An Architecture to Support Model Driven Software Visualization

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Abstract

Program comprehension tools are a valuable resource for navigating and understanding large software systems. Package explorers, fan-in / fan-out views, dependency graphs and coverage analysis are example contributions from the program comprehension community. While many of these research projects have lead to exciting enhancements in our field, many other projects have failed to be adopted because of poor interface design or lack of integration with existing tools. Designing, building, integrating and evaluating interfaces is a challenge to software engineering researchers.

In this paper we borrow from the field of Model Driven Engineering (MDE) to assist with the creation of highly customizable interfaces for software visualization. MDE moves the level of abstraction from implementation to design, and will help improve the efficiency of building software visualizations. By moving away from implementation details, and providing researchers with the ability to customize their visualizations in an efficient manner, software engineers will have more resources to design and evaluate their ideas.

1 Introduction

Large scale software development does not occur without tool support. Integrated Development Environments (IDEs), such as Emacs, Eclipse, or Microsoft Visual Studio, provide a wide range of tools for software developers. IDEs integrate components such as incremental compilers, editors, bug tracking, automated documentation and source code management tools.

Extracting and representing information from these tools is fundamental to software development. The research on just in time comprehension [22] has revealed the importance of extracting information from many of these components and presenting meaningful information to the developers when they need it. As systems continue to get larger, and the amount of information mined from source repositories grows, CASE tool designers have to continually create new and innovative ways to present this information to the software engineers.

Through work with our industry partners, it has become evident that tool developers need more support when designing interfaces for manipulating and displaying complex data, such as the facts extracted from source repositories. Tool development is now being supported, and partially automated, through model driven development. To support these tool developers, we propose combining view creation and model driven development to help improve the efficiency of view creation. Using these techniques, researchers and tool designers will be able to spend more time designing and evaluating their tools and less time building them.

2 Motivating Example

Software artifact interchange languages such as the Graph eXchange Language (GXL) [13] and the Rigi Standard Format (RSF) [17] have allowed program comprehension researchers to integrate their work with one another. Following the reverse engineering process outlined by Chikofsky and Cross [9], researchers have been able to split the process into three distinct parts: the identification of artifacts and their interrelationships (extraction) [16, 8], the representation of these artifacts in another form or at a higher level of abstraction (abstraction) [23, 11], and the rendering of the information in a meaningful way (presentation) [5, 19]. The common exchange formats have allowed

researchers focus on a single area of the pipeline and leverage other tools to validate their work.

While GXL has reduced the barriers that existed between tools, integrating several reverse engineering tools into existing development environments still remains a challenge. Many visualization tools do not directly support GXL, and the tools that do, require hand coding in order to customize the view to meet the user's requirements. For example, consider a simple artifact extractor which generates a GXL document conforming to a programming model. Let us assume that the model contains elements such as **Packages, Classes, Methods,** and **Fields**, with simple relationships such as **Contains, Calls, Accesses,** and **Inherits**. In order to display a class hierarchy view, a traversal algorithm must be designed to walk the model and populate a Tree Control. If the language supports multiple inheritance, then a graph view may be more appropriate. LSEdit [19] and SHriMP [5] can be used to render the graph, but their integration with environments such as Eclipse and Visual Studio is not seamless. Graph Editing frameworks, such as GEF [2], provide a rich interaction with its development environment, however, these frameworks require strong graphical programming skills. Now consider the case in which the user would also like to see a grouping of classes based on packages; this requires yet another traversal algorithm and possibly another set of graph drawing libraries. It is this disconnect between fact extraction and information visualization, which is not addressed by standard exchange formats, that has motivated the need for a more structured method of customizing visual interfaces.

3 Related Work

Several researchers have investigated how to generate customized views for program comprehension. The Bloom system [20] and the work by Consens *et al.* [10] both use a graph query language to generate their views. While both of these tools provide a mechanism to rapidly prototype visualizations, it is not clear whether graph algebra is the most appropriate means of views specification. Mackinlay proposed the use of graphical sentences to generate presentations of relational information [15] a technique that maps more closely to the domain of interaction design. While this work was highly advanced for its time, the views created were limited to static charts.

The Graphical Modeling Framework [4] project for Eclipse has facilities to allow modelers to define graphical editors for their data. These graphical editors can be used as viewers, however, the views they support are limited to simple graphs with containers. Other views such as charts, zoomable interfaces and 3D visualizations are not supported. Software visualizations often contain 100's or even 1,000's of visual entities. GMF does not support the layout or rendering of information spaces of this magnitude. Finally, the GMF project currently lacks the ability to specify "Query Result" visualizations, meaning that the diagram definition language is not as powerful as the relational algebra used by other tools.

Each of these technologies has contributed to the groundwork needed to design Model Driven Visualizations (MDV), however, none of these technologies alone provides a complete solution. In order to generate effective views of a software system, the views should be designed for software engineers and integrated into existing environments. The visualizations must be easy to use and easily customized. We propose leveraging technologies from MDE to meet these requirements.

4 Proposed Solution: MDV

The Object Modeling Group's Model Driven Architecture and the more general MDE [14, 6] initiatives describe how models can be used both to design and to deliver a software system. A model is considered to be a schematic description of a system. The MDE process requires designers to specify models at different levels of abstraction for a given problem and design transformations to translate between the models.

The motivation behind MDE is to move the focus of development from programming to solution modeling [21]. MDE proposes to combat complexity through the use of abstraction, problem decomposition and separation of concerns [21]. Building on these ideas, we believe we have found a balance between the goals of MDE and traditional software development by allowing interaction designers to model their software views, leaving the implementation of visualization components and complex graph algorithms to expert graphics programmers. This technology will allow program compression researchers to spend more time studying their tools rather than building them.

4.1 A Reference Architecture for MDV

From our experience building program comprehension tools and our work with industry partners, several criteria for visualization tools have emerged. Firstly, the views should *integrate with existing development environments*, and whenever a native viewer exists, it should be leveraged. For example, if a development environment supports a charting engine or widget toolkit, these components should be used. Developers become comfortable with their programming environments, and they may be reluctant to spend their time evaluating new stand-alone tools. If a program comprehension tool can be integrated within a familiar development environment, the cost for developers to evaluate it is reduced. Secondly, the toolkit *should allow visual-*

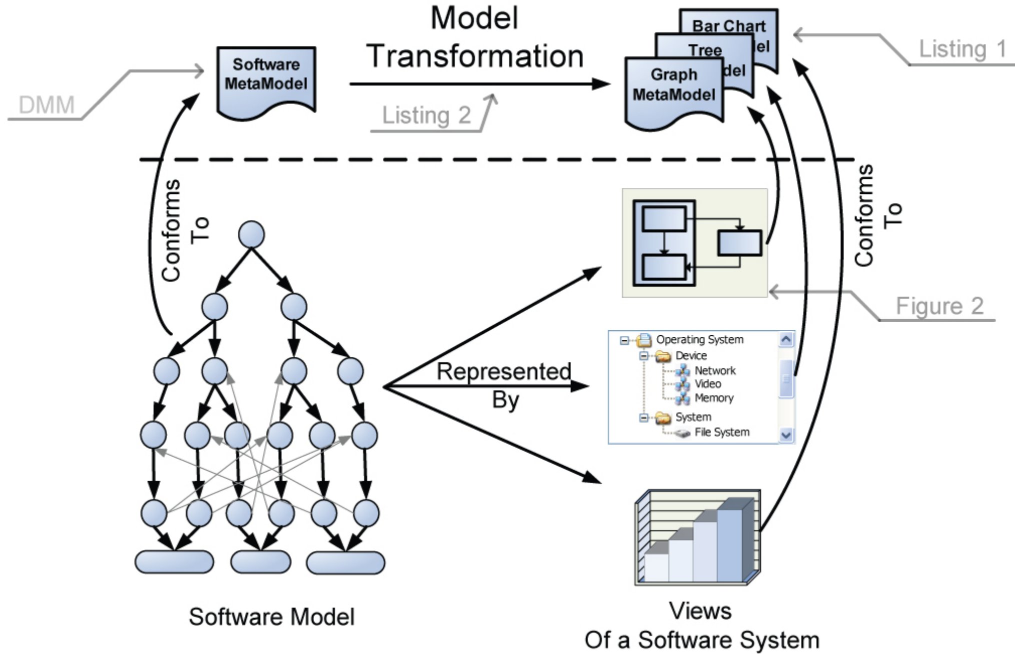

Figure 1: The Reference Architecture for MDV in action

izations to be designed on existing, in-memory models, or at least provide integrated extractors that work on their existing models such as databases. Users are more likely to use a tool that is already included within their environment than they are to export their source code just to produce a view. This is because exporting their data and creating a view involves more cognitive overhead and time. Finally, the views must be *specified in a textual or visual language familiar to the interaction designer.* Domain Specific Languages (DSLs), such as Macros for Excel, or Matlab for evaluating mathematical formulas, provide domain experts with facilities to specify their problem without getting caught up in the details of a general purpose programming language.

Using the criteria listed above, we have designed a reference architecture to describe visualizations (Figure 1). The architecture makes use of techniques prescribed by the MDE community. In particular, the architecture recommends the use of meta-models for both the domain and the viewers. A DSL, targeted at interaction designers, is also needed to describe translations between the domain and viewer meta-models. Model Driven Visualization formalizes the *abstraction* and *presentation* customization phases of the reverse engineering pipeline.

4.2 Viewer Meta-Models

In order for a visualization tool to be leveraged within MDV, a meta-model (or schema) must be defined for the viewer. A viewer is a data-centric user interface control such as a tree or table widget. A view, on the other hand, is an instantiation of a viewer. For example, a system hierarchy displayed as a tree is a view, while the tree control widget is the viewer.

Most information visualization toolkits are built as stand-alone applications to make them easier to use from an end user's standpoint. This design decision makes them more difficult to integrate within other applications such as IDEs. While these tools may be built this way, internally they follow the Model View Controller design pattern, meaning that they have separated the data from the view. We have documented meta-models for several standard widget components including the Tree, List and Table controls. Also, we have successfully decoupled several viewers from the encompassing toolkit and extracted meta-models for these. Among our successes are the Business Integration and Reporting Tool (BIRT) charts [3], the Simple Hierarchical Multiple Perspective (SHriMP) tool [5], and the Prefuse Spring Graph Viewer [12]. To illustrate our approach, we have included the Nested Viewer such as the ones provided by SHriMP, Zest [7] and LSEdit [19].

The meta-model for the Nested Viewer describes both entities and relationships (Listings 1) [1]. Each entity contains a list of incoming and outgoing edges. The edges in this model have a single source and destination, as well as a label, type and weight. Other attributes, such as entity and edge colour could be added to this model.

[1] We have documented the meta-model for our viewers using the Emfatic textual modeling language.

```
class NestedViewer
{
    val Entity[*] entities;
    val Edge[*] edges;
}
class Entity {
    attr String label;
    ref Edge[*]#source outgoingEdges;
    ref Edge[*]#destination incomingEdges;
    ref Entity[*] children;
}
class Edge {
   ref Entity#outgoingEdges source;
   ref Entity#incomingEdges destination;
   attr int weight;
   attr String label;
}
```

Listing 1: Nested Viewer Meta-Model

We have developed a prototype of our framework in Eclipse and imported several viewer meta-models. The framework was then used to generate several interactive visualizations of a small Java application.

5 A Realization of the MDV Architecture

In order to validate our architecture, we have developed a MDV framework for Eclipse [1]. We leveraged the Eclipse Modeling Framework (EMF), the Atlas Transformation Language (ATL), and several visualization tools.

EMF is a modeling framework that supports meta-modeling, code generation and the loading and unloading of instance data. This means that a Java class hierarchy can be generated from the meta-models described in Section 4.2. EMF supports both containment and bi-directional references, as well as a runtime environment capable of serializing and de-serializing the instance data.

ATL supports a hybrid of declarative and imperative syntax to specify the transformation rules. Constraints can be stated using the Object Constraint Language (OCL) from the UML standard.

To render the views, a set of standard viewer are necessary. In our prototype we have leveraged the Eclipse JFace viewers such as Trees, Tables and Lists. BIRT was used to provide static charts, and Zest, an open source visualization toolkit, was included to support interactive graph visualizations. For each viewer an injector was written (usually $<$ 100 LOC) to provide native EMF support. This means that any set of data conforming to a viewer model could be loaded directly into the viewer and rendered.

Using these three technologies, generating visualizations from EMF data consists of designing the appropriate transformation rules.

```
rule Package2Entity {
    from
        p : java!JPackage
    to e : nestedviewer!Entity (
        label     <- p.name,
        children <- p.subPackages
}
rule Method2Edges {
    from
        m : java!JMethod
    using {
        MethodsAccessed: Set(MOF!EClass) =
            m.calls->asSet()
                ->filter(m.parent.package);
    }
    to e : distinct nestedviewer!Edge foreach (
                accessed in MethodsAccessed ) (
          source       <- m.parent.package,
          destination <- accessed.package
}
```

Listing 2: Method to Edges

6 Generating Software Visualizations

Modeling software visualizations involves designing transformation rules which map elements of source and target meta-models. Source meta-models are schemas to which extracted facts conform. One such example is the Dagstuhl Middle Model (DMM). Target meta-models are the meta-models to which the viewers conform.

In order to demonstrate the feasibility of generating visualizations with MDV, we have designed a visualization to help a developer address control dependencies between packages in a Java application. A control dependency between packages is defined as a method call that exists between methods contained within separate packages.

Zest was then used to visualize the package interaction as a nested graph. The elements of the view are the packages. Sub packages are nested within their parent and high-level relationships are computed to show dependencies.

Listing 2 shows the rules that generate the package dependency graph. The first rule matches all packages in the system and produced a visual entity for each. The label for the entity is mapped to the name of the package, and the children of the entity are all subpackages. The second rule matches each method. For each outgoing call from a method, an edge is generated. The source of the edge is linked to the package that contains the “calling” method. The destination of the edge corresponds to the package that contains the “called” method. Using an additional rule, the interaction designer can specify view properties such as the layout to apply. Figure 2 shows the result of this transformation. The interactive nested viewer can now be navigated to explore the control dependencies between packages.

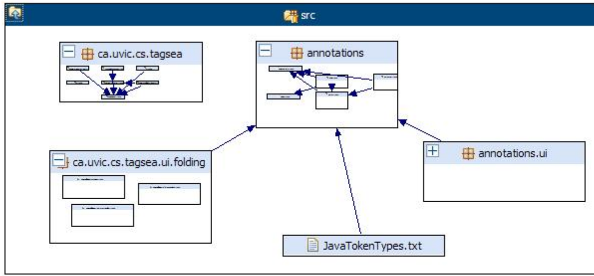

Figure 2: Visualizing Package Interaction with Zest

7 Conclusion and Future Work

Model Driven Visualization is intended to address the customization of information visualization tools, especially in the program comprehension domain. The MDV architecture describes how to leverage the work done in the Model Driven Engineering community and apply it to the problem of designing visualizations tools.

We are currently investigating two open problems in the area of MDV. Firstly, we are designing a more suitable transformation language. We are seeking support from the program comprehension community to help build a Domain Specific Language for describing software visualization. We are currently reviewing the work done by Pacione *et al.* [18], which should provide guidance for the DSL.

Finally, we are investigating the feasibility of an incremental transformation engine. Many program comprehension and reverse engineering tools only work in an "off-line" or "batch" mode. However, with incremental compilers and the continues feeds of information from sources like RSS, a real-time MDV transformation engine would help support just-in-time comprehension.

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