Grailog KS Viz 2.0: Graph-Logic Knowledge Visualization by XML-Based Translation

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Abstract

Knowledge visualization is the expression of knowledge through graphical presentations with the goal of validating or communicating knowledge. Formal knowledge, which is used in Data Modeling, the Semantic Web, etc., is based on ontologies and rules, which can be represented in (Description and Horn) logics and presented as (generalized) graphs. Graph Inscribed Logic (Grailog) can be used to visualize RuleML knowledge. The earlier Grailog KS Viz transforms Datalog RuleML to Grailog visualizations in Scalable Vector Graphics (SVG).

This thesis develops a tool, Grailog KS Viz 2.0, that is able to visualize Horn Logic (Hornlog) with Equality. It uses XSLT 2.0 with internal JavaScript to process arbitrary levels of function nesting in a recursive manner. The tool has also been extended from n-ary relations with $n \geq 2$ to those with $n \geq 1$ (including classes as unary relations), based on the labelnode normal form of Grailog.

JavaScript is used to calculate the coordinates for positioning, and determines the dimensions of, the SVG elements and viewport, but is no longer required in the static image. Our Purifier thus removes the internal JavaScript from the static Grailog/SVG visualization generated by the tool. This assures that there are no malicious scripts, reduces the time required to render the Grailog/SVG visualization, and greatly reduces the final file size.

The visualization of function applications with multiple levels of nesting generated by Grailog KS Viz 2.0 was evaluated using test cases that illuminate knowledge about graph-theoretical definitions. A larger use case was developed for teaching the business rules of managing the financial aspect of a non-profit organization. The processing speed as well as quality and accuracy of the rendered SVG are consistently high across common modern Web browsers.

Grailog KS Viz 2.0 thus provides increased security, expressivity, and efficiency for viewing, sharing, and storing Grailog/SVG visualizations.

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Knowledge Visualization (KV) is an area of research that focuses on the articulation of knowledge through visualizations with the goal of communicating knowledge to others or of analyzing knowledge [22]. Knowledge may be visualized using a variety of 2-dimensional or even 3-dimensional formats, ranging from images and graphs to interactive and dynamic immersive environments [11]. Disciplines including e-learning and e-business can benefit from the use of KV to increase the rate and quality of knowledge transfer [22].

The Semantic Web employs formal knowledge, which may be presented visually using graph theory or represented symbolically using predicate logic. Formal knowledge can be expressed as ontologies or rules, both of which can be visualized using graphs. In a graph, the nodes (vertices) represent instances or classes and the arcs (edges) between them represent binary relationships. Formal knowledge visualizations can also use hyperarcs to connect n $\geq$ 1 nodes: Directed hyperarcs can pass through intermediate nodes, allowing for an encoding-free representation of n-ary relationships [6].

KV is important to be able to teach and study knowledge without need for encoding it as a 1-dimensional (natural or formal) textual document. Instead, KV allows a more immediate 2-dimensional knowledge (re)presentation of entities and their connections. KV provides ways to navigate knowledge - to find entities and their connections more easily. On a yet higher lever, KV can also show the organization of knowledge and give a study road map.

Graph inscribed logic (Grailog) is an expressive approach to KV based both on (generalized) graph theory and (advanced) logic. Grailog graphs contain labelnodes which present individuals or classes/relations, the latter permitted as starting points of directed hyperarcs, which can pass through multiple nodes. The various languages of Grailog roughly correspond to languages of the Rule Markup Language (RuleML) system, which can be serialized in Extensible Markup Language (XML). This work will focus on the Relational Grailog languages, corresponding to Datalog/Hornlog/... RuleML, which can be used for KV of relations in mathematics, science (e.g., biology), engineering, as well as IT (e.g., bioinformatics), including for visualizations of the relational data (facts) and views (rules) provided by relational specification/programming languages such as Prolog.

Grailog KS Viz [20] is a tool that transforms “Data Logic” (Datalog) RuleML/ XML knowledge to Grailog visualizations in SVG/XML (Scalable Vector Graphics) using an XSLT (Extensible Stylesheet Language Transformations) translator. The XSLT translates an XML file containing RuleML into SVG, and a browser maps this SVG-encoded Grailog diagram into a 2-dimensional rendering.

1.1 Objectives

The primary objective of this thesis is to further develop Grailog KS Viz into a KV tool, Grailog KS Viz 2.0, for a computationally complete language on the level of Horn Logic (Hornlog). To achieve this objective, the tool has to be extended to include recursively nested terms visualized as complex nodes (boxes) containing a function-application hyperarc. Two other objectives regarding expressiveness are the visualization of head equality as in Datalog$^+$ (and Hornlog$^+$) represented as a special binary atom, and the visualization of unary relations, which requires the labelnode normal form of Grailog. An implementation-level objective is to remove the internal JavaScript from the generated static SVG/XML file, as it is no longer required after the position and dimension values have been calculated. To accomplish this, an XSLT stylesheet has to be created to complete the transformation to pure SVG. The removal of JavaScript by our “Purifier” will serve a dual purpose. One purpose will be to provide assurances to users that the SVG visualizations do not contain malicious scripts. Another purpose will be to increase efficiency for viewing, storing, and sharing the visualizations by reducing both the file size and the time required to render them.

1.2 Thesis Organization

The remainder of this thesis is organized into the following sections:

- Chapter 2 (Background) provides an overview of knowledge visualization and its benefits, the human readability and usability of graph visualizations, the languages that are used in the tool, the previous implementation of the tool, relevant security aspects, and related work.
- Chapter 3 (Design) describes a usage scenario of the tool, the architecture of the tool, an example test case, the requirements met by the tool, the Grailog constructs supported by the tool, and the SVG elements used to create these constructs.
- Chapter 4 (Implementation) describes the development of the Renderer

XSLT and Purifier XSLT.

- Chapter 5 (Use Case in Mathematics) outlines the test cases in math education, the use case in financial mathematics, the unit testing, and evaluation of the tool.
- Chapter 6 (Conclusion) provides a summary of the work completed in this thesis, the results, and possible extensions of this work.

Chapter 2

Background

The foundations that will be needed to develop this thesis are discussed in the following sections. Section 2.1 describes knowledge visualization and its benefits. The human readability and preferred aesthetics of visualizations are discussed in Section 2.2. In Section 2.3, the languages used in the development of the tool are introduced. In Section 2.4, the previous version of Grailog KS Viz is reviewed. The research areas that are discussed in Section 2.5 address the security aspects of SVG and JavaScript. Lastly, in Section 2.6 existing related tools that are used for knowledge visualization will be reviewed.

2.1 Knowledge Visualization

The goal of KV is to provide a more expressive means in order to improve the creation and transfer of knowledge. KV can also enhance the communication of new perspectives about, or connections between, prior knowledge [9]. Visualization of procedural knowledge, which includes rules and processes, allows ease of sharing knowledge and collaboration by the use of shared mental models [26]. Benefits of employing visual presentations include assisting individuals in communicating, improving the ability to remember and recall knowledge, capturing and retaining the attention, and promoting the discovery of new insights [8]. Knowledge is constantly evolving, and its structure continually changes to adapt [18]. The tool allows the visual presentation of knowledge to be easily and efficiently updated or changed as new connections and understandings are identified.

2.2 Human Readability and Usability of Visualizations

The research that has been conducted on the usability of graph visualizations is based largely on the human readability of graphs [3]. The readability of graphs is most commonly associated with understanding and is determined by the user's ability to answer questions regarding graphs. Purchase [25] conducted an empirical study in order to determine which aesthetics have the most impact on the usability of graphs. In the study, usability was determined by the performance of the participants when answering questions about the structure of the graphs, and the participants' preference of graph based on the visual appeal. The graphs used in the study included both syntactic and semantic graphs. Syntactic graphs are generic and contain no real references or information, while semantic graphs are domain-specific [25]. The semantic graphs used in the study were Unified Modeling Language (UML) graphs. The results of the study indicated that the performance of participants was significantly impacted by the number of edge crossings in the syntactic graphs. Both the response time and the number of errors were significantly greater in graphs with many crossings compared to all other aesthetic considerations [25]. In the semantic experiments, participants were asked to select the UML class diagram they preferred. The highest preference was for the diagrams with the fewest crossings. The study concluded that the most important aesthetic to consider in graph visualizations is reducing the number of edge crossings.

To further investigate the claim that edge crossings have the greatest impact on the human readability of graphs, Huang [15] performed a study to determine the extent of the impact. The study compared the number of edge crossings to the crossing angle, which is the angle between crossing edges.

The purpose of the study was to determine the relative importance of one aesthetic over another by examining the relative impact on human performance. Human performance was based on the accuracy of completing the tasks, and the time and mental effort required. The study also examined the visual efficiency of the graphs. A high visual efficiency is attained when there is high accuracy with short response time and low mental effort [15]. The results of the study indicated that the number of edge crossings had a greater impact on task performance, mental effort and visual efficiency than the crossing angle. The recommendations made as a result of the study were to minimize the number of edge crossings whenever possible, and when edge crossings are necessary the crossing angle should be as large as possible to reduce the negative impact of the crossing [15].

The visualization of large Grailog knowledge bases using node sharing may result in numerous hyperarc crossings. Because of the above-discussed usability findings [25, 15], Grailog KS Viz 2.0 thus uses the Grailog node-copy normal form, which allows us to eliminate all hyperarc crossings. Therefore, the Grailog visualizations produced by the tool should be easier to understand and preferable by users compared to visualizations using node sharing.

Another consideration when using node sharing is the placement of shared nodes in a visualization. The visualization's layout can be significantly altered by the location of a shared node, which can impact the user's perception and understanding of the graph [14]. Therefore, the decision of where to place a shared node in a visualization is non-trivial and can result in layouts of varying readability. The use of node copies in the Grailog visualizations generated by the tool will provide consistent layouts whose readability is not dependent on heuristic node placement.

2.3 Languages

The transformation from RuleML to Grailog visualization utilizes a variety of languages. The languages used in the development of the tool are described in the following subsections.

2.3.1 Graph Inscribed Logic (Grailog)

Grailog presents a given 1-dimensional symbolic data/knowledge representation in a 2-dimensional graph-logic visualization [6]. Grailog visualizations are created by mapping symbolic logic constructs to graph logic constructs [6]. Grailog graphs are designed to support human readability of logic. Graph generalizations used in Grailog include n-ary directed hyperarcs, recursive graphs that contain nested graphs to any level of nesting, and labelnode graphs [6]. The Grailog constructs supported by the tool are described in more detail in Section 3.4.

2.3.2 RuleML

RuleML [5] constitutes a system of families of languages used for knowledge representation. The primary focus of RuleML is the sharing and interoperability of facts and rules on the Web [7]. Pretty-printed (level-indented, tree-visualizing) RuleML/XML text [1] could be dubbed a "1 1/2"-dimensional representation, as it is a 2-dimensional presentation but keeps copies for all tags occurring in multiple locations of the XML tree, as in the 1-dimensional serialization transmitted on the Web. The Grailog presentation used in this thesis likewise keeps duplicate nodes, retaining the node-copy form of pretty-printed RuleML/XML for a similar node-copy form of Grailog. In this thesis, RuleML is assumed to be serialized in XML as input for KV translation to Grailog output. Using XML serialization allows easy access and sharing on the Web as well as translation with an XSLT stylesheet. In the thesis, the focus will be on the Derivation RuleML languages Datalog and Hornlog.

Datalog and Hornlog are used to represent relational information. The information could initially be given in the form of (controlled) natural language but is assumed to be transformed into a set of facts and rules in an XML serialization. The Datalog/XML and Hornlog/XML is then XSLT-transformed to Grailog visualization.

2.3.3 Scalable Vector Graphics (SVG)

The SVG format, itself serialized in XML, is used for visualization as it is compatible with all modern Web browsers and its scalability allows for flexible KV. SVG graphics can be enlarged to show detail without affecting the quality of the image. The scalability of SVG allows the same size graphic to be viewed on devices with different screen resolutions and sizes [33]. SVG can act as a Web application since it may contain scripts that are executed each time the image is rendered [13]. The graphic objects required for Grailog visualizations can all be rendered using SVG. The SVG elements used to represent the Grailog constructs are further discussed in Section 3.5.

2.3.4 Extensible Stylesheet Language Transformations (XSLT)

The transformation from RuleML/XML to SVG is realized by an XSLT stylesheet that contains internal JavaScript. XSLT can be seen as a functional programming language over XML trees [24]. We use XSLT Version 2.0 [30]. An XSLT stylesheet specifies the rules for transformations using XSL vocabulary. Templates are used in stylesheets to transform XML by describing the output formatting for the matching nodes in the source XML [30]. A more detailed description of templates is given in Section 4.1.4. XPath expressions are embedded in XSLT and are used to determine the hierarchical structure and position of nodes in the XML tree. The use of XPath expressions is discussed in more detail in Section 4.1.2. The transformation is completed by an XSLT processor which is built into modern Web browsers. In order to automate the transformation in a Web browser, the source XML must contain a stylesheet processing instruction in the prolog (the term "prolog" refers to the header of XML documents and is unrelated the term "Prolog" referring to the standard logic programming language) that refers to the XSLT stylesheet to be used.

2.3.5 JavaScript

JavaScript is an object-oriented scripting language that can be used on all platforms and Web browsers. JavaScript is commonly used in Web applications and can be executed on-the-fly by Web browsers [28]. Grailog KS Viz 2.0 uses internal scripting in the stylesheet to change the size and position attributes of SVG elements and the dimension of the viewport as required by the input from the XML source document. The security aspects of JavaScript and solutions to security concerns are expanded upon in Section 2.4.

2.4 Grailog KS Viz

Grailog KS Viz [20] was developed in two versions; mono-spaced font and normal. In the mono-spaced font version, the type and size of font is specified. The font is courier which uses the same width for every character. This allows the length of the string to be calculated by multiplying the number of characters in the string by the width of a courier font character. The normal version, as it is referred to in [20], does not specify the font to be used in the visualization. The length of the string is determined using the method getComputedTextLength. In the normal version, the font is determined by the Web browser. The reason given for developing two versions was that the XMLSerializer object was not supported by Google Chrome even when using the SVG file [20]. After testing these two versions, it has been found that the normal version in Internet Explorer (IE) does not render the directed hyperarcs for all font settings. The normal version in Mozilla Firefox does not calculate the length of the nodes properly to fit the text for all font settings. The reason the mono-space font version was not supported by Google Chrome is because the XMLSerializer object was not properly instantiated. The SVG generated by the current implementation, Grailog KS Viz 2.0, that uses XMLSerializer and mono-space font can be viewed in common Web browsers including IE, Google Chrome, Firefox, and Safari. The work done in this thesis uses the XMLSerializer and specifies mono-space font as this provides consistent rendering and is not affected by the Web browser font settings.

The earlier implementation [20] does not allow for the important case of unary (n=1) relations. A unary relation - when there is only a single argument node - corresponds to a type/class of which the argument node is a member. Hornlog relations, characterized by arbitrarily nested functional expressions (i.e., complex terms) as relational arguments, are not supported by Grailog KS Viz either. Hornlog inherits the Datalog relational arguments and extends them to also allow functional expressions [5].

2.5 Security Aspects

SVG is to be considered an application, rather than a plain image, as it may contain active content including scripts [13]. Malicious scripts contained in the SVG, when interpreted by the browser, can present a security risk. The SVG/XML generated by Grailog KS Viz 2.0 contains internal JavaScript which is executed each time the image is generated. The internal JavaScript has two primary functions: to calculate, assign and access the position and size values of the SVG elements and viewport, and to access the contents of nodes provided by the user. Neither of these functions pose a threat to users of the tool. Yet, users may choose to remove the JavaScript from the static image of the SVG, as described in Section 3.2, to assure their clients that the images do not contain malicious scripts.

A commonly used security policy for Web browsers that is employed in Google Chrome, IE, and Firefox is the Same Origin Policy (SOP). This policy requires scripts, and the resources they are accessing, to originate from the same location [4]. The policy only allows the internal JavaScript in the Grailog KS Viz 2.0 stylesheet to access sources or content that have the same origin. Origin is defined as the protocol, domain name and port number for Google Chrome. The SOPs for IE and Firefox are not as strict, as they allow exceptions for the port number. IE only requires the same protocol and domain name, and Firefox only requires the port number to be the same if one is specified [23]. The SOP used in Google Chrome does not recognize files stored locally in the same directory as having the same URL, therefore, they are treated as having unique security origins. Consequently, Google Chrome cannot render the Grailog SVG using files stored in a local directory offline. IE and Firefox allow locally stored files to render the Grailog SVG. In IE, the user is prompted to allow active content to be run, but if the user allows them the browser will properly render the drawing. In all cases, the browser security settings must allow JavaScript to execute in order to render the drawing.

Another security tool that is used with Firefox is NoScript, an add-on that deactivates JavaScript code execution [4]. If users interacting with NoScript are not interactively allowing it, the Firefox browsers employing this add-on would not be able to properly render the SVG as the internal JavaScript would not be allowed to execute.

2.6 Related Work

Similar tools are being developed to support users in the visualization of knowledge. One piece of work is the development of SVG visualization for the Fresnel Editor [17]. This application visualizes Resource Description Framework (RDF) data using SVG. RDF data are statements in the form of triples. The visualization process developed for the Fresnel Editor was also applied to the medical field in a tool called Medico SVG used for diagnosis purposes [17].

Another piece of work is GrOWL, which is a tool used for visualizing and editing Web Ontology Language (OWL) [21]. The visualization is in a graph form that utilizes colour, shape, and shading of the nodes in order to convey distinct properties [21]. The tool was developed as a Java application and applet as well as a Protege plug-in. Applications for GrOWL visualization models include education and economics. GrOWL has been used to provide estimates for ecosystem services using an Ecosystem Services Database [21] and in bioinformatics classes as a learning tool. GrOWL does not use node-copy normal form, creating graphs with crossing edges, which can be difficult to read [25]. In order to provide more meaningful graphs, the tool provides the user with a filtering mechanism and a locality restricted view [21]. These mechanisms alter the graphs to provide the user with only the components that are associated with the selected node they want to view.

PaladinRM [2] is a visualization tool that graphically presents system requirements and their organization. This software is primarily designed to be used in team-based management of projects to show relationships between system requirements. The tool uses hierarchical tree-based graph structures that represent the relationships between defining and complying system requirements. PaladinRM eliminates duplicate nodes that appear in multiple levels of the tree structure when the data is displayed graphically. The tool transforms RDF serialized in XML.

Google's Knowledge Graph enhances Google Search by allowing searches to go beyond simply matching keywords by giving users the relevant information about their search [27]. The Knowledge Graph is composed of objects, facts about the objects, and the relationships between the objects. Information is added to the knowledge graph by collecting data about the entities which represent the nodes of the graph. The entities are then connected to closely related objects in the knowledge graph. Sources for the graph include Freebase, Wikipedia, and the CIA World Factbook [27].

Facebook's Open Graph allows third party applications to read and write content objects, and connections among them, in Facebook's social graph [19].

Facebook users can authorize the application to gain access to the content objects, such as their profile information, photos, and friends, in their Facebook account. Users then create Open Graph stories with the application that are shared with Facebook. These stories consist of actions which are published, retrieved, and modified using the Graph API. The Graph API models the information on Facebook using nodes to represent the entities (i.e., a user, a photo), edges to represent the connections between the entities, and fields to provide information about the entity [10].

Chapter 3

Design

In Section 3.1, a description of how the tool is to be used is given. The high level architecture of the tool is described in Section 3.2 and an example of a RuleML source and its Grailog/SVG rendering is given. The requirements of Grailog KS Viz 2.0 are discussed in Section 3.3. The Grailog constructs that can be presented by the tool are outlined in Section 3.4. In Section 3.5, the SVG elements needed to create the Grailog constructs are described.

3.1 Usage Scenario

Grailog KS Viz 2.0 can be used across all platforms and requires only a modern Web browser. The latest versions, in May 2016, of IE (11), Firefox (45.0.1), Google Chrome (49), and Safari (9) all contain an XSLT processor and support SVG. The transformation does not require the use of an online XSLT processing tool, which would require two explicit inputs, the RuleML/XML and the XSLT stylesheet. Instead, Grailog KS Viz 2.0 completes the transformation using one explicit input, the RuleML/XML, opened in a Web browser. The rendering of the RuleML/XML document is done by the Web browser's built-in XSLT processor, where the stylesheet is given as an implicit input in the processing instruction of the document's prolog [32]. The processing instruction includes a reference to the XSLT stylesheet that the processor uses to transform the source XML document. The use of the Web browser's XSLT processor allows the rendering to be done offline using documents stored as local files. The RuleML/XML source documents can be created and edited using an XML or text editor. Users must be able to represent the knowledge to be visualized in RuleML/XML (which itself can be generated online from the Prolog-like RuleML/POSL syntax: http://www.jdrew.org/oojdrew/demo.html). Reader can refer to Appendix A.1 for the knowledge representation of a test case given in Prolog, POSL, and RuleML. Grailog KS Viz 2.0 does not allow namespaces in the RuleML/XML.

3.2 Architecture

The high level architecture of Grailog KS Viz 2.0 is described in two parts. The Renderer performs the transformation of the RuleML/XML to Grailog visualization in SVG/XML, which contains internal JavaScript. The Purifier removes the JavaScript from the static SVG file that results in pure SVG.

The Renderer requires a source document containing Hornlog RuleML serialized in XML that includes a stylesheet processing instruction in the prolog. The XSLT processor uses the Renderer XSLT, referred to there, to render the Grailog/SVG/XML. The XSLT defines the mapping from the RuleML tags to their Grailog visualization, using JavaScript to calculate the position and size values for the SVG tags. The result of the Renderer XSLT is a Grailog/SVG/XML visualization that contains JavaScript. The values calculated and assigned by the JavaScript are not static in the SVG/XML, instead they are recalculated by the JavaScript each time the image is rendered.

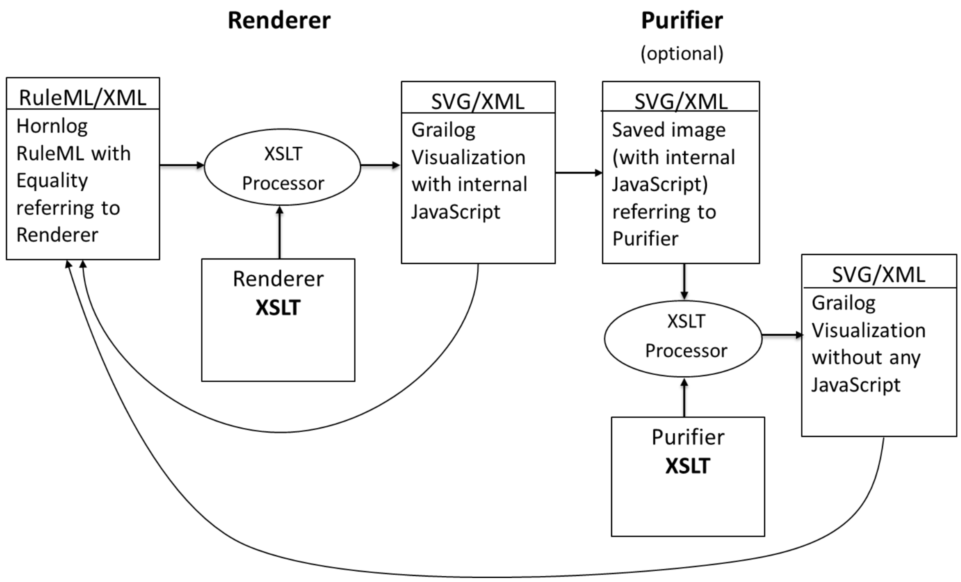


Figure 3.1: High level architecture of the visualization process.

Our first example of a Grailog/SVG visualization (cf. Figure 3.2) is the result of the transformation of graph theory knowledge represented in RuleML/XML by the Renderer XSLT. The box above the"⇒" contains five conjoined rule premises, namely a ternary hyperarc, three unary hyperarcs, and an equality between two variables. The box below the"⇒" contains the rule conclusion, here written as an equality between a variable and a (non-unique) constant name. A controlled natural language sentence describing the graph theory knowledge is given in pretty print formatting.

```
If
    E connects V, U,
    V is Equal to U,
    V is a vertex,
```

```
    U is a vertex,
  And
    E is an edge
Then
    E is Equal to EdgeLoop
```

RuleML is the symbolic representation of the knowledge. The RuleML contained in the source document is transformed by the Renderer XSLT.

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>connects</Rel>
                    <Var>E</Var>
                    <Var>V</Var>
                    <Var>U</Var>
                </Atom>
                <Equal>
                    <Var>V</Var>
                    <Var>U</Var>
                </Equal>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>V</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>U</Var>
                </Atom>
                <Atom>
                    <Rel>edge</Rel>
                    <Var>E</Var>
                </Atom>
```

```
            </And>
            <Equal>
                <Var>E</Var>
                <Ind>EdgeLoop</Ind>
            </Equal>
        </Implies>
    </Assert>
</RuleML>
```

The result of the transformation by the Renderer XSLT is the above-discussed Grailog/SVG visualization in Figure 3.2, which uses Grailog's labelnode normal form, where a hyperarc label becomes the starting node of that hyperarc.

The Purifier uses the input of a static SVG source document that contains a stylesheet processing instruction referring to the Purifier XSLT in the prolog. When the static SVG source is opened in a Web browser, the XSLT processor applies the Purifier XSLT to the document. The formatting instructions of the XSLT produce a pure SVG visualization of Grailog that contains no JavaScript. To maintain the ability to use the tool offline and without requiring additional software or the use of a Web server, the Grailog/SVG/XML must be saved as a static SVG image by the user before the Purifier XSLT is applied. Removing the internal JavaScript may be of interest to users of the tool who want to provide clients with a level of security when sharing their images. In addition to the increased security it provides, removing the JavaScript increases efficiency by reducing both the time required to render the visualization and the file size of the Grailog/SVG. Automating the process of saving a static SVG file from a Web browser is beyond the scope of this thesis.

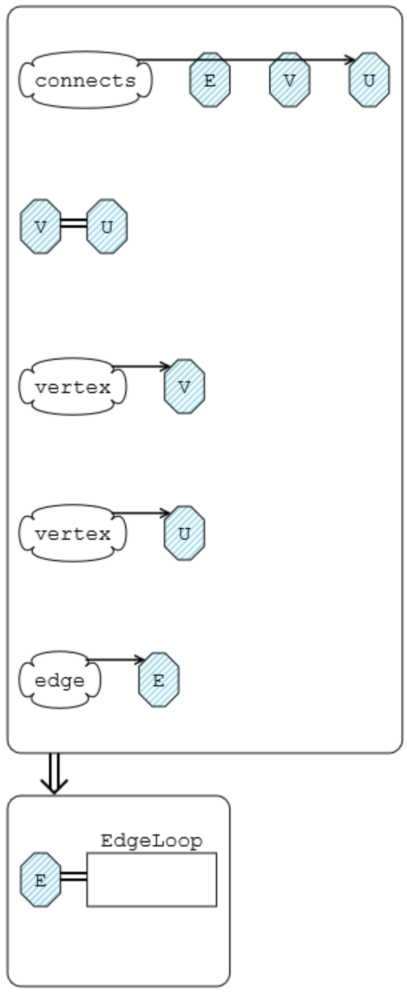


Figure 3.2: Sample Grailog/SVG presentation of graph theory knowledge.

3.3 Requirements

To move from Grailog KS Viz to Grailog KS Viz 2.0, new capability was added to create a tool that visualizes Hornlog, which can address many modeling needs. Hornlog is a Turing-complete RuleML language, more expressive than the Datalog language of the previous tool version, which is not able to visualize Hornlog's function applications. Grailog KS Viz 2.0 has been expanded by developing advanced capability to allow the visualization of Hornlog function applications (complex terms), which can be nested to any depth, and of Hornlog^{+} equalities. The visualizations are now based on the labelnode normal form of Grailog to allow the expression of unary relations such as types or classes.

Grailog KS Viz 2.0 is an intermediary between graph rendering such as Graphviz [12], where node copies are not used, and symbolic pretty printing that uses node copies plus text wrapping with indentation. The tool developed in this thesis uses a normal form where a node is duplicated each time it is referenced, e.g. to avoid hyperarc crossings. Assuming a virtual infinite plane with the origin in the upper-left corner, the visualization can extend without fixed bound in the horizontal and vertical directions, so no equivalent to text wrapping will ever be required. Using this node-copy normal form allows the algorithm's visualization time to grow only linearly in the number of assertions (facts and rules), which is important when dealing with large knowledge bases. Using the normal form thus allows scalability, which is important when dealing with databases containing large amounts of data (facts). Moreover, the node-copy normal form is the more favourable form for human readability as it eliminates hyperarc crossings [25]. In [14], studies determined that the preferred visualization of node-link diagrams is node-copy form. Nesting of nodes, which is required for functional expressions, is another aspect that would complicate the visualization if node sharing were to be used. Therefore, the use of the node-copy normal form is preferable.

3.4 Supported Grailog Constructs

Grailog KS Viz 2.0 allows the visualization of unary (n=1) relations. These relations contain only a single argument node and are used to represent a member of a type or class. In order to accommodate unary cases, the tool uses the labelnode normal form of Grailog.

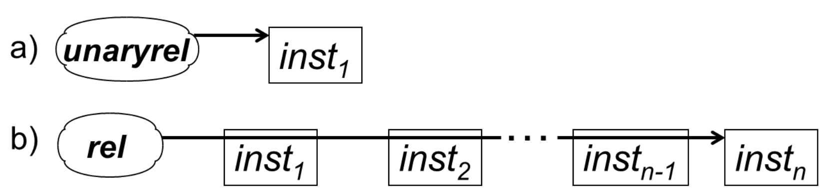


Figure 3.3: Hyperarcs for n-ary relations with a) n=1 and, generally, b) n≥1.

Passive or constructor function applications are supported in Grailog KS

Viz 2.0. The constructor function application contains a function node from which the hyperarc originates, cuts through any intermediate nodes, and points to the final node. The function application may contain n≥1 individual constants, variables, or nested constructor function applications. Used as arguments of relation applications and equalities, constructor function applications can be visualized as complex nodes each containing a function application hyperarc, whose arguments may themselves contain such function applications.

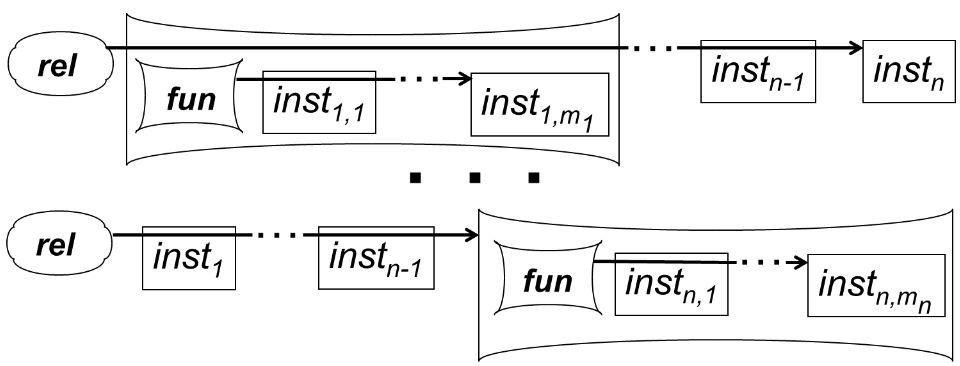


Figure 3.4: Hyperarcs for n-ary relations with (constructor) function application in any argument position.

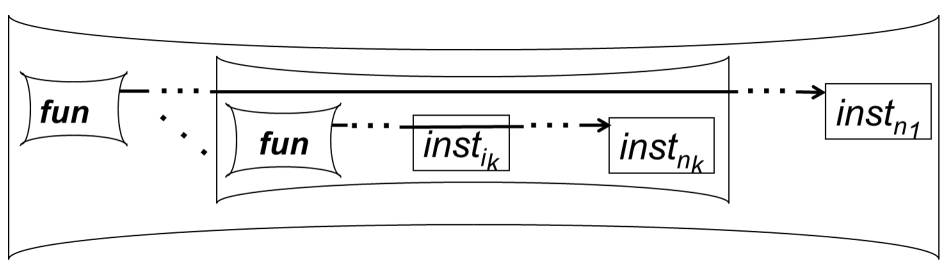


Figure 3.5: Arbitrary levels of nested function applications.

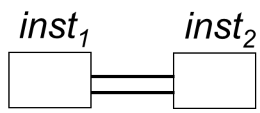


Figure 3.6: Datalog$^+$ equality.

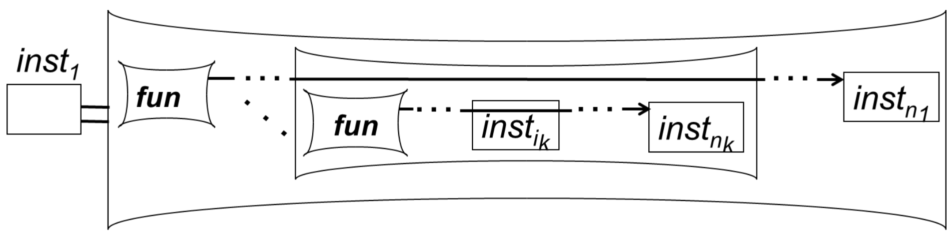


Figure 3.7: Hornlog$^+$ equality.

Datalog$^+$ and Hornlog$^+$ equality can also be visualized. Datalog$^+$ equality is presented as a special binary atom. Elements that may be specified as equal include individual constants with non-unique name specifications and individual variables. Hornlog$^+$ equality allows function applications that may be nested as elements. Both Hornlog$^+$ and Datalog$^+$ with equality in Grailog KS Viz 2.0 are always symmetric and do not have an orientation to distinguish syntax on the left-hand side and right-hand side.

Grailog KS Viz 2.0 has been extended to visualize single- and multi-premise rules that contain any combination of n-ary (n$\geq$1) relations and equalities in the premise(s) and conclusion of the rule. The Grailog structures in the premise(s) and conclusion may also contain nested function applications.

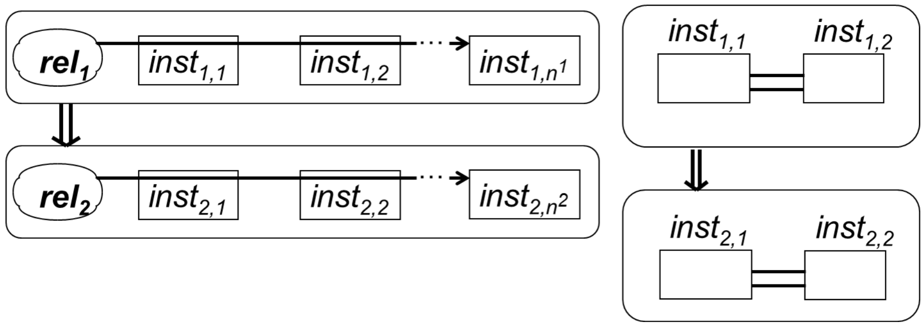


Figure 3.8: Single-premise rules containing n-ary relations (n≥1) and Datalog$^+$ equality.

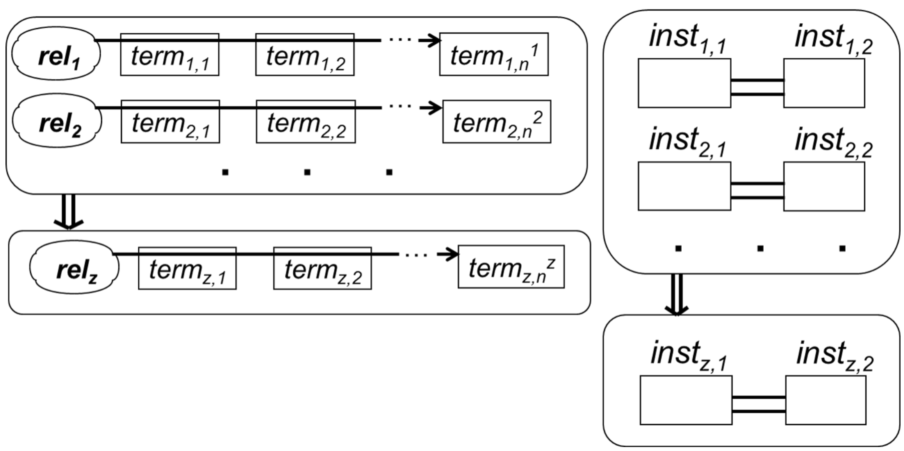


Figure 3.9: Multi-premise rules containing n-ary relations (n≥1) and Datalog$^+$ equality.

3.5 SVG Elements Involved

SVG elements that are used to represent the Grailog constructs include text, rectangles, rounded rectangles, polygons, patterns, markers, straight paths, convex paths, and concave paths. A coordinate system is used to position

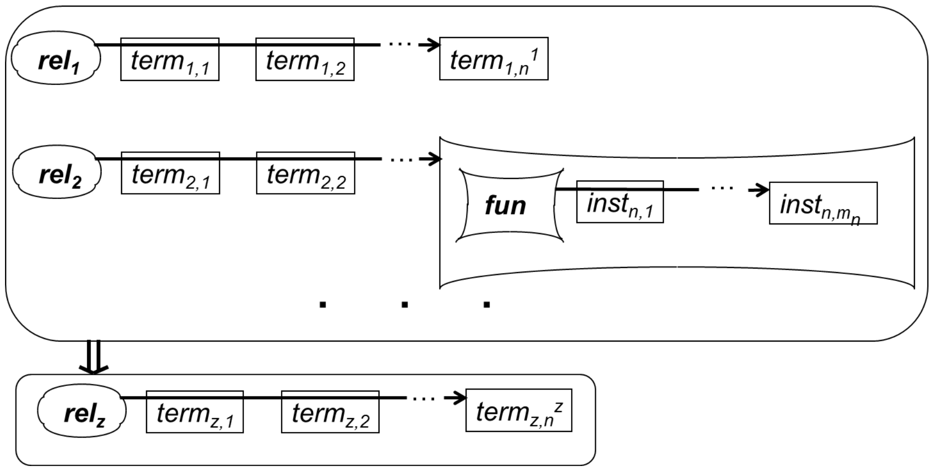


Figure 3.10: Multi-premise rule containing n-ary relations (n≥1) with arbitrary levels of nested function application.

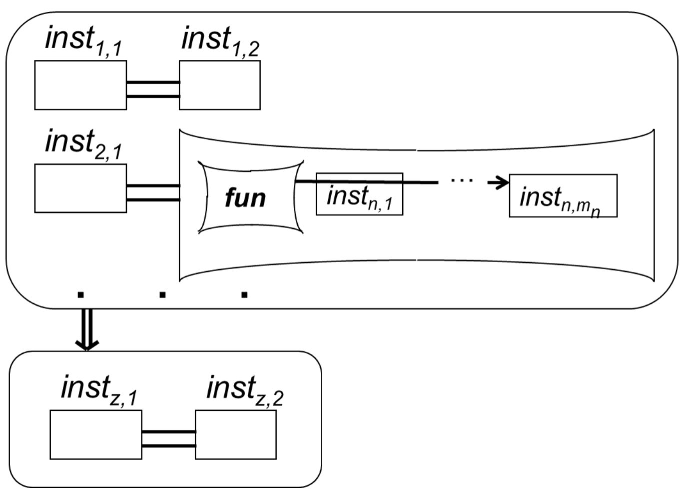


Figure 3.11: Multi-premise rule containing Hornlog^{+} equality with arbitrary levels of nested function application.

the SVG elements on the SVG viewport, a rectangular area of the image that is visible to the user. The coordinates for positioning elements and the dimensions of the viewport are calculated using XPath expressions and JavaScript. The XPath expressions are used to determine the position of the nodes in the XML tree structure and the depth of the tree. JavaScript is used to calculate the size and position of the SVG elements.

Each SVG text element is assigned the contents of the corresponding source RuleML/XML node as its value. The font size and family of the text element is specified so that the rendered SVG is not effected by the Web browser's font settings. The positioning and length of the text is crucial to calculating the positioning of subsequent elements.

The SVG rect element [33] is used to draw a rectangle for individual constants, the size of which is dependent on the length of the text in, or above, the node. The rect element is also used to draw rectangles with rounded corners by specifying the length of the radius of the rounded corners, using the attributes rx and ry. Rounded rectangles are used to contain the premise(s) and conclusion of rules. The dimensions of the rounded rectangles expand vertically and horizontally to accommodate relations and equalities with nested function applications.

The SVG polygon element draws an enclosed shape that consists of connected straight edges [33]. Polygons are used to represent individual variables and are filled with a hatched pattern that is defined using the SVG pattern element [33]. The size of the polygon is dependent on the length of the text in the variable node.

The marker element is used to define the drawing of an arrow head at the end of a path element. To draw hyperarcs pointing from the labelnode to the final node of a relation, the path element is used to draw a straight edge and the marker attribute refers to the arrow head as defined by the marker element to be drawn at the end of the path [33]. The hyperarc pointing from the premise(s) to the conclusion of a rule is drawn using the line attribute of the path element to specify the location of four lines which results in a double-shafted arrow.

The labelnode normal form of Grailog presents the relation as a node from which the hyperarc originates. A labelnode consists of four convex paths that are drawn using the SVG cubic Bézier curve command [33]. The cubic Bézier curve command is also used to draw concave edges that are required to visualize constructor function applications.

Chapter 4

Implementation

In Section 4.1 a description of the Renderer XSLT used to transform the RuleML/XML source document to Grailog/SVG/XML is provided. The Purifier XSLT, which removes the internal JavaScript from the static SVG image of the visualization, is discussed in Section 4.2.

4.1 Renderer XSLT

The Renderer XSLT stylesheet is responsible for creating the root ‘svg’ element, establishing the viewport, and drawing the required Grailog constructs. The Renderer XSLT requires the use of XPath expressions and internal JavaScript. This section will discuss in more detail the elements and templates developed to accomplish the required visualization.

4.1.1 Viewport

The SVG canvas allows for a virtually infinite area for the content to be rendered [33]. The viewport is a finite rectangular subregion of this canvas where the rendered SVG is visible to the user. The viewport is able to expand horizontally and vertically, as required, to accommodate any actual drawing size. The viewport originates at the upper-left corner and its dimensions are determined by the attributes width and height. The width and height attributes of the viewport are set to the global variables maxCoordX and coordY, respectively, that are initialized and updated by the JavaScript. The SVG coordinate system begins at the upper-left corner and the positive x-coordinates point to the right and the positive y-coordinates point down [33]. Since the Grailog constructs are drawn in relation to the text contained in the source RuleML/XML nodes, the initial x and y-coordinates allow the SVG elements to be drawn around (to the left and above) the text element. The unit identifier for the coordinates is not specified, which is equivalent to pixel units and is referred to as user units [33].

The dimensions of the viewport are updated using JavaScript as each SVG element is created. The height of the viewport expands vertically without bound. The JavaScript variable containing the y-coordinate is updated as each SVG element is drawn. The width of the viewport is extended horizontally to the right as required to view the widest Grailog structure. There are two variables that contain x-coordinates that need to be updated using JavaScript as the elements are created. The variable coordX is used to determine the relative placement of the Grailog constructs that are drawn starting on the left-hand side of the viewport and extending across to the right. The variable coordX is overwritten every time a construct is drawn beginning at the left-hand side of the viewport. The variable maxCoordX is used to store the largest x-coordinate of all the structures. After each Grailog structure is drawn, JavaScript is used to compare the x-coordinate for that structure with the largest x-coordinate up to that point stored in the variable maxCoordX, and updates it as required. The following sample code is the JavaScript used to determine the width of the viewport after the last element in a relation is drawn.

```
if (parseFloat(<xsl:value-of select
  ="concat('text','Relation',$countRelations,position())"/>x)
  +parseFloat(<xsl:value-of select
  ="concat('text','Relation',$countRelations,position())"/>
  length)+horizSpace<![CDATA[>]]>maxCoordX){
    maxCoordX=parseFloat(<xsl:value-of select="concat('text',
      'Relation',$countRelations,position())"/>x)
      +parseFloat(<xsl:value-of select="concat('text','Relation',
      $countRelations,position())"/>length)+horizSpace;}
```

4.1.2 XPath Expressions

XPath is used for addressing parts of an XML document by navigating through its hierarchical structure [34]. These expressions are used in the tool to determine the Grailog construct each node is mapped to and the relative position of the node elements in the XML tree. A subset of XPath is used for matching by testing XML-tree nodes against RuleML "type tags" (also called "Nodes", with upper-case "N", as opposed to RuleML "role tags", also called "edges", with lower-case "e"), which determines the appropriate XSLT template to be used. To determine the Grailog construct the nodes are located in and their position in the construct, location paths that select a set of nodes relative to the context node are used. The commonly used location paths include ancestor-or-self, preceding-sibling, parent, child, and descendant. The node set functions count, position, and last are also used. The count function returns the number of nodes in a node set, position returns the position of the context node in the node set, and last returns the position of the last node in the node set [34]. The values returned by XPath expressions are also used in the naming of SVG elements and for calculating the vertical spacing between nested elements.

One limitation of XPath expressions, that had to be overcome in order to recursively nest constructor function applications, was the inability to distinguish between the descendants of siblings that had the same (element-name) path to the parent node. To accomplish this, the NestedExpr template, which is responsible for rendering the function applications, uses the parameter countFunctInLevel. The calling template sets the parameter to the number of preceding-siblings in the node set that are function applications. When a nested function application occurs, the NestedExpr template is called recursively and the parameter is updated by adding the number of preceding-siblings in that node set to the previous value in the parameter. This parameter ensures that when siblings both contain nested functions in the same nested position, their elements will have unique ID names (further discussed in Section 4.1.3).

4.1.3 Constructing ID Names for SVG Elements

All SVG elements have the ID attribute available to them. An element can only specify one ID attribute that is used to identify them and it must be unique for each element [31]. The JavaScript uses the ID attributes of elements in order to retrieve (get) and assign (set) their size and position attributes. Each time a template processes a matching node, unique ID names are assigned to each of the elements. To ensure each element has a unique ID name, they are created by concatenating a sequence of strings and numbers. In order to create meaningful ID names, the strings that are used include the type of SVG element (text, rect, etc.) and the Grailog structure the element is mapped to (relation, rule, etc.). The numbers in the ID name refer to the hierarchical position of the node in the XML tree. By using the position of the nodes for the numerical values in the ID name, the JavaScript can refer to the attributes of other SVG elements by calculating their position relative to the context node.

The numbers used in the ID name of relations and equalities include the number of previous Grailog structures in the XML of that type and a number representing the position of the context node in the node set. In the case of single- and multi-premise rules, the SVG elements require additional numbers in their ID names that are used to index each equality and relation in the premise(s) and conclusion of the rule. The string component of the ID name for elements in rules, relations, and equalities are literal values. The sample code shown below is the XSLT used to specify the ID name attribute for a rectangle element that is used to represent an individual in a relation.

```
<xsl:attribute name="id">
  <xsl:value-of select="concat('rect','Relation',
  $countRelations,position())"/>
</xsl:attribute>
```

The ID names for constructor function application elements contain even more numeric values to represent the level of nesting, the number of preceding siblings on the same level that are function applications, a number that is used to index the descendants of siblings, and the position of the context node in the node set. The string component describing the Grailog structure used in the ID name for the function application elements is a variable instead of a literal value. The string is passed as a parameter to the template to ensure that function applications that occur in different types of Grailog constructs are given unique ID names. The following sample code is the XSLT used to specify the ID name attribute for a polygon element used to represent a variable in a function application.

```
<xsl:attribute name="id">
  <xsl:value-of select="concat('polygon',$constantType,
  $countType,$countFunctions,$countFunctInLevel,
  $functionLevel,position(),$index)"/>
</xsl:attribute>
```

The JavaScript, when referring to the elements using their ID name, must follow the same concatenation pattern that the XSLT used to create them. Since multiple elements are often used in the JavaScript calculations, a single calculation can result in a long line of code.

4.1.4 XSLT Templates

Templates define the processing that can be applied to nodes [30]. The two types of XSLT templates used in Grailog KS Viz 2.0 are templates that are applied to nodes that match a specific pattern and named templates that are invoked when they are called by name [30]. In the Renderer XSLT, the templates applied to matching nodes, including RuleML, Assert, Implies, And, Atom, and Equal are given RuleML tag names. The named templates, Initialize and NestedExpr, are given descriptive names as the templates are called by name; they are not matched against a node pattern. Templates may contain parameters that specify the variables whose values are set when the template is called. Since XSLT variable elements are bound to the supplied value, template parameters are used to update or change the binding of a variable [30].

4.1.4.1 RuleML, Initialize, and Assert Templates

The root SVG node is constructed in a template that matches the pattern of the root RuleML node in the XML source. This template defines the hatched pattern used for variables, and the arrow head marker that is drawn at the end of hyperarcs. The template calls the named template Initialize which assigns the initial x and y-coordinates, and instantiates the JavaScript object XMLSerializer and String variables used for determining the length of text in the nodes. The Initialize template applies the Assert template to nodes with the matching pattern. The Assert template contains only the XSLT apply-templates element with no attribute specified, therefore all the child nodes of Assert are selected. For each child node that is selected, the XSLT processor finds the template that matches the node's pattern and applies the template to the node [30].

4.1.4.2 Implies Template

The Implies template processes matching nodes that are encountered in the RuleML/XML. The template draws the surrounding rectangles for the premise(s) and conclusion of single- and multi-premise rules, and the hyperarc that originates at the bottom of the rectangle surrounding the premise(s) and points down to the rectangle surrounding the conclusion. The template uses JavaScript-calculated values to determine the position and size of the drawings. The rounded rectangles require unbounded vertical and horizontal growth to accommodate nested function applications that may be present in the elements contained in the rule. The height of each rounded rectangle is calculated by finding the difference between the y-coordinate of the first element in the premise(s) and the y-coordinate after drawing the final element in the premise(s). The Implies template allows both relations and equalities in the premise(s) of the rule and either a relation or equality in the conclusion. The template uses conditional statements to match the pattern of child nodes. The XPath count function is used to determine if the rule is single- or multi-premise and if the child nodes are relations or equalities so that the appropriate template is called to draw each element. In a single-premise rule, if the premise or conclusion matches the pattern Atom then the template Atom is applied. If the premise or conclusion of a single-premise rule matches the pattern Equal, then the template Equal is applied. If there is a multi-premise rule which is determined by matching the pattern And, then the template And is applied to draw the elements in the premises, and either the Atom or Equal template is applied to draw the conclusion.

4.1.4.3 And Template

The template And is responsible for drawing the Grailog constructs contained in the multi-premise of a rule. The And template uses a for-each instruction to process the child nodes. Conditional statements are used to determine if the child node matches the pattern Atom or Equal, and draws the appropriate elements. The relations and equalities drawn in the multi-premise of the rule may contain constructor function applications. If the child node of either a relation or equality is a function application, then the named template NestedExpr is invoked and the required parameters are passed.

4.1.4.4 Atom Template

The template Atom processes nodes with a matching pattern. The parent of the Atom node is matched as either Implies or Assert. If the parent node is

Assert, then the JavaScript sets the coordinates to start at the left-hand side of the viewport. If the parent node is Implies, then the template determines if the relation is the premise of a single-premise rule, or the conclusion of either a single- or multi-premise rule and determines the correct starting coordinate for each case.

In order to render Grailog using the labelnode-normal form, the Atom template draws the relation node found in the first position inside a labelnode. Subsequent nodes up to, but not including, the last node are all processed using a for-each instruction. The context node pattern is matched as either a variable, individual, or constructor function application. If the context node is a variable or individual, then the Grailog construct is drawn by the Atom template. If the context node is a function application, then the NestedExpr template is called and the required parameters are passed. As each child node of Atom is processed, the JavaScript updates the x-coordinate by adding the length of the element and additional spacing to separate the elements.

To process the last node, there is a separate for-each instruction. The last element is matched as either a variable, individual, or function application. The path originating at the labelnode and pointing to the final node is drawn first. The coordinates for the path to begin and end at are calculated using JavaScript before drawing the last element. To render the last element, the for-each instruction either draws the variable or individual element, or calls the NestedExpr template to draw the nested function application.

4.1.4.5 Equal Template

The template Equal is applied when nodes with a matching pattern are encountered. Equality is drawn as a special binary atom with no orientation tags that distinguish their placement. The child node in the first position is drawn on the left-hand side and the child node in the second position is drawn on the right-hand side. Datalog$^+$ equality may contain individuals and variables, Hornlog$^+$ equality may additionally contain nested function applications.

The parent of the Equal node is determined by matching it with the pattern Assert or Implies. The starting coordinates of the first child element of Equal is calculated using JavaScript. For each child node in the first position, the template uses conditional statements to determine if it matches the pattern for a variable, individual, or function application. If the child node is a variable or individual, then the Equal template draws the appropriate element. If the child node is a function application, then it is drawn by calling the NestedExpr template and passing the required parameters. A separate for-each instruction is used to process the child node in the second (and last) position. In this instruction the second element and a double path between the elements, representing equality, are drawn. The starting coordinate of the paths are calculated using JavaScript by adding the x-coordinate of the first element to the length of the element. The second element is drawn at the end of the double path.

4.1.4.6 NestedExpr Template

The NestedExpr template is a recursive, named template. The template draws constructor function applications as an element within a relation or equality. The function application may be nested to any depth. There are local parameters declared for the template that are used to create unique ID names for each element that is drawn. The sample code given below is the XSLT that creates the named template NestedExpr and defines the template parameters.

```
<xsl:template name="NestedExpr">
  <xsl:param name="constantType" select="''"/>
  <xsl:param name="functionLevel" select="1"/>
  <xsl:param name="countType" select="0"/>
  <xsl:param name="countFunctInLevel" select
    ="count(preceding-sibling::Expr)+1"/>
  <xsl:param name="index" select
    ="count(preceding-sibling::Expr)+1"/>
```

When the template is invoked, the parameters that are passed replace the default values defined by the template. The parameters that are passed by the calling template include a string that indicates the Grailog structure the function application occurs in. This variable is used as part of each element's ID name. The other parameters include numerical values that are also used in the creation of ID names. The parameter that indicates the number of levels of nesting is set to one by the calling template and is incremented only when the NestedExpr template is called recursively. Another numerical value passed by the calling template is the number of matching Grailog structures (rules, relations, or equalities) that have previously occurred in the XML tree. This value is not changed when the template is called recursively. The following sample XSLT code is from the Atom template. The NestedExpr template is called, and parameter values are passed in order to draw nested function applications within a relation.

```
<xsl:variable name="countFunctionsInAtom" select
  ="count(preceding-sibling::Expr)+1"/>
<!-- call template to draw function in a relation -->
<xsl:call-template name="NestedExpr">
  <xsl:with-param name="constantType"
    select="'FunctionInAtom'"/>
  <xsl:with-param name="functionLevel" select="1"/>
  <xsl:with-param name="countType" select="$countRelations"/>
  <xsl:with-param name="countFunctInLevel"
    select="$countFunctionsInAtom"/>
  <xsl:with-param name="index" select="$countFunctionsInAtom"/>
</xsl:call-template>
```

In order to differentiate between nested function applications that have the same (element-name) path to the root node, a parameter containing the number of preceding-siblings that are function applications in the node set is passed to the NestedExpr template. When the template is called recursively, the number of preceding-siblings in the current level is added to the preceding-siblings in the previous level. Lastly, the number of preceding-siblings that are function applications in the node set of the calling template is passed as a parameter and is not changed when the template is called recursively. The following sample code is the XSLT for calling the NestedExpr template recursively.

```
<xsl:if test="ancestor-or-self::Expr">
  <xsl:call-template name="NestedExpr">
    <xsl:with-param name="constantType"
      select="$constantType"/>
    <xsl:with-param name="functionLevel"
      select="$functionLevel+1"/>
    <xsl:with-param name="countType" select="$countType"/>
    <xsl:with-param name="countFunctInLevel" select
      ="$countFunctInLevel+$countCurrentLevelFunctions"/>
    <xsl:with-param name="index" select="$countFunctInLevel"/>
  </xsl:call-template>
</xsl:if>
```

The template processes the child nodes of the function application using for-each instructions. The child node in the first position of the function application, the function element, is processed inside its own for-each instruction. The coordinates of the function element are determined by examining the current level of nesting. For the first level of nesting, the function element is drawn using the last updated x and y-coordinate. For levels of nesting deeper than one, the x-coordinate is incremented by a global constant to leave a horizontal space between elements. The y-coordinate of the function element, for levels deeper than one, is calculated by adding a multiple of the level of nesting to the y-coordinate of the first level function element. This allows the function applications to expand vertically to accommodate any depth of nesting. The subsequent nodes up to, but not including, the last node are drawn using another for-each instruction. Each node's pattern is matched using conditional statements to either variable, individual, or expression tags. The variable and individual elements are drawn in the matching conditional statements. If the node is an expression, the NestedExpr template is called recursively and the appropriate parameters are incremented or updated. The final for-each instruction in the template processes the last node in the function application. In addition to this, the instruction draws the hyperarc that originates from the function element and points to the last node, and the four paths that form the rectangle with a concave top and bottom that encloses all the elements of the function application. The coordinates for each path in the rectangle are calculated using JavaScript. The first and last position elements in the node set, along with the number of descendants of the context node that are function applications, are used to calculate the coordinates of the paths. The number of descendants of the context node that are function applications does not give the exact depth of nesting within the node as it counts child nodes and siblings of child nodes. However, this measure of depth allows enough vertical spacing to enclose all nested elements as the number of descendants is greater than or equal to the level of nesting.

4.2 Purifier XSLT

The Purifier XSLT stylesheet removes the internal JavaScript from the static SVG image of a Grailog visualization. The use of this stylesheet is optional as it does not change the presentation of the SVG elements. The Purifier XSLT is made up of two templates. The identity template [30], which is widely known, matches all nodes and their attributes, and just copies them. To remove the JavaScript, an empty template that matches the script nodes is used. This script template matches a specific node pattern and therefore has a higher priority than the identity template, which matches all nodes. Therefore, the script nodes are only processed by the empty template where nothing is generated, resulting in the script elements not being copied. All other nodes are matched only by the identity template, which copies the node and its attributes. The result of applying the Purifier XSLT is pure SVG. The following code is the XSLT for the two templates used in the Purifier XSLT.

```
<!-- Identity template recursively copies
    nodes and their attributes -->
<xsl:template match="@*|node()">
  <xsl:copy>
    <xsl:apply-templates select="@*|node()"/>
```

```
  </xsl:copy>
</xsl:template>
<!-- Empty template does not copy script elements -->
<xsl:template match="svg:script"/>
```

Reader can refer to Appendix A.1 for the underlying SVG/XML without JavaScript, which is provided for the test case. The JavaScript was removed by applying the Purifier XSLT.

Chapter 5

A Use Case in Mathematics

In Section 5.1, the test cases in math education that were developed to evaluate the tool are described. A larger use case in financial mathematics is discussed in Section 5.2. In Section 5.3, a description of the unit testing that compares Grailog KS Viz and Grailog KS Viz 2.0 is given. An evaluation of the size and time efficiency of Grailog KS Viz 2.0 is given in Section 5.4.

The evaluation of the tool will include its practicability (visualization accurateness, response times, file size, maintainability) for users of the system. Users must be able to represent the knowledge to be visualized in RuleML.

5.1 Test Cases in Math Education

Grailog visualization can have many uses in education, science, and IT. Education uses a variety of graphic organizers to present knowledge, including concept maps which show relationships between concepts. KV tools have many applications in the science domain. For example, KV is used in the medical field for diagnosis and for mapping of scientific knowledge. By extending the Grailog visualizations to include Hornlog, Grailog KS Viz 2.0 can be used to present equality-defined mathematical functions, thereby expanding its use to math and science education.

In order to evaluate the capability of the KV tool, a set of input and output pairs were used for unit testing. The test cases were designed to test specific features by designing inputs to ensure the output requirements are met [16]. The test cases demonstrate the tool's visualization accurateness, including its ability to visualize functions for building complex terms with multiple levels of nesting. There were five test cases created to visualize graph theory knowledge. Portions of graph theory in textbook English were first manually visualized in Grailog. The RuleML/XML was then written and the visualization rendered using the tool in order to validate the output against the manual visualization. The ensuing feedback loop led to the 2.0 version of the tool. Using graph theory as the topic of the test cases also serves another purpose, as background knowledge in this field is relevant for understanding Grailog visualization. Reader can refer to Appendix A for the complete set of test cases, including the RuleML/XML source and the rendered Grailog/SVG visualization.

5.2 Use Case in Financial Mathematics

A single larger use case was developed in the area of financial mathematics. The use case is for teaching business rules for managing the financial aspect of a non-profit organization. Ultimately, the use case could evolve into a form of corporate memory which captures the knowledge of domain experts in an organization in such a way that it can be used, e.g., for knowledge transfer (such as training new personnel) and knowledge validation.

For concreteness, business rules for the non-profit organization RuleML Inc were employed as a use case instantiation. These financial rules were first represented in Hornlog RuleML and then transformed to Grailog/SVG by the Renderer XSLT. The financial rules that are covered by the use case include incoming and outgoing transactions, and transfers between accounts. Reader can refer to Appendix B for the Hornlog RuleML and resulting Grailog/SVG visualization.

5.3 Unit Testing

The evaluation of the Datalog visualization using Grailog KS Viz and Hornlog visualization using Grailog KS Viz 2.0 compares the expressiveness of the graphs and the suitability of the tools. Sample knowledge bases of increasing graph-logic expressivity were visualized by the Grailog KS Viz and Grailog KS Viz 2.0 tools. The resulting KVs were systematically contrasted with each other and tool benchmarks were taken (cf. Table 5.1). The criteria for expressiveness comparison are obvious from the table.

To compare the quality of the SVG that is produced as a result of using the tool to transform RuleML/XML to Grailog/SVG/XML, the W3C Markup Validation Service [29] was used. The same RuleML/XML source was transformed by both Grailog KS Viz and Grailog KS Viz 2.0 and the resulting SVG was tested online using the validation service. The SVG/XML that was generated when Grailog KS Viz was referenced in the stylesheet processing instruction was considered invalid. The validation service found errors while checking the SVG produced by Grailog KS Viz as SVG 1.1. The SVG/XML that was generated using Grailog KS Viz 2.0 to transform the same RuleML/XML source was checked as valid. The online service successfully performed a formal validation of the SVG produced by Grailog KS Viz 2.0 as SVG 1.1. The validation was performed before the Purifier XSLT was applied and is therefore independent of the Purifier.

Grailog KS Viz	Grailog KS Viz 2.0
Relation labels on hyperarcs	Labelnode normal form
Visualizes n-ary (n>1) relations	Visualizes n-ary (n≥1) relations
Source code containing JavaScript	Source code with JavaScript (optionally) removed
	Visualizes Datalog$^+$ with equality as a special binary atom
	Visualizes Hornlog nested function applications
	Visualizes Hornlog$^+$ with equality as a special binary atom

Table 5.1: Comparison of Grailog KS Viz and Grailog KS Viz 2.0 features.

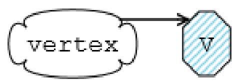
5.4 Evaluation

The testing of response time was carried out by using increasingly large file sizes of RuleML/XML transformed by Grailog KS Viz 2.0. Testing was conducted using files stored in offline directories and the built-in XSLT processor in IE. The visualization of a RuleML/XML source was evaluated based on the time required to render the Grailog/SVG which included executing the internal JavaScript. The Grailog/SVG was subsequently saved as a static image with the calculated values embedded in the SVG, which does not require the scripts to recalculate the values. The time required to render the static image was then measured. Finally, the Purifier XSLT was applied to the static Grailog/SVG and the internal JavaScript was removed. The time required to render the pure Grailog/SVG was also measured. Another aspect of evaluating the efficiency of the tool was to compare the file sizes of the generated Grailog/SVG before and after applying the Purifier XSLT.

Employing Grailog KS Viz 2.0 to render any SVG/XML visualization in a Web browser requires the use of JavaScript. The transformation of any RuleML/XML source by the Renderer XSLT will invoke the Initialize template. The Initialize template uses JavaScript to initialize the height and width variables used in calculating the dimensions of the viewport, as well as variables used in other templates. Each additional element that is required in the visualization utilizes JavaScript to calculate the dimensions of the element and the coordinates for placement of the element on the viewport. Therefore, even the most basic SVG visualization will contain JavaScript that can be removed by the Purifier XSLT, resulting in a smaller file size. To demonstrate this, a small visualization of a unary relation represented in RuleML/XML was transformed to Grailog/SVG/XML using the Renderer XSLT. The RuleML/XML representation contained in a file size of 1KB is given below.

```
<RuleML>
    <Assert>
        <Atom>
            <Rel>vertex</Rel>
            <Var>V</Var>
        </Atom>
    </Assert>
</RuleML>
```

The resulting visualization was saved as a static SVG file, which contains JavaScript. The static SVG file was 9KB in size and contained 121 lines of code. The Purifier XSLT was then applied to the static Grailog/SVG to remove the internal JavaScript. The file size of the pure Grailog/SVG was 2KB and contained 26 lines of code. Its visualization is provided below.



Larger file sizes of RuleML/XML were then used to compare the rendering time and file sizes of the Grailog/SVG in its various forms. The visualization of a 28KB RuleML/XML file containing 1,607 lines required on average 2.70 seconds to complete, which includes executing the internal JavaScript. Rendering the visualization using the static image required less time, since the scripts do not have to be executed again, and took on average 1.23 seconds. The file size of the static Grailog/SVG file was 4,049KB. After the Purifier XSLT was applied to the static Grailog/SVG, the resulting SVG file was reduced to 577KB in size. The time required to render the pure Grailog/SVG was on average of 0.439 seconds.

The input RuleML/XML file size of 55KB, which has 3,207 lines, completed the JavaScript execution and visualization in an average of 6.41 seconds. The file size of the static SVG image was 8,118KB. The rendering of the static Grailog/SVG required on average 2.57 seconds. The removal of the JavaScript using the Purifier XSLT resulted in a file size of 1,159KB, whose rendering took on average 0.992 seconds.

When the file size was increased to 108KB with 6,407 lines, the time to visualize the Grailog/SVG was on average 13.94 seconds. The static Grailog/SVG image was 16,392KB in size. The time required to render the static SVG image was on average 6.59 seconds. The file size was 2,348KB after the Purifier XSLT removed the JavaScript and the rendering of the visualization required 1.89 seconds on average.

From the results of the three data groups it is hypothesized that the visualization time for the input RuleML/XML increases linearly with the file size. The removal of the JavaScript using the Purifier XSLT reduces the time required to render the visualization, and results in significantly smaller file sizes. Grailog KS Viz 2.0 thus provides users the option to more efficiently view, store, and share visualizations.

Chapter 6

Conclusions

The objective of this thesis was to move from Grailog KS Viz to Grailog KS Viz 2.0 by adding new capability including visualizing Hornlog, a computationally complete language. In Section 6.1, a summary of the results of this work is given. Suggestions for future work that could enhance the tool are provided in Section 6.2.

6.1 Results

Grailog KS Viz 2.0 has been extended to the labelnode normal form of Grailog including n-ary (e.g., unary) relations. The tool is able to visualize Datalog$^+$ with (head) equality as a binary atom and Hornlog, including Hornlog$^+$ equality, allowing complex terms with arbitrary levels of nested function applications. Single- and multi-premise rules containing any combination of n-ary relations, Datalog$^+$ equality, and Hornlog in the premise(s) and conclusion are visualized using the tool.

The tool developed in this thesis uses a normal form of visualization where node copies are created, instead of node sharing. A main reason for this approach is the scalability of the node-copy normal form for large databases. On the other hand, the growth rate when sharing nodes is not scalable since reuse requires searching for the location of each node in the graph. Another benefit is that the readability of the node-copy form, which avoids any hyperarc crossings, is significantly greater (while the graph connectivity is not made explicit).

In order to draw nested function applications, a recursive template with parameters is used. The recursive template utilizes parameters to set the variables that are required in the creation of unique ID names for the SVG elements. When the template for nested function applications is called, the parameters are passed by the calling template. This approach is significantly different from the original design in that the recursive template is used to draw nested function applications that occur in any construct by using parameters.

To provide assurances that there are no malicious scripts contained in the generated SVG, the internal JavaScript can be removed. The rendered SVG, when saved as a static image and by referencing the Purifier XSLT in its stylesheet processing instruction, can be transformed to contain only pure SVG. The removal of JavaScript, which is no longer required in the static image, provides increased security when sharing the Grailog/SVG visualizations.

The removal of JavaScript from the Grailog/SVG also results in faster generation of the SVG and smaller file sizes for more efficient storage and sharing. The file size of the efficiency test cases used in the evaluation of the tool was each reduced by 86%. The gains of time efficiency by using the pure SVG to render the visualization were increasingly greater as the file size increased. The time required to render the visualization of the largest file was reduced by 53% when the static Grailog/SVG image was rendered compared to the Grailog/SVG with active scripts. When the JavaScript was removed using the Purifier XSLT, the time to render the Grailog/SVG was reduced by another 71% compared to the rendering time of the static image. When large knowledge bases are being visualized, these time and space efficiencies become increasingly more important and evident.

The SVG/XML generated by the Renderer XSLT of Grailog KS Viz 2.0 has been validated using the W3C Markup Validation Service [29], and was successfully checked as SVG 1.1. The tool has been successfully tested on common Web browsers using only their built-in XSLT processor to complete the rendering. The quality and accuracy of the visualizations are consistent for all tested Web browsers. IE and Firefox are able to render the Grailog visualization using a RuleML/XML source file stored in a local or online directory. Google Chrome and Safari transform the RuleML/XML source file stored in an online directory.

The advantages of using KV were evident in the development of the test cases and use case. The Grailog/SVG visualization was consistently chosen by the users over the source RuleML representation when working collaboratively on improvements.

6.2 Future Work

The work done in this thesis uses only the XSLT processor built into the Web browser. This approach requires the RuleML/XML source to contain a stylesheet processing instruction in the prolog referring to the Renderer XSLT. Likewise, the static SVG image must also contain a stylesheet processing instruction referring to the Purifier XSLT. The user must edit the static SVG image and add the stylesheet processing instruction. The benefit of using the built-in XSLT processor is that the tool can be used offline and without the need for additional tools. Another approach would be to use an online XSLT processing tool to complete the transformations by providing both the RuleML/XML and the Renderer XSLT as inputs. The use of an online processing tool would allow the user to apply the Purifier XSLT to the static SVG image without having to first add the stylesheet processing instruction. Other considerations for future work could include the use of a Web service that would automate the saving of the rendered Grailog visualization as a static image file and apply the Purifier XSLT stylesheet.

The recursive template to visualize nested function applications, which was developed to meet the main objective of this thesis, demonstrates how the software could be improved to increase reusability for future development. This template demonstrates how improvements to existing templates could be made that will allow the tool to be expanded more efficiently.

A possible extension to the tool, for the visualization of nested functions, is to have them appear increasingly smaller in size according to their depth of nesting. The scaled-down functions could then be viewed using the zoom function of the browser.

Other future work could include the optional merging of labelnode copies. Eliminating duplicate nodes is a common approach to visualization and is used in tools such as GrOWL [21] and PaladinRM [2]. When node copies are removed, readability of the graphs is diminished. Therefore, if node copies are eliminated, then other capabilities should be added to allow the user the option to select a narrow view of the graph to reduce confusion from crossing edges. As a follow-up on our experimental findings, the time and space complexity of Grailog KS Viz 2.0 could be formally analyzed.

A complementary tool that could be developed would be an inverse translator. Such a conversion of Grailog visualization to RuleML knowledge representation could lead to visual editing of machine-readable logic.

New capability could also be added to the tool in order to visualize more languages of (Deliberation) RuleML. For example, the tool could be extended to allow First Order Logic (FOL), Higher-Order, or Modal RuleML.

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Appendix A

Graph-Theory Test Cases

The test cases depicting graph theory knowledge were developed using Horn-log RuleML serialized in XML. The Renderer XSLT was applied to the RuleML/XML using the XSLT processor built into the Web browser. The resulting Grailog/SVG visualization accurately displays the RuleML/XML.

A.1 Test Case 1

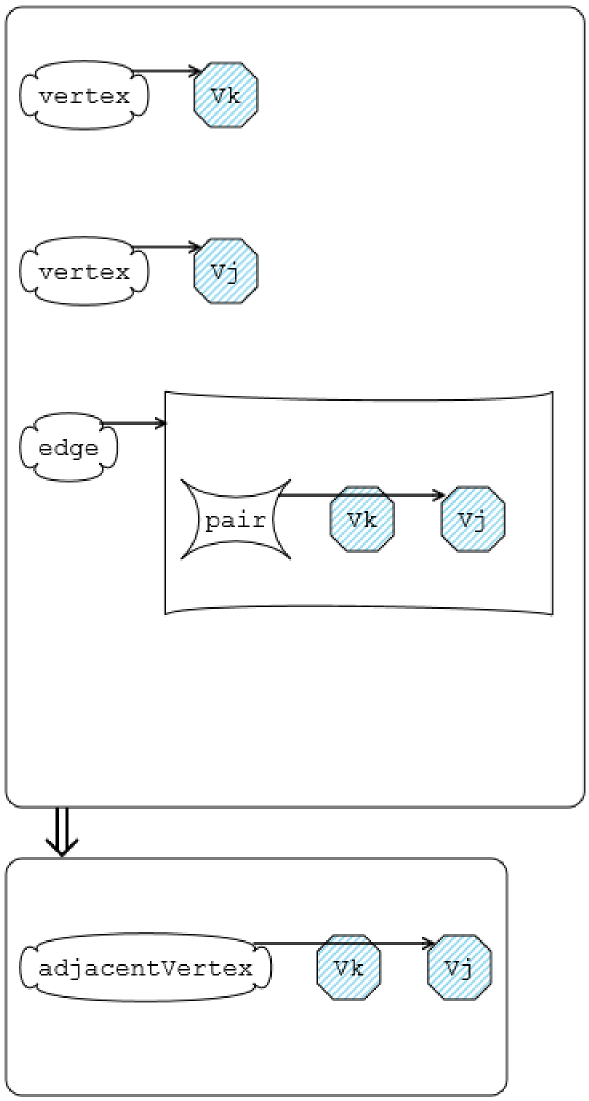
This test case is written in controlled natural language, then represented in machine-readable logic using Prolog, POSL, and RuleML, and then presented in Grailog/SVG as rendered by the tool. The underlying SVG/XML after the internal JavaScript is removed by the Purifier XSLT is also given. Due to the large size of the SVG/XML source with the internal JavaScript (607 lines) it is not provided here but can be viewed online (GraphTheory-TestCase1.ruleml.xml) by selecting view source from the context menu of the browser.

```
If
    Vk is a vertex,
    Vj is a vertex,
  And
    the pair of vertices Vk, Vj is an edge
Then
  Vk is an adjacent vertex to Vj
```

```
adjacentVertex(Vk,Vj) :-
   vertex(Vk),
   vertex(Vj),
   edge(pair(Vk,Vj)).
```

```
adjacentVertex(?Vk,?Vj) :-
   vertex(?Vk),
   vertex(?Vj),
   edge(pair[?Vk,?Vj]).
```

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vk</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vj</Var>
                </Atom>
                <Atom>
                    <Rel>edge</Rel>
                    <Expr>
                        <Fun per="copy">pair</Fun>
                        <Var>Vk</Var>
                        <Var>Vj</Var>
                    </Expr>
                </Atom>
            </And>
            <Atom>
                <Rel>adjacentVertex</Rel>
                <Var>Vk</Var>
                <Var>Vj</Var>
            </Atom>
        </Implies>
    </Assert>
</RuleML>
```


vertex
Vk
vertex
Vj
edge
pair
Vk
Vj
adjacentVertex
Vk
Vj

```
<?xml version="1.0" encoding="iso-8859-1"?>
<?xml-stylesheet type="text/xsl" href="Purifier.xslt"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.1//EN"
  "http://www.w3.org/Graphics/SVG/1.1/DTD/svg11.dtd">
<svg id="rootSVG" width="491.313" height="900" version="1.1"
  xmlns="http://www.w3.org/2000/svg">
<defs>
<marker id="arrow" viewBox="0 0 15 15" refX="1" refY="6"
  markerUnits="strokeWidth" markerWidth="10" markerHeight="7"
  orient="auto">
<path style="fill: none; stroke: black; stroke-width: 2;"
  d="M 0 1 L 10 6 L 0 11 L 10 6 L 0 6"></path>
</marker>
<pattern id="hatched" patternUnits="userSpaceOnUse"
  patternTransform="rotate(45)" x="0" y="0" width="3.5"
  height="3.5">
<path fill="none" stroke="#01a9db" stroke-linecap="square"
  stroke-width="1" d="M 0 0 l 0 3.5"></path>
</pattern>
</defs>

<path id="double_arrowRule1" style="fill: none; stroke: black;
  stroke-width: 2;" d="M 55 580 L 65 590 L 75 580 L 68 587
  L 68 560 L 68 587 L 65 590 L 62 587 L 62 560"></path>
<rect id="round_rect1Rule1" style="fill: none; stroke: #000000;
  stroke-width: 1;" x="30" y="60" width="361.313" height="500"
  rx="10" ry="10"></rect>
<rect id="round_rect2Rule1" style="fill: none; stroke: #000000;
  stroke-width: 1;" x="30" y="592" width="312.969" height="148"
  rx="10" ry="10"></rect>
<path id="curvePathMPRule1111" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 105 C 35 90 122.656 90 107.656 105">
  </path>
<path id="curvePath2MPRule1111" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 107.656 105
  C 122.656 90 122.656 140 107.656 125"></path>
<path id="curvePath3MPRule1111" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 107.656 125
```

```
  C 122.656 140 35 140 50 125"></path>
<path id="curvePath4MPRule1111" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 105 C 35 90 35 140 50 125"></path>
<text id="textMPRule1111" style="font-family: courier,monospace;
  font-size: 16px;" x="50" y="120">vertex</text>

<polygon id="polygonMPRule1112" style="fill: url(#hatched);
  stroke:#000000; stroke-width: 1;" points="157.656,95 176.875,95
  186.875,105 186.875,125 176.875,135 157.656,135 147.656,125
  147.656,105"></polygon>
<text id="textMPRule1112" style="font-family: courier,monospace;
  font-size: 16px;" x="157.6563" y="120">Vk</text>
<path id="pathMPRule111" fill="none"
  marker-end="url(&quot;#arrow&quot;)"
  stroke="black" stroke-width="1.5"
  d="M 107.656 100 L 144.656 100"></path>

<path id="curvePathMPRule1121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 215
  C 35 200 122.656 200 107.656 215"></path>
<path id="curvePath2MPRule1121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 107.656 215
  C 122.656 200 122.656 250 107.656 235"></path>
<path id="curvePath3MPRule1121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 107.656 235
  C 122.656 250 35 250 50 235"></path>
<path id="curvePath4MPRule1121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 215
  C 35 200 35 250 50 235"></path>
<text id="textMPRule1121" style="font-family: courier,monospace;
  font-size: 16px;" x="50" y="230">vertex</text>

<polygon id="polygonMPRule1122" style="fill: url(#hatched);
  stroke:#000000; stroke-width: 1;" points="157.656,205 176.875,
  205 186.875,215 186.875,235 176.875,245 157.656,245 147.656,235
  147.656,215"></polygon>
<text id="textMPRule1122" style="font-family: courier,monospace;
  font-size: 16px;" x="157.6563" y="230">Vj</text>
```

```
<path id="pathMPRule112" fill="none"
  marker-end="url(&quot;#arrow&quot;)" stroke="black"
  stroke-width="1.5" d="M 107.656 210 L 144.656 210"></path>

<path id="curvePathMPRule1131" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 325
  C 35 310 103.438 310 88.4375 325"></path>
<path id="curvePath2MPRule1131" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 88.4375 325
  C 103.438 310 103.438 360 88.4375 345"></path>
<path id="curvePath3MPRule1131" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 88.4375 345
  C 103.438 360 35 360 50 345"></path>
<path id="curvePath4MPRule1131" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 325 C 35 310 35 360 50 345"></path>
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  font-size: 16px;" x="50" y="340">edge</text>

<path id="pathMPRule113" fill="none"
  marker-end="url(&quot;#arrow&quot;)" stroke="black"
  stroke-width="1.5" d="M 88.4375 320 L 123.438 320"></path>
<text id="textMPRule1132" x="88.4375"></text>

<path id="curvePathFunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;" d="M 139.438 355
  C 154.438 370 192.875 370 207.875 355"></path>
<path id="curvePath2FunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;" d="M 207.875 355
  C 192.875 370 192.875 390 207.875 405"></path>
<path id="curvePath3FunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;" d="M 207.875 405
  C 192.875 390 154.438 390 139.438 405"></path>
<path id="curvePath4FunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;" d="M 139.438 355
  C 154.438 370 154.438 390 139.438 405"></path>
<text id="textFunctionInMPMPRule1311111"
  style="font-family:courier,monospace; font-size: 16px;"
  x="154.4375" y="385">pair</text>
```

```
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  style="fill: url(#hatched); stroke: #000000; stroke-width: 1;"
  points="242.875,360 262.094,360 272.094,370 272.094,390 262.094,
  400 242.875,400 232.875,390 232.875,370"></polygon>
<text id="textFunctionInMPMPRule1311121"
  style="font-family: courier,monospace; font-size: 16px;"
  x="242.875" y="385">Vk</text>

<path id="pathFunctionInMPMPRule131111" fill="none"
  marker-end="url(&quot;#arrow&quot;)" stroke="black"
  stroke-width="1.5" d="M 199.875 365 L 297.094 365"></path>

<polygon id="polygonFunctionInMPMPRule1311131"
  style="fill: url(#hatched); stroke: #000000; stroke-width: 1;"
  points="312.094,360 331.313,360 341.313,370 341.313,390 331.313,
  400 312.094,400 302.094,390 302.094,370"></polygon>
<text id="textFunctionInMPMPRule1311131"
  style="font-family: courier,monospace; font-size: 16px;"
  x="312.0938" y="385">Vj</text>

<path id="curvePathExprFunctionInMPMPRule131111"
  style="fill: none; stroke: black; stroke-width: 1;"
  d="M 129.438 300 C 139.438 305 366.313 310 371.313 300"></path>
<path id="curvePathExpr2FunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;"
  d="M 371.313 300 L 371.313 440"></path>
<path id="curvePathExpr3FunctionInMPMPRule131111" style="fill: none;
  stroke: black; stroke-width: 1;" d="M 371.313 440
  C 361.313 435 134.438 430 129.438 440"></path>
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  stroke: black; stroke-width: 1;"
  d="M 129.438 300 L 129.438 440"></path>

<path id="curvePathRule121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 650
  C 35 635 199.531 635 184.531 650"></path>
<path id="curvePath2Rule121" style="fill: none; stroke: black;
```

```
  stroke-width: 1;" d="M 184.531 650
  C 199.531 635 199.531 685 184.531 670"></path>
<path id="curvePath3Rule121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 184.531 670
  C 199.531 685 35 685 50 670"></path>
<path id="curvePath4Rule121" style="fill: none; stroke: black;
  stroke-width: 1;" d="M 50 650 C 35 635 35 685 50 670"></path>
<text id="textRule121" style="font-family: courier,monospace;
  font-size: 16px;" x="50" y="665">adjacentVertex</text>

<polygon id="polygonRule122" style="fill: url(#hatched);
  stroke: #000000; stroke-width: 1;" points="234.531,640 253.75,
  640 263.75,650 263.75,670 253.75,680 234.531,680 224.531,670
  224.531,650"></polygon>
<text id="textRule122" style="font-family: courier,monospace;
  font-size: 16px;" x="234.5313" y="665">Vk</text>

<polygon id="polygonRule123" style="fill: url(#hatched);
  stroke: #000000; stroke-width: 1;" points="303.75,640 322.969,
  640 332.969,650 332.969,670 322.969,680 303.75,680 293.75,670
  293.75,650"></polygon>
<text id="textRule123" style="font-family: courier,monospace;
  font-size: 16px;" x="303.7501" y="665">Vj</text>
<path id="pathRule12" fill="none"
  marker-end="url(&quot;#arrow&quot;)" stroke="black"
  stroke-width="1.5" d="M 184.531 645 L 290.75 645"></path>
</svg>
```

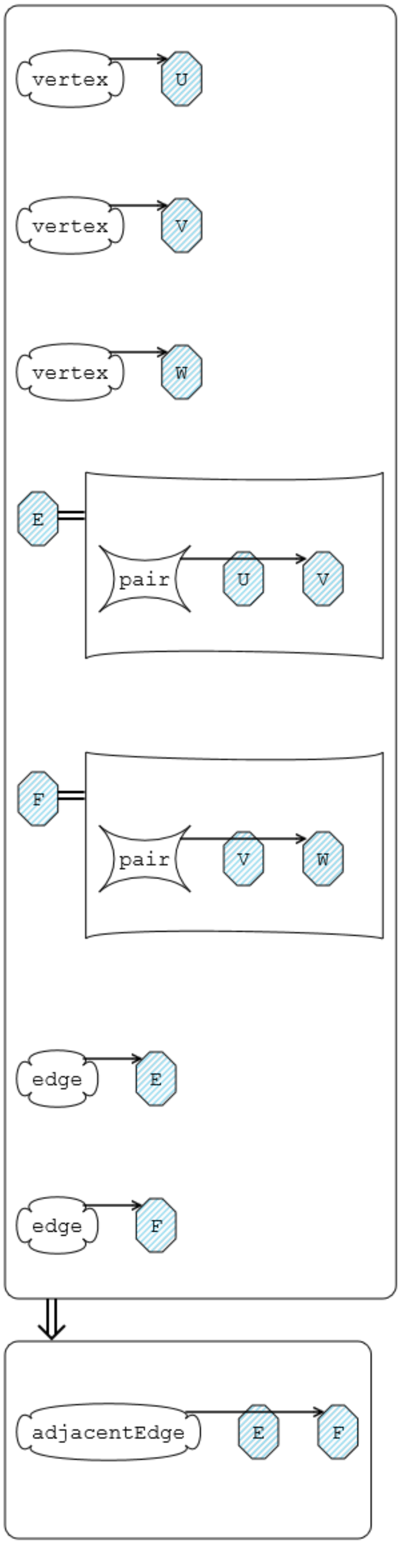
A.2 Test Case 2

This test case is again written in controlled natural language, then represented in RuleML logic, and finally presented in Grailog/SVG as rendered by the tool.

```
If
    U is a vertex,
    V is a vertex,
    W is a vertex,
      E is
    Equal to
      the pair of vertices U, V,
      F is
    Equal to
      the pair of vertices V, W,
    E is an edge,
  And
    F is an edge
Then
    E is an adjacent edge to F
```

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>U</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>V</Var>
```

```
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>W</Var>
                </Atom>
                <Equal>
                    <Var>E</Var>
                    <Expr>
                        <Fun per="copy">pair</Fun>
                        <Var>U</Var>
                        <Var>V</Var>
                    </Expr>
                </Equal>
                <Equal>
                    <Var>F</Var>
                    <Expr>
                        <Fun per="copy">pair</Fun>
                        <Var>V</Var>
                        <Var>W</Var>
                    </Expr>
                </Equal>
                <Atom>
                    <Rel>edge</Rel>
                    <Var>E</Var>
                </Atom>
                <Atom>
                    <Rel>edge</Rel>
                    <Var>F</Var>
                </Atom>
            </And>
            <Atom>
                <Rel>adjacentEdge</Rel>
                <Var>E</Var>
                <Var>F</Var>
            </Atom>
        </Implies>
    </Assert>
</RuleML>
```

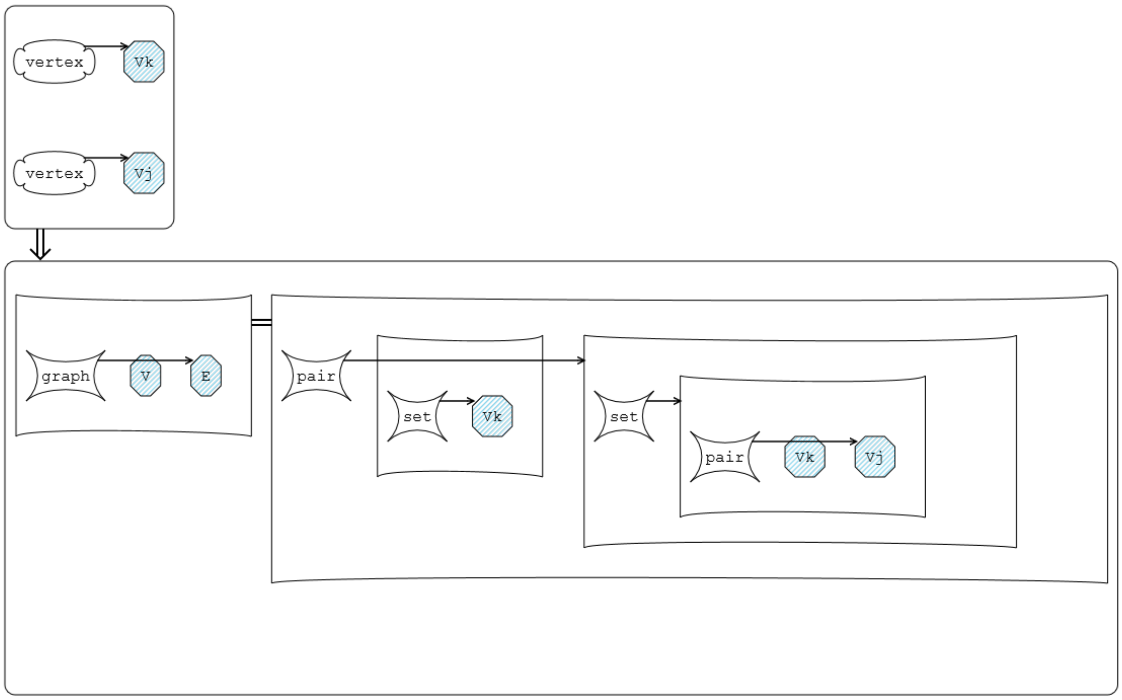

vertex
U
vertex
V
vertex
W
E
pair
U
V
F
pair
V
W
edge
E
edge
F
adjacentEdge
E
F

A.3 Test Case 3

This test case is a way to capture: The graph over a vertex set and edge set is the same as the pair constructed from the set of vertices and the set of pairs of vertices.

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vk</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vj</Var>
                </Atom>
            </And>
            <Equal>
                <Expr>
                    <Fun per="copy">graph</Fun>
                    <Var>V</Var>
                    <Var>E</Var>
                </Expr>
                <Expr>
                    <Fun per="copy">pair</Fun>
                    <Expr>
                        <Fun per="copy">set</Fun>
                        <Var>Vk</Var>
                    </Expr>
                    <Expr>
```

```
                        <Fun per="copy">set</Fun>
                        <Expr>
                            <Fun per="copy">pair</Fun>
                            <Var>Vk</Var>
                            <Var>Vj</Var>
                        </Expr>
                    </Expr>
                </Expr>
            </Equal>
        </Implies>
    </Assert>
</RuleML>
```

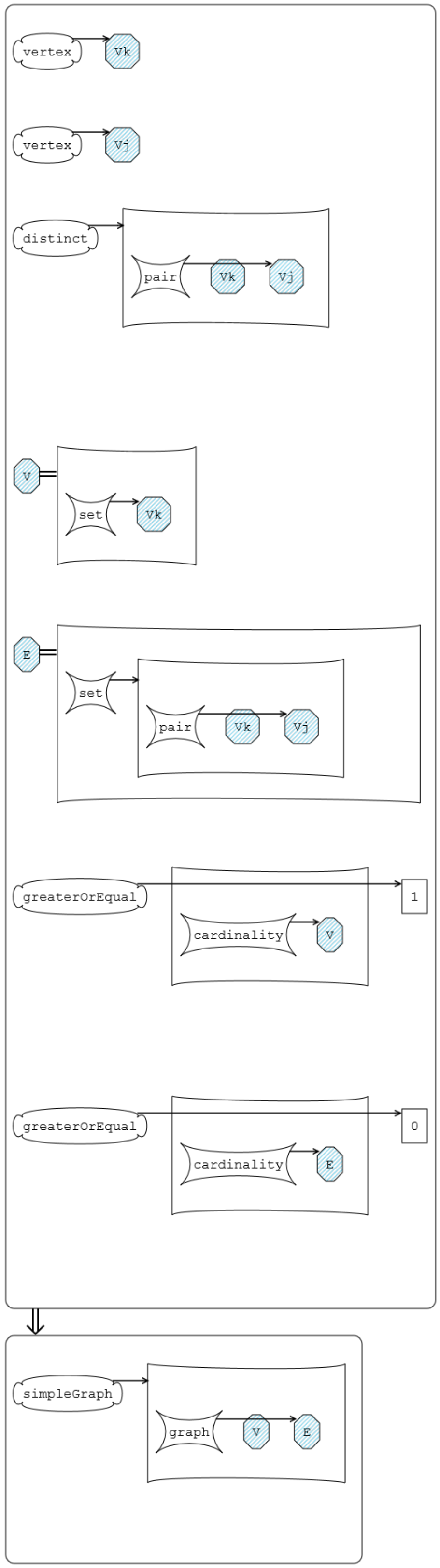


A.4 Test Case 4

This test case is a way to capture: A graph over a vertex set and edge set is a simple graph if there is a vertex set of 1 or more vertices and an edge set of 0 or more pairs of vertices, where the pairs of vertices must be distinct.

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vk</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>Vj</Var>
                </Atom>
                <Atom>
                    <Rel>distinct</Rel>
                    <Expr>
                        <Fun per="copy">pair</Fun>
                        <Var>Vk</Var>
                        <Var>Vj</Var>
                    </Expr>
                </Atom>
                <Equal>
                    <Var>V</Var>
                    <Expr>
                        <Fun per="copy">set</Fun>
                        <Var>Vk</Var>
                    </Expr>
                </Equal>
                <Equal>
                    <Var>E</Var>
                    <Expr>
                        <Fun per="copy">set</Fun>
                        <Expr>
                            <Fun per="copy">pair</Fun>
                            <Var>Vk</Var>
                            <Var>Vj</Var>
                        </Expr>
                    </Expr>
                </Equal>
```

```
                <Atom>
                    <Rel>greaterOrEqual</Rel>
                    <Expr>
                        <Fun per="copy">cardinality</Fun>
                        <Var>V</Var>
                    </Expr>
                    <Ind>1</Ind>
                </Atom>
                <Atom>
                    <Rel>greaterOrEqual</Rel>
                    <Expr>
                        <Fun per="copy">cardinality</Fun>
                        <Var>E</Var>
                    </Expr>
                    <Ind>0</Ind>
                </Atom>
            </And>
            <Atom>
                <Rel>simpleGraph</Rel>
                <Expr>
                    <Fun per="copy">graph</Fun>
                    <Var>V</Var>
                    <Var>E</Var>
                </Expr>
            </Atom>
        </Implies>
    </Assert>
</RuleML>
```


vertex
Vk
vertex
Vj
distinct
pair
Vk
Vj
V
set
Vk
E
set
pair
Vk
Vj
greaterOrEqual
cardinality
V
1
greaterOrEqual
cardinality
E
0
simpleGraph
graph
V
E

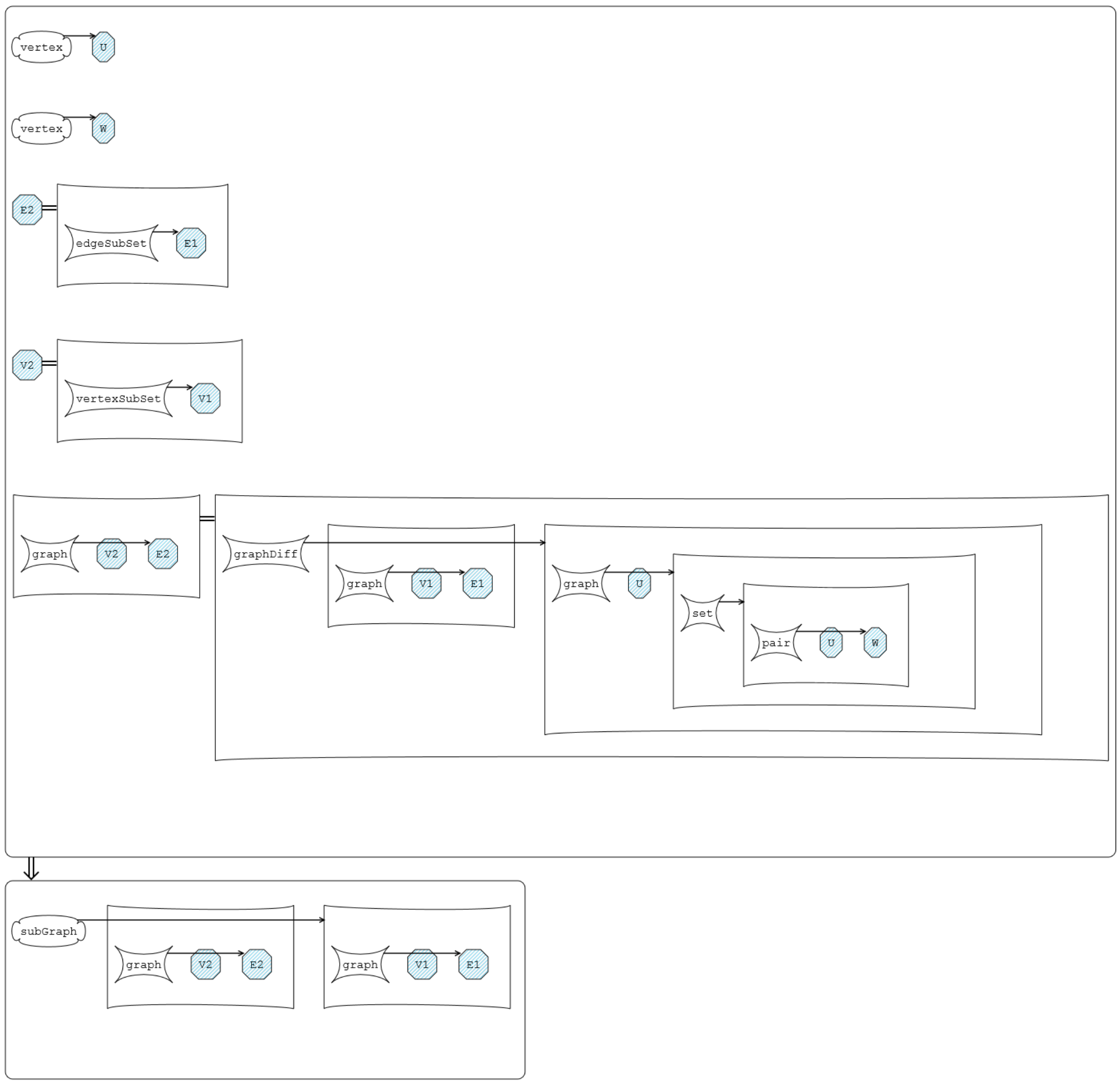
A.5 Test Case 5

This test case is a way to capture: A graph constructed from a set of vertices and edges is a subgraph if it contains a subset of edges and vertices that are the result of removing a graph over some vertex and edge elements from a larger graph.

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>U</Var>
                </Atom>
                <Atom>
                    <Rel>vertex</Rel>
                    <Var>W</Var>
                </Atom>
                <Equal>
                    <Var>E2</Var>
                    <Expr>
                        <Fun per="copy">edgeSubSet</Fun>
                        <Var>E1</Var>
                    </Expr>
                </Equal>
                <Equal>
                    <Var>V2</Var>
                    <Expr>
                        <Fun per="copy">vertexSubSet</Fun>
                        <Var>V1</Var>
                    </Expr>
                </Equal>
                <Equal>
```

```
        <Expr>
            <Fun per="copy">graph</Fun>
            <Var>V2</Var>
            <Var>E2</Var>
        </Expr>
        <Expr>
            <Fun per="copy">graphDiff</Fun>
            <Expr>
                <Fun per="copy">graph</Fun>
                <Var>V1</Var>
                <Var>E1</Var>
            </Expr>
            <Expr>
                <Fun per="copy">graph</Fun>
                <Var>U</Var>
                <Expr>
                    <Fun per="copy">set</Fun>
                    <Expr>
                        <Fun per="copy">pair</Fun>
                        <Var>U</Var>
                        <Var>W</Var>
                    </Expr>
                </Expr>
            </Expr>
        </Expr>
    </Equal>
</And>
<Atom>
    <Rel>subGraph</Rel>
    <Expr>
        <Fun per="copy">graph</Fun>
        <Var>V2</Var>
        <Var>E2</Var>
    </Expr>
    <Expr>
        <Fun per="copy">graph</Fun>
        <Var>V1</Var>
        <Var>E1</Var>
```

```
                </Expr>
            </Atom>
        </Implies>
    </Assert>
</RuleML>
```


vertex
U
vertex
W
E2
edgeSubSet
E1
V2
vertexSubSet
V1
graph
V2
E2
graphDiff
graph
V1
E1
graph
U
set
pair
U
W
subGraph
graph
V2
E2
graph
V1
E1

Appendix B

Financial Use Case

Typical financial business rules for international non-profit organizations such as RuleML Inc were transformed from RuleML/XML to Grailog/SVG visualization. The financial rules that were covered by the use case include incoming and outgoing transactions.

B.1 Hornlog RuleML

In developing the use case, the financial rules involving different sources of income and expense were expressed in Hornlog RuleML. The size of this RuleML/XML input file is 8KB.

```
<RuleML>
    <Assert>
        <!-- Sponsor Level is associated with
          a colour and amount in USD -->
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Ind>Bronze</Ind>
            <Ind>500.00</Ind>
        </Atom>
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Ind>Silver</Ind>
            <Ind>1000.00</Ind>
        </Atom>
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Ind>Gold</Ind>
            <Ind>3000.00</Ind>
        </Atom>
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Ind>Platinum</Ind>
            <Ind>5000.00</Ind>
        </Atom>
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Ind>Emerald</Ind>
            <Ind>7500.00</Ind>
        </Atom>
        <!-- Sponsor of RuleML Symposium -->
        <Atom>
            <Rel>sponsor</Rel>
            <Expr>
                <Fun per="copy">name</Fun>
                <Ind>OASISLegalXML</Ind>
            </Expr>
            <Ind>Silver</Ind>
        </Atom>
```

```
<!-- Speakers at RuleML Symposium -->
<Atom>
    <Rel>speaker</Rel>
    <Expr>
        <Fun per="copy">name</Fun>
        <Ind>MichaelGruninger</Ind>
    </Expr>
    <Ind>Keynote</Ind>
</Atom>
<Atom>
    <Rel>speaker</Rel>
    <Expr>
        <Fun per="copy">name</Fun>
        <Ind>BenjaminGrosof</Ind>
    </Expr>
    <Ind>InvitedTalk</Ind>
</Atom>
<!-- Type of speaker is associated
with a reimbursement -->
<Atom>
    <Rel>reimburse</Rel>
    <Ind>Keynote</Ind>
    <Ind>400.00</Ind>
</Atom>
<Atom>
    <Rel>reimburse</Rel>
    <Ind>InvitedTalk</Ind>
    <Ind>0.00</Ind>
</Atom>
<Atom>
    <Rel>reimburse</Rel>
    <Ind>Tutorial</Ind>
    <Ind>0.00</Ind>
</Atom>
<!-- Registration fee is associated
with a type of participant -->
<Atom>
    <Rel>registrationFee</Rel>
```

```
    <Ind>Student</Ind>
    <Ind>Early</Ind>
    <Ind>150.00</Ind>
</Atom>
<Atom>
    <Rel>registrationFee</Rel>
    <Ind>Student</Ind>
    <Ind>Late</Ind>
    <Ind>250.00</Ind>
</Atom>
<Atom>
    <Rel>registrationFee</Rel>
    <Ind>MemberOrPartner</Ind>
    <Ind>Early</Ind>
    <Ind>400.00</Ind>
</Atom>
<Atom>
    <Rel>registrationFee</Rel>
    <Ind>MemberOrPartner</Ind>
    <Ind>Late</Ind>
    <Ind>500.00</Ind>
</Atom>
<Atom>
    <Rel>registrationFee</Rel>
    <Ind>NonMember</Ind>
    <Ind>Early</Ind>
    <Ind>450.00</Ind>
</Atom>
<Atom>
    <Rel>registrationFee</Rel>
    <Ind>NonMember</Ind>
    <Ind>Late</Ind>
    <Ind>550.00</Ind>
</Atom>
<!-- The web service fee is associated
with a type of participant -->
<Atom>
    <Rel>webServiceFee</Rel>
```

```
        <Ind>Student</Ind>
        <Ind>4.74</Ind>
    </Atom>
    <Atom>
        <Rel>webServiceFee</Rel>
        <Ind>MemberOrPartner</Ind>
        <Ind>9.95</Ind>
    </Atom>
    <Atom>
        <Rel>webServiceFee</Rel>
        <Ind>NonMember</Ind>
        <Ind>9.95</Ind>
    </Atom>
    <!-- Participants at RuleML Symposium -->
    <Atom>
        <Rel>participant</Rel>
        <Expr>
            <Fun per="copy">id</Fun>
            <Ind>179676719</Ind>
        </Expr>
        <Ind>Student</Ind>
        <Ind>Late</Ind>
    </Atom>
    <Atom>
        <Rel>participant</Rel>
        <Expr>
            <Fun per="copy">id</Fun>
            <Ind>177691773</Ind>
        </Expr>
        <Ind>MemberOrPartner</Ind>
        <Ind>Early</Ind>
    </Atom>
    <!-- Conversion from USD to CAD
    at a rate of 1.3 -->
    <Implies>
        <Atom>
            <Rel>mulitply</Rel>
            <Var>USDAmount</Var>
```

```
        <Ind>1.3</Ind>
        <Var>CADAmount</Var>
    </Atom>
    <Atom>
        <Rel>convertUSDToCAD</Rel>
        <Var>USDAmount</Var>
        <Var>CADAmount</Var>
    </Atom>
</Implies>
<!-- Income of sponsorship from an organization
is converted and deposited into the CAD account -->
<Implies>
    <And>
        <Atom>
            <Rel>sponsor</Rel>
            <Expr>
                <Fun per="copy">name</Fun>
                <Var>Organization</Var>
            </Expr>
            <Var>Level</Var>
        </Atom>
        <Atom>
            <Rel>sponsorLevel</Rel>
            <Var>Level</Var>
            <Var>AmountUSD</Var>
        </Atom>
        <Atom>
            <Rel>convertUSDToCAD</Rel>
            <Var>AmountUSD</Var>
            <Var>AmountCAD</Var>
        </Atom>
        <Atom>
            <Rel>incoming</Rel>
            <Expr>
                <Fun per="copy">name</Fun>
                <Var>Organization</Var>
            </Expr>
            <Var>AmountCAD</Var>
```

```
            <Ind>CIBCToronto</Ind>
        </Atom>
    </And>
    <Atom>
        <Rel>income</Rel>
        <Expr>
            <Fun per="copy">sponsorship</Fun>
            <Expr>
                <Fun per="copy">name</Fun>
                <Ind>OASISLegalXML</Ind>
            </Expr>
            <Var>Level</Var>
            <Var>AmountCAD</Var>
        </Expr>
    </Atom>
</Implies>
<!-- Conversion from gross income to net income -->
<Implies>
    <And>
        <Atom>
            <Rel>webServiceFee</Rel>
            <Var>ParticipantType</Var>
            <Var>FeeAmount</Var>
        </Atom>
        <Atom>
            <Rel>subtract</Rel>
            <Var>GrossUSDAmount</Var>
            <Var>FeeAmount</Var>
            <Var>NetUSDAmount</Var>
        </Atom>
    </And>
    <Atom>
        <Rel>convertGrossToNet</Rel>
        <Var>GrossUSDAmount</Var>
        <Var>NetUSDAmount</Var>
        <Var>ParticipantType</Var>
    </Atom>
</Implies>
```

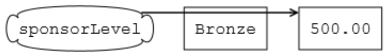
```
<!-- Income of registration from a participant
is deposited into the Paypal account -->
<Implies>
    <And>
        <Atom>
            <Rel>participant</Rel>
            <Expr>
                <Fun per="copy">id</Fun>
                <Var>IDNumber</Var>
            </Expr>
            <Var>ParticipantType</Var>
            <Var>RegistrationType</Var>
        </Atom>
        <Atom>
            <Rel>registrationFee</Rel>
            <Var>ParticipantType</Var>
            <Var>RegistrationType</Var>
            <Var>AmountUSD</Var>
        </Atom>
        <Atom>
            <Rel>convertGrossToNet</Rel>
            <Var>AmountUSD</Var>
            <Var>NetAmountUSD</Var>
            <Var>ParticipantType</Var>
        </Atom>
        <Atom>
            <Rel>incoming</Rel>
            <Expr>
                <Fun per="copy">id</Fun>
                <Var>IDNumber</Var>
            </Expr>
            <Var>NetAmountUSD</Var>
            <Ind>Paypal</Ind>
        </Atom>
    </And>
    <Atom>
        <Rel>income</Rel>
        <Expr>
```

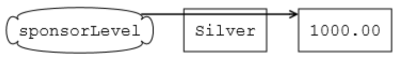
```
            <Fun per="copy">registration</Fun>
            <Expr>
                <Fun per="copy">id</Fun>
                <Var>IDNumber</Var>
            </Expr>
            <Var>ParticipantType</Var>
            <Var>RegistrationType</Var>
            <Var>NetAmountUSD</Var>
        </Expr>
    </Atom>
</Implies>
<!-- Expense of a speaker is converted and
withdrawn from the CAD bank account -->
<Implies>
    <And>
        <Atom>
            <Rel>speaker</Rel>
            <Expr>
                <Fun per="copy">name</Fun>
                <Var>SpeakerName</Var>
            </Expr>
            <Var>SpeakerType</Var>
        </Atom>
        <Atom>
            <Rel>reimburse</Rel>
            <Var>SpeakerType</Var>
            <Var>AmountUSD</Var>
        </Atom>
        <Atom>
            <Rel>convertUSDToCAD</Rel>
            <Var>AmountUSD</Var>
            <Var>AmountCAD</Var>
        </Atom>
        <Atom>
            <Rel>outgoing</Rel>
            <Expr>
                <Fun per="copy">name</Fun>
                <Var>SpeakerName</Var>
```

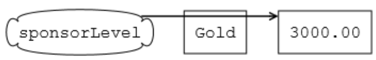
```
                </Expr>
                <Var>AmountCAD</Var>
                <Ind>CIBCToronto</Ind>
            </Atom>
        </And>
        <Atom>
            <Rel>expense</Rel>
            <Expr>
                <Fun per="copy">symposiumSpeaker</Fun>
                <Expr>
                    <Fun per="copy">name</Fun>
                    <Var>SpeakerName</Var>
                </Expr>
                <Var>SpeakerType</Var>
                <Var>AmountCAD</Var>
            </Expr>
        </Atom>
    </Implies>
</Assert>
</RuleML>
```

B.2 Grailog/SVG

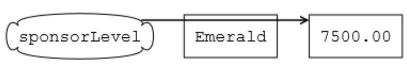
The Renderer XSLT was used to transform the Hornlog RuleML/XML source to Grailog/SVG visualization of the financial rules. The size of the Grailog/SVG/XML output file with JavaScript is 634KB, and without JavaScript is 97KB. It took on average 0.410s to render the visualization from the RuleML/XML. The rendering using the static SVG required on average 0.082s, and the pure SVG with the JavaScript removed took on average 0.076s to render.

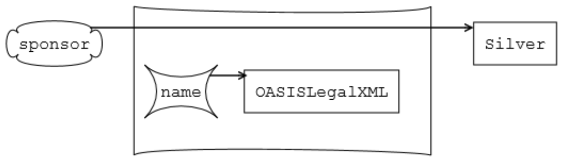

sponsorLevel
Bronze
500.00

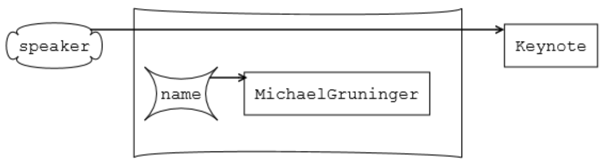

sponsorLevel
Silver
1000.00

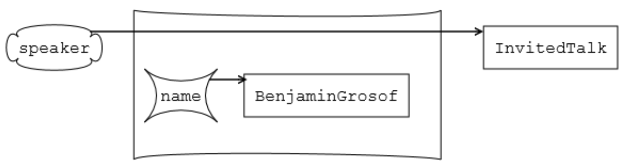

sponsorLevel
Gold
3000.00

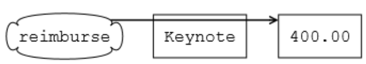

sponsorLevel
Platinum
5000.00

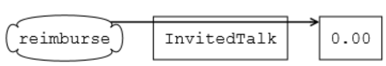

sponsorLevel
Emerald
7500.00


sponsor
name
OASISLegalXML
Silver

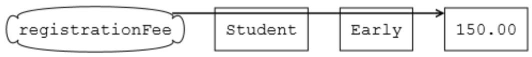

speaker
name
MichaelGruninger
Keynote

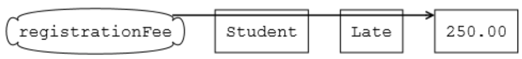

speaker
name
BenjaminGrosof
InvitedTalk


reimburse
Keynote
400.00


reimburse
InvitedTalk
0.00


reimburse
Tutorial
0.00


registrationFee
Student
Early
150.00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Student
Late
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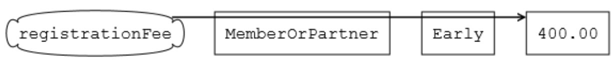
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MemberOrPartner
Early
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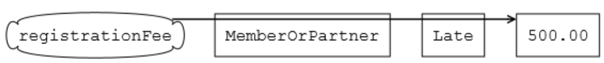
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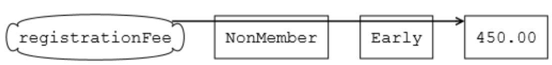
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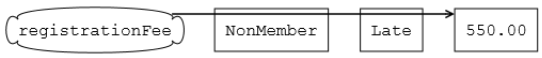
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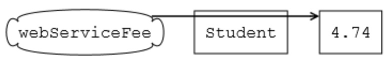
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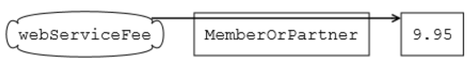
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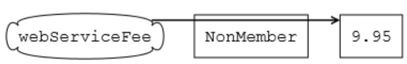
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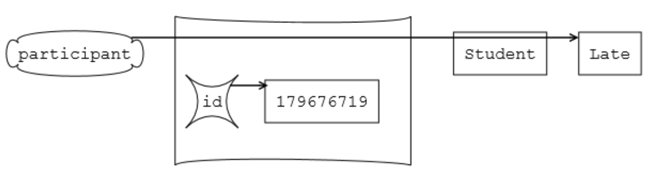
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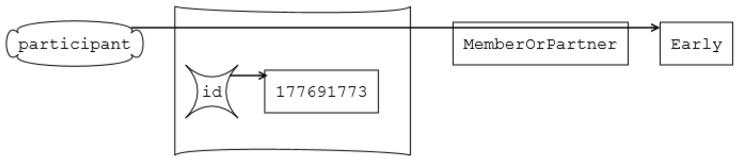
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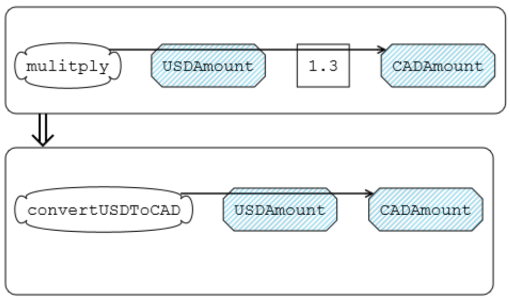
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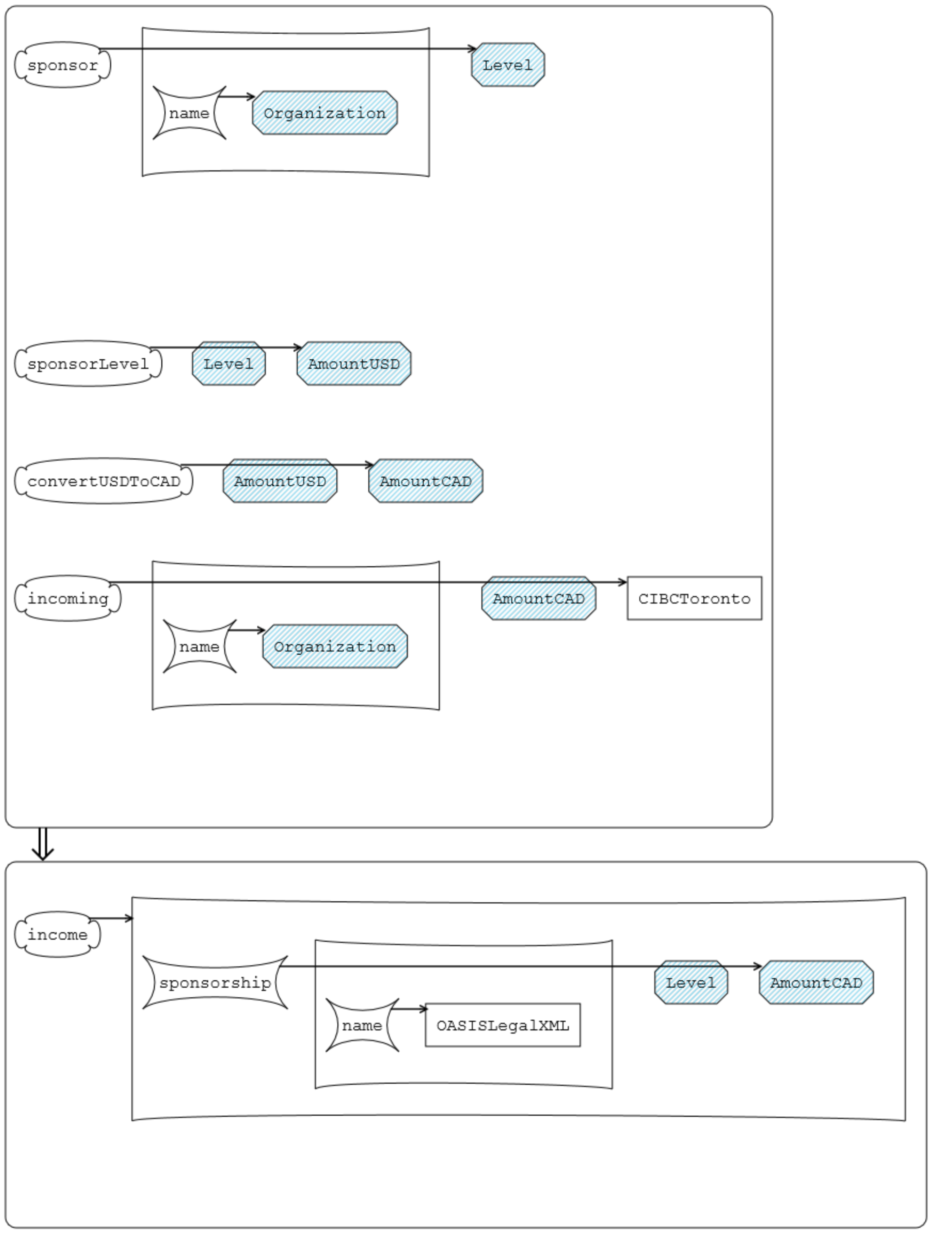

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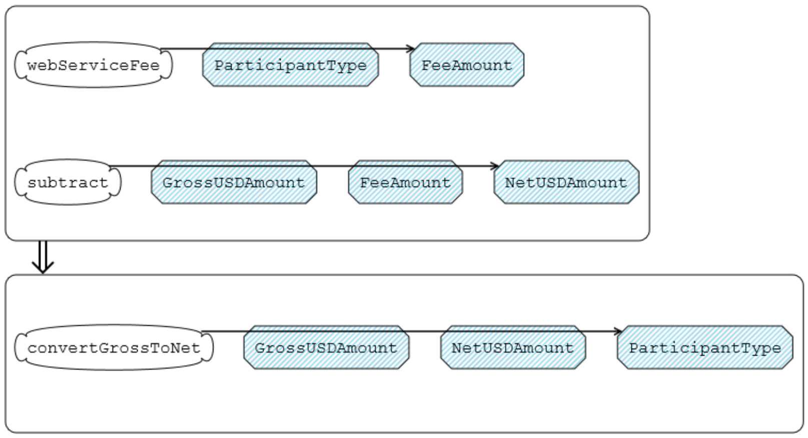
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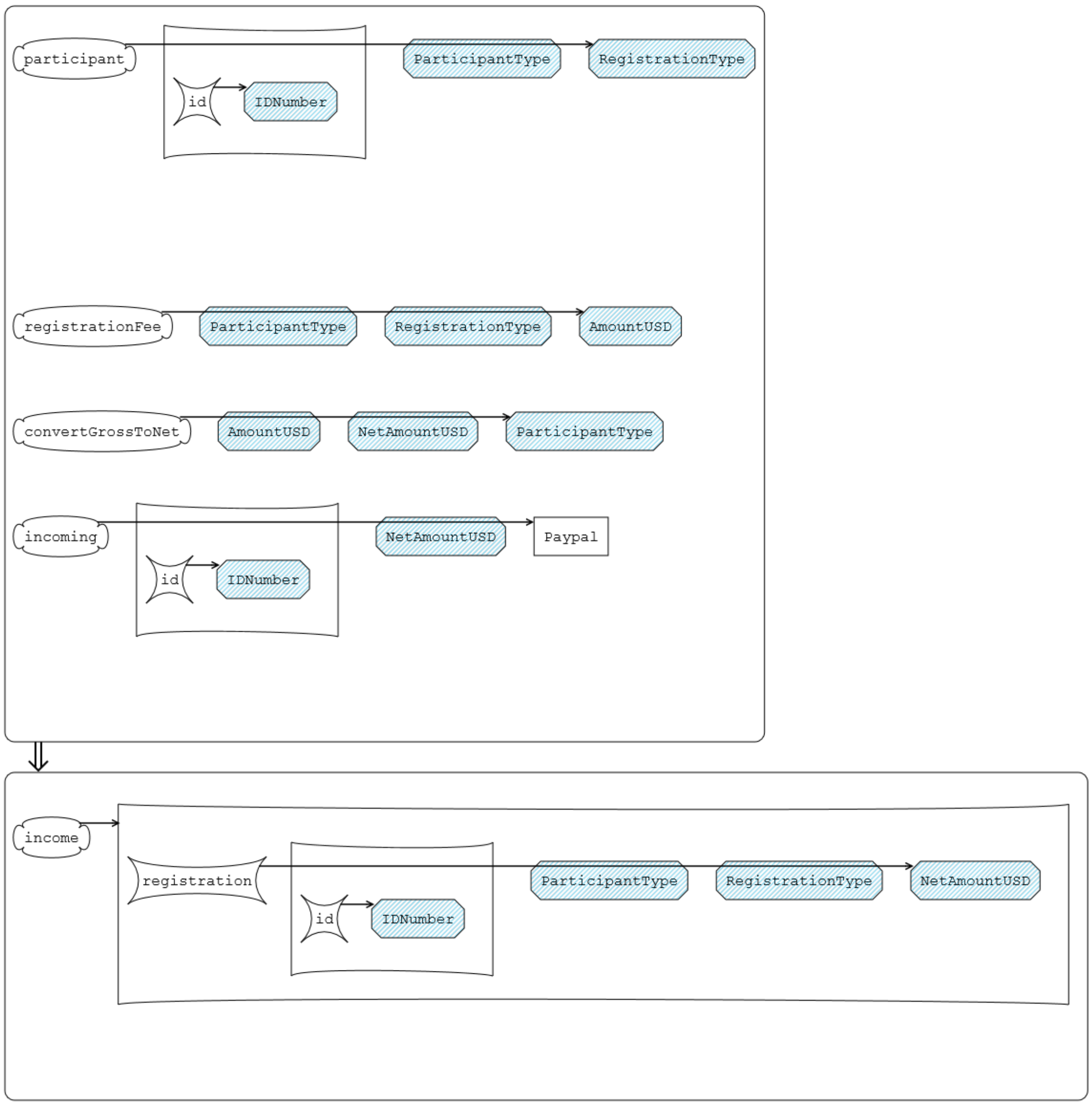
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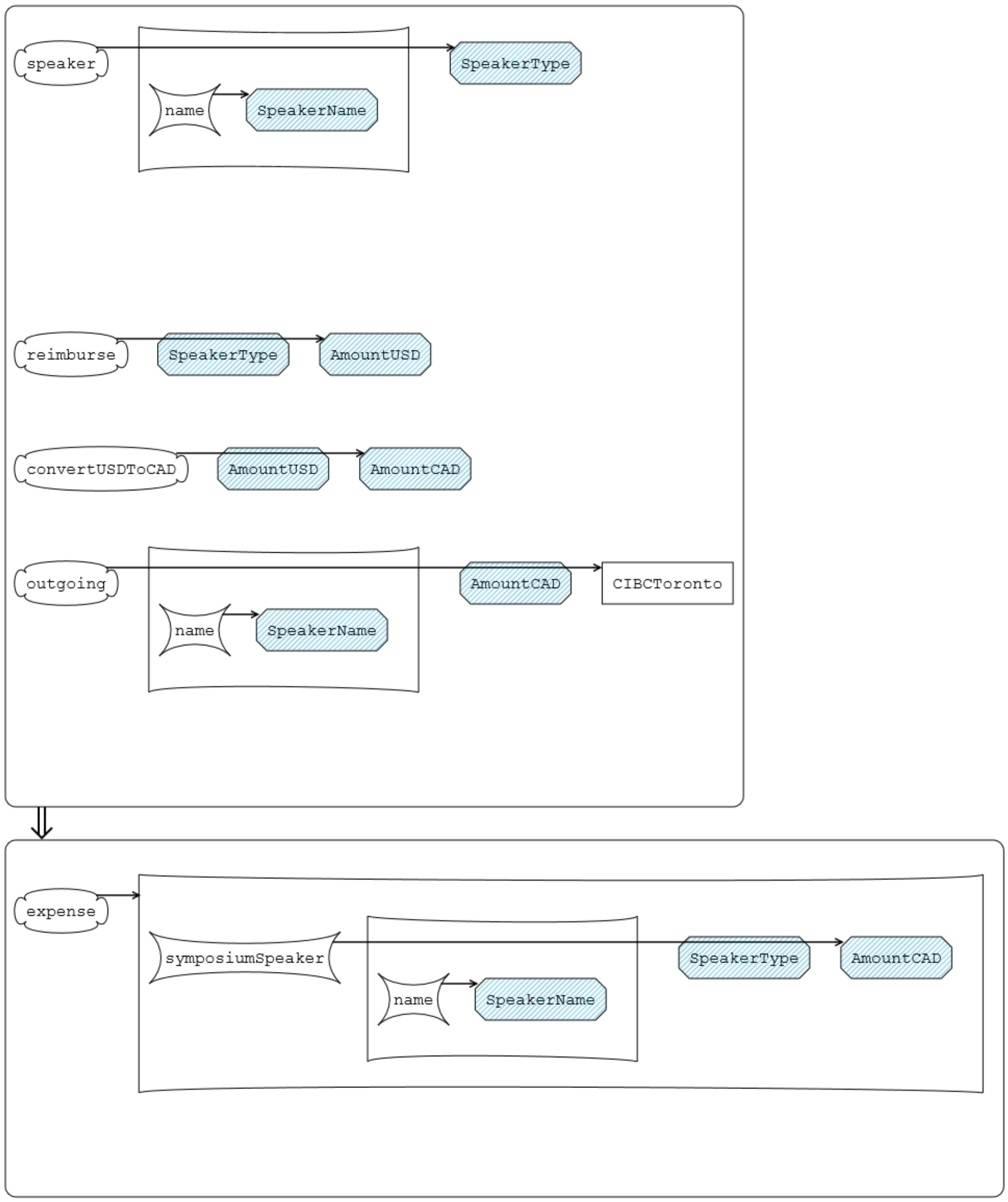
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expense
symposiumSpeaker
SpeakerType
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name
SpeakerName

Appendix C

Installation and Use

Grailog KS Viz 2.0 is employed to visualize rule-knowledge bases in RuleML/XML as Grailog graphs in SVG/XML using common modern Web browsers. The SVG initially contains internal JavaScript that is used to calculate and assign position values and attribute values. The Grailog KS Viz 2.0 files, referred to in this guide using relative URL's, are located at the root URL https://github.com/RuleML/GrailogKSViz/blob/2.0/. The GraphTheory test case for testing Grailog KS Viz 2.0 was implemented: starting with a RuleML/XML document GraphTheory.ruleml (GraphTheory.ruleml.xml) (save file and open in an XML or text editor to view and edit the source RuleML), adding a stylesheet processing instruction in the prolog, and visualizing it with any common Web browser as SVG/XML document

GraphTheory.svg. The RuleML/XML as input is transformed using the Web browser's XSLT 2.0 processor. To perform all testing using only the browser's XSLT processor, the XML document's prolog must contain a stylesheet processing instruction that references the XSLT to be applied. For local and online testing browser security settings must allow JavaScript to run.

C.1 Local Testing of the Renderer

For testing Grailog KS Viz 2.0 on local machines, all documents must be stored as local files in the same directory. The RuleML/XML document must contain a reference to the Renderer XSLT stylesheet (Renderer.xslt) in order to apply the transformation. Open the saved GraphTheory.ruleml file in an editor and copy the stylesheet processing instruction into the prolog:

```
<?xml-stylesheet type="text/xsl" href="Renderer.xslt"?>
```

To view the Grailog visualization, open the RuleML/XML document in a common Web browser (e.g., IE or Firefox), either by dragging and dropping the RuleML/XML file onto the application (shortcut) or choosing the 'open with' option from the context menu and selecting the Web browser application. Local testing cannot be done using Google Chrome due to its strict Same Origin Policy (SOP), which does not recognize the files stored in the same local directory as being from the same origin.

C.2 Online Testing of the Renderer

For testing Grailog KS Viz 2.0 online, the RuleML/XML document GraphTheory.ruleml and the Renderer XSLT stylesheet must be stored in the same online directory. Then create a hyperlink to the RuleML/XML document. In the Web browser, select the hyperlink to the RuleML/XML document: the browser's XSLT processor will render the Grailog visualization. Online testing can be done using common Web browsers (e.g., IE, Firefox, Google Chrome, or Safari).

C.3 Using the Purifier

The internal JavaScript can be removed (only) after the visualization has been rendered and saved as a static SVG image. The Purifier XSLT stylesheet (Purifier.xslt) must be stored in the same directory as the static SVG image. Due to strict security policies, Google Chrome cannot be used to perform the purifying. To remove JavaScript tags from the generated Grailog SVG/XML:

1. render the Grailog visualization in browser

2. save the SVG image in the same directory as the Purifier XSLT by selecting from the browser's context menu:
   (a) 'Save picture as' in IE
   (b) 'Save page as' in Firefox
3. open the saved SVG file in an editor and copy the stylesheet processing instruction into the prolog:

```
<?xml-stylesheet type="text/xsl" href="Purifier.xslt"?>
```

4. open the edited file in IE or Firefox to get the Purifier XSLT applied

The final SVG may be saved to any location and will not contain any JavaScript. The final rendering may be viewed in IE and Firefox. Due to strict security policies, to view the final SVG in Google Chrome, the file must be edited again to remove the stylesheet processing instruction from the prolog, which is no longer required after the Purifier has been applied. Once the reference is removed, the SVG can also be viewed in Google Chrome.

C.4 GraphTheory Test Case

In the current section the RuleML/XML for the GraphTheory test case employed in this Installation and Use guide is provided. The test case is written in controlled natural language, then represented in RuleML logic, and finally presented in Grailog.

```
If
    N1 is a node
  And
    N2 is a node
Then
    the undirected arc from N1 to N2 is
  Equal to
    the undirected arc from N2 to N1
```

```
<RuleML>
    <Assert>
        <Implies>
            <And>
                <Atom>
                    <Rel>node</Rel>
                    <Var>N1</Var>
                </Atom>
                <Atom>
                    <Rel>node</Rel>
                    <Var>N2</Var>
                </Atom>
            </And>
            <Equal>
                <Expr>
                    <Fun per="copy">undirectedArc</Fun>
                    <Var>N1</Var>
                    <Var>N2</Var>
                </Expr>
                <Expr>
                    <Fun per="copy">undirectedArc</Fun>
                    <Var>N2</Var>
```

```
                <Var>N1</Var>
            </Expr>
        </Equal>
    </Implies>
  </Assert>
</RuleML>
```

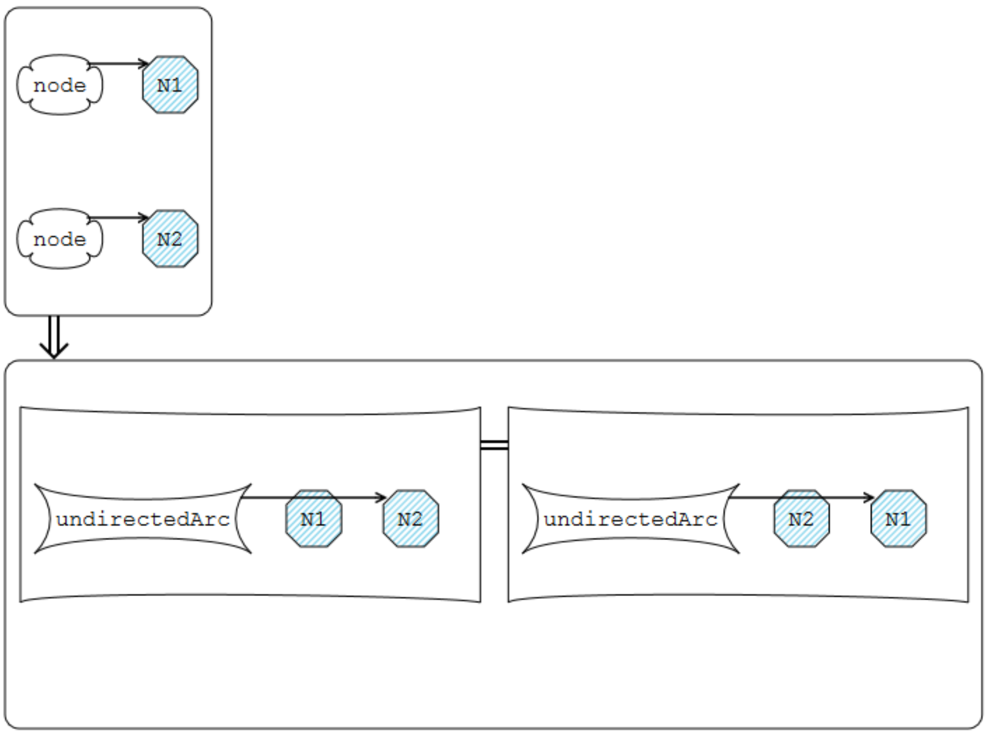

Figure C.1: Grailog/SVG visualization of GraphTheory RuleML/XML.

Vita

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University attended:

- University of New Brunswick (Fredericton) 1999-2005 Bachelor of Computer Science
- University of New Brunswick (Fredericton) 1999-2005 Bachelor of Education

Presentations:

- *Grailog KS Viz 2.0: Graph-Logic Knowledge Visualization by XML-Based Translation* **The 6th Atlantic Workshop of Semantics and Services (AWoSS)**, December 9, 2015. University of New Brunswick, Fredericton, NB
- *Translating HornlogEq RuleML to Grailog for SVG Visualization* **RuleML Webinar**, June 20, 2016