using CSS and the developer has complete control over the appearance of the final product.

Using D3 also allowed the developer to have more control over how the content is updated. One of the main features of the ProB 2.0 API is its ability to manipulate its data structures dynamically through the use of the scripting language groovy. Because the D3 visualizations are written in Javascript, the thought was to give the user similar control over the visualizations. Using D3 selectors, it is easy to select the exact SVG and HTML elements of your visualization that you want to edit. Then you add or manipulate the attributes of the selected elements to obtain the desired visualization. It would also be theoretically possible to lift some of the functionality of the selectors from the Javascript level into the Java core. Then the user would be able to manipulate the visualization using the Groovy scripting language.

D3 includes an API for visualizing many different kinds of data sets. Simple examples support for pie charts, line graphs, and bar graphs. More complex data structures such as the graph and tree data structures can be represented using the spring and tree layouts respectively. Extensive reference materials and examples are available on the D3 website.

2.3.1 Spring Layout

For the visualization of graphs, d3 has made the Spring layout available. The algorithm used for the layout algorithm is based on the work of Dwyer and Jakobsen ([Jak03],[Dwy09]).

2.3.2 Tree Layout

In order to visualize trees, d3 has made the tree layout available. It is also relatively easy to build in a function so that the different nodes in the tree can be expanded or hidden.

2.3.3 Graphs and Charts

Preparing the data for charts is as simple as generating the data points that are to be visualized. D3 includes support for determining and drawing the needed scale for the x and y access.

3 Motivation

The ProB standalone application written in Tcl/Tk uses Dotty as the library to create visualizations of certain data structures within the ProB application. Unfortunately, these data visualizations are completely missing in both the Java APIs. The intention of this work is to inspect the data visualizations that are available in the Tcl/Tk application and recreate these in the Java 2.0 API. The visualizations should not be hard coded, but should use D3 and the existing webserver structure to create a framework so that similar visualizations can be created in the future using the same principles.

Central to the ProB application is the concept of the state space. The state space is a directed multigraph. The states are saved as vertices in the graph and the operations within the graph are saved as directed edges that transition from one state to another. The main purpose of the ProB software is to verify this state space for inconsistencies. For instance, it is possible to use ProB to find states within the graph that violate the invariant for specification. It is also possible to find states from which there are no further operations possible. This is called a deadlock.

The ProB 2.0 API extracts the information about the existing state space from the ProB CLI and saves it in a programmatic abstraction of the state space. This abstraction saves the information about the different states in a graph data structure using the Java JUNG graph library. The state space object already supports the use of Dijkstra's algorithm to find the shortest trace from the root state to a user defined state. This can be used to find traces that show how an invariant violation or deadlock can be found. What is missing, however, is a visualization of the actual state space itself.

Because the state space is a directed multigraph, this visualization problem is not trivial. It was necessary to find a graph library that would be able to draw a complicated graph. Because the state space varies drastically depending on the machine that is being animated, it was also necessary that the graph library be able to handle graphs of all different shapes and sizes.

A useful feature for the visualization of a state space would also be the ability of the user to manipulate the graph. For instance, the Tcl/Tk version of ProB supports the capability for the user to specify a formula and to merge all states for which the formula evaluates to the same result. Similar functionality was desired for the visualization in the ProB 2.0

API. A useful visualization would also allow the user to specify how the graph should be colored.

Although the visualization of the state space was the focus of this work, there were other sets of data for which a visualization would be useful. The ProB Tcl/Tk version supports a useful visualization of B formulas. The user specified formula is broken down into subformulas and colored so as to specify the value of the formula (e.g. if a given predicate evaluates to true at the specified state, the predicate would be colored green). A similar visualization exists in the ProB 1.3.6 API but not in the ProB 2.0 API.

Another useful visualization that falls into the scope of this work was a visualization of the value of a user defined formula over time. No such visualization exists in any of the ProB applications yet, but it was thought that such a visualization would be relatively simple to generate and useful.

4 Contribution

4.1 Visualization framework

One of the main issues that had to be dealt with at the beginning of the development process was the issue of how to integrate the visualizations into the ProB 2.0 API. At the time, the software already contained a functioning web server using Java servlets. Since the visualizations are written using Javascript and the d3 Javascript library, they needed to use the same framework. Because the visualizations needed to react to changes that take place during the animation of a model, they needed to be able to communicate with the ProB kernel. In order to accomplish this, a javascript function is invoked when the HTML page is loaded. This javascript sets up an interval so that the servlet that is responsible for the visualization is polled every 300 milliseconds to see if there are any changes. Both the servlet and the javascript function keep track of a counter that functions as a time stamp. This number is sent back and forth. If the javascript function identifies a discrepency between the numbers, it polls the servlet and then updates the visualization.

A problem quickly arose because the servlet is a singleton object. There is only one servlet responsible for all of the visualizations of a particular type. The solution for this was to generate a unique session id for every visualization. Using this id, HTML content for the visualization is generated. When the HTML content is loaded, it calls the correct javascript function which sets up the polling interval and generates the visualization for the calculated data.

Once I implemented a way to integrate the visualization servlets into the ProB 2.0 application, it was still necessary to implement an easy way for the user to interact with the visualizations. One of the main advantages of the D3 visualization framework is the flexibility for the user. Using the D3 selectors, it is possible for the user to select and change the attributes of any of the elements of the visualization. In order to offer this functionality to the users from within the ProB 2.0 application, we decided that we needed to lift the functionality from the javascript level into the existing groovy console in the Java 2.0 API. This was accomplished by creating a `Selection` object that represents the action that the user wants to carry out in the visualization. Then the `Selection` object is added to the particular visualization and is applied the next time the visualization is redrawn. The `Selection` object was written so that its functionality is similar to what the user would actually write using the D3 library.

```
\\In the Groovy Console
\\Define an object to tell the visualization to select the
\\ elements with ids #croot and #c1 and color them pink
x = viz.selectAll("#croot,#c1").attr("fill","#f36")

\\Add this selection to the visualization with session id "0"
viz.addToSession("0",x)
```

4.2 Visualization of the State Space

During the preliminary experiments for State Space visualization, several different graph libraries were tested out. D3 was chosen because it could process graphs of relatively large size in a way that was eye pleasing for users. Visualization of the state space uses the Spring layout that is available from the D3 library. Unfortunately, when visualizing state spaces with a very large amount of states and inputting them all at the default intitial position, it took rather long for a good visualization to emerge. Therefore, the FRLayout from the JUNG graph library was used as a static rendering engine to calculate the ideal initial positions for the states to be visualized in the graph.

One of the main problems with the web framework that was discovered at the start of the development process was the problem of how different state spaces should be visualized at the same time. The ProB 2.0 API supports the animation of multiple state spaces at any given time. When a state space visualization is created, it is created using the state space that is currently being animated. When the animation is switched, a new state space visualization can be created using the new state space that is being animated. The problem is that a state space visualization is not static. Since the state space that is being visualized changes over time when states are added into the graph, the visualization also needs to adapt and grow correspondingly. The solution to this is to have the instance of the state space visualization poll the state space regularly to get any new states that have been discovered. The problem occured because the servlet responsible for dealing with the state space was static. When the polling occured, the servlet did not know which instance of the state space was supposed to be polled.

(NOT YET IMPLEMENTED) (ONCE IMPLEMENTED DESCRIBE THE DETAILS OF HOW IT IS IMPLEMENTED) The visualization of the state space is interactive. The user can grab the nodes within the state space and move them around so that they appear exactly as the user desires. Because it the whole visualization is completely written in d3 and Javascript, it is also possible for the user to interact with the visualization using JQuery to change the appearance of the different objects.

The user can also input Classical B formulas and thereby filter the graph. This uses the algorithms described in [LT05]. The formula is applied to the state space and all states are merged for which the formula evaluates to the same result. The result is a smaller state space that can be viewed by the user.

4.3 Visualization of the Value of a Formula Over Time

During animation in the ProB 2.0 API, the animation steps that have been taken are saved in a trace. A particular formula can take on different values over the course of a trace. In the implementation of the B state space, a particular state is determined by the different values that a variable takes on. Therefore it is particularly interesting to be able to examine the value of a variable over the course of a trace when dealing with a Classical B or Event B formula. Evaluation of a formula for takes place in the ProB prolog core. In the ProB 2.0 API, a feature was implemented that takes the list of all the states that the trace covers and a particular formula and returns the list of the values that the formula takes on in the course of the trace. This feature was used in order to create a line plot of the values that the formula takes on. This works for all formulas that take on either an integer value or a boolean value (IMPLEMENT BOOLEAN VALUE).

4.4 Visualization of a formula

The ProB CLI already supported the functionality of expanding a formula into its subformulas and finding its value at a given state. However, this functionality would only return the subformulas that were directly beneath the desired formula. For the visualization, it was desired that a given formula could be completely expanded and evaluated and then sent to the ProB 2.0 API. This would ensure that performance would not become an issue. It is now possible to register a Classical B formula in the core and then access the expanded and evaluated formula.

In order to implement the visualization, the d3 tree layout was used. (ADD DIAGRAM OF VISUALIZATION)

This visualization is interactive. The user can select the nodes to expand or to retract the subformulas. It provides a visualization so that the user can easily interpret the formula. If the formula was evaluated to true for the given formula, the text of the formula is displayed in green. If the formula was evaluated as false, the text is displayed in red. This allows the user to automatically identify the parts of the formula that may have produced the problem.

5 Related Work

d3, Alloy, etc.

6 Conclusion

The Conclusion

7 Future Work

This work has created graphic visualizations using the d3 Javascript library. The same framework can be used to create other visualizations for other needs. For instance, there is no graphical representation of a state in the ProB 2.0 API. One future project could be to create a graphical representation of this state.

It is also possible to adapt the new visualizations in order to add functionality. For instance, in order to view the information about a particular state within the state space, it would make sense to combine the state space visualization with the proposed state visualization. Then, when a state is clicked on within the state space visualization, a window could pop up displaying the state visualization for that particular state.

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