Visualization of Tool overlapping Dependencies in a Traceability Framework

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Abstract

In the developing process of a technical system a large number of artifacts is created. In order to manage the dependencies between different artifacts created by different tools, the tool overlapping traceability framework RiskTest has been developed. RiskTest administers the artifacts and their dependencies as a graph. While it is already possible to connect different artifacts via RiskTest, the resulting graph needs to be visualized properly to allow the user to easily identify traces throughout the whole project. The visualization needs to provide an efficient way for the user to gain insight into a complex graph structure. In this bachelor thesis the necessary requirements for such a visualization are analyzed, different approaches for dealing with graph visualization are evaluated, different frameworks and tools are closer looked upon, their usefulness for these particular requirements is assessed and finally a fitting visualization is implemented and added to the RiskTest traceability framework.

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Chapter 1

Introduction

Modern software development of almost any scale is accompanied by a number of processes that help organize and order the work that has to be done to build a reliable, fitting and robust software solution to a real-life problem. These processes can differ quite substantially but what almost all of them share is that the production of the software is accompanied by the production of several different artifacts. An artifact can be almost anything from a full scale requirements catalogue to a use-case diagram illustrating one of the software's user interfaces to a single result of a unit-test.

These artifacts are essential for both programmers and customers to understand the requirements of the software and its current state. Typically, there are a number of specialized tools involved to create those artifacts. It is clear that the artifacts have semantic links between them. For example in order to analyze and visualize security risks, a developer may have used tool A to create diagrams. A common solution after identifying security risks is to employ test patterns in order to cover those. These test patterns however are probably not administered by the same tool, so another tool (tool B) needs to be employed. After choosing test patterns it is only logical to write test cases according to the pattern. This however can be automated by some tools, which would mean that once again another tool (tool C) needs to be employed.

While the usage of many different tools may not seem to be a problem at the first glimpse, there is quite a substantial drawback. The drawback is that it can become quite difficult to maintain the semantic links between artifacts created

by different tools. Nonetheless maintaining these semantic links is crucial. A simple example: In order to answer the question whether a security risk has been successfully addressed, it is necessary to look at the associated test patterns from tool B, find the test cases that were created from this pattern by tool C and only then, by looking at the successful or unsuccessful test case results, is it possible to determine if the security risk(visualized by a diagram created with tool A) has been addressed or whether some work still remains to be done. Without a thorough management of these semantic links questions like the one above become almost impossible to answer.

For the purpose of maintaining semantic links, the Fraunhofer FOKUS institute developed the RiskTest traceability framework [GBV13]. It was developed for risk-based tests and test managements but could be used in a different context as well. RiskTest supports the usage of different tools and allows the user to create semantic links (traces) between artifacts created by these tools. In order to maintain these semantic links it is essential that the underlying data structure that administers the traces is visualized properly, so that incorrect linkings can be spotted and corrected and missing links can be added. The underlying data structure is of course a network of artifacts, hence a graph.

The aim of this bachelor thesis is to create a fitting visualization for traceability data. In this context it is necessary to collect and analyze requirements of such a visualization. It was already mentioned that the actual data structure to visualize is a graph, thus this bachelor thesis also deals with the visualization of graphs and automatic graph layout algorithms. For the task of implementing a visualization the usefulness of different tools and frameworks that provide graph algorithmic functionality is assessed. The most fitting of these is decided on. Finally the resulting concept for visualizing traceability data is implemented and integrated into the RiskTest traceability framework.

Chapter 2 explains the state of the art in both traceability as well as graph visualization. It covers the existing approaches to traceability, deals with the abstract task of graph drawing, determines the desirable properties of a graph layout and lists different approaches to automatic layouts algorithms. Chapter 3 deeply analyzes the task of creating a visualization for traceability data in RiskTest. For this purpose a closer look on RiskTest is taken, requirements for a visualization of

traceability data are collected, categorized and illustrated. The software architecture of RiskTest is analyzed, graph drawing tools and frameworks are introduced and fitting graph layout algorithms are decided on. Chapter 4 shows the design of the visualization and chapter 5 explains its implementation. Subsequently chapter 6 validates that the implementation satisfies the requirements that were collected in chapter 3 and it demonstrates the usage of the visualization at an example project. Finally chapter 7 concludes the thesis.

Chapter 2

State of the Art: Traceability Tools and Graph Drawing Algorithms

This chapter covers the State of the Art in both traceability as well as graph drawing. The basic knowledge that is introduced here, especially concerning graph drawing, is needed in the later chapters.

2.1 Traceability

First a short introduction to the topic of traceability is given, followed by an overview over the different domains in which traceability has already been dealt with.

2.1.1 Traceability in General

Traceability management can be best defined as the management of relationships between different artifacts. These relationships (also called traces) are semantic links that imply that two or more artifacts belong together in some sort of way. For example a test pattern could be linked to a security risk, therefore implying that the test pattern is used to cover the security risk. [GBV13]

2.1.2 Traceability in Different Domains

The first context in which traceability became relevant was requirements engineering. Traceability tools like Reqtify [Req] or Rhapsody gateway [Rha10] were created. The overall goal of these tools was to display that the system fulfilled the requirements. For that purpose these tools administer semantic links between requirements and source code.
Another application domain of traceability is the development of safety critical systems in which traces are administered between safety requirements, software requirements and the source code. [KS]
In the domain of secure software applications in which security is a main aspect of the requirements, traceability tools are rarer which led to the necessity of developing RiskTest. Apart from RiskTest there is the JESSIE project, a tool for security assurance [BJY]. JESSIE allows the creation of traces but its focus is on the aspect of handling the trace model and run-time verification in contrast to good usability when dealing with the actual traces [GBV13]. An additional motivation for the creation of RiskTest was that other traceability tools are often separate and need to import the data from the other tools used during the development process. This may lead to a high effort at the end of the development. When all artifacts are created they need to be imported into the traceability tool in which the tracing can be handled. Another disadvantage of a separate tool is that its visualization of the artifacts will most likely differ from the visualization used by the original tools.
RiskTest aims to correct that by integrating different tools and their native user interfaces. That way RiskTest allows continuous updates to the traces while the development is still in progress [GBV13]. A closer look on the current state of RiskTest is taken in the beginning of chapter 3.
It was already mentioned that traceability data can be considered to be a graph. Since the goal is to create a visualization of dependencies (traces), graph visualization is the main task. Therefore the next section is about graph drawing and graph layout algorithms and deals with the visualization of abstract graphs. While it is useful to keep traceability with its artifacts and traces in the back of one's head when looking at different approaches to graph visualization, the next

section is nonetheless deliberately kept abstract in order to give an overview.

2.2 Graph Drawing

Graph drawing is the field of study that deals with the visualization of graphs. A visualization of a graph can be best described as a graph layout. Graph layout is an intuitive term so a formal definition is not necessary in this thesis. Nevertheless a short description is given to clarify what is meant by this term in this thesis specifically. Details may differ from other sources.

Graph Layout A graph layout is a mapping that assigns each vertex of a graph a point in a coordinate system. Usually the Cartesian coordinate system is used but this does not necessarily have to be the case. Furthermore a graph layout maps each edge to a line in the same coordinate system. This line can have any shape as long as it connects the two vertices incident to the edge.
In short a layout is a formal description of how to draw the graph.

2.2.1 Layout Evaluation

Before considering algorithms for automatic graph layouts it should be clarified what the desirable properties of a layout are. The overall aim is of course to enable the beholder to correctly identify relations between vertices, provide an overview over the whole graph and avoid confusing or misleading the viewer. This intuitive goal is described by Purchase, Cohen and James in their study about the validation of graph drawing aesthetics (see [PCJ95a]). Their study was published in [Bra95].

2.2.1.1 Edge Crossings

In the study mentioned above Purchase, Cohen and James (see [PCJ95a]) have found clear evidence for the intuitive assumption that the higher the number of

edge crossings in a graph drawing, the harder it is to understand the structure of the graph. Thus the number of edge crossings in a graph layout should be kept as small as possible.

2.2.1.2 Edge Bends

In the same study that found evidence for the harmful influence of edge crossings Purchase, Cohen and James have found out that a high number of edge bends decreases the understandability of a graph (see [PCJ95a]). Thus, similar to the number of edge crossings, the number of edge bends in a layout should be kept as small as possible.

2.2.1.3 Local Symmetry

Purchase, Cohen and James also tested the impact of local symmetry on the readability of the graph and expected that the more symmetrical a graph drawing, the higher the understandability of the graph. While this intuitively seems to be a good hypothesis they did not find significant evidence for it. They still believe that symmetry may improve the readability of a graph, and suspect that their study failed to confirm this due to a ceiling effect:

> "[...] *,but the symmetry hypothesis is inconclusive. We believe that this is due to a 'ceiling effect'. The length of time for the subjects to answer the questions (45 seconds for dense, 30 seconds for sparse), was too generous: most of the subjects managed to get all the questions right for the symmetrical graphs (even those which had a low measure of symmetry).* " [PCJ95b]

So the positive influence of local symmetry on readability remains unclear, but it is probably correct to at least assume that symmetry does not hinder the readability of a graph.

2.2.1.4 Edge length

The Sugiayma method, a popular algorithm for the visualization of hierarchies, claims that long edges hinder readability and that therefore edge length should be

kept as small as possible (see [HN07]). While this is certainly true for extremely long edges there is of course a lower bound for this, since vertices should not overlap and possible labels need to stay readable.

2.2.1.5 Vertex Distribution

The Sugiayma method claims that vertices should be distributed uniformly to ensure order (see [HN07]). This is somewhat contrary to the approach of some other graph drawing algorithms. In force-directed algorithms for example, clusters of vertices that are positioned very close to each other may emerge. These clusters may have the advantage of grouping (structural) similar vertices. This goes to show that while both approaches to automatic layouts are valid, they put their focus on different aspects, and rate the uniformity of vertex distribution differently. It remains unclear whether uniform vertex distribution is superior due to order and overview, or whether clusters are preferable.

2.2.2 Graph Drawing Algorithms

In his book about graph drawing and graph visualization Roberto Tamassia gathers a number of authors that contribute different chapters (see [Tam07]). Most of these deal with automatic graph layout algorithms of all sorts. Many of the different algorithms require a specific type of graph, for example an acyclic or a planar graph, which leads to different categories of graph drawing algorithms. It is important to note that even if a graph does not fulfill all requirements for an algorithm, the graph can be temporarily modified in order for the algorithm to work, and after an automatic layout has been generated the created layout can be changed back in order to restore the original graph. This approach is suggested by the Sugiyama framework, an algorithm of the hierarchical drawing algorithms category (see [HN07]). Depending on the amount of changes that had to be made, the resulting layout may of course be far from optimal since the graph did not satisfy important properties the algorithm relied on in order to create the layout. The next sections give a very brief overview over the different categories of graph layout algorithms and their most important characteristics. Specific algorithms of some of these categories are explained in detail in section 5.5. Unless it is

said otherwise the algorithms produce layouts for a two-dimensional Cartesian coordinate system.

2.2.2.1 Planar Graph Drawing Algorithms

Planar graph drawing algorithms focus on planar graphs (graphs that can be drawn without edge crossings). If a graph is planar it is desirable to find a planar drawing since it was already established that edge crossings hinder readability (2.2.1.1). Given a graph, most planar drawing algorithms either return a planar layout or the information that the graph is not planar. In the latter case it is still possible to reduce edge crossings. However, minimizing edge crossings of a non-planar graph drawing is proven to be NP-hard, so heuristics need to be employed [BCG+07].
There are a large number of specialized drawing algorithms for planar graphs such as orthogonal and polyline drawing algorithms, rectangular drawing algorithms and many more.
For planarity testing algorithms see [Pat07]. Crossing minimization algorithms are presented in [BCG+07]. Planar straight line drawing algorithms are dealt with in [Vis07] and for planar orthogonal and polyline drawing algorithms see [DG07]. Rectangular graph drawing algorithms (of planar graphs) are discussed in [NR07].

2.2.2.2 Symmetric Graph Drawing Algorithms

Symmetric graph drawing algorithms focus on the symmetry aspect of the layout evaluation criteria. They try to maximize symmetry in a graph layout. Given a graph $G = (V, E)$ symmetry can be formally expressed by functions $\delta : V \to V$ that preserve adjacency (automorphisms). However not all automorphisms of a graph can be transformed into one symmetrical drawing. This means that it is the aim of symmetric graph drawing algorithms to find the automorphisms that can be transformed into a graph drawing with maximum symmetry. In their chapter about symmetric graph drawing Eades and Hong explain that the most precise specifications of the symmetric graph drawing problem are NP-complete,

so once again heuristics have to be found. An exception is the problem of finding a symmetrical layout for a planar graph, which can be done in linear time. [EH07]

2.2.2.3 Hierarchical Graph Drawing Algorithms

Hierarchical graph drawing algorithms specifically deal with hierarchies which are typically modeled as directed, acyclic graphs. A common approach to specify the hierarchy is to partition the vertices of the input graph into distinct sets, the so called layers. Healy and Nikolov describe the Sugiyama framework as the most popular method for drawing hierarchies. This thesis deals with this algorithm again in section 5.5.2. [HN07]

2.2.2.4 Tree Drawing Algorithms

Tree drawing algorithms focus on drawing undirected, acyclic graphs. Trees are commonly drawn as hierarchies but other layouts are possible which distinguishes this category from the hierarchical drawing algorithms. [Rus07]

2.2.2.5 Spine and Radial Graph Drawing Algorithms

Spine and radial graph drawing algorithms partition the vertices of a graph into distinct sets which are called layers, very much like hierarchical drawing algorithms. One main difference is that spine and radial drawings allow cyclic graphs. Furthermore, layers are allowed to be drawn as any type of curve. In practice they are almost always drawn as either straight lines or circles. [GDL07]

2.2.2.6 Circular Graph Drawing Algorithms

Circular graph drawing algorithms partition the vertices of a graph into clusters. The vertices of each cluster are then distributed on the circumference of a circle and edges between vertices are drawn as straight lines or as an arc if the vertices are neighbors on the circle. Both single circular drawings (all vertices are placed on the same circle line) and multi circular drawings are possible. The input graph is not restricted in any way which means that circular drawing algorithms can be applied to any type of graph. [ST07]

2.2.2.7 Simultaneous Graph Drawing Algorithms

Simultaneous graph drawing algorithms, also called simultaneous graph embedding algorithms, do not aim to draw one single graph but an entire set of graphs that have a (partly) common vertex set. These algorithms have to find a good tradeoff between readability of the individual graphs and global overview, which are both desirable, but often contradictory. The chapter in Tamassia's book by Blaesius specifies on simultaneous embedding of planar graphs. [BKI07]

2.2.2.8 Force-Directed Graph Drawing Algorithms

Force-directed graph drawing algorithms achieve their layouts by modeling the graph as a physical system in which there are repulsive forces between all vertices, but also attractive forces between vertices that are connected by an edge. A 3-dimensional, physical example of this could be a space with zero gravity in which the vertices are spheres, that are all equally, negatively charged, and if there is an edge between two vertices, the corresponding spheres are connected by a spring. For this reason force directed layout algorithms are also known as spring embedders. Force directed drawing algorithms are extremely flexible and can be applied to any graph. They can also create 2-dimensional drawings as well as 3-dimensional drawings. This thesis provides a detailed look on a specific force-directed algorithm in section 5.5.1. [Kob07]

2.2.2.9 Three-Dimensional Graph Drawing Algorithms

Three dimensional graph drawing algorithms create layouts for the three dimensional Cartesian coordinate system. Compared to two-dimensional graph drawing algorithms and layouts there has been little research in the area of three-dimensional graph drawing algorithms.
This category can be roughly subdivided into polyline-grid drawing algorithms, orthogonal grid drawing algorithms and non-grid drawing algorithms. Each of these subcategories has a different approach to vertex distribution. One of the main advantages of three-dimensional drawing algorithms is that all graphs can be drawn without edge-crossings. This however comes at the cost of Volume, since in order to remove crossings the size needs to be increased. [VW07]

Chapter 3

Analysis

This chapter analyzes the task of creating a visualization for the dependencies managed by RiskTest in depth. First the RiskTest traceability framework is closer looked upon followed by the collection of the actual requirements for the visualization. Subsequently graph drawing tools and frameworks are closer looked upon. This chapter finishes by revisiting the different categories of graph drawing algorithms and the assessment of their usefulness for the visualization of traceabitlity data in RiskTest.

3.1 The RiskTest Traceability Framework

Before the actual requirements can be collected, it is necessary to take a closer look on the current state of RiskTest and to examine parts of its software architecture.

3.1.1 Current State of RiskTest

RiskTest is a plugin for the popular and widely used development platform Eclipse. It integrates different Eclipse-based tools which are Eclipse plugins themselves. The design purpose of RiskTest is to support as many tools as possible that are helpful in the development of software systems. The users of RiskTest will work with these tools in their native user interfaces but still be able to create semantic links between artifacts of the supported tools via RiskTest. RiskTest

currently supports:

- CORAS - A tool to conduct security risk analysis.
- ProR - A tool for requirements engineering that allows the user to organize and administer test patterns.
- Papyrus - A tool for modeling that supports both EMF and UML as well as a couple of other modeling languages.
- TTWorkbench - A tool for automated test generation and execution.

The support of these four tools is no coincidence. The main reason for the development of RiskTest was to create a traceability framework for the context of security. Figure 3.1 shows the intended usage of these four tools. As already

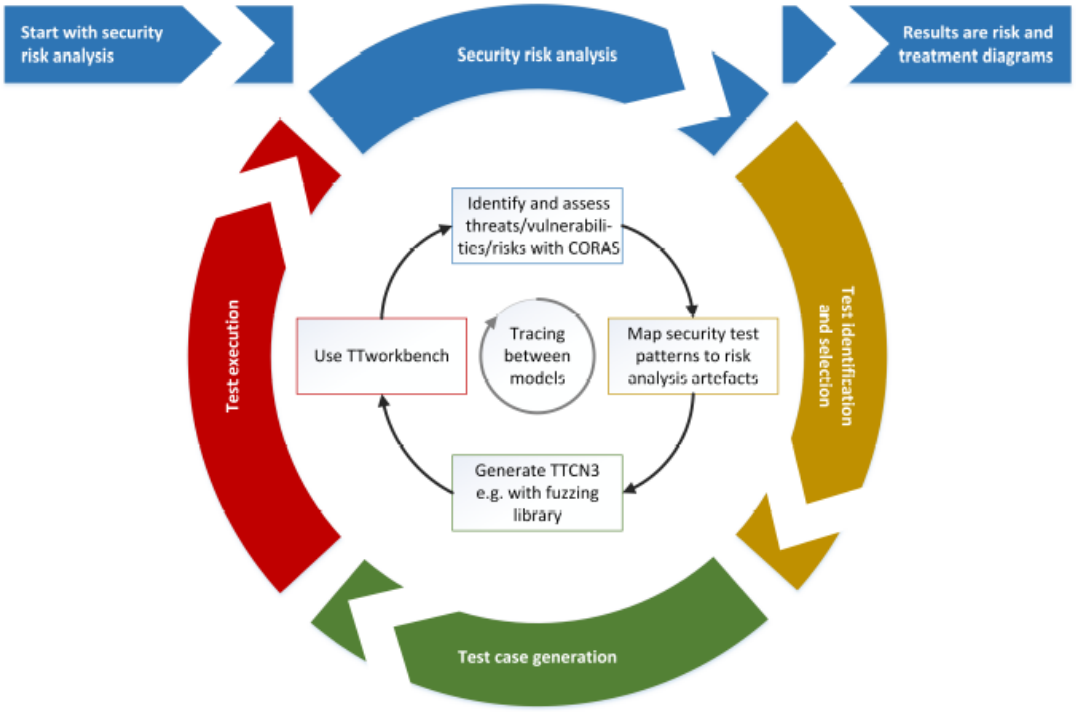


Figure 3.1: Usage of RiskTest, taken from: [GBV13]

mentioned the current user interface of RiskTest includes all native user interfaces of the supported tools.

Figure 3.2 shows a configuration that depicts the views of CORAS, ProR and Papyrus. At the very left border there is the project browser. At the center the CORAS view is located, on its right is the view of ProR and below both of these is the view of Papyrus. The position of the views can be adjusted as common

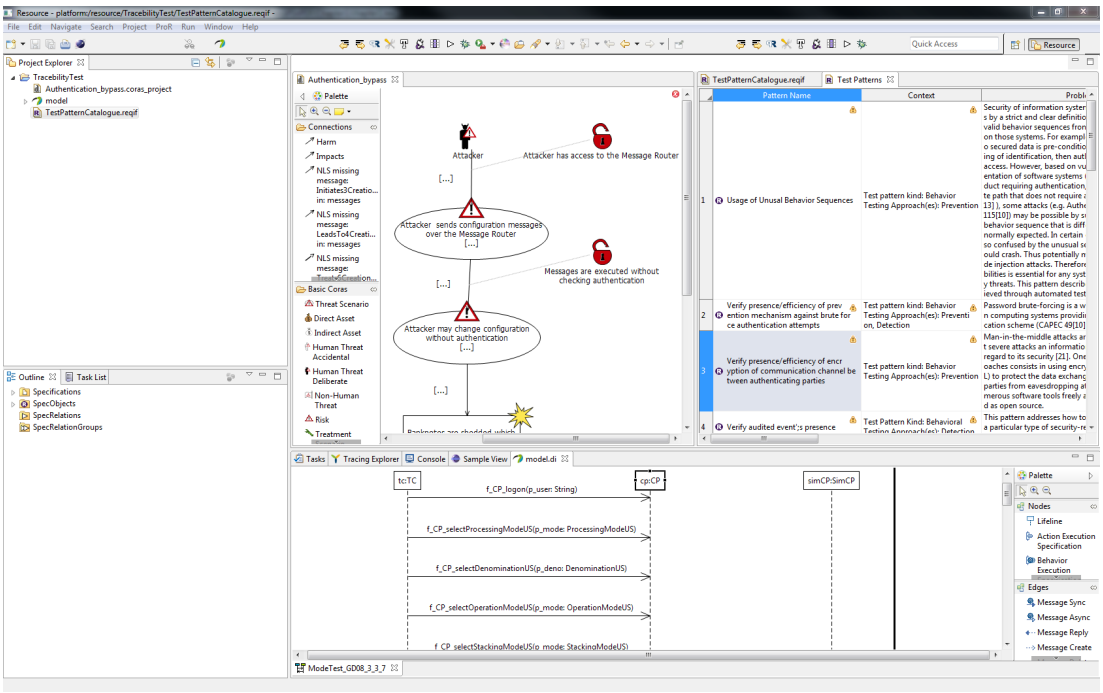


Figure 3.2: RiskTest user interface

in Eclipse-style interface layouts. Each of the tools could run on its own, but by starting multiple tools in RiskTest it is now possible for the user to edit traces, for example via the context menu. An example of this interaction is shown in figure 3.3. As already mentioned the current user interface of RiskTest includes all native user interfaces of the supported tools. Note that the native user interfaces keep their full functionality since RiskTest loads all tool-specific interactive buttons and icons if a native view is selected. This means that RiskTest does not decrease the usability of any of the supported tools, while adding more functionality.

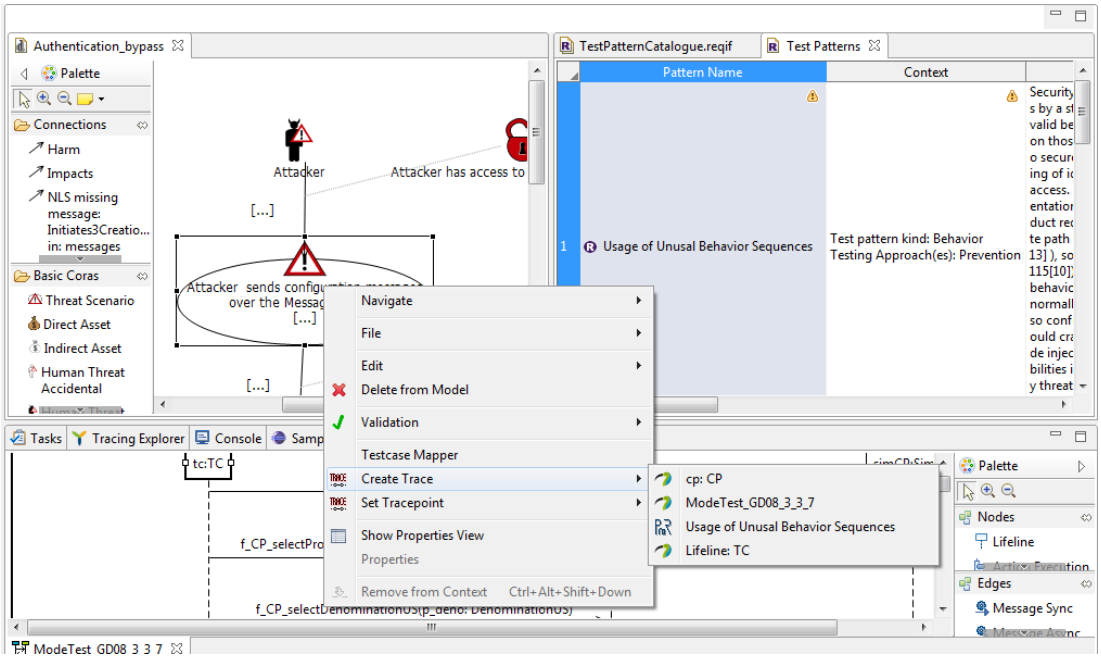


Figure 3.3: Editing semantic links by using the RiskTest context menu

3.1.2 Software Architecture of RiskTest

Since RiskTest itself is an Eclipse plugin it is not surprising that it consists of a number of interdependent plugins for Eclipse. Each plugin typically has a number of java packages which contain the relevant classes. The most important package for data administration is *org.yakindu.crema.model.tracing*. Figure 3.4 shows an excerpt of the relations between the classes contained in this package. The three most important classes are the ones that also introduce important terminology. These are *TraceProject*, *TracePoint* and *TraceConnector*. Technically the names of the depicted classes are actually names of interfaces, the implementations simply have ”-Impl” as a suffix. For example the implementation of the *TracePoint* interface is called *TracePointImpl*.

The class diagram shows that in RiskTest a *TraceProject* can consist of multiple resources, which in turn may consist of multiple *TracePoint* instances. Trace points model the artifacts between which traces are to be administered. Each *TracePoint* can once again have more than one *TracePointEnd*, which means that

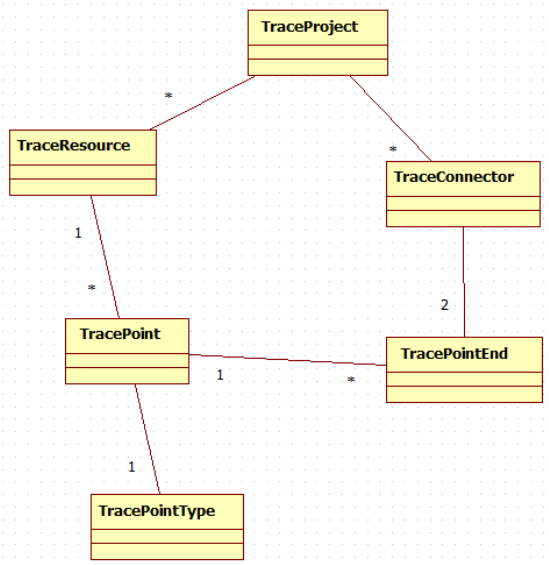


Figure 3.4: Class diagram of *org.yakindu.crema.model.tracing*

it can be related to any number of other *TracePoint* instances. These relations are modeled by the *TraceConnector* instances. They relate two *TracePointEnd* instances with each other, thus modeling that there is a trace between the two corresponding trace points. A *TraceProject* instance can of course have multiple *TraceConnector* instances. The *TracePointType* object provides additional information about the specific trace point it is associated with. Among other things it contains a string that identifies the tool in which the artifact that is represented by the trace point was created. This tool is also called the trace point's provider. In order to easily extract information out of *TraceProject* objects or modify them, there are useful utility classes such as *de.fraunhofer.tracing.util.TraceManager* and *org.yakindu.crema.model.tracing.util.ModelUtil*.

3.2 Requirements Collection

The requirements for the visualization were collected over multiple meetings with the developers of RiskTest from the Fraunhofer FOKUS institute. Table 3.1 gives an overview about the different categories of requirements. The requirements of

each category are then specified in the corresponding subsection.

Requirements Category	Description	Subsection
Data and Appearance	Deals with data constraints and the visual representation of information	3.2.1
Interaction	A summary of all the interactive features the visualization needs to include	3.2.2
Hierarchies	Deals with information about hierarchies in the trace project	3.2.3
Filtering	A more detailed look on the interactive possibility of filters	3.2.4
Summary	A brief summary containing the most important aspects of the other categories	3.2.5

Table 3.1: Requirements overview

3.2.1 Data and Appearance

- The Visualization allows the user to view a freely chosen subset of all trace points of one trace project.
- The chosen subset of trace points will be visualized as a graph. The following constraints or restrictions apply:
  - The trace points form the set of all vertices.
  - The trace connectors are a part of the set of all edges. It may be the case that all edges in the visualized graph are also trace connectors, but it is also possible that they are virtual edges, meaning they cannot be mapped to a single trace connector. The notion of virtual edges and their purpose is explained in subsection 3.2.4.
  - The visualization must be able to deal with a trace project that contains up to 2000 trace points and any number of trace connectors.
  - The trace project contains at most one trace connector for each pair of trace points.

  - The trace connectors have no direction, that means if a, b are two trace points and c is a trace connector between a and b then a is a neighbor of b and b is a neighbor of a in the resulting graph.

- The providers can be interpreted to be in a hierarchical order, for more details see subsection 3.2.3.

- The visualized graph can be dynamically changed by employing filter mechanisms. See subsection 3.2.4 for more details.

- Changes to the structure of the graph made in the visualization are automatically applied to the original trace project. See subsection 3.2.2 for possible modifications of the graph by the user.

- The graph should be automatically drawn in an aesthetic way, so that the user is able to clearly recognize the traces between the trace points and confusion is avoided.

- When drawing graph vertices, the following should be considered:
  - Each vertex is to be labeled with the name of its corresponding trace point.
  - Each vertex is depicted as the icon of the corresponding provider.
  - Additional information considering a trace point can be revealed by the user. See subsection 3.2.2 for more details.

- When drawing edges, the following should be considered:
  - Virtual edges are to be drawn differently than edges that can be mapped to a trace connector.
  - Edges are to be labeled by information contained within, if such information is present.

- As it is explained in subsection 3.2.2 the user will be able to select edges or vertices. These selected graph components are to be displayed differently than unselected graph components.

3.2.2 Interaction

The visualization allows the user to interact with it. In order to logically describe the possibilities of interaction, a definition of a view is necessary:

View A view consist of the following things:

- A graph, meaning a set of trace points and a set of edges (either real trace connectors or virtual edges).
- A set of positions mapping each trace point to a coordinate.
- An edge style specifying how the edges are to be drawn.

In short: a view encompasses all relevant information to create a drawing of a graph.

- The visualization allows the user to create a view by browsing all trace points of the trace project and selecting some of them. While browsing, filter mechanisms can be employed. These filter mechanisms are:
  - Name of the trace points (normal substring search)
  - Provider of the trace points
- The visualization allows the user to open multiple views and switch between them.
- The visualization allows the user to interact with views. The possible ways of interaction are:
  - Creation and deletion of edges. If an edge is deleted or created the trace project is updated, meaning an equivalent trace connector is deleted or created.
  - Dynamic addition and removal of vertices.
  - Filter trace points of a certain provider. This is discussed in detail in subsection 3.2.4.
  - It should explicitly not be possible to create or delete trace points via the visualization.

- The visualization allows the user to either select automatic layouts or manually arrange the visualized trace points. Both possibilities can also be combined, for example an automatic layout algorithm can be applied to generate a layout which can then be adapted by the user.
- The visualization offers saving and loading options for views.
- The visualization allows the user to reveal additional information for a vertex. These information include its neighborhood.

3.2.3 Hierarchies

The requirements of the data and appearance category (subsection 3.2.1) already mentioned that the tools integrated by RiskTest may have a hierarchical connection. This directly leads to the notion of hierarchies in the trace project. A closer look on these hierarchies is necessary: Trace points are artifacts that belong to exactly one tool (the provider). Each tool belongs to a domain, for example risk assessment or automatic test generation. In the developing process of a technical system these domains can usually be considered to be logically ordered (risk assessment is done earlier than test generation). Thus these domains are forming a hierarchy with regard to the specific process in which they were used. An example trace project is given in figure 3.5 where such a hierarchy is depicted. The trace points are drawn as yellow squares, the trace connectors are drawn as black lines connecting the trace points. The domains are labeled by the green squares and sorted from high (top) to low (bottom). This figure gives a typical example of semantic links in a RiskTest project. The trace points created by CORAS are artifacts from the security risk analysis, ProR administers test patterns to ensure the fulfillment of requirements, TTWorkbench is used for automated test generation and execution.
The intended use of RiskTest depicted in figure 3.1 shows that the process puts the tools that are currently supported by RiskTest in a hierarchical order: First security risk analysis is done with the help of CORAS, then ProR is used to find fitting security test patterns, afterwards Papyrus is used to generate test cases and finally these test cases are executed by TTWorkbench.

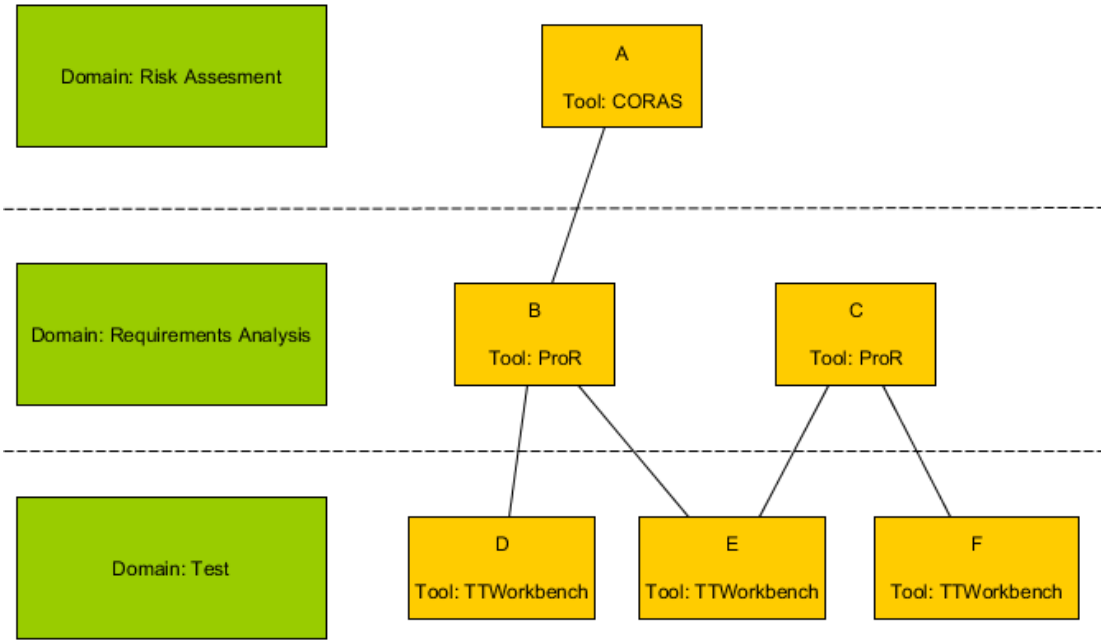


Figure 3.5: Hierarchy among the domains

It is important to note that the hierarchy of the tools is dependent on the process that is employed. The same tools may be ordered differently in two distinct processes.

Hierarchical Trace Project A trace project is hierarchical, if all tools providing the trace points can be put into a logical order (hierarchy).

This logical hierarchy between tools becomes important when filtering is discussed (see subsection 3.2.4).
In the example shown in figure 3.5 it is clear that there not only exists a trace between A and B, but also between A and D as well as A and E (the test cases D and E cover the security risk A). The above example may lead to the assumption, that the definition of a trace could be transitively extended. In other words if a, b and c are trace points and there is a trace between a and b as well as between b and c then there is a trace between a and c. This would mean that it would be sufficient to find a path in the resulting graph in order to say for two trace points

that they are semantically linked. This looks promising at first but after a more detailed analysis it becomes clear that it would be a wrong assumption.
Figure 3.5 shows that there is also a path in the trace project leading from A to C because C and E are connected. C however does not have any semantic connection to A, since the test pattern that C represents was not used to cover the security risk represented by A (otherwise there should be a trace connector between them). This means that it would be wrong to say that A and C are linked by a trace. Further restrictions are necessary:

Hierarchical path Let $G = (TP, TC)$ be the graph that is formed by a hierarchical trace project, where TP (all trace points) are the vertices and TC (all trace connectors) are the edges and let $Dom : TP \rightarrow \mathbb{N}$ be a function that maps each trace point to a number according to the hierarchical position of its domain(the highest tool in the hierarchy has the lowest number), then a hierarchical path from a to b $(a, b \in TP)$ is a sequence $S = \{tp | tp \in TP\}$ of trace points, with the following constraints:

- $|S| > 1$
- $S_0 = a$
- $S_{|S|-1} = b$
- $\forall i \in \{0, ..., |S| - 2\} : (S_i, S_i + 1) \in TC \wedge Dom(S_i) \leq Dom(S_i + 1)$

In the example shown in figure 3.5 the path from A to D is a hierarchical path, since it fulfills the criteria specified above. The path from A to trace point C is no hierarchical path since the last condition of a hierarchical path is violated. If the trace project is hierarchical, then it is useful to extend the definition of a trace to:

Trace Two trace points a and b are connected by a trace if there exists a hierarchical path either from a to b or from b to a.

The notion of hierarchies and this extended definition as well as the concept of a hierarchical path is needed when filtering is discussed in detail in the next subsection.

3.2.4 Filtering

The user is supposed to be able to filter the views by trace point providers. While this does not seem to be a problem at the first glimpse, complications can arise. Consider once again the hierarchy depicted in figure 3.5. If trace points of a provider would be removed without any additional actions then the removal of the provider "ProR" would result in the graph depicted in figure 3.6 When

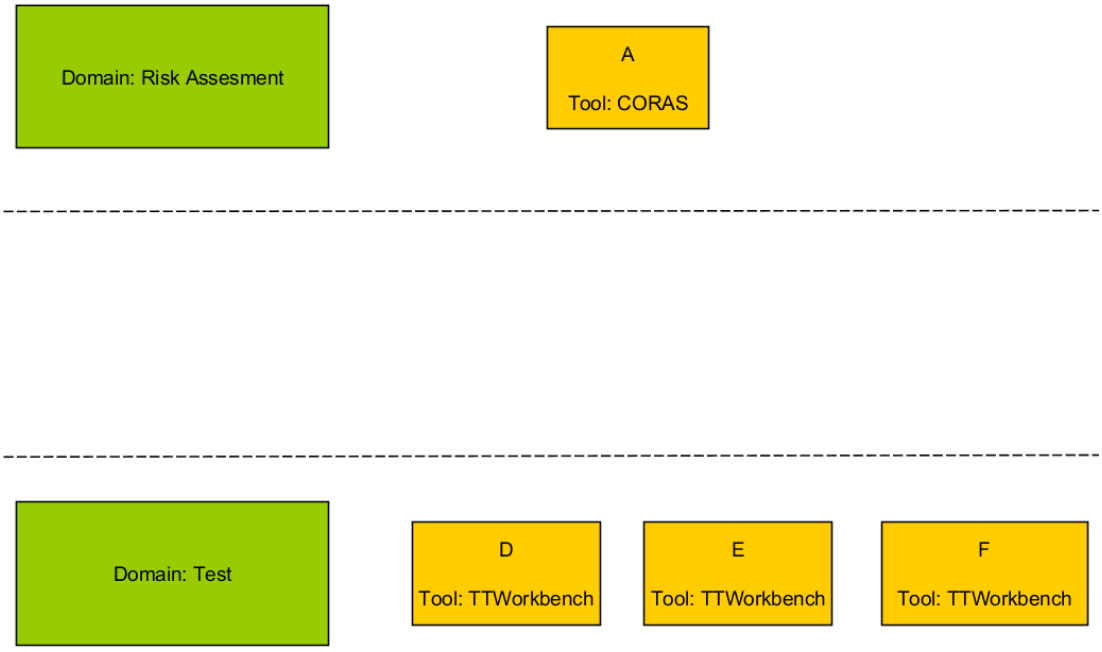


Figure 3.6: Filtered graph with ProR's trace points hidden

looking at the diagram the beholder could be misled into believing that there are no traces between any of the depicted trace points. This is of course a false assumption, since they are just hidden by the filter mechanisms. To avoid this, the notion of virtual edges that was already mentioned in subsection 3.2.1 is now applied. The rule for the addition of virtual edges is as follows:
Let $G = (TP, TC)$ be a graph of a view and the graph resulting from a filtering action is $G' = (TP', TC')$ where $TP' \subseteq TP$ and $TC' \subseteq TC$. Then $\forall(tp1, tp2) \in TP' \times TP'$ add a virtual edge between $tp1$ and $tp2$ if $(tp1, tp2) \notin TC'$ and there exists a hierarchical path from either $tp1$ to $tp2$ or from $tp2$ to $tp1$ in the original

graph G. With the notion of virtual edges the removal of all trace points of the provider "ProR" from the graph in figure 3.5 now results in the graph shown in figure 3.7.
Through the virtual edges the filtered graph now preserves the information that

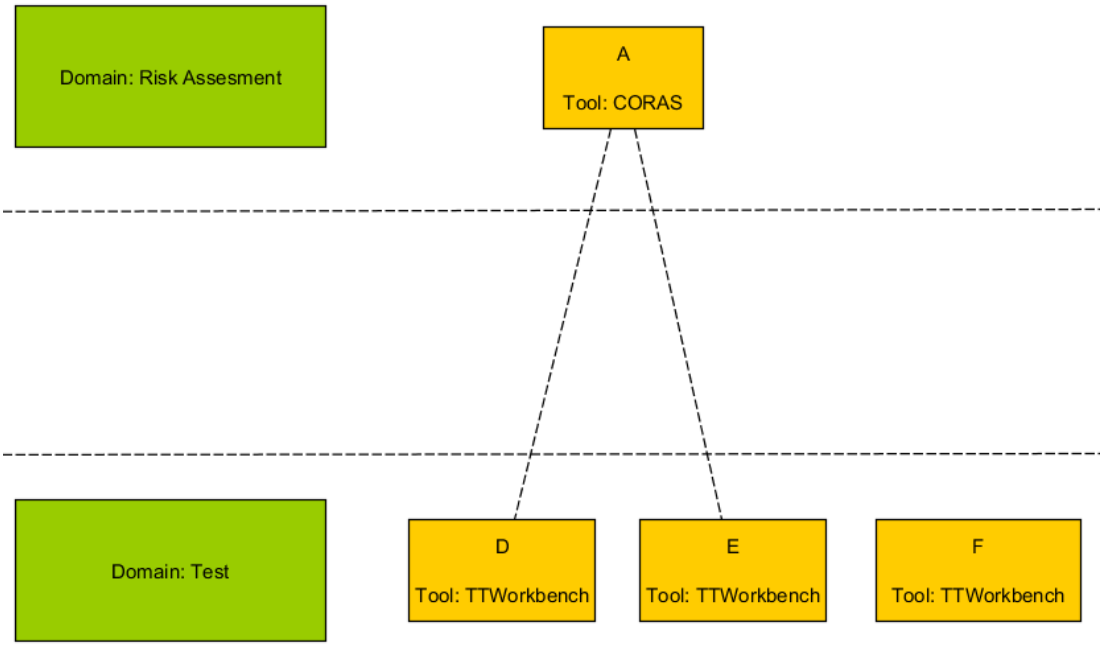


Figure 3.7: Filtered graph with ProR's trace points hidden and virtual edges added

the original graph had, which is a clear improvement compared to the filtered graph in figure 3.6.
If the original graph is restored by the user (the filter is removed) then the virtual edges should be removed again, since they are then obsolete.

3.2.5 Summary

The most important requirements of the ones listed above are:

- The data structure to be visualized is the trace project of RiskTest.
- The trace project must be visualized as a graph.

- A static display is not enough, the visualization needs to be interactive.
- The trace project can be hierarchical in which case the use of a filter may lead to the addition of virtual edges in the new graph. This has the goal of preserving information.

The requirements underline that graph visualization is the central task when creating an interactive visualization for RiskTest. Therefore the next section deals with existing graph drawing frameworks and tools.

3.3 Graph Drawing Tools and Frameworks

This thesis is only one of many examples where the visualization of a graph is the essential problem that needs to be dealt with. Thus there are already several tools and frameworks that offer graph visualization functionality. This section gives an overview over some of these and analyzes their usefulness for this particular problem. Finally one of the solutions is picked. The advantages and disadvantages refer to the specific task of building a visualization for RiskTest. They are no general assessments of the tool's or framework's usefulness.

3.3.1 Tool: yEd Graph Editor

The yEd Graph Editor (see [yED]) is a tool that has been developed by yWorks. It is a mighty tool for diagram and graph creation and modification. Figure 3.8 shows the main user interface with a simple graph displayed. The yEd Graph Editor offers a large amount of functionality, some of which is very useful, for example a number of automatic layout algorithms.
The most important advantages and disadvantages of the yEd Graph Editor are summarized in table 3.2.

3.3.2 Framework: yFiles

The yFiles framework (see [yFia]), also developed by yWorks, is the underlying framework with which the yEd Graph Editor was realized. The yEd Graph Editor itself shows that yFiles is a powerful framework for graph drawing and

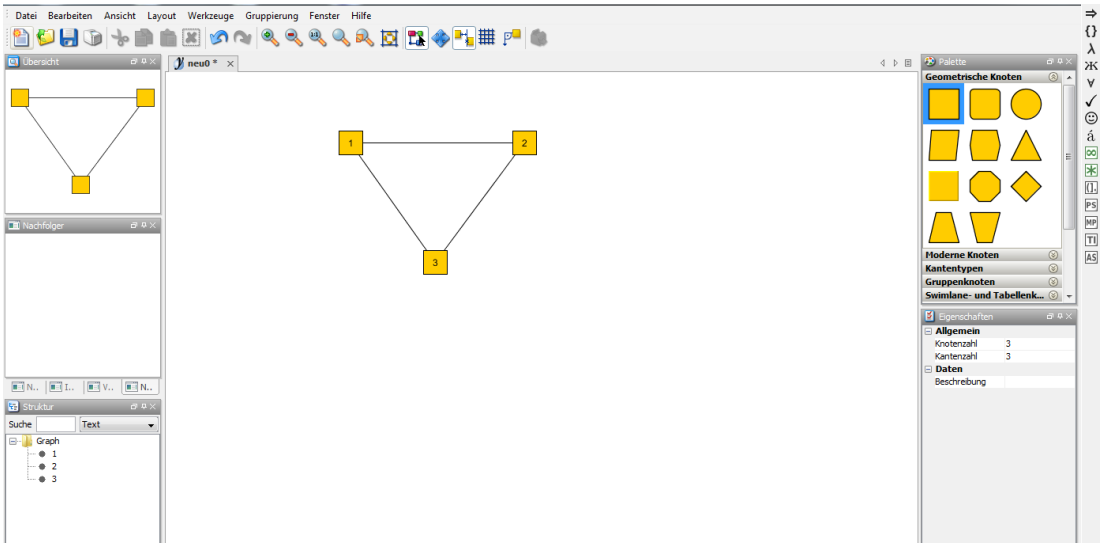


Figure 3.8: Main user interface of the yEd Graph Editor

that comfortable tools can be created using it. The advantage of the framework in contrast to the tool is of course that the framework can be used to create a specialized visualization that is cut down to the exact requirements and no external tool needs to be employed.
The biggest disadvantage in this context is that yFiles is not free to use ([yFib]). A license is required. This is such a severe disadvantage in the context of a bachelor thesis that a further analysis of advantages and disadvantages is obsolete.

3.3.3 Framework: JUNG

The Java Universal Network/Graph Framework (JUNG-framework) is an open source framework for java (see [JUNa]). It encompasses among other features:

- Basic interfaces like graph, hypergraph, forest, etc. as well as basic implementations of these.
- Algorithms from graph theory, such as shortest path, minimum spanning tree, but also algorithms from specialized graph theoretic problem domains like social network analysis.
- Visualization classes that ease the task of drawing graph layouts.

Advantages	Disadvantages
The yEd graph editor is an already completed tool, so very little effort needs to be spent in order to build a visualization	Very difficult or even impossible to integrate into the user interface of RiskTest, needs to be used externally
Very comfortable and intuitive user interface with a large amount of graph customization possibilities	Data transfer could be problematic, communication with RiskTest needs to run over files.
Some automatic layout algorithms are already implemented	Communication is especially difficult when data is changed in the visualization and the trace project needs to be updated
	Not open-source which means that extensions are not possible
	Direct filtering of the visualized graph not possible to implement, visualized part of the trace project could only be prefiltered

Table 3.2: Advantages and disadvantages of the yEd Graph Editor

The most important advantages and disadvantages of the JUNG framework are summarized in table 3.3.

3.3.4 Framework: OGDF

The Open Graph Drawing Framework (OGDF) is a framework similar to the JUNG-framework (see [OGD]). The major differences are:

- OGDF is a c++ library
- OGDF implements more of the approaches that were discussed in chapter 2 than JUNG
- OGDF does not provide support for the visualization of the graph itself, only layouts are implemented.

Advantages	Disadvantages
JUNG is a java framework, so it can be easily integrated into the Eclipse environment	Visualization needs to be built, leads to a higher expenditure of time
Good Documentation: several examples and tutorials exist that demonstrate the correct usage	Visualization is only embedded into swing, RiskTest uses SWT, this could lead to the necessity of an external swing window
Some automatic layout algorithms are already implemented	Several automatic layout approaches discussed in chapter 2 are not implemented
JUNG is a free, open source framework	
Clear and logical software architecture, different interfaces for different functionalities	
Several graph specific algorithms that could be useful are implemented	
Supporting java classes designed for an easy visualization of graph layouts exist	

Table 3.3: Advantages and disadvantages of the JUNG framework

The most important advantages and disadvantages of the OGDF framework are summarized in table 3.4.

3.3.5 Overall Comparison and Decision

As the tables listing the advantages and disadvantages already hinted, the JUNG framework is suited best for the creation of a visualization for RiskTest. While the yEd Graph Editor offers great usability in dealing with visualized graphs, the usage of an unchangeable external tool brings too many drawbacks, especially in the category of data transfer and communication. These drawbacks do not even arise if an own visualization is built.
yFiles is likely a high quality framework for graph drawing and visualization, however it not being free to use is unacceptable in the context of a bachelor

Advantages	Disadvantages
More automatic layout approaches implemented than in JUNG	OGDF is a c++ library, which may lead to difficulties and drawbacks when integrating it into RiskTest, which is a java application
OGDF might outperform JUNG. Note that no tests were made to confirm this assumption. It is purely based on the fact that properly written c++ code is usually faster than java code	No built-in support for interactive graph visualization, even higher amount of time needed than with the JUNG framework
OGDF is free to use	
Good Documentation: several examples and tutorials exist that demonstrate the correct usage	
Clear and logical software architecture, different interfaces for different functionalities	
Several graph theoretic algorithms that could be useful are implemented	

Table 3.4: Advantages and disadvantages of the OGDF

thesis, especially since free alternatives exist.
Finally the OGDF framework does have two advantages over JUNG, but in the following it is explained why they are not that important or outweighed by the disadvantages:

Performance: It is important to keep in mind that algorithms from OGDF might not even run faster than the JUNG algorithms, as it was already explained in table 3.4. Even if that is the case though, the requirements stated that for this bachelor thesis it is sufficient to assume that the trace project can have at most 2000 trace points. 2000 vertices is a moderate number in terms of algorithm runtime. There are no bounds on the number of trace connectors except that multiple trace connectors between the same

pair of trace points are not allowed. This results in a maximum number of 1.999.000 edges in the (very unlikely) worst case of a complete graph.
In short this means that the worst possible case of a graph on which to run algorithms is: $G = (V, E)$ with $|V| = 2000$ and $|E| = 1.999.000$. While 2 million edges is undeniably a large number, runtime for most graph theoretic algorithms on this graph should still be tolerable, even in a "slow" programming language like java. The only restricition is that one might want to avoid algorithms with $O(|E|^2)$ time or higher.
While the analysis for the worst case is theoretically interesting, it is highly unlikely that any graph with that size will ever need to run through a layout algorithm since viewing all 2000 vertices at once will seldom be the intention of the user. It is much more likely that only a small subgraph is of interest in which case the question of performance becomes negligible.

More layout approaches implemented: The availability of fully implemented layout algorithms does save time, but given a clear specification of the layout algorithm, implementing it should not take too much time either. JUNG does already provide some algorithms, which makes the amount of time that is needed for additional layout algorithm implementations manageable.
In addition JUNG provides utility classes that greatly reduce the effort for actually visualizing the graph which more than makes up for the possible effort of implementing a missing layout algorithm.

To sum it up one can say that OGDF does offer some advantages over JUNG, but they are not relevant in this case. On the other hand, the two advantages that JUNG has over OGDF (support for visualization and being a java-library) are very relevant. That means that the JUNG framework is suited best. Now that the framework that is to be used was determined, it is time to choose useful graph drawing algorithms the visualization should encompass.

3.4 Graph Drawing Algorithms

Chapter 2 laid out different approaches to graph drawing and categorized them. Now it is time to revisit those categories and decide whether an algorithm of it

should be included in the visualization. This is done in table 3.5. Each of the categories from which an algorithm is implemented in the visualization is revisited and the algorithm is explained in detail in chapter 5.

Algorithm category	Included	Justification
Planar Graph Drawing Algorithms (2.2.2.1)	No	Neither a normal, nor a hierarchical trace project is assuredly a planar graph, so algorithms would often fail, or result in non-planar drawings.
Symmetric Graph Drawing Algorithms (2.2.2.2)	No	It is unclear how many symmetries the algorithms would be able to find in a trace project. Results from the same algorithm could strongly differ with different subgraphs. As it was already stated, symmetry can come at the cost of an increased number in edge crossings, which again hinders readability. Additionally the JUNG-framework does not provide an algorithm specialized on symmetrical layouts, thus additional time would be needed to implement one.
Hierarchical Graph Drawing Algorithms (2.2.2.3)	Yes	If a trace project is hierarchical (which it is in the standard uses of RiskTest) it fits the requirements of the Sugiyama method. That means that the algorithm is specialized to aesthetically draw graphs of exactly the type the trace project and all possible subgraphs are. This promises good results and is worth the effort of implementing it, which is necessary because JUNG does not provide it.

Tree Drawing Algorithms (2.2.2.4)	No	A non-hierarchical trace project is not necessarily acyclic, which means that tree drawing algorithms could only be applied for hierarchical trace projects for which the Sugiyama method should return better results.
Spine and Radial Graph Drawing Algorithms (2.2.2.5)	No	Spine and radial drawing algorithms might yield interesting results for non-hierarchical trace projects and their subgraphs, but for the hierarchical ones the Sugiyama method will most likely do better.
Circular Graph Drawing Algorithms (2.2.2.6)	Yes	Circular drawing algorithms can visualize any type of graph and might yield good results for some non-hierarchical trace projects, where the Sugiyama method cannot be applied. JUNG does provide a single-circular drawing algorithm, so implementing this in the visualization barely costs any effort.
Simultaneous Graph Drawing Algorithms (2.2.2.7)	No	The requirements state nothing about visualizing two or more trace projects at the same time, or that different trace projects are even supposed to operate on a common set of trace points. Thus simultaneous graph drawing algorithms are not needed.

Force-Directed Graph Drawing Algorithms (2.2.2.8)	Yes	Force directed drawing algorithms are flexible and tend to yield viable results for any graph, provided it is not too large. They promise to work well for non-hierarchical trace projects and therefore present themselves as an alternative to the circular drawing algorithms. JUNG provides an implementation of the Fruchtermann-Reingold algorithm, which is a refined force directed algorithm.
Three-Dimensional Graph Drawing Algorithms (2.2.2.9)	No	Three dimensional drawings call for different user interaction possibilities (for example rotation) than two dimensional drawings, so mixing both in the same application may lead to complications or confusion.

Table 3.5: Graph drawing algorithm categories and their usefulness for the RiskTest visualization

Now that the requirements were collected, a suitable framework has been found and promising automatic layout algorithms for graphs were chosen, the visualization can be designed.

Chapter 4

Design

When designing the visualization two aspects need to be considered: The actual visual design and the design of the underlying software architecture. Both are subsequently dealt with in this chapter.

4.1 Design of the Visualization

As the requirements stated, the visualization of the trace project is not simply a static display of information, but must allow the user to interact with it and thus manipulate the underlying data. This means that the visualization of the trace project needs to be included in a basic user interface. To distinguish this new user interface from the current user interface of RiskTest the user interface that is to be designed and implemented will from now on be called the RiskTest Graph User Interface (RTGUI) The general design of the RTGUI is presented in figure 4.1. The data-part of the requirements (subsection3.2.1) specified that the user should be able to browse all trace points of a trace project and employ filter mechanisms. For that purpose another window was designed: the trace point browser. Its basic design can be seen in figure 4.2. In the resulting implementation the user should then be able to open the trace point browser via the RTGUI (fiugre 4.1) in order to add trace points to the view.

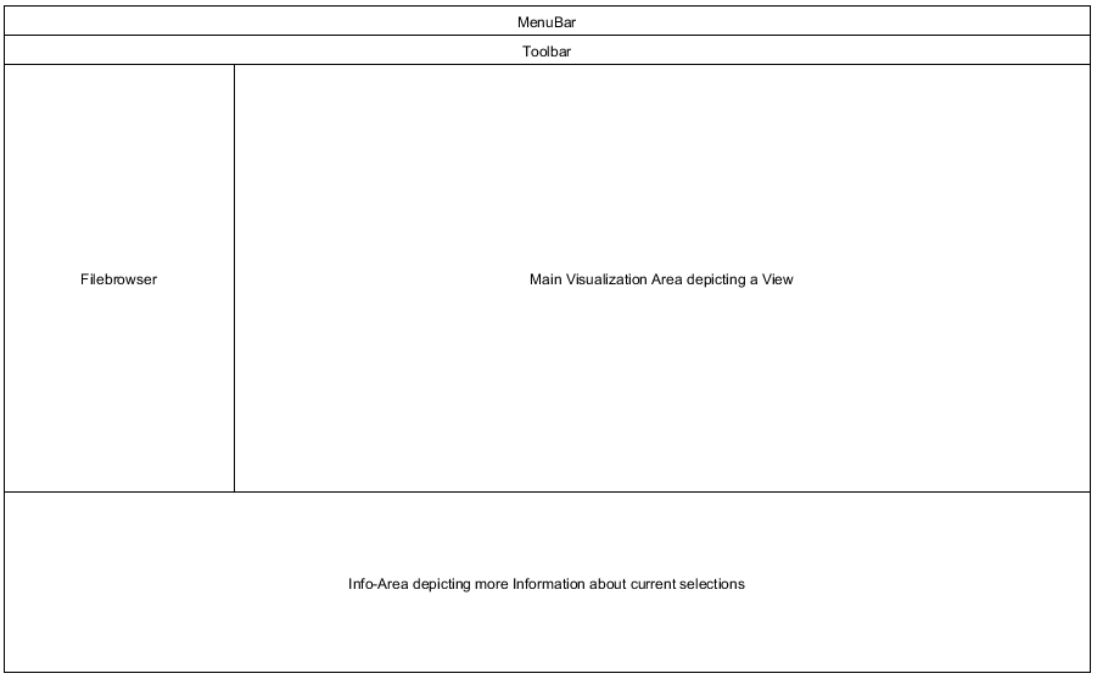


Figure 4.1: Basic design of the RiskTest-GraphUI (RTGUI)

4.2 Design of the Software Architecture

The RTGUI is not only supposed to allow interaction with the layouts, but also manipulation of the underlying trace project. In order to avoid confusion and unwanted side effects a good software architecture for dealing with data, its visual representation and user interaction is needed. The model-view-presenter (MVP) software pattern offers exactly this by clearly separating visualized data from the underlying data-model. A slightly modified version of the MVP pattern is used in the implementation of the RTGUI. The normal MVP pattern only has one model-class, which is not enough in this context. Two models are needed because the actual underlying data model is already given through the trace project of RiskTest but it was already established that the trace project may differ from the visualized graphs since these may include virtual edges introduced by filtering mechanisms. The flow of information in the resulting application is visualized in figure 4.3. As it was pointed out in the analysis, the JUNG framework does have a natural support for visualization included. This support

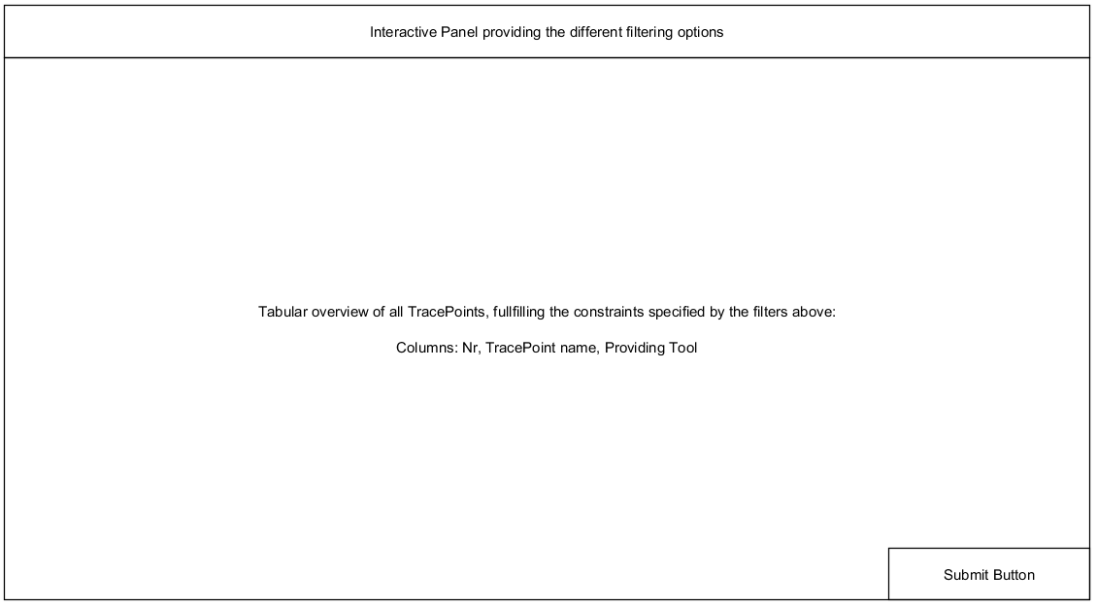


Figure 4.2: Basic design of the trace point browser

however is only able to interact with the swing library of java, which leads to the necessity of developing the visualization as a swing application. This is not problematic for the development of the RTGUI itself since swing offers a large amount of functionality. It does however have the drawback that the RTGUI cannot be easily integrated into a window in the existing interface of RiskTest since that interface uses SWT classes instead of swing. It is however easy to open the user interface in a second window parallel to the interface of RiskTest. The only alternative to that would be not to use the classes of JUNG that support the visualization of graphs which would lead to a much higher expenditure of time since the functionality of these classes would have to be at least partly reimplemented into SWT compatible classes.

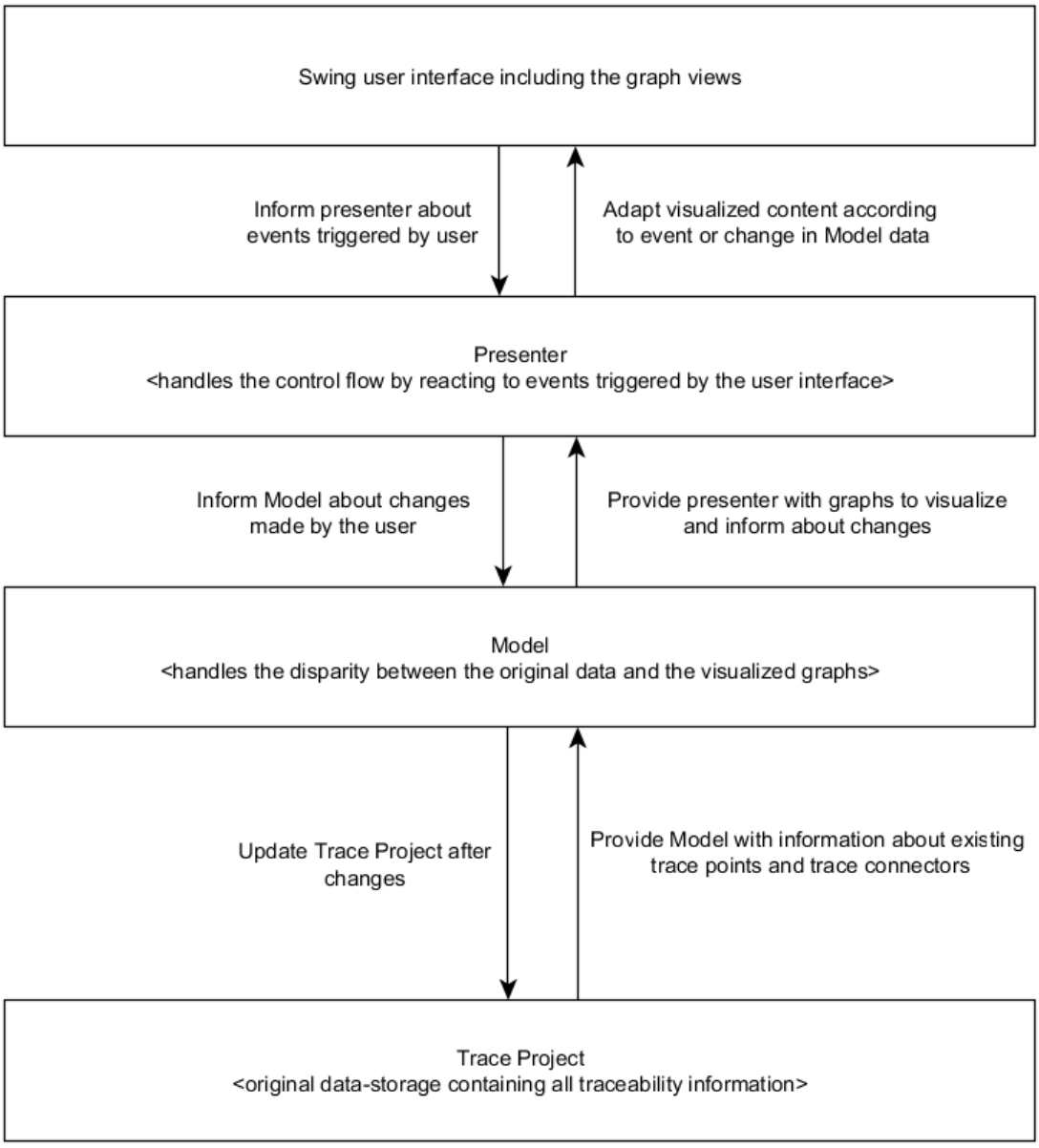


Figure 4.3: Software architecture with regard to the exchange of information

Chapter 5

Implementation

This chapter illustrates the results of the implementation of the RTGUI. At first a closer look on the resulting user interface is taken. The chapter then proceeds with an enumeration of all packages contained in the eclipse plugin that implements the RTGUI. Afterwards the usage of the JUNG-framework is explained, followed by a description of the most important classes and their interactions. This chapter then concludes with a detailed explanation of the algorithmic core of the RTGUI: The automatic graph layout algorithms.

5.1 Resulting User Interface

Chapter 4 introduced the basic design of the RTGUI. The result of the implementation is shown in figures 5.1 and 5.2. The implementation is close to the actual design. Only the following changes or additions were made:

- The Main-Visualization area consists of multiple tabs that can be opened or closed by the user. This allows the user to quickly switch between different views.
- The visualized graphs are drawn inside a window with scrollbars, which means that graph layouts that are larger than the area of the tab can be displayed.
- The bottom area displaying additional information only shows the neighbor-

hood of the selected trace point. Other additional information is revealed by mouseover effects.

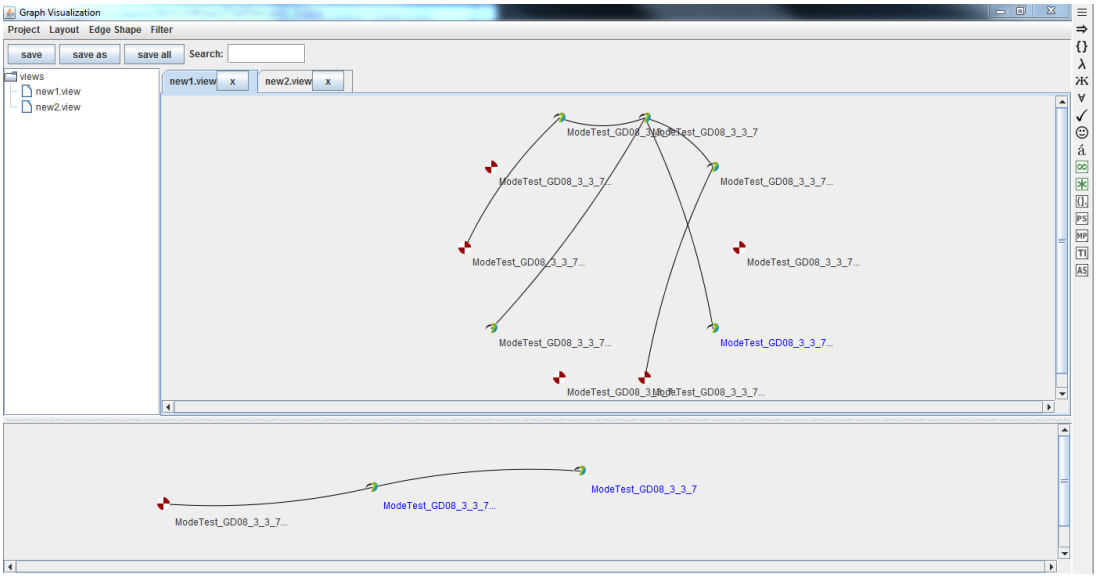


Figure 5.1: RTGUI implementation

The interactive features specified by the requirements were implemented. The following enumeration lists all interactive features of the menu bar, as well as the toolbar.

- The "Project" menu allows the user to
  - save the current view to a file.
  - load a new view from a file.
  - open the trace point browser.
- The "Layout" menu allows the user to select between the three different automatic layout algorithms that are included and apply them to the currently selected view.
- The "Edge Shape" menu allows the user to change the way the edges are drawn in the current view.

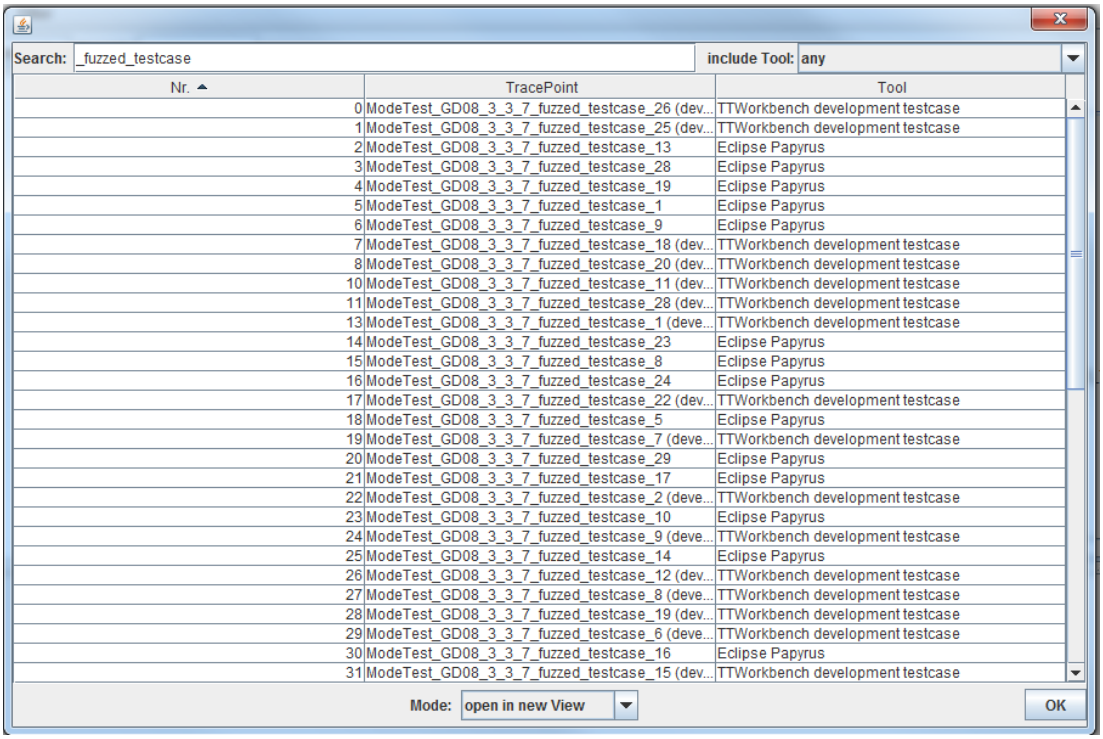


Figure 5.2: Implementation of the trace point browser

- The "Filter" menu allows the user to
  - activate or deactivate filtering in the current view.
  - change the filter configuration in the current view.
- The three buttons in the toolbar provide additional view-saving functions.
- The "Search" text field in the toolbar allows the user to enter any string and the visualized trace points that contain this string in their name are selected.

The following enumeration lists all interactive features that are not contained in the menu bar or toolbar.

- Double-click on one of the view files shown in the left component opens this view in a new tab.

- Left-clicking vertices or edges selects them, shift modifier expands the selection instead of creating a new one.
- Left-clicking a vertex additionally shows its neighborhood (concerning the trace project) in the bottom component (neighborhood-view). The neighborhood-view may also show trace points that are not included in the currently selected view.
- Left-clicking on a selected vertex and dragging the mouse moves all selected vertices.
- Right-Click in a tab opens a context menu, which allows the user to
  - create traces.
  - delete traces.
  - remove trace points (this does not change the trace project, the vertices are simply no longer depicted in the view).

The trace point browser allows the user to browse through all trace points of the current project. The trace points can be filtered by their name or by the providing tool. Selected trace points can either be opened in a new view or can be added to the current one.

5.2 Packages

The implementation is a java eclipse plugin with the following packages:

presenting The *presenting* package includes all classes that work on the level of the presenter in the MVP pattern.

dataModels The *dataModels* package includes all classes that work on the level of the model in the MVP pattern. Additionally it includes classes that are needed for the data of some RTGUI components such as the class *CustomTableModel* which is needed for the trace point browser.

layouts The *layouts* package includes all possible graph layouts that can be applied to a graph. Most of these are subclasses of classes already existing in the JUNG framework.

graphUI Standard package for the eclipse plugin that only contains the class activating the plugin if it is needed, as well as the *Main* class responsible for the initialization of the RTGUI and a class defining a basic SWT-window that provides a button to open the external swing user interface.

extensions The *extensions* package contains subclasses of already existing classes. These subclasses usually have a highly specialized purpose, for example dummy trace points, that act as dummy vertices in a graph, which the Sugiyama method requires.

interfaceComponents The *interfaceComponents* package contains all components of the RTGUI windows.

projectConverter The *projectConverter* package contains a number of utility classes for the purpose of transforming information obtained by the trace project into graph structures that the RTGUI requires.

transformers The *transformers* package contains any classes that implement the Transformer interface. They are necessary for the correct drawing of the graph.

util The *util* package contains utility classes that provide commonly needed functionality.

5.3 Usage of the JUNG Framework

This section gives an overview over the most important interfaces and classes provided by the JUNG framework and how they are used in the implementation.

Graph The most basic yet important interface is of course the *Graph* interface. It defines a large amount of essential methods that allow the manipulation of the graph as well as tests for adjacency or incidence. JUNG also provides implementing classes, such as *SparseGraph* or *SparseMultiGraph*.

Layout The *Layout* interface is basically a transformer that maps vertices of a graph to a coordinate. Implementations are the different existing graph layout algorithms. Used in this visualization are the classes *FRLayout* and *CircleLayout*.

VisualizationServer This interface is the main support for visualization. Its implementation, *VisualizationViewer*, takes a graph layout as input and then visualizes the graph. To do so it subclasses *JComponent* and therefore can be put anywhere in a swing window. The interaction with the graph visualization is highly customizable. The *VisualizationViewer* class offers several methods that can modify the default interactive behavior.

RenderContext Each *VisualizationViewer* has a reference to an object that implements this interface. The *RenderContext* offers several more ways to customize the graph visualization, for example vertex appearance, edge shape, vertex and edge labeling or edge painting.

For the full Javadoc of the JUNG framework see [JUNb].

5.4 Important Classes and Interactions Between Them

5.4.1 Realization of the MVP Pattern

The modified MVP pattern that was decided on in the design (see figure 4.3) was applied. The class *interfaceComponents.GraphUI* is the main class concerning the user interface. It integrates all parts of the user interface into one frame. It is instantiated and called upon by the *presenting.Presenter* class. This class handles the logic of the user interface by reacting to user actions, communicating with the data model and updating the interface via method calls to the GraphUI-object. The *dataModels.Model* class administers the data to be presented to the user. It is instantiated and called upon by the presenter object. Furthermore the *dataModels.Model* class is responsible for separating visualized data from the

original traceability data (trace project). For this purpose it uses the *projectConverter.ProjectConverter*. This class provides abstract methods in order to transform information from the trace project into user presentable data.

5.4.2 Bridge to the RiskTest Plugin

Obviously the data model requires access to the data of the RiskTest plugin. All communication is handled with the help of the *de.fraunhofer.tracing.util.TraceManager* class and the *org.yakindu.crema.model.tracing.util.ModelUtil* class. These classes access the trace project which contains all traceability related information.

5.4.3 Visualization of the Views

As figure 5.1 already illustrated the views are visualized inside scroll areas. These scroll areas are visualized inside of tabs so that multiple views can be opened at the same time. The structure of the implementation can be seen in figure 5.3. The central class administrating all relevant information for drawing a view is *TabDataStructure*. The *Presenter* class obviously has a number of references to these, depending on how many views are currently opened. One *TabDataStructure* object has a reference to a *File* object, which contains the path of the corresponding file. A *TabDataStructure* instance has two layouts, one filtered and one unfiltered. Which of these layouts is currently being visualized is stored in a boolean. The filter rules that were applied are stored in the *FilterConfig* class. A *TabDataStructure* object also has a reference to the *VisualizationViewer* that is managing the actual visualization and a reference to the *GraphZoomScrollPane* that contains the *VisualizationViewer*. The *TabDataStructure* instance is also able to configure the *RenderContext* of its *VisualizationViewer*. *TabDataStructure* objects are configured, initialized and manipulated by the *Presenter*.

5.5 Graph Layout Algorithms

This section describes the layout algorithms that were implemented in detail.

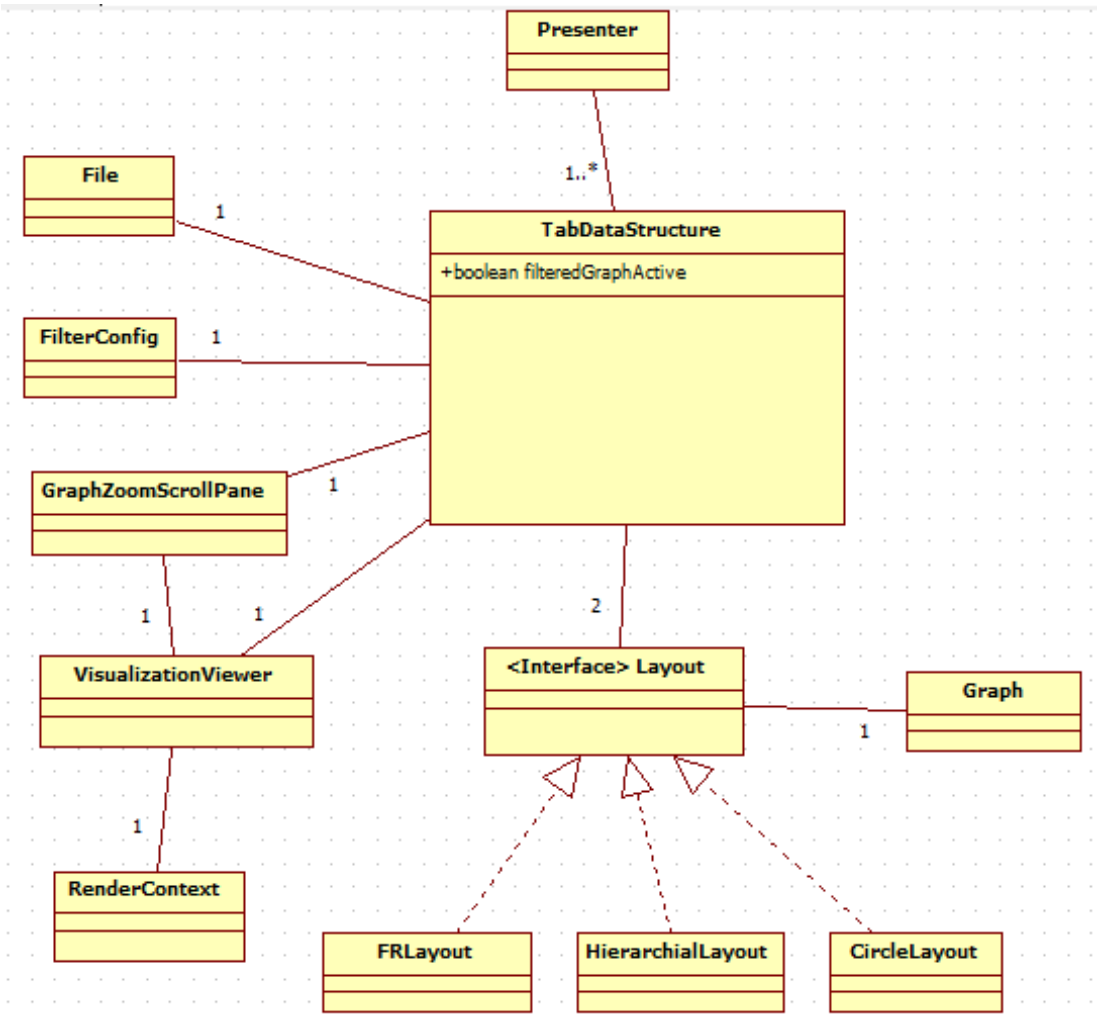


Figure 5.3: Classdiagram showing the implementation of the views

5.5.1 Fruchtermann-Reingold Algorithm

The Fruchtermann-Reingold Algorithm is a force-directed graph drawing algorithm. As subsection 2.2.2.8 already explained, force-directed graph drawing algorithms belong to the most flexible and universal graph drawing algorithms. The basic concept behind all force-directed drawing algorithms is inspired by physical forces between the vertices. The vertices will be moved according to the sum of all forces exerted on them until either they have stabilized and no more movements occur or a certain number of iterations is exceeded. Then all edges are drawn (usually as a straight line, but other methods of drawing edges are possible).
The pseudocode given in algorithm 1 shows the general principle of a force directed algorithm. The formulas for calculating the attractive and repulsive

```
Data: Graph G = (V,E) , Integer n
Result: positions: A Map of positions
positions = new Map();
positions = initWithRandomValues();
i=0;
while i < n do
    newPositions = new Map();
    for v ∈ V do
        f = calculateResultingForce(v,positions,G);
        newPosition[v] = calculateNewPosition(f,positions[v]);
    end
    positions = newPositions;
    i = i + 1;
end
```

Algorithm 1: Simple Force-Directed Layout Algorithm

forces, as well as the distance the vertices are to be moved per unit of force can be adjusted quite a bit. This results in many different force-directed algorithms. One of them is the Fruchtermann-Reingold algorithm, which is already implemented in the JUNG framework. The Fruchtermann Reingold algorithm has the additional idea of a global temperature that starts at an initial value and then linearly decreases. If the temperature is lower, the vertices are moved less distance per unit of force. This means that as the algorithm progresses (and the

layout becomes better) the adjustments become smaller. The most important functions for the Fruchtermann Reingold algorithm in a graph $G = (V, E)$ are:

- The optimal distance between two vertices $k = C\sqrt{\frac{area}{|V|}}$
- attractive force: $f_a(d) = d^2/k$,where d is the distance
- repulsive force: $f_r(d) = -k^2/d$,where d is the distance

The complete algorithm is given in algorithm 2. An example layout calculated by the Fruchtermann-Reingold algorithm can be observed in figure 5.4. For more information on force-directed algorithms see [Kob07].

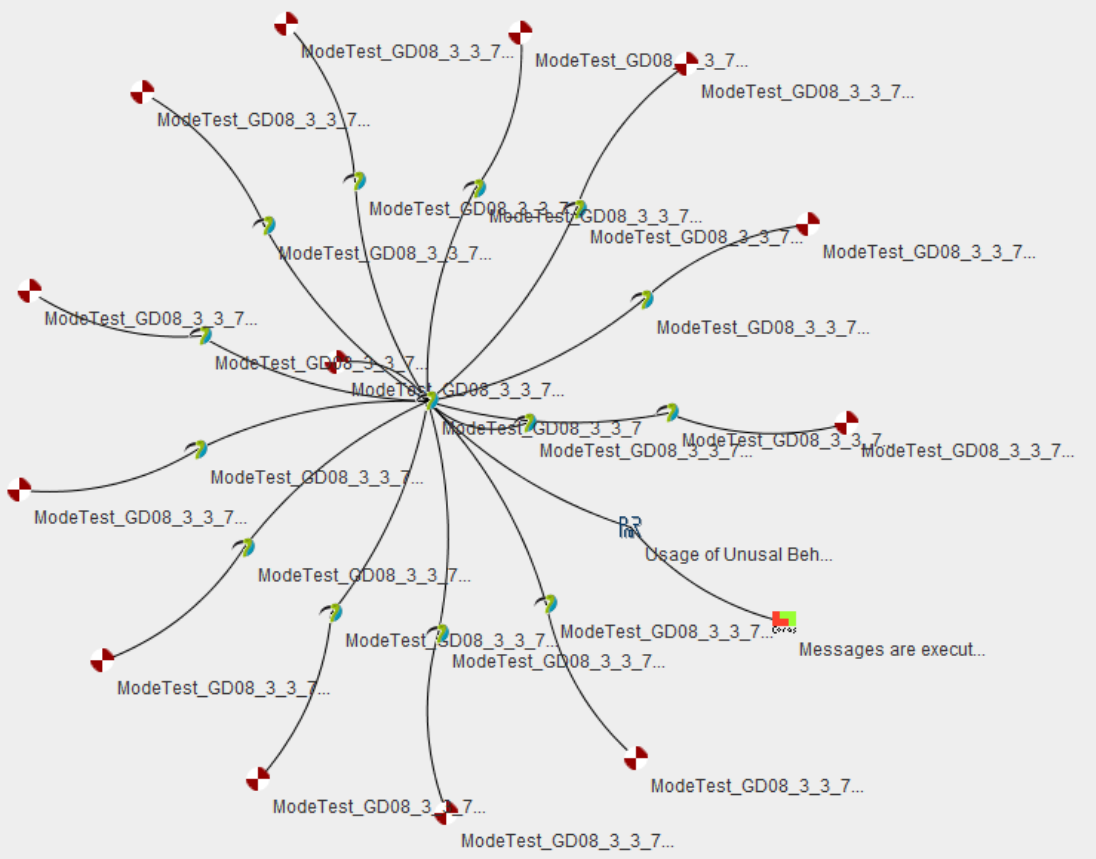


Figure 5.4: Layout created by the Fruchtermann-Reingold algorithm

Data: Graph $G = (V, E)$;
Integer n; //number of iterations
$area = W * L$; //W and L are width and length
$k = \sqrt{\frac{area}{|V|}}$;
for *(i=1 to n)* **do**
  `// calculate replusive forces`
  for $v \in V$ **do**
    `// each vertex has two vectors as attributes: .pos and .disp`
    $v.disp = 0$;
    for $u \in V \backslash u$ **do**
      $\delta = v.pos - u.pos$;
      $v.disp = v.disp + (\delta / |\delta|) * f_r(|\delta|)$;
    end
  end
  `// calculate attractive forces`
  for $e \in E$ **do**
    `// each edge is an ordered pair of vertices: .v and .u`
    $\delta = e.v.pos - e.u.pos$;
    $e.v.disp = e.v.disp - (\delta / |\delta|) * f_a(|\delta|)$;
    $e.u.disp = e.u.disp + (\delta / |\delta|) * f_a(|\delta|)$;
  end
  `// update positions, limit maximum displacement to current temperature and prevent displacement being out of the frame`
  for $v \in V$ **do**
    $v.pos = v.pos + (v.disp / |v.disp|) * min(|v.disp|, t)$;
    `// Previous line was modified, original source had` $v.disp$ `instead of` $|v.disp|$ `when calculating the minimum`
    $v.pos.x = min(W/2, max(-W/2, v.pos.x))$;
    $v.pos.y = min(L/2, max(-L/2, v.pos.y))$;
  end
  `// reduce temperature`
  $t = cool(t)$;
end

Algorithm 2: Fruchtermann-Reingold Algorithm, taken from [Kob07]

5.5.2 Sugiyama Method

Healy and Nikolov describe the Sugiyama method or Sugiyama framework as the most popular approach to drawing hierarchical graphs (see [HN07]). In order to yield good results it requires directed, acyclic graphs as an input. If the trace project is hierarchical then it can be interpreted as a graph that is nearly completely acyclic and directed, which makes the Sugiyama method applicable. The Sugiyama method can be divided into 5 steps:

1. Cycle Removal
2. Layer Assignment
3. Edge Concentration
4. Vertex Ordering
5. x-Coordinate Assignment

The algorithm that is described here is at times a modified version, specifically created for the context of traceability.

Cycle Removal

The first step, cycle removal, is done to transform an input graph of any kind into a directed acyclic graph, which the following step requires. The trace project can be transformed into a directed acyclic graph by employing knowledge about the domain hierarchies. Therefore the suggested algorithms for cycle removal are not explained in this thesis. If these methods are of interest they are described in [HN07]. The transformation of the trace project into a directed acyclic graph works in the following way:

1. Edges between trace points of different domains are interpreted as directed edges, the trace point of the higher domain is the head, the other one the tail.
2. Edges between trace points of the same domain are ignored for the calculation of the Sugiyama method's layout and are dealt with afterwards. An

alternative to this would be to impose directions on these edges as well, but it is unclear how to do that in a reasonable way. Furthermore, it would complicate the next step (layer assignment). Additionally, edges between trace points of the same domain are rare, so ignoring them will probably not hurt the resulting layout too much.
A disadvantage of this decision is however that the method will now certainly fail to produce good layouts for non-hierarchical trace projects. These are not dividable into a clear hierarchy, which means that the amount of layer internal edges will be much higher.

After these two steps the trace project is now a directed acyclic graph, which is necessary for the next step.

Layer Assignment
The second step, layer assignment, requires a directed acyclic graph $G = (V, E)$ as an input and returns a proper layering L of G. Important terminology and explanations (also see [HN07]):

Layering Let $L = \{L_0, L_1...L_h\}$ be a partition of the vertex set of a graph $G = (V, E)$ then L is called a layering of G with the layers $L_0, ..., L_h$ if $\forall(u, v) \in E$ if $u \in L_i \wedge v \in L_j$ then $i > j$.

Vertex rank The layer or rank of a vertex is the number of its corresponding layer. The function that returns the rank for each vertex is called l. It short: $l(u, L) = i \leftrightarrow u \in L_i$.

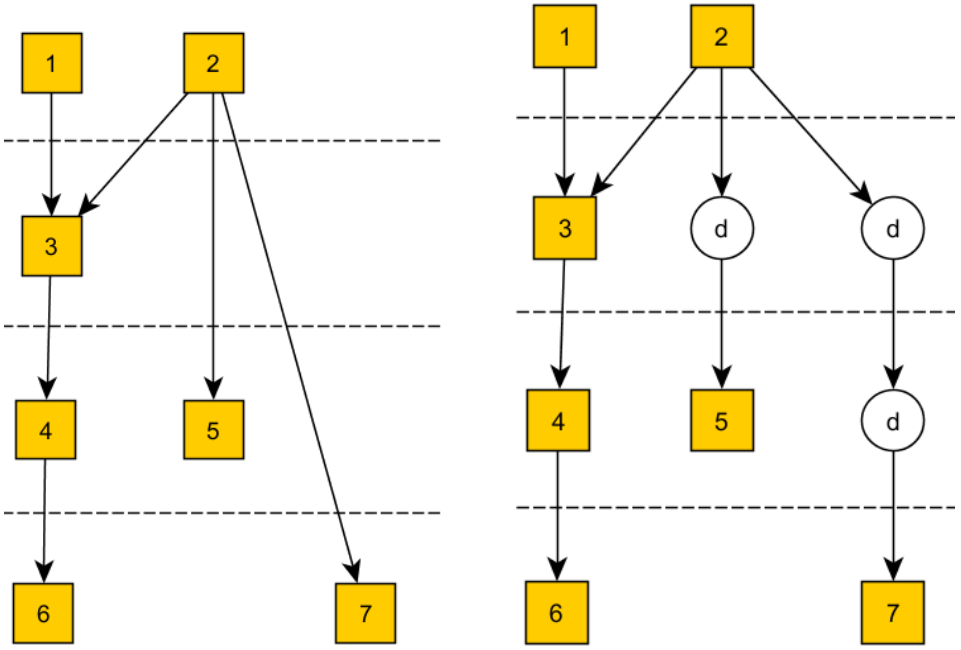
Edge span The span of the edge $e = (u, v) \in E$ in the layering L is defined as $s(e, L) = l(u, L) - l(v, L)$.

Tight Edges An edge $e \in E$ is tight in the layering L if $s(e, L) = 1$.

Proper Layering A Layering L of a graph $G = (V, E)$ is proper if all edges of E in L are tight.

It is clear that by categorizing trace points according to their domains and imposing direction on the edges as it was done in step 1 (cycle removal) a layering

was already obtained. Thus the layering algorithms described by the Sugiyama method are not further described in this thesis. They can be consulted in [HN07]. To make a layering proper Healy and Nikolov suggest the introduction of dummy vertices to split all edges that are not tight. Figure 5.5 shows the creation of a



(a) (b)

Figure 5.5: (a) shows a non-proper layering, that is made proper by the introduction of dummy vertices in (b)

proper layering from a normal layering via dummy vertices. This algorithm is intuitive enough that pseudocode is skipped here.

Edge Concentration

The third step is optional. It aims to reduce the number of dummy vertices, edges and therefore also edge crossings. This however comes at the cost of additional, artificial layers which is undesirable, since the current set of layers has the desirable feature of reflecting the involved domains. Therefore it is advisable to skip the step in this application.

Vertex Ordering

The vertex ordering step is also often called crossing minimization since it solely aims to reduce edge crossings between adjacent layers. The number of crossings is determined by the relative order of the vertices. What is ideally searched for is a sequence of vertex-permutations (one for each layer) so that the number of global edge-crossings is minimized. When attempting this one meets the problem that this is proven to be NP-hard. Even for the comparably simple case of only 2 layers (a bipartite graph), with one layer already having a fixed order of vertices, the problem of minimizing edge-crossings remains NP-hard (see [HN07]).
Nonetheless there are a number of heuristic and exact methods solving this problem. Running time of the exact ones will of course exponentially increase with the number of vertices but for small graphs they are viable. The different methods can be categorized into one-layer minimization, two-layer minimization and multi-layer minimization.
In the context of the RTGUI the greedy-insertion heuristic of the one-layer minimization category is used. While not ideal, the algorithm is simple and can easily be applied to a multilayered graph. The basic idea is: If V_1 and V_2 are the two vertex partitions of a bipartite graph and the order of V_1 is fixed, do the following: Order the vertices of the free layer from left to right by starting with the first position and insert the vertex $v \in V_2$ at the current position if v minimizes the edge crossings of its incident edges to all edges incident to unchosen vertices.
In order to reduce crossings between all layers this is done iteratively for each pair of adjacent layers. Additionally, edges between dummy vertices should not be allowed to cross, since this would strongly reduce the readability of these long edges in the final layout. This is achieved by assigning dummy vertices an already fixed position when introducing them and ignoring them in the crossing reduction step.

x-Coordinate Assignment

The previous step results in a layered graph with a fixed order of vertices for each layer. This step is called x-coordinate assignment because most of the times hierarchies are drawn from top to bottom, meaning that the first layer is drawn on top, the last one on the bottom. Normally the distance between each of the layers is the same which only leads to the necessity of now determining an x-

coordinate for each vertex (y-coordinate is determined by its layer). Of course hierarchies can also be drawn left to right. This results in a rotation of 90 degrees, which means that for hierarchies drawn from left to right, the step x-Coordinate assignment actually determines the y-coordinates of the vertices. The algorithms for the coordinate calculation are of course applicable in both cases.
The main goal of this step is to straighten as many edges as possible by vertically (horizontally if left to right) aligning connected vertices. There are different approaches for this problem. The algorithm that was used here is the algorithm by Brandes and Koepf [BK01] which Healy and Nikolov describe as one of the best. The basic idea of the algorithm is to place a vertex at the median of its lower neighbors' positions, thus minimizing the sum of the lengths of its incident edges. This can result in different types of conflicts which need to be resolved. Note that during this step, the order of the vertices should no longer be changed, since this was done in the step before. A detailed description of the algorithm can be looked up in [BK01]. The paper about their algorithm was published in [MJL01].

Layer internal edges
This step is not present in the Sugiyama framework because the layer assignment algorithms that are normally applied result in a layering without edges between vertices of the same layer. In the context of RiskTest these edges were simply removed for the calculation of the layout. After adding them back to the graph the layers may become unreadable due to edges intersecting vertices. There are several possible methods in order to deal with this problem. Note that they should not significantly alter the layout achieved by the Sugiyama method. The imaginable solutions are:

- Do nothing, but inform the user that hierarchy internal edges may obstruct the overview. The user is then able to use the layout as a basis and manually manipulate it until a satisfying layout is created. This has the advantage of being both convenient and reasonable in most cases, since hierarchy internal edges are rare.

- Draw all of the internal edges in an orthogonal way. That way, internal

edges may overlap, but at least they do not intersect vertices.

- Move vertices with many layer internal neighbors a bit up or down (in case of left to right layer drawing: left or right), so that edges no longer overlap and do not intersect vertices. The difficulty here is to determine a border on the number of internal neighbors that needs to be exceeded in order for a vertex to be moved. Additionally if too many vertices are moved by the same amount and these also share edges, the original problem arises again.

Since it is known that hierarchy internal edges are rare, the first method was decided on. While it is certainly not ideal to have the user correct flaws in an automatic layout algorithm, it is a practical solution. After all, the user knows best what kind of adaptions to the layout make it the most readable for him or her.

The adapted variant of the Sugiyama method described above was implemented in the RTGUI. Its implementation is done by the class *layouts.HierarchialLayout*. An example layout calculated by the Sugiyama method is shown in figure 5.6.

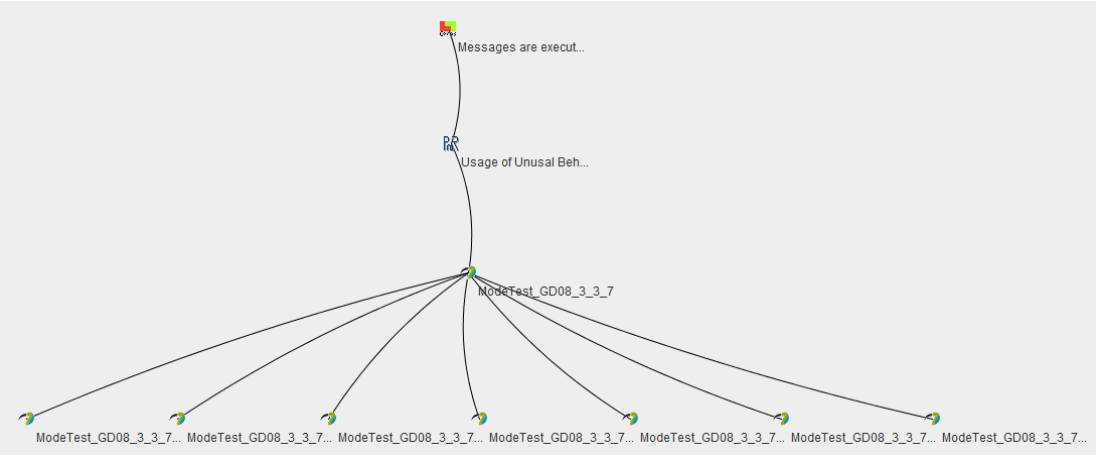


Figure 5.6: Layout created by the Sugiyama method after slight user modifications

5.5.3 Circle Layout

Circular drawing algorithms can be applied to any graph. Thus they provide an alternative to force-directed graph drawing algorithms when dealing with non-hierarchical trace projects. The JUNG-framework provides a single-circular drawing algorithm which is included in the visualization. Since it remains unclear which specific algorithm is implemented by the JUNG-framework, no further description can be given. An example layout calculated by the circular layout algorithm can be observed in figure 5.7.

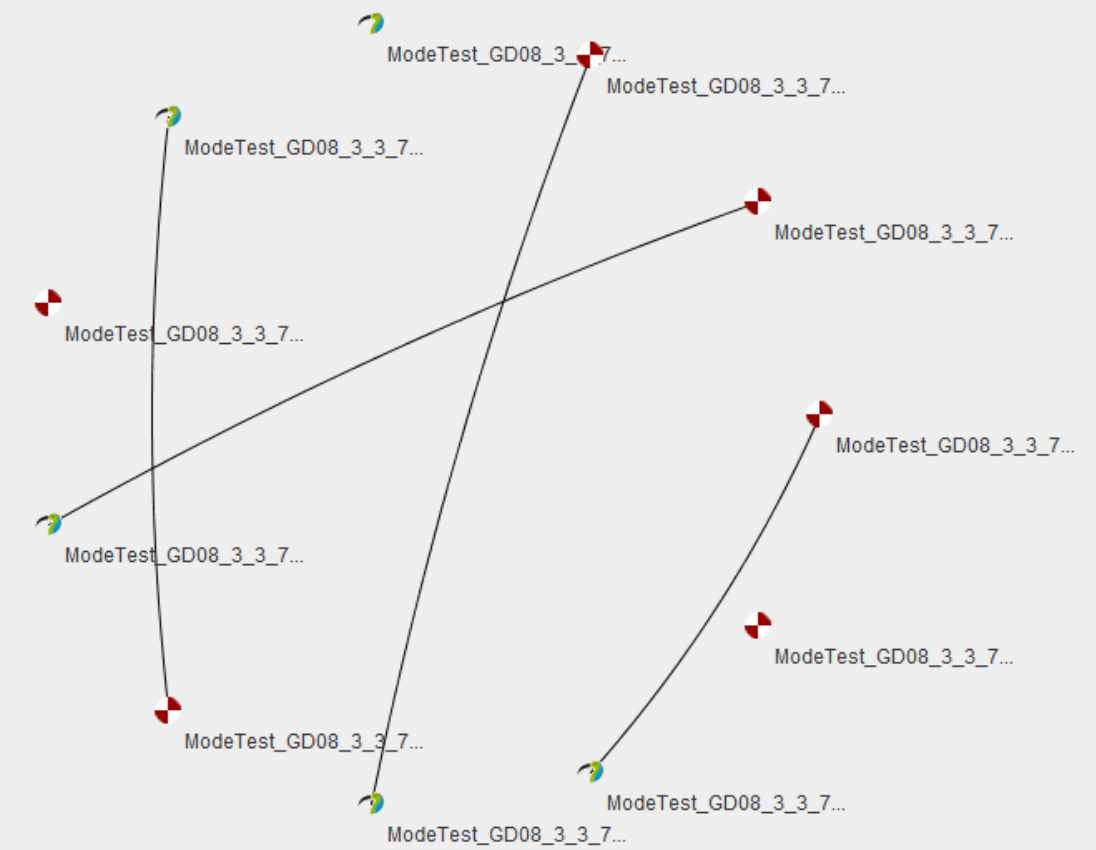


Figure 5.7: Layout created by the circular layout algorithm provided by the JUNG framework

Chapter 6

Validation

This chapter validates that the implementation of the RTGUI satisfies the requirements that were collected.

Section 5.1 already explained the interactive features that the implementation offers. By comparing these with the requirements that were collected in chapter 3 one can already see that all of them were met. To further demonstrate that, this chapter presents an example usage of the RTGUI. With an example project, the following shall be achieved via RTGUI:

1. Get a general overview over the traceability structure of the example trace project.
2. If necessary, manually change the layout of the visualized graph until a clear and aesthetically pleasing layout is achieved.
3. Save this layout as a view.
4. Modify the example trace project via the RTGUI.
5. Find out how many test cases can be traced to a security risk.
6. Save another view depicting these traces.

At first the RTGUI is opened and it displays its initial state (see figure 6.1). One can see in the project browser on the left that there are no views saved in the

project directory at the moment.
To access the trace project the trace point browser is opened (see figure 6.2). It

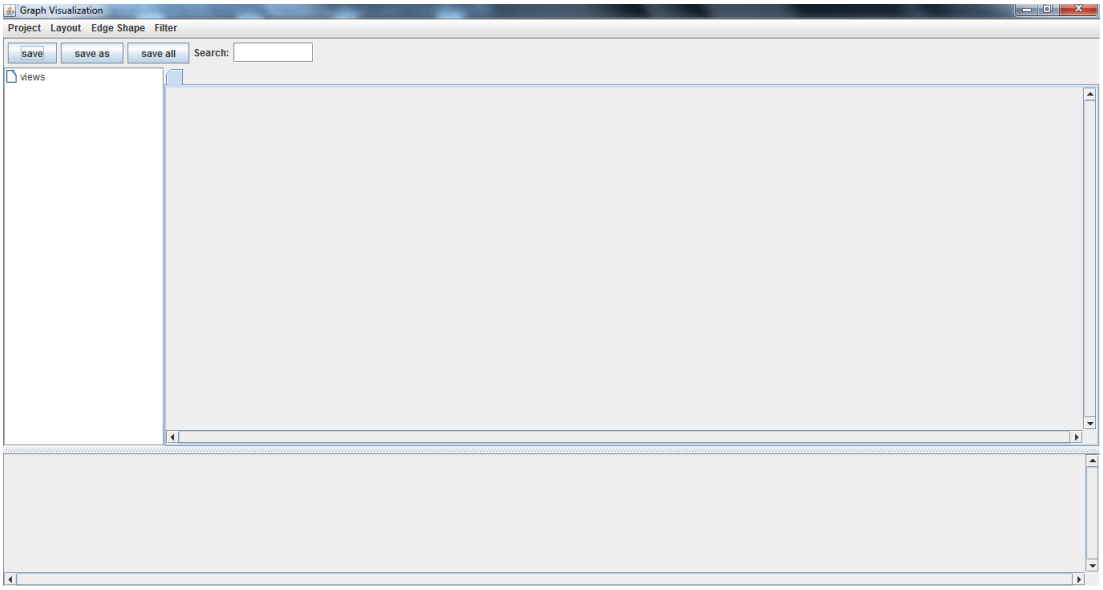


Figure 6.1: RTGUI is initially opened

reveals that there are 63 trace points in this project. By employing the filter at the top-right corner, one can quickly get an overview over the distribution of these trace points among the different providing tools:

- 1 trace point by CORAS
- 1 trace point by ProR
- The rest of the trace points are almost evenly divided among Eclipse Papyrus and TTWorkbench: 31 trace points by Eclipse Papyrus and 30 by TTWorkbench.

63 is a comparably low number of trace points for a trace project, but a rather large number of vertices to visualize in one graph (the higher the number of vertices, the more complex the graph, thus the more difficult to find a good visualization). Nonetheless it shall be tested how the layout algorithms perform. All trace points are selected and opened in a new view.

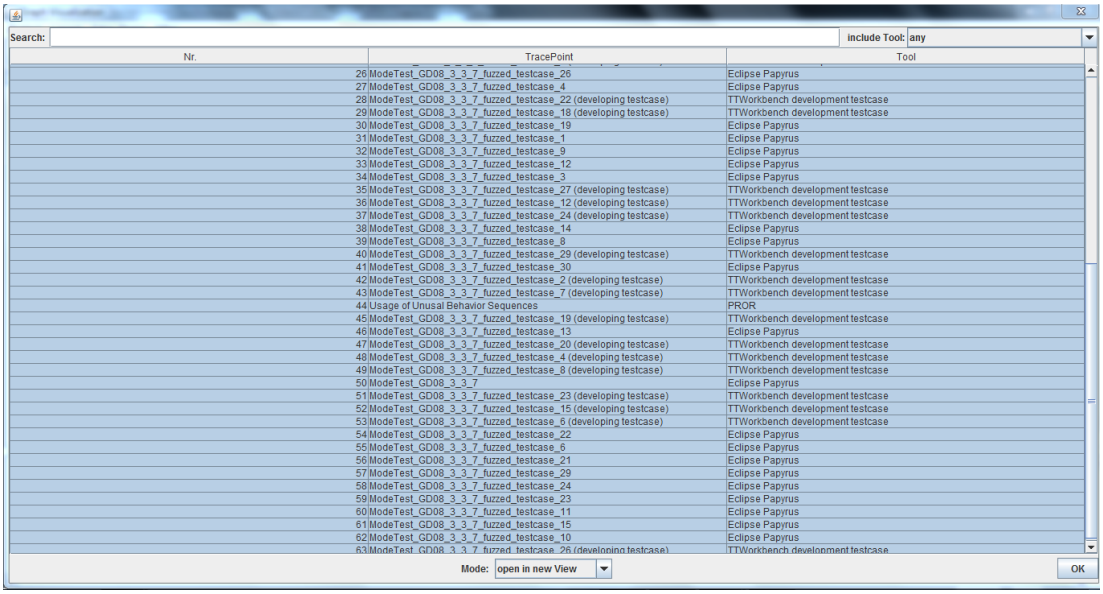


Figure 6.2: The trace point browser reveals all trace points in the example trace project

Figure 6.3: The whole trace project is visualized as a graph

The standard layout algorithm that is applied to the traceability graph is the hierarchical layout algorithm (Sugiyama method). The layout algorithm correctly identifies the hierarchies, the layout does however seem to have the flaw of many layer internal edges (discussed in subsection 5.5.2) in the third layer which makes the layout hard to read. Additionally the layout is space consuming due to high minimum vertex distances. Thus the layout is switched to the Fruchtermann-Reingold layout (see figure 6.4).
The Fruchtermann-Reingold layout immediately returns more pleasing results. It

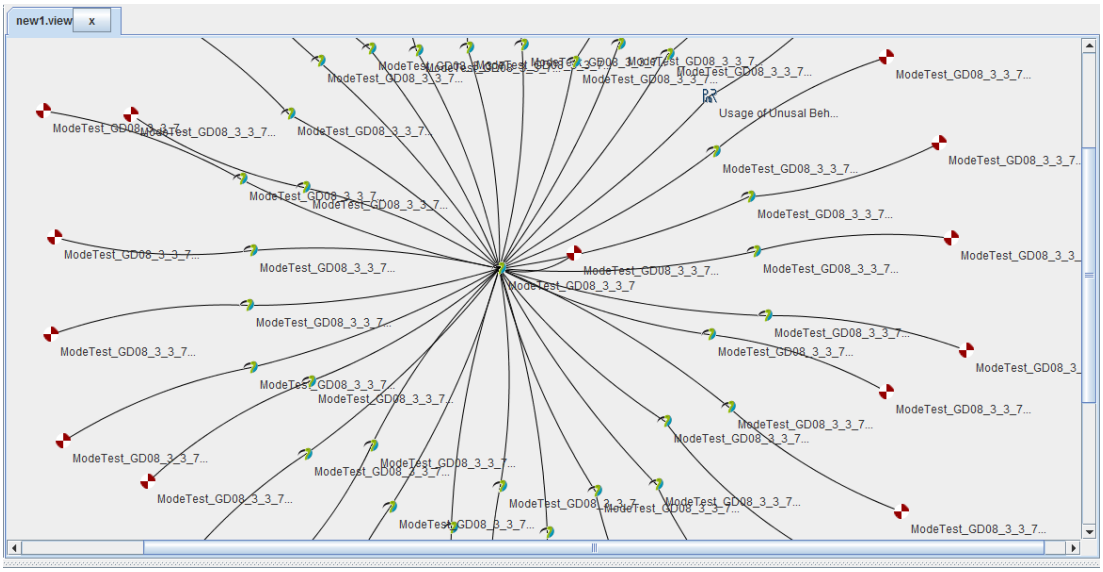


Figure 6.4: Switch to the Fruchtermann-Reingold layout

manages to reduce the area in which the graph is drawn, resulting in smaller distances the beholder needs to scroll in order to view the whole graph. Additionally and more importantly one can now identify the traces much better since edges no longer overlap. The problem for the hierarchical layout seemed to have been a central trace point in the layer of Papyrus, which is connected to all other trace points of Papyrus. A look on the neighborhood of this vertex confirms this (see figure 6.5). The neighborhood can be viewed by selecting the vertex and moving the border between the visualized graph and the neighborhood view upwards.
A disadvantage of the Fruchtermann-Reingold Layout is that the labels of the vertices are not always readable, a problem that did not arise in the hierarchical

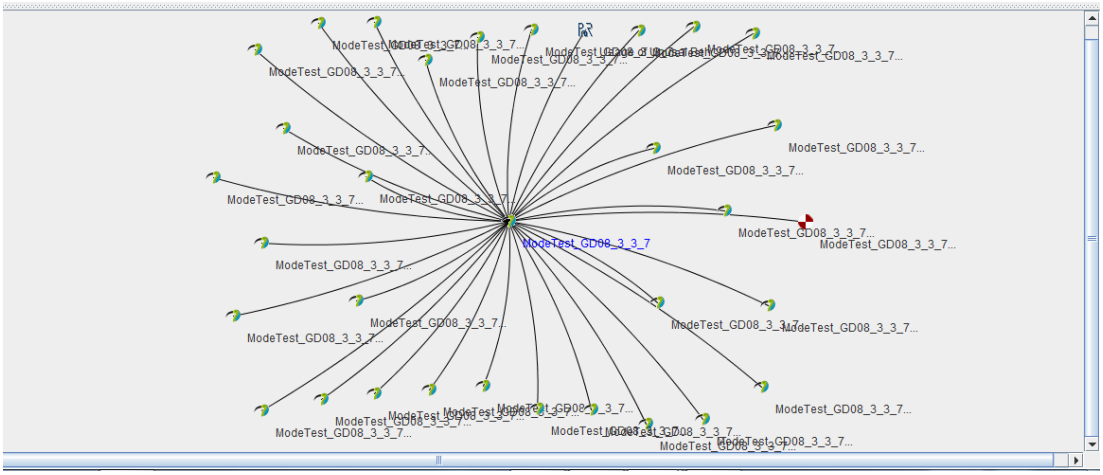


Figure 6.5: Neighborhood of the central trace point

layout, due to the high minimum vertex distances. In order to have both advantages, the view that was achieved by the Fruchtermann-Reingold layout is saved, and the layout is once again changed to the hierarchical layout. The central vertex is now manually moved upwards, which resolves the issue of the layer internal edges (see figure 6.6).

What remains to note about the hierarchical layout though is that the number of edge crossings between the third layer(Papyrus) and fourth layer(TTWorkbench) is very high, which results in bad readability in this part. The Fruchtermann-Reingold layout clearly showed the fact, that in this project one actual test case (TTWorkbench) is connected to exactly one modeled test case (Papyrus). The hierarchical layout fails to do so due to the high number of edge crossings between the two layers. It seems that the vertex ordering heuristic that was chosen in the crossing minimization step of the Sugiyama method(see subsection 5.5.2) is not ideally suited for this particular trace project.

The manually improved layout is saved as well. Now, as an example of project modification, the traces between four trace points shall be swapped. The swap is done by creating the new traces and deleting the old ones (see 6.7).

That the modification of the trace project was successful is shown in figure 6.8 which depicts the tracing explorer, a part of the RiskTest user interface that allows to see relations between the trace points in a tree-like structure.

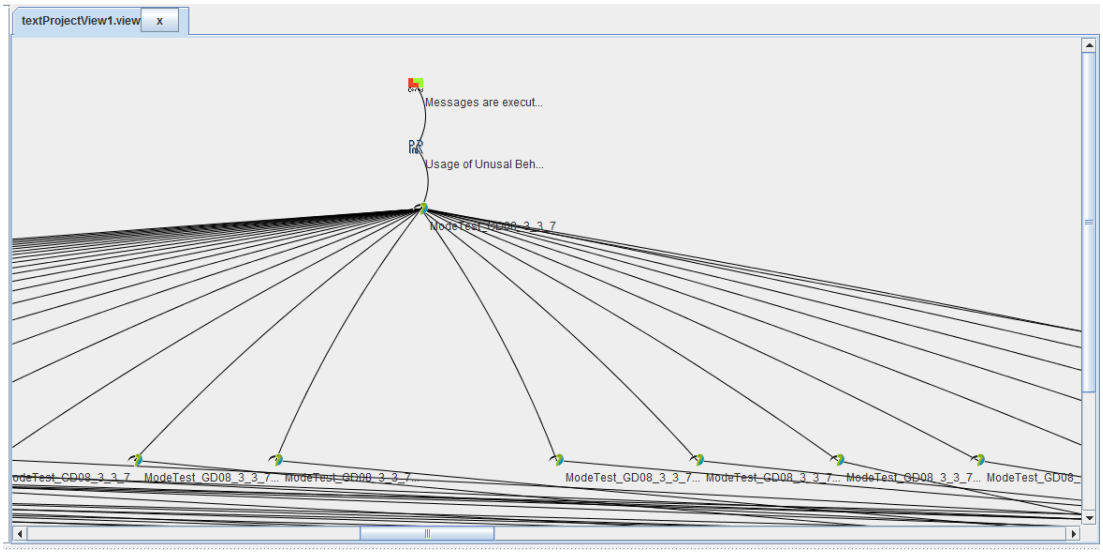
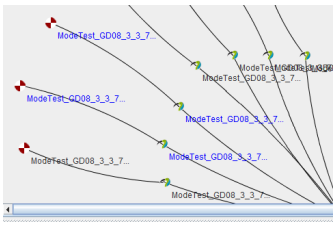
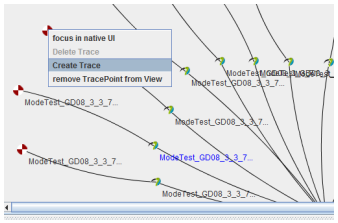


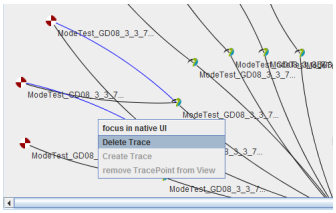
Figure 6.6: Manually improved hierarchical Layout



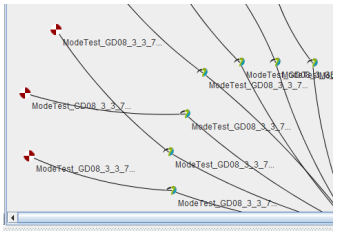
(a) initial state, trace points of interest are marked



(b) new trace is created via context menu



(c) old trace is deleted via context menu



(d) state after the modifications

Figure 6.7: Example modification of the trace project

The tracing explorer shows that indeed the *fuzzed_testcase_8* of Papyrus is now

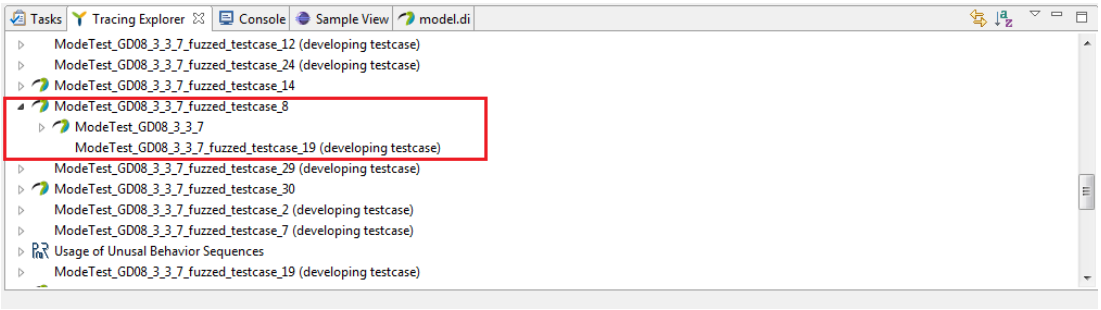
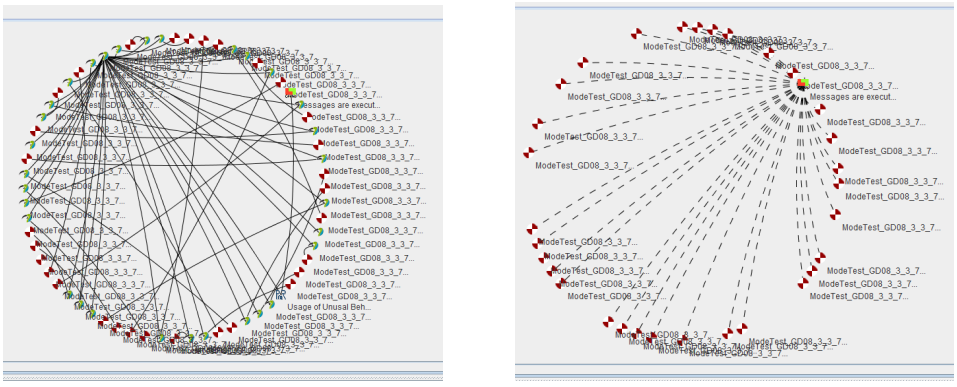


Figure 6.8: TraceExplorer reflects the changes made via RTGUI

linked with the *fuzzed_testcase_19* of TTWorkbench.
It is now of interest how many test cases can be traced to the security risk(trace point of tool CORAS). In order to properly visualize this, the trace points of ProR and Papyrus do not need to appear in the visualized graph. Since this trace project reflects the standard use of RiskTest, the providers can be put into hierarchical relations. Thus the filtering options that are applied do not result in the loss of any information, since virtual edges will be inserted. In order to find a compact visualization the circle layout is chosen and the providers ProR and Papyrus are filtered from the view. The comparison between the unfiltered



(a) unfiltered circle layout (b) filtered circle layout

Figure 6.9: New layouts to find out how many test cases can be traced to the security risk

layout and the filtered layout in figure 6.9 shows that filtering options combined with the notion of virtual edges are a powerful approach to strongly reduce complexity while still preserving traceability information. The filtered layout can now be further improved by moving the security risk to the center (see figure 6.10). Figure 6.10 also shows that the actual neighborhood of the security risk in the trace project has not changed. The actual neighborhood is depicted in the neighborhood view below the circle layout.
After applying the filter it is easy to see that all 30 test cases in this trace project have traces to the security risk.

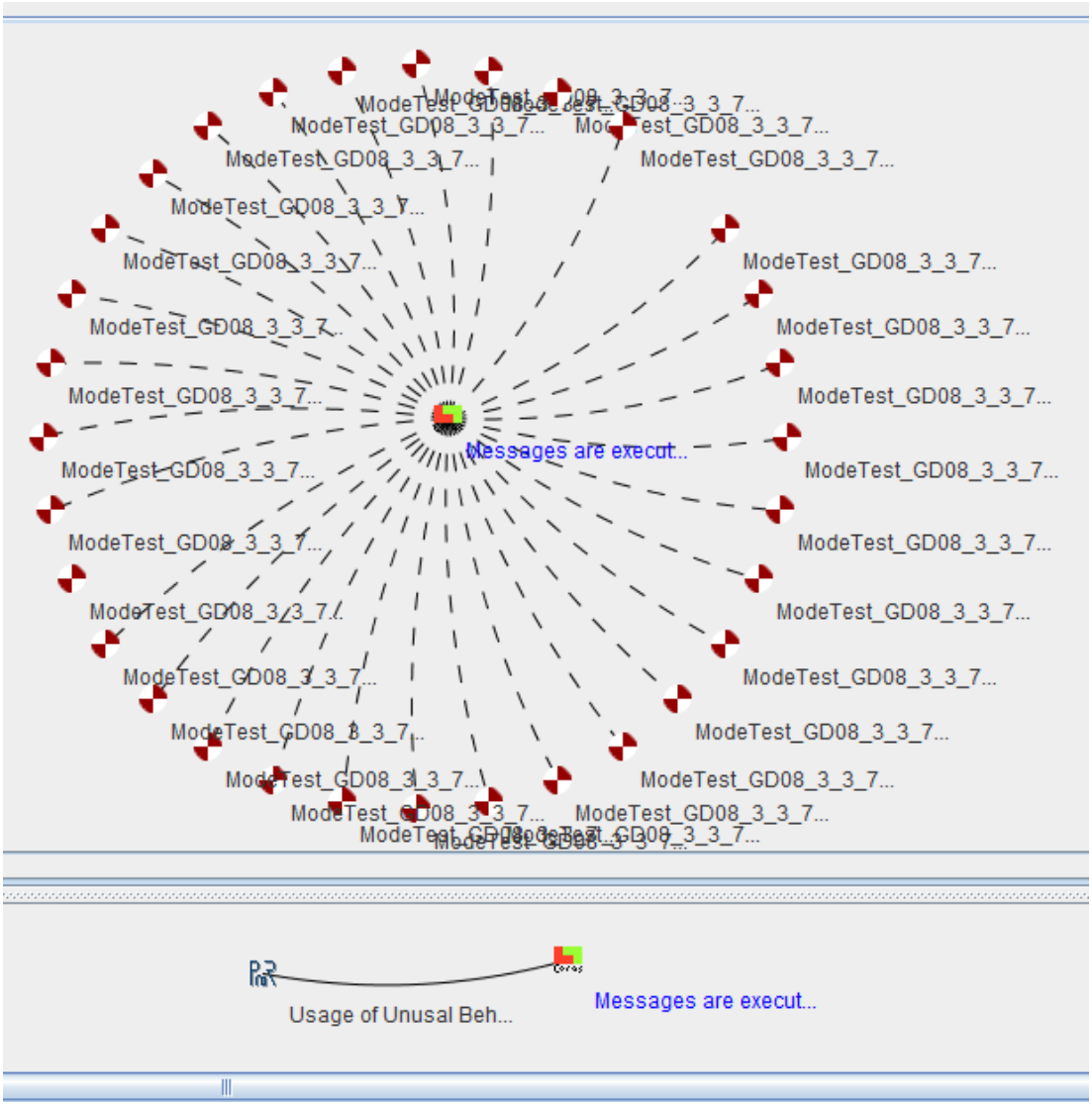


Figure 6.10: Final layout, including the neighborhood view of the security risk

Chapter 7

Conclusion and Prospects

This chapter concludes the thesis and gives an overview over possible goals in the future.

7.1 Conclusion

The goal of this thesis was to create a visualization for dependencies (traces) between artifacts of different tools in the RiskTest traceability framework.
Traceability data, that means a set of artifacts and a set of links between those, has the form of a graph which made graph visualization a central topic of this thesis. It was shown that while there are many categories of graph drawing algorithms, not all of them are viable for the domain of traceability, since some of them require constraints that are not given in the very general task of visualizing traceability data. The algorithms that were decided on are the Fruchtermann-Reingold algorithm, a force-directed graph drawing algorithm, the Sugiyama method, a hierarchical graph drawing algorithm, and a single circular graph drawing algorithm. All of these algorithms were of use during the validation phase, which implies that the choice was justified.
Furthermore it was established that a static visualization is not sufficient. The visualization was required to have many interactive features which led to the necessity of developing of a basic user interface containing the visualized data. Therefore the RiskTest Graph User Interface (RTGUI) was developed, which combines the visualization of traceability data with interactive possibilities. To facilitate

the development of the RTGUI, several graph drawing frameworks and tools were inspected out of which the JUNG framework (Java Universal Graph/Network Framework) was suited best for the development of the RTGUI.
The RTGUI was successfully implemented and integrated into the RiskTest traceability framework which means that the overall goal of this thesis was achieved. Even though the visualization of traceability data was successfully implemented there are still relevant topics and open issues that were not extensively dealt with in this thesis. The last section briefly mentions each of these.

7.2 Prospects

Usability Usability, although undoubtedly an important factor when creating user interfaces, was not the main topic of this thesis, since its focus was laid on finding appropriate ways to visualize traceability data. Thus the usability of the RTGUI could still be enhanced, for example through the addition of key bindings, drag and drop functionality, improved look and feel and many other factors that affect usability.

Integration of the RTGUI into the RiskTest Window The necessity of an external swing window came through JUNG's natural support for swing. RiskTest however uses SWT as the basis for visualization. There are some methods that can be applied to integrate swing components into SWT windows. One could try to apply these here. If they are successful, the RTGUI could be integrated into the main Window of RiskTest, which would improve the overall handling of RiskTest.

Graph Drawing: Add a labeling algorithm Currently the labels are placed in default positions by the JUNG framework. In some of the resulting layouts this can result in the overlapping of labels with other labels, edges or vertices. This is of course undesirable since it makes the labels hard to read or can even lead to wrong assumptions if the beholder is confused which label belongs to which vertex. There are algorithms specifically designed for the purpose of labeling a map or a drawing of a graph (see [KGT07]).

These algorithms could be reviewed and applied to further improve the graph layouts.

Graph drawing algorithms for large graphs The layout algorithms that were chosen work well for small to medium sized graphs. They are practical for uses in smaller projects or excerpts of larger projects. However, if it is desirable to view the complete traceability graph of a large project at once, different algorithms will need to be employed. To find out which of these are viable choices for visualizing large amounts of traceability data could be a field of study in the future.

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