Software architecture visualisation

Andrew Hatch

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Andrew Hatch

Department of Computer Science

University of Durham

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Abstract

Tracing the history of software engineering reveals a series of abstractions. In early days, software engineers would construct software using machine code. As time progressed, software engineers and computer scientists developed higher levels of abstraction in order to provide tools to assist in building larger software systems. This has resulted in high-level languages, modelling languages, design patterns, and software architecture. Software architecture has been recognised as an important tool for designing and building software. Some research takes the view that the success or failure of a software development project depends heavily on the quality of the software architecture.

For any software system, there are a number of individuals who have some interest in the architecture. These stakeholders have differing requirements of the software architecture depending on the role that they take. Stakeholders include the architects, designers, developers and also the sales, services and support teams and even the customer for the software. Communication and understanding of the architecture is essential in ensuring that each stakeholder can play their role during the design, development and deployment of that software system.

Software visualisation has traditionally been focused on aiding the understanding of software systems by those who perform development and maintenance tasks on that software. In supporting developers and maintainers, software visualisation has been largely concerned with representing static and dynamic aspects of software at the code level. Typically, a software visualisation will represent control flow, classes, objects, import relations and other such low level abstractions of the software.

This research identifies the fundamental issues concerning software architecture visualisation. It does this by identifying the practical use of software architecture in the real world, and considers the application of software visualisation techniques to the visualisation of software architecture. The aim of this research is to explore the ways in which software architecture visualisation can assist in the tasks undertaken by the differing stakeholders in a software system and its architecture.

A prototype tool, named ArchVis, has been developed to enable the exploration of some of the fundamental issues in software architecture visualisation. ArchVis is a new approach to software architecture visualisation that is capable of utilising multiple sources and representations of architecture in order to generate multiple views of software architecture. The mechanism by which views are generated means that they can be more relevant to a wider collection of stakeholders in that architecture. During evaluation ArchVis demonstrates the capability of utilising a number of data sources in order to produce architecture visualisations. ArchVis' view model is capable of generating the necessary views for architecture stakeholders and those stakeholders can navigate through the views and data in order to obtain relevant information. The results of evaluating

ArchVis using a framework and scenarios demonstrate that the majority of the objectives of this research have been achieved.

Acknowledgements

Since starting this PhD, there have been a number of very significant events, many of which have shaped this thesis in some way. I believe that those people who have shared some part of my life since October 1999 will realise how they have helped in my completion of this thesis, and some will need a little encouragement to realise it. If you are not mentioned below, it is purely a result of my dysfunctional memory!

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Declaration

No part of the material provided has previously been submitted by the author for a higher degree in the University of Durham or any other University. All the work presented here is the sole work of the author and no one else.

This research has been documented, in part, within the following publication:

> **A. S. Hatch, M. P. Smith, C. M. B. Taylor and M. Munro,** *No Silver Bullet for Software Visualisation Evaluation*, Proceedings of the Workshop on Fundamental Issues of Visualization, Proceedings of The International Conference on Imaging Science, Systems and Technology (CISST), Las Vegas, USA, June 2001, pp. 651-657

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Chapter 1: Introduction

1.1 Introduction

This thesis is an investigation of the application of software visualisation principles and practices to software systems at the architecture level of abstraction.

Software systems are often large, complex and difficult for developers to understand. Software visualisation aims to assist in the comprehension of these types of software systems. There is a clear need for developers and maintainers to understand software at the source-code level, and much of software visualisation and program comprehension research has been focused at this abstraction. Recently, however, it is widely accepted that software benefits from high-level consideration from its design through implementation and post-implementation analysis. With the uptake of architecture practice, there should also be a corresponding push to develop the techniques and tools to effectively communicate software architecture to those who have some interest in that architecture – the stakeholders. As software visualisation has been focused on lower level aspects of software, there is a need to examine software architecture in order to determine how to change or tailor software visualisation practice to deal with this higher level of abstraction.

1.2 Objectives

It is useful to consider the architecture of a software system during its design, implementation and maintenance phases for many reasons. This research deals with the application of visualisation techniques in order to assist in the understanding of a software system's architecture. By supporting a stakeholder in their task of understanding a software system's architecture, several benefits should be realised. These benefits include reducing costs by reducing the time required for gaining an appropriate understanding, and improving the visibility of the software architecture in order to increase the depth of understanding.

This research investigates the current practical application of software architecture during the lifecycle of a software system. In doing so, several key activities, roles and stakeholders are identified for consideration when constructing a software architecture visualisation strategy. Also, an investigation will be made into the current use of software architecture visualisation highlighting the issues, challenges and merits facing existing software architecture visualisations. It is these aspects that will form the basis for developing a new strategy for visualising software architectures.

In order for this research to be applicable to real world software systems, the visualisation strategy must be shown to support information extraction techniques that would be supported in practice. The visualisations

identified in this research will be represented in a proof of concept tool that will allow for the evaluation of both the visualisation strategy itself, and the information extraction techniques that are required.

Visualisations produced by this research are intended to assist in the understanding of software architectures by various stakeholders for different activities. Towards the end of this thesis, there is a discussion of some of the areas of research opened up that can be tackled in the future.

1.3 Criteria for Success

This research aims to investigate the applicability of software architecture visualisation in order to assist in the understanding of software systems by different stakeholders in that system. The success of the research will be judged against the following criteria:

a) Identify the current use of architecture visualisation in practice by showing the tasks different stakeholders perform.

b) Address the visualisation issues of representing software architecture for different stakeholders.

c) Identify a mechanism for providing architectural information to an architecture visualisation.

d) Develop visual representations of software architectures that are suited to the identified tasks.

e) Develop a proof of concept prototype tool to demonstrate the visualisations.

f) Demonstrate that the visualisations can be generated automatically with minimal disruption to the software system itself.

g) Create a feature based evaluation framework suitable for software architecture visualisation.

An evaluation of this research against these criteria is provided in chapter 9.

1.4 Thesis Overview

Broadly speaking, there are two main areas of research that this thesis is based on. The structure of this thesis follows the logical progression of bringing these two areas together.

Chapter 2 provides the background to Software Architecture by identifying why software architecture is important, and the role that it takes in present day software engineering. It also describes how architectures are encoded and how these architecture descriptions are used. Definitions are provided for Software Architecture that delimits the scope of this research.

Chapter 3 distinctly addresses Software Visualisation, examining its history through to its current use. This includes descriptions of a number of existing software visualisations that broadly represent the research area. Important areas of the psychology of software visualisation are presented in order to help define what software visualisation is aiming to achieve. By detailing these fundamental areas, a definition is presented that the remaining thesis can be based on. Major areas of research are outlined in order to position the subject of software architecture visualisation in the wider context.

Chapter 4 focuses on software architecture visualisation, detailing existing work relating to software architecture visualisation. Existing architecture visualisation systems are selected for examination, and their approaches critiqued – specifically, their approach to data extraction and storage, stakeholder support and style and representation choice. This chapter concludes with a summary of some of the challenges facing software architecture visualisation.

Chapter 5 introduces the ArchVis approach to software architecture visualisation. The ArchVis visualisation attempts to address the issues identified in chapter 4, and describes how this is achieved. Firstly, the ArchVis approach to extracting relevant data from software systems is described. Next, the views that ArchVis supports are presented, including how these views are constructed. Along with the descriptions of the views, this chapter describes the types of stakeholders that would make use of those views. Finally, issues regarding the interaction between views are described.

Chapter 6 outlines the implementation of the ArchVis tool. Here, the design and build of the tool is presented along with the choices of technology. This chapter also describes what types of systems ArchVis is able to visualise without customisation, and describes how the ArchVis framework can be extended to increase its functionality.

Chapter 7 provides an overview of evaluation strategies that can be used to evaluate this research, indicating their relative merits. The selected evaluation approach is then described in detail, along with a justification for the approach.

Chapter 8 uses the evaluation approach described in chapter 7 to evaluate ArchVis. This consists of the application of a feature-based framework and a set of usage scenarios. Following this, an informal discussion of the issues and merits of ArchVis concludes the chapter.

Chapter 9 concludes the thesis by summarising the research and identifying its contribution. The criteria for success, as defined in chapter 1, are compared to the results of the thesis. From this, future research areas are suggested for both ArchVis and software architecture visualisation.

Chapter 2: Software Architecture

2.1 Introduction

This chapter is concerned with defining and exploring important areas of software architecture. Current architecture definitions are presented and out of these a working definition will be identified that defines the scope of software architecture within this thesis.

Both the theory and practice of software is explored as this provides a basis for showing how using software visualisation as a development tool can support reasoning about, and developing with software architecture in the real world. For each software system, there are many stakeholders that use software architecture in different ways. This chapter attempts to classify the roles that the stakeholders will take when utilising aspects of software architecture.

A key part of the use of architecture is architectural style, so a significant part of this chapter identifies key architectural styles and also how architecture is seen in different views. Also, this chapter identifies the forms in which architecture takes, be it on paper, or in running software systems.

2.2 Definition

Definitions are a necessity in providing premises from which to base and formulate theories, arguments and proofs. Firstly, existing ideas on the definition of software architecture are presented before identifying the definition to be used in the remainder of the thesis.

Software engineering practice has produced successively higher abstractions of software with the progression of time. Beginning with manipulation of physical switches, software has moved from machine language and assembly language to higher-level programming languages of differing paradigms. The activities of module writing in high level languages and the connection of these modules together were soon seen as distinct, and software design can be seen as a further abstraction. Software architecture sits at the design level, indicating elements from which the system is built along with descriptions of their interaction, composition and imposed constraints [Shaw96]. Software architecture can be viewed as the highest level of abstraction that software engineers work with today.

Two roles that architecture can take are one of prescription – describing how the software system's architecture should be, and description – describing how a software system's architecture is. Part of the usefulness of architecture analysis is to measure the discrepancy between the prescribed architecture and the architecture that describes the software produced.

Feijs and de Jong describe software architecture as an art and science for the structuring of very large programs [Feijs98] where architectural decisions strongly influence system attributes such as efficiency and maintainability [Moriconi95]. However, some would argue that the discipline is not just limited to 'very large' programs as all software systems have an architecture, whether the designers or developers know it or not [Kazman99]. Frequently, architecture is applied to software systems whose size is large enough to warrant reasoning on a higher level than the module or class level.

In the IEEE 1471-2000 standard [IEEE1471], architecture is defined as '*the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution*'. This sentiment is perhaps the most pervasive in the architecture literature. Many writers adopt the view that architecture is concerned with the gross structure of a system, describing high-level computational elements and their interactions [Monroe96].

Eden [Eden01] categorises architecture in a different manner by identifying concrete architectures and generic architectures. Respectively, these refer to architectures that are concerned with a particular instantiation of an architecture, possibly realised in an implemented system. Being concrete, these specifications consist of constant symbols that correspond to entities in the architecture. Generic architecture specifications comprise of variables rather than constants and are similar to architectural styles in that they distil a set of different concrete specifications to identify fundamental aspects that describe that set.

Attempting to amalgamate the above views and ideas on software architecture yields the following definition: '*Software architecture is a representation of a software system at its highest level of abstraction, consisting of a set of fundamental building blocks for the software system and their interconnection*'.

2.3 Architecture in Practice

In order to understand the need for Software Architecture Visualisation, it is important to understand how architecture is currently used in practice. Firstly, the motivation of the use of architecture is considered, and then a generic software life cycle is examined in order to identify the people and tasks that are involved, and how software architecture plays its role.

2.3.1 Motivation

Software systems have become larger and more complex over time. Architecture becomes more important in line with this increase in size and complexity [Batman99] as it provides a suitable level of abstraction for reasoning about the high-level entities and relationships in that system. There are several reasons as to why some organisations choose to use software architecture as a tool during the software development processes.

From a purely technical stance, software architecture provides the basis for design, as it is the highest level of abstraction. Decisions that are made at the architecture level are often the first decisions made regarding a software system, and so have a high impact to all activities that follow. Software architecture provides support for early stage trade-off decisions that determine what functional and non-functional requirements will be supported by the software [Barbacci98]. The architecting process produces initial designs that can be further decomposed by lead software designers.

Communication between stakeholders in a software system is greatly improved by having documented software architectures as it provides a common reference point for all activities. It is through the architecture that conflicting goals and requirements are worked through and resolved. It can form the pivot point for implementing management decisions and project management through resource allocation.

When software systems are released to customers, they enter into the maintenance phase. Each time a change is made, the software architecture can be checked to ensure that changes made do not violate the software architecture. Changes that impact the software in an adverse way are said to 'erode' the software architecture or cause 'drift' [Perry92]. By keeping software architecture as a utility for impact analysis, erosion and drift can be ameliorated.

Cost and efficiency are of high importance to commercial software production. Here, software architecture can provide motivation for a number of areas. As identified above, software architecture can improve the efficiency of the software development process by being a common reference point, a communication vehicle, and by being an analysis tool for monitoring the impact of changes. On top of this, software architecture can be a basis for cost estimation through various metrics related to the construction of the components of the architecture. Process management can also benefit from software architecture by mapping the software development process onto the architecture itself. Architecture reuse can prove yet another area for cost reduction. It is suggested that the role architecture plays in software developing organisations is an important indicator as to how successful that organisation will be in producing complex systems which meet requirements in an efficient way [Batman99].

2.3.2 Roles and Use

The previous sections identify areas in which to describe the role that architecture plays for the various stakeholders in a software system. The following roles have an interest in software architecture:

- Architect
- Designer
- Development manager
- Developer
- Sales and field support
- System administrator
- End-user

These roles are equivalent to the stakeholder types identified by Clements [Clements96]. This discussion is important in order to illustrate how each of the stakeholders in the architecture of a software system might benefit from visualisation systems.

2.3.2.1 Software Architect

An individual who has the role of software architect will require a different skill set depending on the environment in which they are operating. In a commercial software-producing organisation, the architect will require a great many more skills in business, management and organisational politics [Bredemeyer00]. This section describes the role of software architect from a technical perspective only.

Principally, the software architect role is associated with the initial creation of architectures. Bredemeyer [Bredemeyer99] outlines an architecting process shown in Figure 2-1.

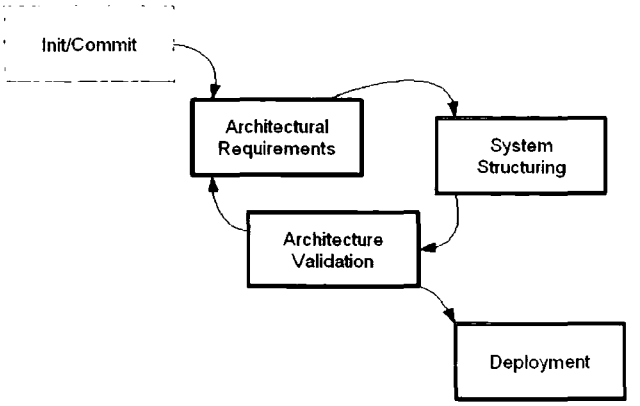


Figure 2-1 Architecting process

Here, the four steps of Architectural Requirements, System Structuring, Architecture Validation and Deployment are important. The Init/Commit step is not considered here as it relates to managerial and sponsorship issues within an organization. During the 'architectural requirements' step, the architect will be performing the following activities (abridged from [Bredemeyer99]):

- Understand the system context... including technical drivers affecting the architecture.
- Identify stakeholder goals and architecture scope.
- Document functional requirements by translating user goals into use cases.
- Document non-functional requirements, associating measurable qualities with use cases.
- Model common/unique usage and infrastructure requirements across systems.

One of the outputs from these activities are architecture requirements. These requirements, along with architectural styles and patterns are provided as input into the 'system structuring' step which consists of the following activities:

- Define the meta-architecture, including the style.
- Define the conceptual architecture: partition the system and allocate responsibilities to components.
- Define the logical architecture: model collaborations, design interfaces, complete component specifications.
- Define the execution architecture: map components to processes and threads; determine location on physical nodes.
- Specify architectural guidelines and standards, and select key technologies.

Architecture documents and models that result from this are inputs to the 'architecture validation' step:

- Construct prototypes or 'proof of concept' demonstrators.
- Conduct reviews of the architecture.
- Conduct architectural assessments.

This is then iterated in a number of passes (see original text for details), as illustrated in Figure 2-1. Finally, the architecture reaches the 'architecture deployment' phase:

- Communicate the architecture.
- Educate and consult with developers as they apply the architecture.
- Review designs with respect to the architecture.
- Identify needs for evolving the architecture.

Many of the principles behind this simple model of top-down software architecting are shared with other architecting processes such as the Quality Attribute-oriented Software Architecture QASAR design method [Bosch00]. Bosch notes that bottom-up architectural design is not feasible as working in this fashion would require dealing with details of the system.

2.3.2.2 Designers and Developers

Designers and developers utilise software architecture in a number of ways. Initially, software architecture provides a set of constraints on the design of individual components within the system. As noted above, definitions of the high level components and connectors are created during the architecting process. Interfaces, constraints, functional requirements and non-functional requirements should form part of the documented architecture. It is the responsibility of the designers who are involved in the detailed design of the individual components to adhere to the prescribed architecture. In reality, the designers will work closely with the architect in iterating the architecture further if required.

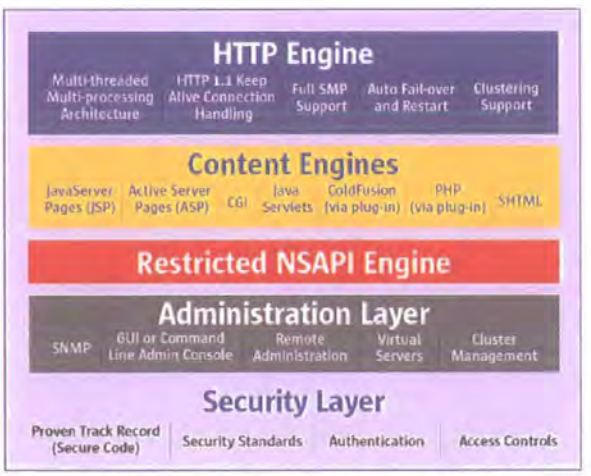
Implementers of software systems are also required to develop the software within the boundaries and constraints made by the architecture [Clements96] and its detailed design. During the maintenance phase, any changes made to the software system should conform to the architecture. It is the responsibility of tester to ensure that they are able to measure the impact of a change against the architecture in order to ensure that a change has not eroded the architecture.

2.3.2.3 Development Manager

Development teams are often structured to reflect the structure of the software. Architectural components are often the basis of development team structure as the interfaces between architectural components are well defined. Communication structure between development teams can also be based on major software components [Clements96]. As each component of the system can itself have its own architecture, each team's development manager can utilise architectural structures to allocate work to individual developers. In this way, project management can be supported by the architecture.

2.3.2.4 Sales, Field support and End Users

Initial impressions of software architecture might lead to the view that software architecture is only useful for the development processes of the organisation. In reality, software architecture is of fundamental importance to the sales department and support operation. During the sales cycle of a particular software product, the architecture is often presented to customers as a selling point. At this level, these architectural diagrams will be stylistic and are often designed to be as aesthetically pleasing as possible.



Sun™ ONE Web Server 6.0 Architecture

Figure 2-2 Sun™ ONE web server architecture

Further down the sales cycle, the customer will often wish to read white papers that describe the software architecture in more detail. A customer's technical team will make recommendations to purchasers based on architectures described in these white papers.

During installation, it is useful for system administrators to be aware of the architecture of a software system in order to understand the impact that the software will have on the physical deployment environment. After

the software has been installed on the client site and is in use, architecture is important for mapping bugs and issues back to high-level components. In doing so, the team responsible for the development of the component or components in question can be sent the observation report. Mapping bugs onto the architecture can indicate possible impact at the support level before obtaining more specific information from the development teams.

In the case of software being sold as shrink-wrapped products, the end user will often wish to have no knowledge of the architecture. However, if the product is a framework, platform or API, then the architecture will be very important.

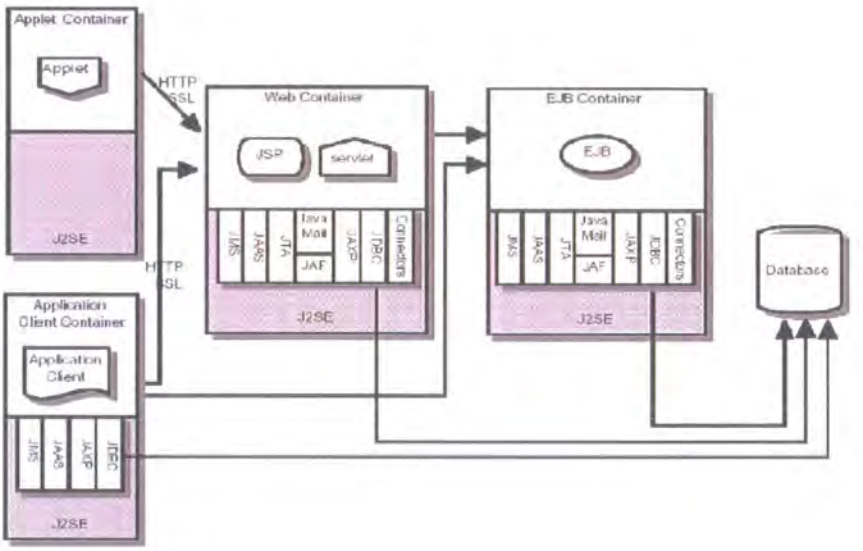


Figure 2-3 Enterprise web application architecture

Gaining an understanding of how the system works is essential in being able to develop systems onto the framework, API or platform.

2.4 Software Architecture Styles

Garlan and Shaw [Garlan93] define an *architectural style* as a term of classification for families of systems that adhere to a pattern of structural organisation. Perry and Wolf [Perry92] define architectural style as being less constrained and possibly less complete than a specific architecture, the focus being on certain aspects which characterise a set of architectures. In their view, the boundary between architecture and architectural style is somewhat blurred depending on how they are used. It is architectural style that establishes the

vocabulary of components and connectors that can be used in specific instances of that style and also provides a set of constraints on how they can be combined [Garlan93]. To illustrate, the 'client-server' notion of architecture might provide a vocabulary of connectors that include 'client' and 'server' components along with connector vocabulary such as 'HTTP' and 'RPC'.

Such a style emerges through the consideration of the components and connectors of a set of similar software systems along with their configuration. Some elements will be common to most systems and configured in similar ways. Identifying these elements and relationships can bring about a notion of a style for that family of systems.

Styles are useful for both analysis and design of software [Klein99]. Design is supported through architecture as the system architect can choose a style by referring to known quality attributes of architecture styles [Klein99]. It is hoped that, in a similar way to software design patterns, there will be an architecture handbook to assist architects in choosing a style to suit a software system. This handbook would list architecture styles along with their known attributes such as performance and security measures. To some extent, prediction of these attributes is possible for a particular implementation of the architectural style [Klein99]. Garlan considers many benefits of using style in practice, which is not the consideration here. What is important in this description of style is the applicability of style to visualisation, and on this, Garlan states that it is usually possible to construct visualisations that are style-specific [Garlan95].

Some common architectural styles as identified by Garlan and Shaw [Garlan93] are summarised from their text below. It is by no means a definitive list and in practice, the boundaries of these styles can overlap.

2.4.1 Examples

2.4.1.1 Pipes and Filters

Filters are computational components that take as input a set of data streams and produce a set of output streams. It is usual for the filter to incrementally read the input streams, apply a transformation to it, and write data to the output streams. In this way, output can be produced before input is completely consumed. Filters are connected by way of pipes that transfer data from one filter to another. Therefore, in this style, components are termed 'filters' and connectors are termed 'pipes'.

Constraints for this style state that filters are completely independent of other filters. Specifically, they must not share state with other filters and that they must remain unaware of the identity of other filters either upstream or downstream. Input and output specifications might restrict what data can appear as input and make guarantees about its output, but they must be unable to identify other filters which are attached to the ends of those pipes.

Variations on the pipe and filter style exist. One such variation is the 'pipeline' that are linear sequences of filters, commonly found in basic compilers. Another is the batch sequential system where each filter processes all input as a single entity before being passed on to the output. Batch sequential systems are a degenerate case of the pipe and filter style and can be considered as distinct style.

Pipe and filter systems are commonly found on UNIX based operating systems where processes (filters) can be connected via pipes to each other. Compilers are often pipeline systems where phases of the compilation process are the filters converting source code into machine code, for example.

2.4.1.2 Repositories

Repository systems are comprised of two distinct component types. Firstly, there is a central data structure that represents the current state of the system (repository). Secondly, there is a collection of one or more independent components that access and perform functions on the central data store.

Computation can proceed in two ways. If the input to the system is such that the components modify the central store in response to the input directly, then the repository can be thought of as a traditional database. However, if the current state of the repository is the main trigger for components, then the repository can be a blackboard. To clarify, in the first instance, components access and change the repository in response to input. In the second instance, actions of components are determined by the contents of the central repository.

The blackboard model can be decomposed into three major parts. A knowledge source is where world and domain knowledge is partitioned into separate independent computations. Interaction among knowledge sources takes place solely through the blackboard. Blackboard data structure is problem solving state data, organised into an application-dependent hierarchy. Knowledge sources make changes to the blackboard that lead incrementally to a solution to the problem. Here, the blackboard is the only means by which knowledge sources interact to yield a solution. Control is where components are driven entirely by the state of blackboard. Knowledge sources respond opportunistically when changes in the blackboard make them applicable. Blackboard systems are traditionally used in signal processing such as speech and pattern recognition.

2.4.1.3 Layered Systems

Layers are organised hierarchically where a layer provides a service to the layer above and is also a client to the layer below. Constraints are imposed in some variations such that inner layers are hidden from all other layers except for the layer immediately above it. Further to this, certain functions may be open for export as necessary. Connectors are defined by the protocols that determine how the component layers will interact.

This style supports design based on increasing levels of abstraction reducing a complex problem into a hierarchy of incremental abstractions. Enhancements are implemented by adding layers onto the top of the current top layer. A good example domain is the network protocol domain such as the ISO/OSI seven layer network model.

2.4.1.4 Data Abstraction and Object-Oriented Organisation

In this style, components are 'objects', also known as managers. They are responsible for the management and integrity of a particular resource, for example, a queue. Inter-object communication is achieved through function and procedure calls.

Two important aspects relating to this style have been identified. They are that (a) objects are responsible for preserving the integrity of its representation and (b) this representation is hidden from other objects.

Object oriented systems have become increasingly commonplace, yielding variations on this basic architectural style. For example, objects in some systems can be concurrent tasks, through multithreading, and others, including Java, allow objects to adhere to multiple interfaces.

2.4.2 Heterogeneous Software Architectures

Most systems typically involve some combination of several 'pure' architectural styles. There are, of course, many different ways in which architectural styles can be combined. One particular way is through hierarchy: components in a system may be organised in one architectural style whereas the internal structure of a sub-component may be represented in a completely different architectural style as required.

A component could also use a mixture of architectural connectors instead of using a single type of connector. In order to interact with one set of components it may use, for example, a pipe interface. In order to communicate with a different set of components, it may access a repository – a different type of connector.

2.5 Representation

Software architecture is represented in a multitude of ways. This section examines some of the more common techniques of representing architecture to stakeholders in a system.

2.5.1 Undocumented

It is often stated that all software has an architecture, even if it is not explicitly stated. It is not surprising that the architecture of a software system is often undocumented – particularly for small software systems written by single developers. Documentation at any level is often neglected at this level of development. A high

level description of a software system may exist, but can be labelled in another way, such as 'high level design'. It is not the focus of this thesis to change this failing, but to enhance architecture documentation when it is used.

2.5.2 Overview Diagrams

Diagrams are used throughout all software engineering disciplines, from 'back of the napkin' drawings through to drawings produced by diagramming software. In some instances, the only representation of the software architecture is through an overview diagram. These types of diagrams are often referred to as 'the architecture' but a formal architecture description is not given, for various reasons. Overview diagrams are intended to give stakeholders an impression as to what the fundamental components of the software are.

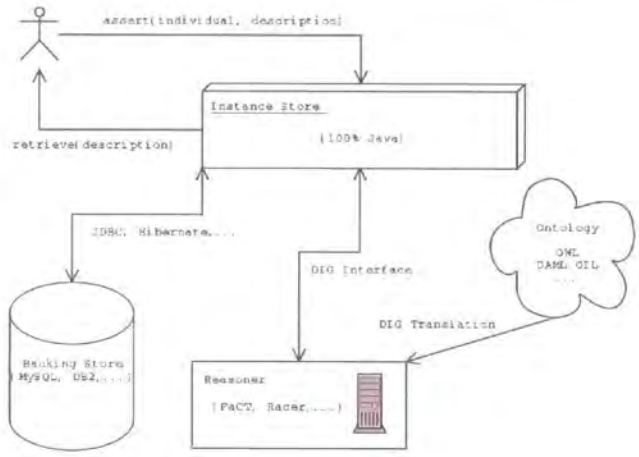


Figure 2-4 Instance Store API Architecture Overview

Figure 2-4 is an example of an architecture overview diagram of the "Instance Store" API [Instance Store].

The quality of these representations varies dramatically. In some cases, the diagrams are clearly presented with well-defined meanings for all graphical elements used to construct the diagram. In other cases, it is unclear as to what the boxes and lines actually mean, and interpretation of the architecture overview can vary considerably.

2.5.3 Documented

A distinction between documented architectures and overview diagrams is drawn on the boundary of intent. The intention of overview diagrams is to just provide an impression as to what the high level components are whereas properly documented architecture formally describes the architecture.

The IEEE1471 standard [IEEE1471] gives six elements that should be included in an architecture description:

- Architecture document identification, version and overview information.
- Identification of stakeholders and concerns.
- Specifications of viewpoints.
- A number of architectural views.
- A record of known inconsistencies.
- A rationale for selection of the architecture.

At its core, this standard uses a selection of architectural views to present the software architecture. These views can be represented using different languages, methods and models. Along with this, a inter-view consistency analysis is presented in order to align the views together.

2.5.4 ADLs

Architecture Description Languages (ADLs) focus on the high level structure of software systems rather than the implementation details of any specific module [Vestal93] and have been developed in response to the following problems [Garlan97]:

- The practice of architectural design is largely ad hoc, informal and idiosyncratic.
- Architectural designs are often poorly understood by developers.
- Architectural choices are frequently not based on solid engineering principles.
- Architectural designs cannot be analysed for consistency or completeness.
- Architectural constraints are not enforced during system evolution.
- Virtually no tools to help architecture designers.

ADLs are considered to be important for software architecture as they provide a conceptual framework and allow for a concrete syntax in characterising architectures. The syntax allows for the decomposition and representation of a software system in terms of its respective high-level components and connectors. Along

with this decomposition, specifications are made as to how these elements are combined to form a configuration [Allen97].

Fundamentally, ADLs represent architecture and are generally concerned with components, connectors, architectural configuration and interface definitions [Medvidovic97]. However, each ADL has its own specific concerns. A summary of a selection of ADLs are presented in Table 2-1. The comparison is taken from Garlan et al [Garland 97] and Medvidovic et al [Medvidovic97].

ADL	*Specific concerns*
Aesop	Supports use of architectural styles. Provides capabilities for expressing properties that permit real-time schedulability analysis.
Meta-H	Specific guidance for designers of real-time avionics control software, and is concerned with real-time shedulability analysis. Suitable for architectures in the guidance, navigation and control (GN&C) domain.
C2	Architectures of highly distributed, evolvable and dynamic systems. Supports description of user interface systems using message-based style
LePUS	Aimed at specifying object-oriented software architectures. Conformance can be verified.
Rapide	Allows simulation of architectural designs and for analysing the results of those simulations. Interactions are represented in terms of events.
SADL	Provides formal basis for architectural refinement and is concerned with the expression of stylistic invariants.
UniCon	Has a high-level compiler for architectural designs that support a mixture of heterogeneous component and connector types.
Wright	Supports specification and analysis of interactions between architectural components. Interactions are represented in terms of events.

Table 2-1 Summary of ADLs

As many ADLs arose from the uptake of interest in software architecture, Acme has emerged as both an ADL and an ADL interchange language. An interchange language is considered necessary as many ADLs were

developing associated toolsets, and having a capability of translating between these languages would allow these tools to be useful to a wider community. Other practical uses of ADLs include code generation and simulation.

2.5.5 UML

Grady Booch, James Rumbaugh and Ivar Jacobson [Booch98] created the Unified Modelling Language (UML) and released version 0.8 of the language in 1995, and was later adopted by the Object Management Group (OMG) in 1997. Prior to the formation of the UML, each of its creators were independently developing their own method to Object Oriented software design.

The UML is a language for specifying, visualising, constructing and documenting artefacts of software systems [OMG][Abdurazik00]. It provides modellers with a visual modelling language that integrates best practices and is independent of development processes. There are four diagrams used for modelling software in the UML [OMG]:

- Use case diagram.
- Class diagram.
- Behaviour diagram.
- Implementation diagram.

By modelling software in multiple diagram types, more than one perspective of the software can be represented.

The UML is often used to describe and document software architectures. Researchers in the field of software architecture differ in their views on whether the UML is a suitable language to represent software architecture. However, what cannot be avoided is that the UML is often used to represent software systems, and some of these representations are labelled as software architecture. Abdurazik [Abdurazik00] notes that the following UML constructs can be used in the description of software architecture:

- Class
- Classifier
- Package
- Interface
- Component
- Subsystem
- Model

Also, the UML can be used to specify heterogeneous architecture as subsystems can be used as components. Some researchers have suggested various mechanisms by which the UML's capability for extensibility can be exploited in order to provide better facility for modelling architecture [Medvidovic97]. Others research has sought to bring UML together with other languages to provide a language with direct capabilities for expressing architectural concerns [Robbins97].

2.5.6 Source Code and Configuration Files

Whilst higher levels of representation may afford a much more amenable way of using software architecture, every software system that is implemented realises a software architecture, whether it be the intended architecture or not. Source code, configuration files, data sources and all other collateral that form the software system will represent the software architecture.

One example of how configuration can contain architectural information is that of a web application built using the Jakarta Struts framework [Struts]. This framework provides a controller component that utilises an XML configuration file that determines page flow within the web application. Page flow is a useful representation of architecture both in terms of both data flow and user flow throughout the application.

2.6 Conclusions

Software architecture is important for software engineering, and its recognition is becoming more widespread in all aspects of software engineering. This chapter has discussed the various views and definitions on what architecture is and presented a definition to be used in the remainder of this thesis. Also, this chapter has looked at the motivation behind using software architecture – that is to determine why software architecture is being used within software development organisations. In light of this, the way in which particular roles in a software development project were examined with respect to the way those roles might incorporate the use of software architecture. By examining these roles, it is possible to determine how architecture visualisation may be suited to those roles.

When considering the use of software architecture in practical software development, the environment in which the software is to be deployed in plays a significant role in shaping it, by defining boundaries and interfaces, and enforcing both functional and non-functional constraints. Other factors that influence architecture include technological and political issues. For 'green field' development, where environmental constraints are few, software architecture can be designed with relative freedom. Even for highly constrained environments where a component must fit into an existing architecture, the new component itself may warrant reasoning at an architecture level of design.

As architectural style constitutes a significant part of software architecture research, this chapter has described a selection of the more prolific architecture styles, and how software systems can be composed of many different architectures using many different styles. Styles are important in the context of this thesis as they strong associations with graphical representation.

Finally, the chapter discussed a number of ways in which software architecture is represented. Architecture representation will be key to visualisation, as a visualisation system will require some means by which it can obtain architectural information of a software system. Architecture description languages are one form of representation of a software system's architecture. The intention of ADLs is clear, but the practical uptake in modern day software development is limited. The value of architecture description languages for architecture visualisation is obvious – they can be parsed easily in order to derive visual representations. One principle reason why ADLs in the traditional sense have not been used for practical software development may be due to the uptake of UML as an architectural design aid. Whilst opinion in the research community is divided on the use of UML to describe architectures, it has become a de facto standard that cannot be ignored.

Chapter 3: Software Visualisation

3.1 Introduction

Presenting information visually is highly beneficial to the perceiver, and this benefit has become widely accepted. Software visualisation attempts to retrieve and present information about a software system to a user in a visual format. By doing so, the user is often able to understand the information presented in a shorter period of time, or to a greater depth. Time is important in the production of software, so the benefits afforded by software visualisation are obvious: it can help reduce costs through saving time, improve the understanding of the software system by developers and other team members, reduce incorrect knowledge about a software system and ensure a common view of the software.

Visualisation, the process, can refer to the activity that people undertake when building an internal picture about real world or abstract entities. A visualisation is a graphical or pictorial representation of real world or abstract entities. Visualisations can range from box and line drawings on paper through to graphs through to interactive 3D environments. Visualisation can also refer to the process of determining the mappings between abstract or real world objects and their graphical representation. This process also includes decisions on metaphors, environment and interactivity.

The term software visualisation in this document describes the process of mapping entities in the software domain to graphical representations. Motivation for visualising software, as stated earlier, is to reduce the cost of software development. Software visualisation can support the software development process by helping stakeholders to understand the software at various levels and at different points of the software lifecycle.

3.2 Current Uses of Software Visualisation

During the lifecycle of a software system there are many occasions where designers, developers or maintainers will need to learn or re-learn some aspects of the software's structure. It may be that they wish to learn some of the higher-level structures, or wish to understand the operation at a line-by-line basis. Software visualisation is intended to assist in the understanding of the software.

A key motivator in the development of the software visualisation field is the issue of software maintenance. Some have identified as much as 90 percent of the time required performing a maintenance activity can be attributed to the maintainer attempting to understand the software [Standish84]. By reducing the time required to understand software, costs can be reduced as efficiency is improved.

Several taxonomies exist that classify software visualisation system. Myers' classification [Myers90] is useful as it identifies broad areas of software, and two temporal frames. It involves the following categories:

- Static code visualisation
- Dynamic code visualisation
- Static data visualisation
- Dynamic data visualisation
- Static algorithm visualisation
- Dynamic algorithm visualisation.

Static aspects of software are those that are features of software in a non-running state, whereas dynamic aspects are those of the software during its execution. The code, data and algorithm categories are generally representative of software visualisation systems at the time, but do not include all levels of software abstraction.

Call graphs are usually static code visualisation systems. The CodeViz visualisation [CodeViz] generates call graphs.

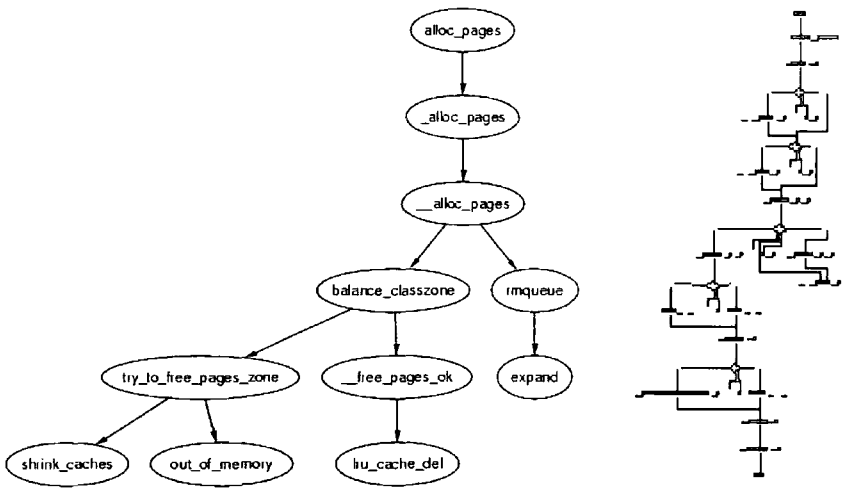


Figure 3-1 Call graphs

Figure 3-1 shows two call graphs. The leftmost call graph is of the alloc_pages() function in the Linux kernel. The rightmost image is an image produced by the Visualisation of Compiler Graphs (VCG) system

[Sander95]. Call graphs illustrate the control flow of a program, showing how one procedure or function will call another. Visualisation techniques are well suited to call graphs as they can quickly become difficult to understand in textual form given the volume of calls, even in simple software.

Whilst call graphs are suited to procedural languages such as COBOL, Pascal and C, the object oriented paradigm introduces new structures and mechanisms. In an object oriented language, messages are passed between classes and components.

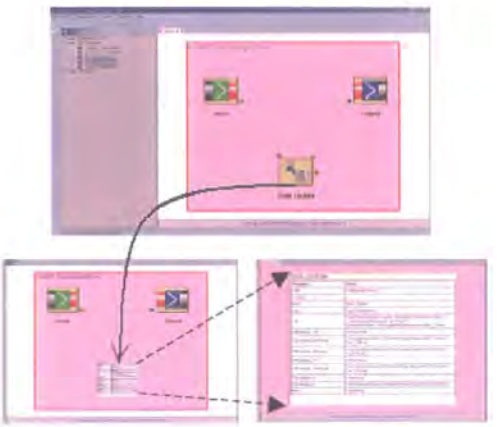


Figure 3-2 Data flow in the ShriMP visualisation system

Figure 3-2 shows a message flow diagram in the SHriMP visualisation system [Storey02]. The SHriMP visualisation system uses a newsted graph view, suited to hierarchical information, and utilises navigation techniques such as animated panning and zooming in order to provide for continuous orientation and context.

Other features of the object oriented paradigm include inheritance, encapsulation and polymorphism. Object oriented languages such as C++, Java and C# have structures such as namespaces, packages, classes and interfaces. Integrated development environments (IDEs) for such languages are often found to have visualisations of the software included, from pretty printing to structure navigation.

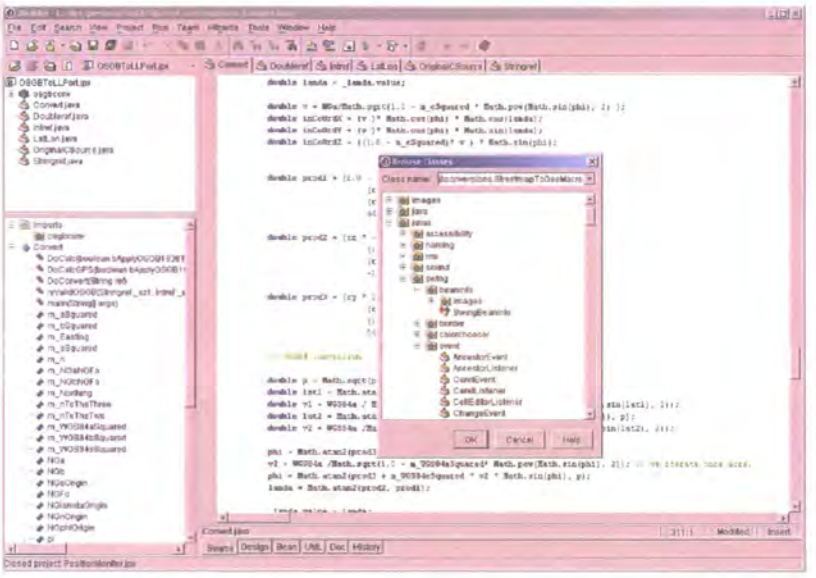


Figure 3-3 JBuilder Integrated Development Environment

Figure 3-3 is an example of the JBuilder IDE (www.borland.com) showing several aspects of software visualisation. In the upper corner of the display is a project view that allows the user to add and remove resources to the project. The bottom left hand side of the view contains a browser for the currently open class definition. This view includes package imports along with variable and method declarations. These declarations are decorated with symbols to indicate various properties such as 'public', 'static' and 'final'. In the main window, the source code itself is pretty printed, and an interactive code completion system further assists in visualising source structure. Finally, in the foreground, a class browser window allows the user to navigate through available packages in order to determine which classes are currently available.

It is often useful to extract source code metrics from software for various purposes, from simple statistics collection to cost estimation.

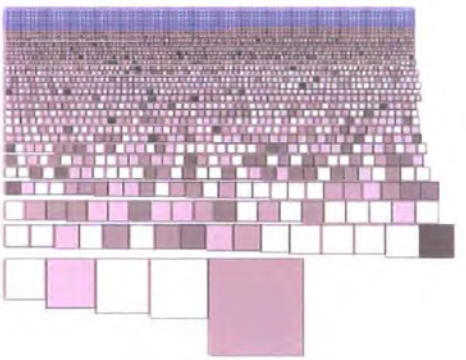


Figure 3-4 Systems hotspot view in Geocrawler

Figure 3-4 is an image of the systems hotspots view of the CodeCrawler visualisation system [Lanza02]. At a glance, this view indicates the number of methods contained in classes, identifying the more prominent heavyweight classes.

Software evolves during development, and some visualisation systems aim to represent this information visually.

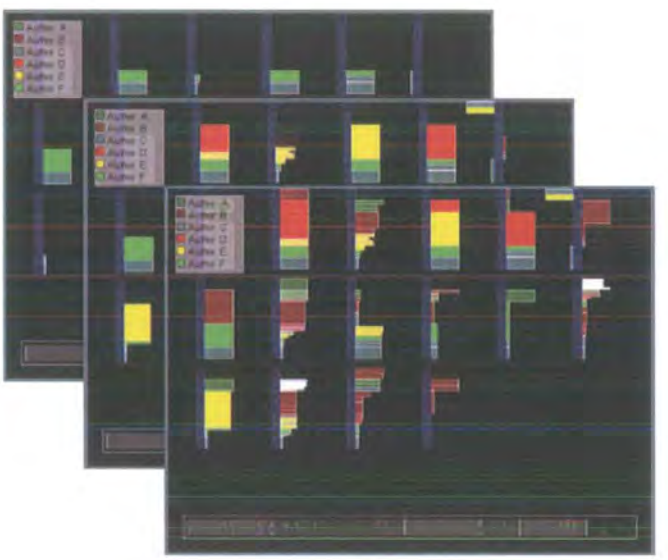


Figure 3-5 Revision Towers visualisation

Figure 3-5 is an image from the Revision Towers [Taylor02] visualisation, a system that indicates the evolution of a software project through parsing CVS log files. Information contained in CVS logs are useful, and this visualisation aims to present animations on how project files change over versions and who changed the file. This is useful in gaining an overview of activity in a project.

Dynamic aspects of software visualisation require the analysis of software at runtime. Runtime information is extracted in a variety of ways, from instrumentation of source code through to virtual machine data gathering.

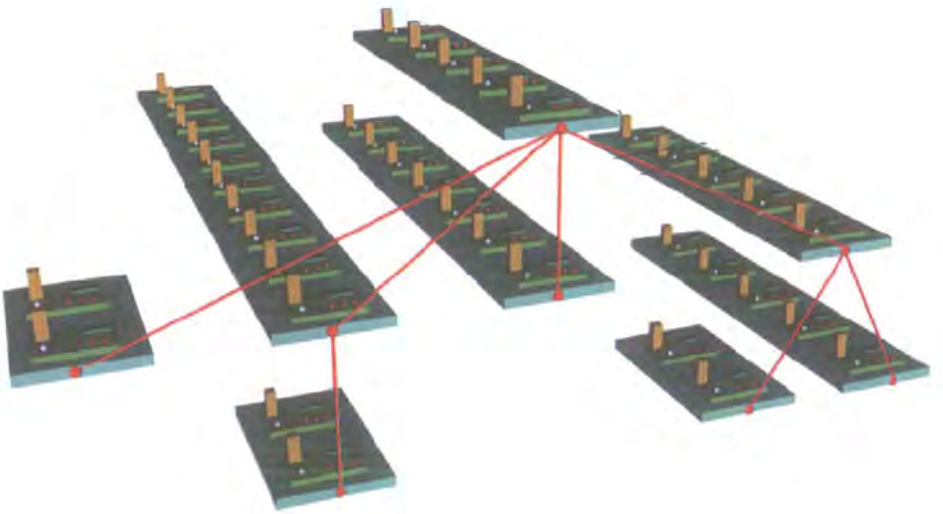


Figure 3-6 DJVis runtime view

The DJVis visualisation system [Smith02] represents Java software executing at runtime. Figure 3-6 is an image taken from DJVis' runtime view, showing a thread group hierarchy. Other views in this visualisation show call stacks, changing variables and static information such as class hierarchies.

Another aspect of running systems is algorithm visualisation.

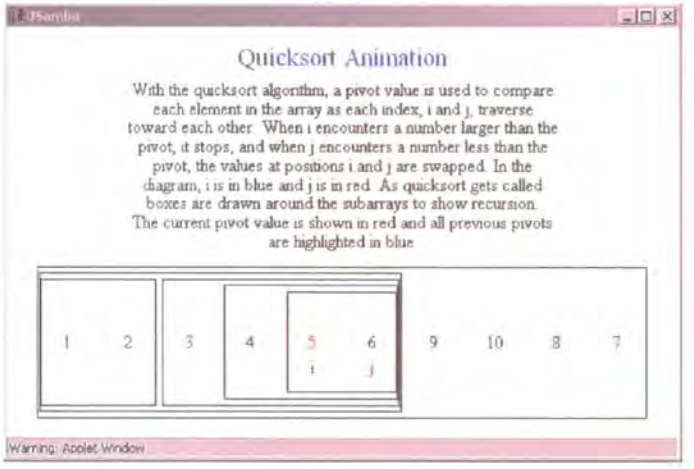


Figure 3-7 Quicksort algorithm animation in SAMBA

SAMBA (Graphics, Visualization and Usability Center at Georgia Institute of Technolgoy) is an animation system that developers can use to create visualisations of algorithms. Figure 3-7 shows a frame from an animation of the quicksort algorithm. These algorithm animation visualisations are often used in the teaching of algorithms [Kehoe99].

3.3 History, Trends and Issues

In order to set the context for this research, the following sections describe four areas of software visualisation in order to outline the direction in which software visualisation has taken.

3.3.1 Graphs

Much of the work in early visualisation is based on the use of graphs: node and arc diagrams used to represent software concepts and constructs. Graph drawing algorithms concern themselves with taking a graph data structure as input and giving a drawing of that graph [DiBattista88] as its output. Graph readability, or aesthetics, plays an important role in order to produce drawings that can quickly convey the meaning of the graph. These aesthetics are expressed as optimisation goals for the algorithm, such as minimising the number of crossing lines. A key area of this research has been into graph layout algorithms.

3.3.2 2D and 3D

Some researchers in software visualisation have considered applying 3D technology to the problem of visualisation. In particular, they have commented on the trend for 3D visualisations to be simply modified versions of 2D visualisations and as a result have not exploited the full capability of three-dimensional representation. 3D representations of call graphs have been produced in order to exploit the depth of space that three dimensions offers.

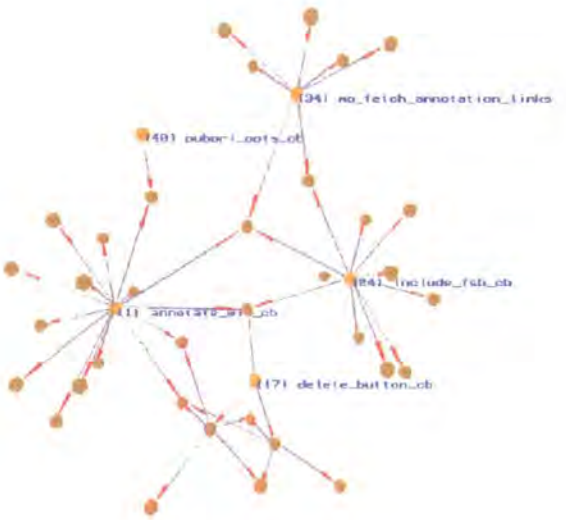


Figure 3-8 Call graph in 3D

Figure 3-8 is a call graph generated in 3D using a force directed placement layout algorithm [Young97].

One criticism levelled at the conversion between 2D and 3D is the reliance on node and arc graphs. Smith [Smith03] and Knight [Knight00] demonstrate strategies by which 3D representation can move away from node-arc representation to provide alternative ways of showing relationships between entities.

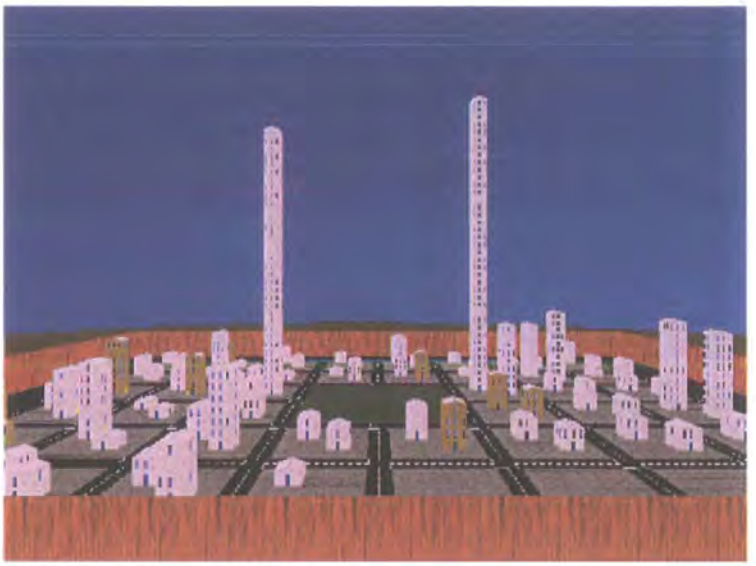


Figure 3-9 Software World class visualisation

Figure 3-9 is an image taken from Software World [Knight00], showing a visualisation of a Java class, represented as a district with heights of buildings showing relative method size.

3.3.3 Dynamic and Static Software Visualisation

Software can be thought of in broadly two forms – the software as described statically, and the software as a running system. These two forms have been investigated for use in software visualisation. Software, in its static form, comprises of source code and other material. Software visualisation has often taken to the parsing of source code in order to build abstract representations of the software for diagrammatic presentation. On the other hand, software visualisation has also looked at capturing information from running software systems in order to present this information diagrammatically. Several approaches have been made in the capture of runtime information, some invasive, some non-invasive. Invasive methods involve actually changing the code of the software in order that reporting procedures be called – relaying captured information to a monitoring component. This monitoring component could simply be a log that records the information for later processing. However, other implementations have the monitoring component be a graphical display that updates the display with real-time information relating to the running system. Non-invasive methods do not modify the source of the software to be examined. This is typically utilised when the software is running on a virtual machine, such as the Java Virtual Machine (JVM). Instrumentation deployed in the JVM can report information back to the monitoring component.

3.3.4 Abstraction

The history of computer science and software engineering has included a repeated succession in the level of abstraction that software design is engaged at. Shaw [Shaw96] describes this sequence by examining a selected history of computer science.

Initially in the 1950s software was written entirely in machine language. It was quickly realised that memory layout and update of references could be automated; so symbolic names were used for operation codes and memory locations. Symbolic assemblers were the result, followed up with macro processors that allowed a single symbol to represent a commonly used sequence of instructions. Software visualisation has typically ignored this level of abstraction, perhaps because this is the lowest level at which software is written, and it is not common practice to write software at this level. When assembly language is used, it is primarily for performance reasons. Games designers work in higher-level languages such as C and intersperse assembly language where required.

Some elements of software were realised to be useful across many different software systems, and they could be automatically created from a mathematical-style language. What resulted were early high-level languages. The way in which data was represented and manipulated became of primary importance, leading to the notion of abstract data types. Object oriented languages were to follow procedural high-level languages, focussing on providing well-defined interfaces to software modules. The field of software visualisation has placed a high degree of attention on high-level languages. Static analysis and representation of software written in high-level languages has dominated much of the research.

Module Interconnection Languages (MILs) arrived after the realisation that describing modules and describing how they are glued together are separate concerns and best served by different notations. Software Visualisation has not yet investigated visualisation of MILs.

Architecture has been alluded to at various points in history, but is only recently become an area for serious interest. Software visualisation has only begun to examine software at this high level of abstraction.

3.4 Fundamental Principles

This section outlines the fundamental principles that are thought to govern software visualisation today. It is widely recognised that the key area of study is cognitive psychology. A broad definition of cognitive psychology is that it is the study of those mental processes and activities that are used in perceiving, remembering and thinking. Card, Mackinlay and Shneiderman [Card99] suggest six ways in which visualisations can be used to enhance these cognitive processes:

- Visualisations can increase external memory and processing resources available to a user.
- Visualisations can reduce the need to search for information as the information is placed within reach.
- Visualisations can enhance the user's ability to detect patterns in data or events.
- Visualisations can facilitate the drawing of some inferences through direct perception of the information rather than through more complex cognitive processing.
- Visualisations can facilitate the monitoring of change in large numbers of events.
- Visualisations can encode information in a medium that is suitable for manipulation.

Sometimes visualisations are of real world entities, but they can also be about representing entities and relationships that do not have any direct physicality [Hewett99]. The challenge of the visualisation designer is to produce a visualisation that maps in a relatively natural way to the cognitive structures of the end user [Hewett99].

3.5 Conclusions

Software visualisation has its roots in program comprehension, and has used visual and cognitive psychology in order to make software more accessible to those who need to understand it. Software visualisation work has been primarily concerned with one level of abstraction – that of the high-level languages used to implement software. There are other levels of abstraction that software visualisation has not considered adequately, and software architecture is one of those.

A criticism levelled at software visualisation is that they are not extensively used during the development of software in industry today. However, recent Integrated Development Environments (IDEs) are beginning to incorporate visual representations of various aspects of software. These visualisations range from simple tree-

structured class hierarchies to UML diagrams to more innovative visualisations such as page flow. Cognitive psychology has demonstrated the value of imagery in cognitive processes, and scientific visualisation is widely accepted as a means for representing large amounts of data in an understandable form. However, some visualisation presented in research is explorative of the field rather than concentrating on the practical impact of the work. This type of research is essential for developing the field and should have the ultimate goal of moving towards practical instances.

Chapter 4: Software Architecture Visualisation

4.1 Introduction

This chapter describes the current state of research in software architecture visualisation. A number of existing software architecture visualisations are identified and reviewed. Also, two models to architectural views are examined. From these analyses, the trends, issues and challenges that face software architecture visualisation are identified.

4.2 Existing Software Architecture Visualisations

4.2.1 Feijs and de Jong

Feijs and de Jong's approach to understanding is to suggest walking through the architecture rather than struggling to understand large amounts of abstract code [Feijs98]. By following the architecture analysis activities of extraction, visualisation and calculation, Feijs and de Jong have produced an architecture visualisation that presents the use relations in software systems.

Firstly, use relations such as import or call tree are extracted from software source code using extraction tools. These relations are stored in a set of files that are read by the TEDDY browser. This browser also reads layout information files and allows the selection of shapes and the manual configuration of layout. Finally, a set of tools are used to operate over the set of relations to perform, for example, the Hasse operator or a lifting operation [Feijs88].

Once the TEDDY browser has been used to prepare layouts in each plane, a VRML generator called ArchView creates a 3D representation of the software using the 2D layouts and layer position.

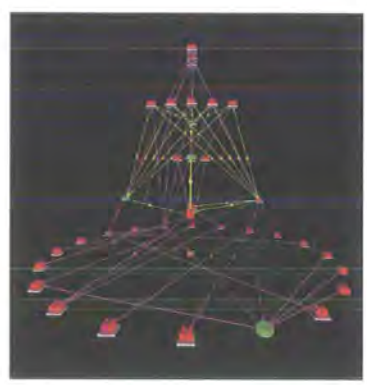


Figure 4-1 ArchView architecture visualisation

Figure 4-1 shows the 3D representation generated from import relations of a software system. Once this 3D representation has been created in VRML, users can 'walk around' the representation using VRML viewing software. Feijs et al. illustrate how viewing these relations can lead to the discovery of architectural design flaws. They argue that even informal reasoning about software architecture reproduced pictorially in 3D can result in the discovery of properties affecting relations among multiple modules, and suggest that system designers should view the architecture in this way during the construction of the architecture.

Feijs and de Jong represent a single view of software architecture – that of the use relation between modules. As such, the visualisation can only ever meet the needs of a limited number of stakeholders. This single view is rendered in three dimensions and allows for the user to move the camera to see this view from different locations in 3D space. As noted in chapter 3, some researchers take the stance that 3D can provide many benefits over 2D, however this visualisation retains a node and arc basis. Interaction in this visualisation is limited to moving the camera in 3D space, it does not allow the user to search or query the data directly. This visualisation only considers a single aspect of static data on the software system, it does not consider data associated with the runtime of the software, and also does not support dynamically changing architectures.

4.2.2 The Searchable Bookshelf

When developers or maintainers undertake a software comprehension, they can approach the task in two ways: browsing or searching. During a browsing activity, the developers or maintainers will be formulating their understanding of the software by following concepts, whilst searching is essential for fact finding and hypothesis testing.

Sim et al state that software architecture visualisation tools have tended to support the browsing of software, but often do not support searching [Sim99] and have produced the Searchable Bookshelf architecture visualisation to address this issue.

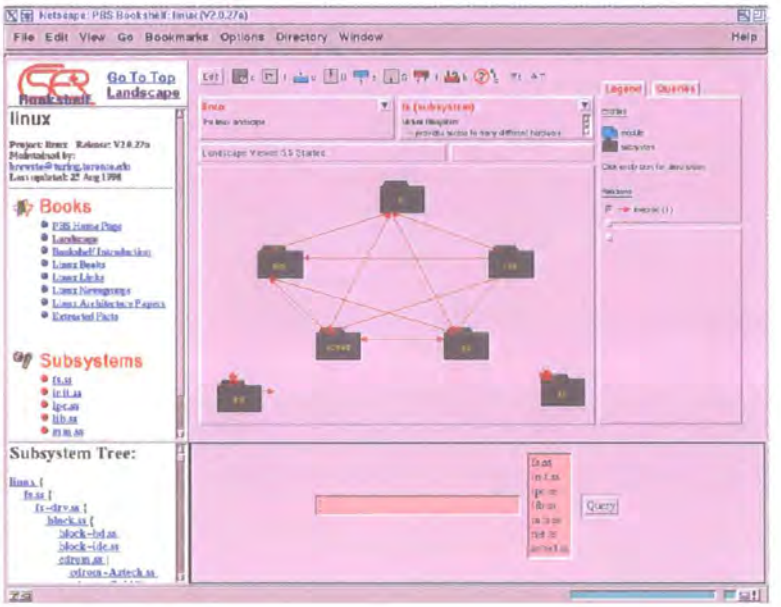


Figure 4-2 Searchable Bookshelf

The Searchable Bookshelf visualisation attempts to combine both searching and browsing approaches to software comprehension. The searchable bookshelf extends the Software Bookshelf tool by adding a set of search capabilities. A user would then be able to browse the software structure from an initial overview by navigating through both the HTML style display, shown at the left of Figure 4-2, and the software landscape central view. Search capabilities are afforded by a tool name grug, an extension to the Unix grep utility that adds semantic and structural search capabilities taken from the GCL query language. This tool is accessed from the search form at the bottom of the user interface.

Clearly, the purpose of this visualisation is, to demonstrate the activities of both searching and browsing in visualisations, specifically for software architecture in this case. This visualisation also affords the user with a number of different views to work with, however the number of views is limited and the user cannot add custom views. In the searchable bookshelf, transient data (that data that relates to the runtime of the system) is not linked to the static representations of the architecture. Further, the visualisation is therefore unable to deal with architectures that change configuration during runtime.

4.2.3 SoftArch

Grundy's SoftArch [Grundy00] is both a modelling and visualisation system for software, allowing information from software systems to be visualised in architectural views. SoftArch supports both static and dynamic visualisation of software architecture components, and does so at various levels of abstraction – not just at an architectural level. In this context, dynamic visualisation refers to the visualisation of a running

system and SoftArch's implementation of dynamic visualisation is that of annotating and animating static visual forms.

SoftArch defines a meta-model of available architecture component types from which software systems can be modeled. The main abstractions of this model are shown in Table 4-1 along with example elements of those types.

Component Type	*Examples*
Architecture components	Server, machine, store
Associations	Local area network, wide area network, connection
Annotations	SQL commands

Table 4-1 Abstractions in SoftArch

Each of these elements may have typed properties associated with it. An example of SoftArch's basic notational elements in the architecture modeling visual language is shown in Figure 4-3.

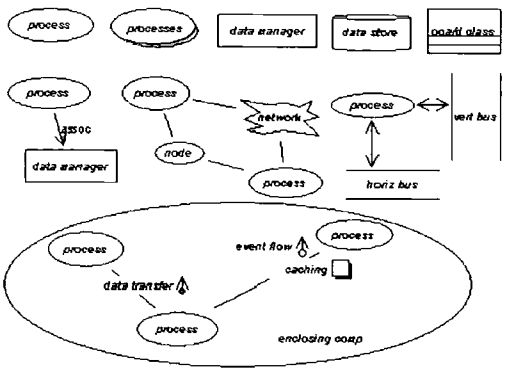


Figure 4-3 SoftArch's visual language

The visual language has the following graphical element mappings (Figure 4-3):

- Oval = architecture component types
- Horizontal bars = inter-component association types
- Labelled vertical arrows = association and component annotation types
- Dashed arrowed lines between types = indicate refinement
- Solid arrowed lines = association relationships

Developers can then specify multiple architecture views allowing the system to be visualised from a number of perspectives, revealing different aspects of the system from high level abstractions to detailed views.

SoftArch will then export a completed architecture model into the JComposer CASE tool [Grundy98]. Developers can then implement the system, creating Java classes in accordance with the components produced in JComposer. When the system is run, JComposer components are created and will communicate between themselves both locally and remotely. The JVisualise dynamic visualisation tool can then inspect the running system, retrieving component information and listening to inter-component communication. During this inspection and monitoring process, JVisualise sends events to SoftArch so that it can show components being created, and calls between components (Figure 4-4).

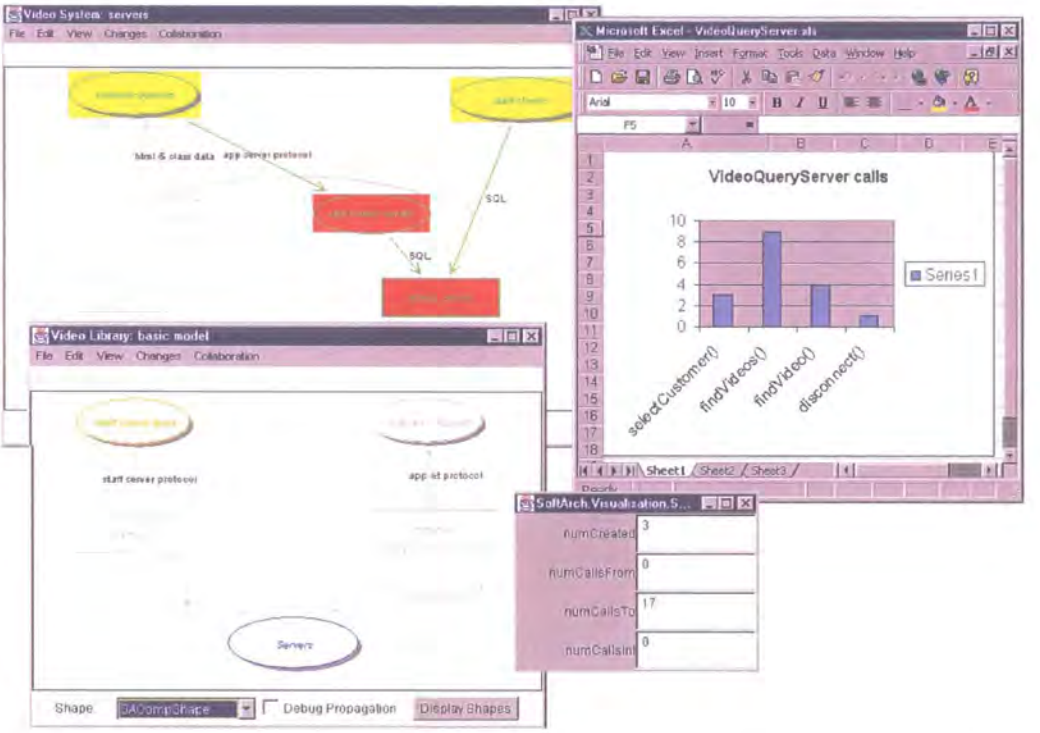


Figure 4-4 SoftArch dynamic view

In this way, a system's behaviour can be visualised using copies of static visualisation views at varying levels of abstraction, to show both the highly detailed or high-abstracted running system information.

SoftArch is a visualisation system that is both practical and informative. By integrating into a development environment, SoftArch addresses a key criticism of other visualisations in that it provides a mechanism by which it can be used by developers during software development. Architectural representations are very much lower level, so other aspects of architecture such as project management, architecture comparison and architecture evaluation are not directly supported in SoftArch.

4.2.4 SoFi

Source File (SoFi) is a tool that performs source code analysis in order to extract structure. Carmichael et al. [Carmichael95] demonstrate the use of the Software Landscape visualisation on structures extracted by SoFi in order to compare intended architecture with implemented architecture.

SoFi's approach to clustering of source files into a structure is based on source file naming schemes. An example of a system's structure as extracted by SoFi is shown in Figure 4-5. The system here is a 300kloc piece of software organised into approximately 200 source files.

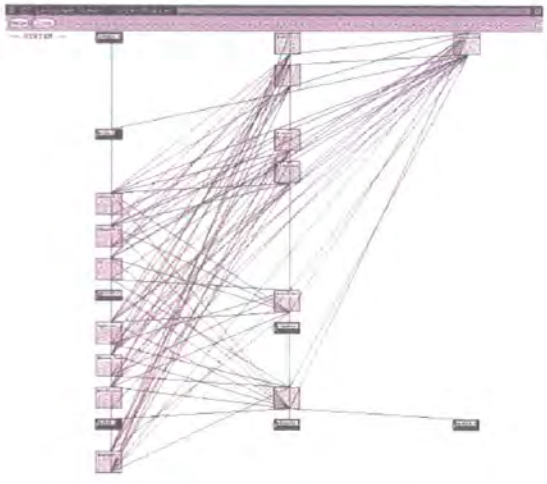


Figure 4-5 System structure extracted from SoFi

After using the system's designer's expert knowledge the structure could then be further clustered and re-drawn.

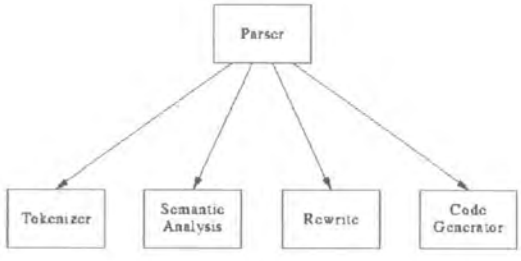


Figure 4-6 System structure redrawn by system designer

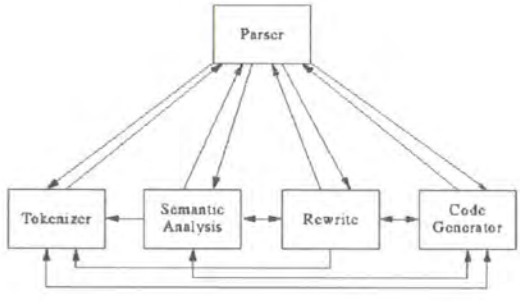


Figure 4-7 Extracted architecture

Figure 4-6 shows the major subsystems of the software as intended in the design of the system. Figure 4-7 shows the extracted architecture. This demonstrates the applicability of architecture visualisation for

identifying breaches of architecture design. Carmichael et al. [Carmichael95] go on to identify a set of reasons why the two architectures are different.

SoFi relies heavily on the intervention by an architect. This restricts the applicability of this visualisation to scenarios that require automated generation of the visualisation. SoFi is another example of an architecture that is focused on lower-level areas of architecture and does not cater for transient data.

4.2.5 LePUS

LePUS is a formal language dedicated to the specification of object-oriented design and architecture [Eden01] [Eden02]. LePUS diagrams are intended to be used in the specification of architectures and design patterns, and in the documentation of frameworks and programs.

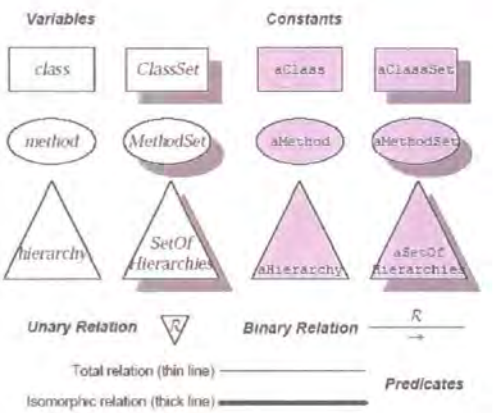


Figure 4-8 LePUS building blocks

Figure 4-8 shows the 'building blocks' of a LePUS diagram – the elements that are considered to be ubiquitous in every object-oriented program.

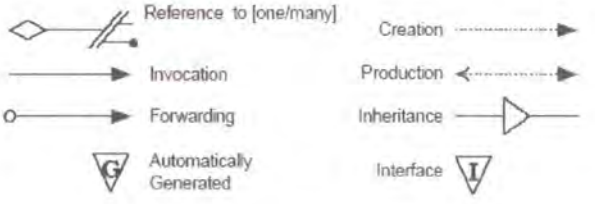


Figure 4-9 Additional LePUS symbols

Figure 4-9 shows additional symbols used in LePUS diagrams.

The architectural structure of a software system, according to the LePUS language, consists of ground entities and relations. Ground entities has a type, either class or method. Properties of ground entities as well as correlations between them are represented as relations. "C is a class" is a unary relation and "D inherits from B" is a binary relation. LePUS diagrams consist of:

- Terms (variables and constants)
- Relations
- Predicates
- Operators

These elements are illustrated in the example below.

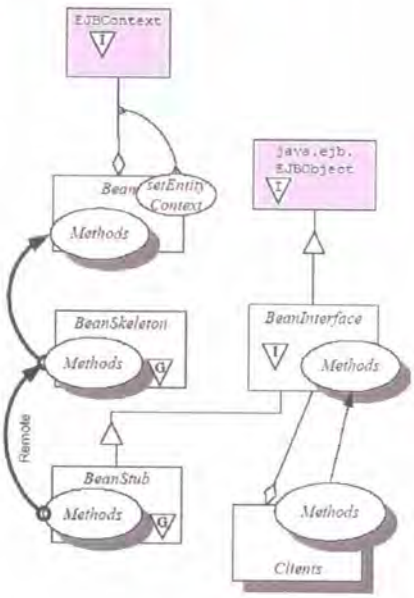


Figure 4-10 LePUS diagram of the Enterprise JavaBeans framework

Figure 4-10 is a LePUS diagram of the Enterprise JavaBeans application framework. This diagram, an architectural specification, contains only a fraction of the volume of the application framework detail.

As a visual language, LePUS is not concerned with the extraction of architectural information from systems, but is simply a means by which an architect can encode software architecture for communication to other stakeholders in that architecture. This will allow for some activities such as construction, evaluation and comparison, but is not suited to core visualisation activities such as searching and query building.

4.2.6 Enterprise Architect

Enterprise Architect (EA) is a UML CASE tool that allows software architects, designers and analysts to design software from several viewpoints [EA]. Much of the software lifecycle is catered for, from requirements capture, to UML modelling to testing and project management.

EA utilises a graphical user interface that sits above an entity-relationship style repository. The primary mechanism for modelling software systems in EA is to use diagrams. Several diagram types are supported, some of which are listed in the table below. Entities are then dragged onto the diagram area, causing a new entity to be created. These entities (some of which are listed in the table below) can be edited using the graphical user interface. Links can be formed between diagram entities by means of relationships, some of which are listed in Table 4-2. These links cause relationships to be formed between entities in the underlying model.

Diagrams	*Entities*	*Relationships*
Analysis	Diagram	Associate
Use case	Package	Aggregate
Class	Class	Inherit
State	Interface	Association
Activity	Object	Dependency
Collaboration	Actor	Realise
Sequence	Database Table	Trace
Component	Boundary	Nesting
Deployment	Use Case	Association
Custom	Requirement	Object Flow

Table 4-2 Diagrams, entities and relationships in Enterprise Architect

Existing entities can be dragged onto newly formed diagrams, and any existing relationships are automatically shown. This clearly illustrates the fact that the entity-relationship model is distinct from the visual representations that form the user-interface.

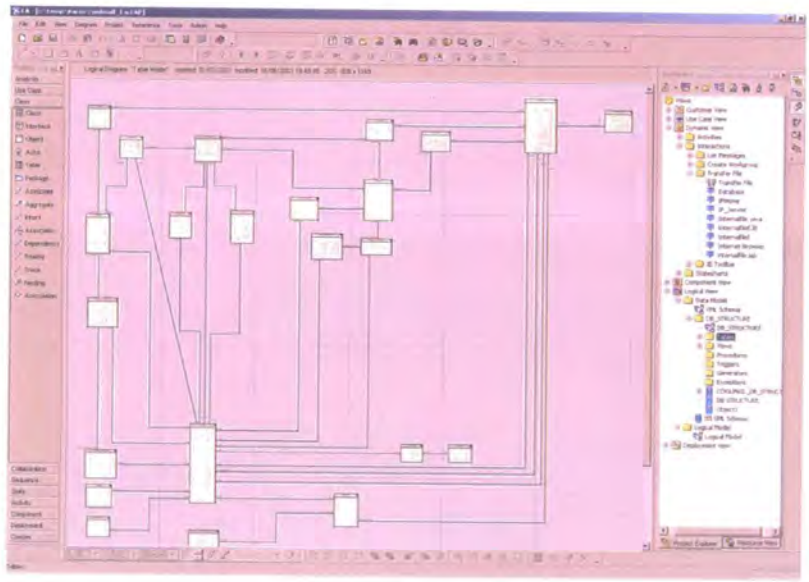


Figure 4-11 Enterprise Architect

Figure 4-11 is an image of Enterprise Architect showing the graphical display in the centre and the hierarchical model representation on the right.

EA's primary use is for designing new software, but also offers a broad range of other tools. For example, it has an auto-code generation tool that will build packages, classes and database tables as described in the EA project. EA also allows existing software to be parsed and imported.

Enterprise Architect is a well-rounded visualisation tool that supports many activities and is suited to a wider audience of stakeholders. It does not support transient data at all, and will have difficulty in showing architectural evolution. However, the approach EA takes in constructing new views is useful as a 'scratch pad' for quickly locating information required for a task.

4.3 Views of Architecture

Earlier in this chapter, several architecture visualisations were considered. Some research has pointed to architectural views that do not have an associated visualisation. This section identifies two of these models.

4.3.1 4+1 View Model

Ad-hoc, poorly defined, and over-ambitious diagrams are the motivation for Kruchten's 4+1 view model of software architecture [Kruchten95]. When many aspects of architecture are combined into a single diagram, it can become unclear as to what graphical components are attempting to represent. Kruchten describes model composed of five views, or perspectives. They are the logical, process, physical and development views along with selected use cases or scenarios. Each view is described in terms of its elements, form and rationale/constraints, a decomposition identified by Perry and Wolf [Perry92]. Each view can have its own architectural style and has its own notation.

The 'Logical Architecture' or 'logical view' is an object-oriented decomposition that closely maps to the functional requirements of the system. Simplified class diagrams and class templates are used to represent this view. The style for the logical view is an object-oriented style with one guideline to keep a single object model across the entire system.

The 'Process Architecture' or 'process decomposition' addresses issues such as concurrency and distribution, showing where independently executing units, called processes, are to be deployed across hardware, networks and other platforms. Individual processes can be manipulated at an architectural level with operations such as start-up, reconfigure, shutdown and so on. This level of description takes into account non-functional requirements such as performance, availability and fault-tolerance. Several architectural styles fit this particular view, including client-server, pipes and filters, and so on.

The 'Development Architecture' or 'subsystem decomposition' describes the division of the software into units named 'subsystems' such as namespaces, packages, modules, libraries, classes and so on. Each of these units can be assigned to a group of developers as each subsystem is given a well defined interface through which the subsystem can communicate with other layers. The development architecture view is represented by module and subsystem diagrams that illustrate import and export relations. This particular view is largely internal in its relevance. It helps in project management, task assignment and so on, allowing for cost evaluation and planning, monitoring, reuse and analysis of portability and security. As mentioned previously, the recommended style for this view is the layered style as upper layers only depend on subsystems that are in the same layer or layers below it allowing for simple release strategies by layer.

The 'Physical Architecture' shows the mapping of software to hardware. Identified elements such as networks, processes, tasks and objects are all to be assigned processing nodes. During the life-cycle of the software system, it is possible that many hardware configurations will be used, in development, testing and deployment, so the elements should require the minimum of change for each configuration.

Finally, scenarios bind the four views together in instances of more general use cases. Scenarios are redundant, hence the '+1'.

4.3.2 IEEE 1471-2000

The purpose of IEEE standard 1471-2000 (IEEE Recommended Practice for Architectural Description of Software-Intensive Systems) is to facilitate the expression and communication of architecture of software-intensive systems [IEEE1471].

According to the IEEE 1471-2000 standard, every system has an architecture that can be documented by an architectural description. In this model, the architecture is a conceptual entity whereas architectural descriptions are concrete entities that exist in order to describe the conceptual architecture. Architectural descriptions are comprised of architectural views, each of which addresses one or more concerns of the system's stakeholders. Each stakeholder, therefore, has a set of concerns – interests that they have with respect to the system's development and operation.

Viewpoints exist to define the conventions by which a view is depicted. It determines the languages, notations and models that are used to describe that view. A view is an expression of the system's architecture with respect to a particular viewpoint.

The standard requires that an architectural description identify the stakeholders and concerns of the software. As a minimum, this should include:

- Users
- Acquirers
- Developers
- Maintainers

A set of viewpoints are defined, each of which address the concerns of particular stakeholders. A number of architectural views are then defined, each including:

- An identifier for the view (e.g. functional view, operational view)
- Representation of the system (constructed with the languages and models defined in the associated viewpoint)
- Configuration information.

Each view may contain more than one architectural model. Additionally, the architectural description includes the rationale for the architectural concepts selected.

4.4 Current Trends Issues and Challenges

A large number of existing software visualisations are aimed at developers and maintainers of software systems. Whilst this may represent a significant proportion of the stakeholders in a software system, there are other areas of the software life-cycle that can be addressed by software visualisation, and therefore apply to a larger number of stakeholders. Software architects and designers are often less involved in the detail of software such as method variables, message passing and class properties. Instead, they are more involved with components, connectors, APIs and deployment objects such as machines, clusters and networks. By focussing on high levels of detail, existing visualisations often exclude software architecture as a view of software in its own right. Several architecture visualisations have attempted to address the issues posed. This section describes the trends and issues associated with current architecture visualisations and identifies the challenges raised.

4.4.1 Definitions, Views and Models of Architecture

Several definitions of architecture exist. This may be a reflection on the fact that there are a large number of views on what software architectures are, what they are used for, who uses them, and what they are comprised of. It is clear from the research background that some research has clearly drawn a line around what entities comprise software architecture. For example, ADLs clearly define these entities as they are formal language with defined structure and semantics. In other cases, class structure is referred to as the architecture of a software system, without any formal architectural named entities such as 'component' or 'connector'. Similarly, views of architecture can be formally defined in some research, but in other cases it is very much left to the designer to formulate what views exist within the architecture.

It is beyond the scope of this thesis to determine which of these extremes are correct, but it is important to recognise that there are extremes when considering the design of an architecture visualisation.

4.4.2 Representation and Mappings

Related to the issue of models and views, there is a wide variety of what graphical components can be used to describe an architecture. The increasing use of UML in modern software engineering is evident in current software architecture visualisations. However, this is not common across all architecture visualisations, and therefore there are directly conflicting mappings.

It is impossible to reconcile these mappings, so the design of an architecture visualisation should cater for these differences in representation.

4.4.3 Roles and Stakeholders

Many of the software architecture visualisations that have been considered in this chapter say very little of stakeholders in a software system other than architects and developers. It is obvious that the focus of the software architecture visualisations is very much towards these two roles.

4.4.4 Obtaining Architectural Data

4.4.4.1 Static Capture

Static processing is perhaps the most often used strategy for recovering the information needed for visualisation. Typically for detailed visualisations, a language parser is coupled to a data store and operates over the source repository for the target system. The parser is built or configured such that the data store is populated with entities that are deemed important for the visualisation. This data store is then used by the visualisation system to construct visual elements for display and navigation.

The data store of an architecture visualisation may contain large amounts of highly detailed information regarding the target system – it is the responsibility of the visualisation to present only that information that is required. For example, some views of architecture do not require method and variable level information.

4.4.4.2 Dynamic Capture

Static representations of software are often very different to the dynamic runtime reality of that software. Dynamic capture attempts to retrieve information regarding a running software system.

Augmentation of software is an invasive procedure that allows the addition of code to the source of a software system that will cause logging events, or update a visualisation display. Augmentation can be a manual process, where a developer or system expert adds the required code to the appropriate places. Augmentation can also be an automatic process where a precompiler tool inserts appropriate code into the source before compilation occurs. This code performs the appropriate function according to the visualisation, such as updating a repository, sending events to another system or updating a display. Another method for augmentation can be found used with the Java language, where classloaders are used to load classes into a running virtual machine. Custom classloaders can be used to automatically augment software without the need for recompiling the source code. The Java Virtual Machine also offers a debugging interface that allows external software to access all runtime information generated by the virtual machine.

4.4.4.3 Online and Offline

The visualisation process can occur in one of two temporal frames: online or offline. When a visualisation is carried out online, the visualisation is running alongside the system being visualised, and the display is updated as soon as possible after the event that caused it is triggered. If a visualisation is offline, the trigger events cause updates to a store such as a log file or database. After the system execution has completed, or the process terminated, the store can then be used by the visualisation in order to render the necessary views.

Both approaches offer relative merits and disadvantages. For online visualisation, the events can be viewed in real-time. This lends itself to situations where responses to such information are required in a live environment. For example, identifying a component that has failed in real-time is useful for contingency procedures to be executed. Online visualisation is necessary for situations where the choice of view depends on the current state of the system. For example, the user may only choose a particular view of component X if component Y has failed. Conversely, online approaches have their problems. Firstly, given the large volumes of visualisation information that can be provided by a system can overwhelm the rendering capability of the visualisation system, causing it to lag behind the data.

Offline visualisation can help with the problem of data volume. If the visualisation system cannot cope with the data volume, filters can be deployed to reduce the data flow into the visualisation system.

4.4.4.4 Storage

A typical visualisation system will comprise of the following data-sets:

- System data retrieved from static processing and description capture
- System data retrieved from dynamic processing
- Representations and mappings for the visualisation.
- Internal representation of the visualisation
- External representation of the visualisation

The choice of storage system for each of these areas will depend on the structural support and performance of that system. Typical choices include:

- Relational Database
- Flat-file (for example, a log file)
- XML Document
- Object/data-structure persistence
- Objects/data-structures in memory

Relational databases are well understood and provide for query languages, analysis tools and a variety of connectivity methods. Performance can be achieved with careful structuring of the data store, and by adjusting database management system parameters (DBMS) parameters. Flat-files are typically used where data processing requirement are to be kept to a minimum. Usually the only operation carried out on a log file during data capture is to append a line to the file. The log file can then be used with the visualisation system by replaying events back to the visualisation system, or more typically the log file is parsed and processed, and the resulting information stored in a database for access by a visualisation system.

A recent trend for software in general is to make use of the XML language. XML is often used for storing structured information, and here lends itself to many areas where validation and querying is required. For example, XML is useful for storing mappings, representations and metaphors. One of the advantages of XML over databases for structured information is that the XML data is human readable. Another is that XML documents can conform to and therefore be validated against XML schemas.

Whilst a visualisation system is running, visual objects, system objects, configuration information and data structures are all held in memory. This is the fastest store for visualisation information in comparison to the other methods described here. Visualisation system can use object serialisation to persist the state of the visualisation to a long-term store to be utilised at a later time. In this way, visualisation state can be saved, replicated and reverted to.

4.5 Conclusions

By examining a selection of existing software architecture visualisation systems, a number of trends, issues and challenges that face this area of research have been identified. Firstly, the definition and scope of what software architecture actually is does vary considerably from one organisation to another, and from one software system to another. The representation of such software architecture also varies, and is dependent on many factors including organisational policy, and individual preference. There are a number of roles and stakeholders in a software system, but existing software architecture visualisations often fail to address all of those stakeholders. Finally, this chapter considered the process of obtaining architectural information, and identified the types of data that are relevant to software architecture.

Chapter 5: The ArchVis Approach

5.1 Introduction

This chapter describes the ArchVis approach to software architecture visualisation. It examines the nature of the ArchVis visualisation concept, its aims, and presents the mechanisms by which it achieves those aims. A standard set of terminology is outlined to provide consistency in describing ArchVis, which is followed by a description of the elements used to describe software architecture. Then, an overview of the ArchVis approach is given in order to provide context for the rest of the chapter. Next, the mechanisms for the extraction of architectural data are examined. Following this, the system for creating a visualisation of the data is presented when render models and renderers are considered. This then provides a basis for looking at the ArchVis view model, looking at how views are defined and constructed. A number of views are developed and illustrated: component views, developer views, project manager views, technology and deployment views, and sales and marketing views. From here, the topic of interaction is discussed by looking at context sensitive actions and describing the activities that ArchVis supports.

5.2 ArchVis Visualisation System Overview

ArchVis is an approach to software architecture visualisation that is seated in current software visualisation techniques. The approach addresses key concerns identified in previous chapters:

- ArchVis supports multiple representations of software architecture – it is not limited to source code representations.
- ArchVis supports multiple stakeholders of software architecture – it supports stakeholders other than developers and maintainers.
- ArchVis supports both static data and transient data.
- ArchVis utilises a flexible data model allow for the capture of a wide spectrum of architecture.
- ArchVis utilises a flexible render pipeline for defining any number of different views.
- ArchVis utilises a flexible render model that allows for the creation of many graphical components for use in rendering a view.

In order to visualise the architecture of a software system, a number of actions need to be performed in the following order Visualisation Definition, Data Extraction and Visualisation (Figure 5-1).

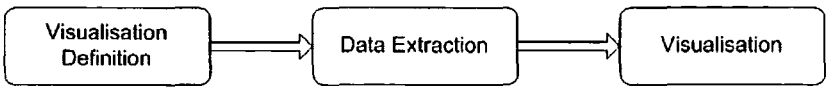


Figure 5-1 ArchVis Visualisation System Overview

The first two are performed before the visualisation occurs, and the last item is the running of the visualisation itself. Each is discussed in more detail below.

5.2.1 Overview of Visualisation Definition

ArchVis is controlled by configuration, called the *visualisation profile*, and this configuration determines the behaviour of ArchVis during visualisation. The two main aspects of the visualisation profile reflect the two types of data: static and transient. Static data conforms to the data model described later in this chapter, and transient data is comprised of events.

For static data, a number of views are defined. These views determine what elements of the available data are useful, and how that data is to be retrieved. The view specifies how data is to be filtered in order to produce a data set that is suitable for rendering. Finally, the view defines how a render model is constructed from the filtered data by using a renderer.

For transient data, the visualisation profile determines how events are mapped into actions on the render model. These actions will change elements in the render model in an appropriate manner.

This thesis describes five sets of views (component views, developer views, project manager views, technology and deployment views, and sales and marketing views) but an essential capability in this visualisation is that views can be added and removed both before the visualisation begins, and during the visualisation process.

5.2.2 Overview of Data Extraction

Data extraction here refers to the extraction of static data, and the extraction of transient data. Static data is data that is generated before the visualisation process, and transient data is data that is generated during the visualisation process and concerns the execution of the software architecture being visualised. Typically, static data is recorded in some long-term store such as a database or file store, and transient data is received as a sequence of events. Transient data pertains to the visualisation at the time of execution and its lifetime does not extend beyond a particular execution of the system.

A number of extraction methods are defined by which architectural data is retrieved and passed to the visualisation.

5.2.3 Overview of Execution

Execution of the visualisation means taking the visualisation profile and the static data and creating the defined views. It also encompasses all elements of interactivity and the use of transient data.

As the visualisation begins execution, it will create the relevant views. These views define how data is to be filtered before being passed to the renderer that has been set for that view. Once the render model has been constructed and displayed, transient data events can cause changes to elements in that model. Also, the user can interact with the visualisation in a number of ways.

5.3 Architecture Representation Choice

Programming languages are structured entities; they are well-defined constructs that can be parsed easily. Software architecture, however, is interpreted in many different ways with its constituent entities and relationships selected from different domains. For example, in the enterprise software domain, platforms and machines may represent architecture whereas in the compiler domain, architecture may be represented by data structures and their relationships. Some software systems have their architecture explicitly recorded, whereas others do not. Within ArchVis, the choice of a data model that gives greatest flexibility ameliorates many of these problems.

In simple terms, software architecture in ArchVis is represented as a set of entities and a set of relationships between those entities. Both entities and relationships also have properties. This ER model has historically proven useful for describing and modelling aspects of software architecture [Soni95].

5.3.1 Entities

Entities comprise of three elements:

- Name
- Type
- Properties

One entity is considered to be equal to another entity if both the names of both entities are equal, and the types of both entities are equal. The third element, the entity's properties, is a convenience for associating a set of key-value pairs with an entity. Properties are typically used when the property may not have further entities associated with it. For example, an entity 'rectangle' that has a relationship to another entity 'red' may be more suited to having 'red' as a property rather than an explicit entity and relationship.

Table 5-1 gives a number of examples of the types of entities that are commonly used in architectural representations.

	Categories				
	Computation	***Connector***	***Physical***	***Platform***	***OS***
Example Entities	Module	Protocol	Server	Web Server	Log
	Class	Transport	Machine	App Server	File
	Bean	Interconnect	Net Device	DB Server	File-system
	EJB		Location	Framework	Kernel
	Package				

Table 5-1 Examples of entities used in architectural representations

The collection of entities associated with an architecture depends on the domain of the software, amongst other aspects. An enterprise software system will have very different entities compared to, for example, a compiler's architecture.

5.3.2 Relationships

Relationships consist of the following elements:

- Name
- Type
- Source
- Destination
- Direction
- Properties

Here, the source and destination elements are references to entities. The direction indicates whether the relationship is forwards, backwards or bi-directional. For two relationships to be equal, the names, types, sources and destinations have to be identical.

Table 5-2 lists examples of the types of relationships that are commonly used in architectural representations.

		Categories				
	Computation	*Connector*	*Physical*	*Platform*	*OS*	*Generic*
Example Entities	Contains Has type Imports	Protocol Connects over	Deployed on Situated at Stored on	Interfaces to Built on	Written to Read from	Is a Uses

Table 5-2 Examples of relationships used in architectural representations

The categories used in Table 5-2 are for ease of description rather than being a prescriptive taxonomy. Relationship names, types and properties also depend on the domain of the software and also the data source. Relationships found in static UML diagrams will differ to relationships found in sequence diagrams, for example.

5.4 Data Extraction and Storage

Architectures are represented in a great number of different ways. In order to be successful in a real-world application, the ArchVis approach has to be able to support a potentially large number of sources of data, and also support large volumes of data. It is possible to recover architectural information from data at lower levels of abstraction, and so the ArchVis approach should be capable of exploiting this fact.

In the visualisation process, the first step is to obtain the data from various locations by various means. From a temporal perspective, data input into ArchVis is either static data or transient data. ArchVis has two interfaces: one for static data and the other for transient data (Figure 5-2)

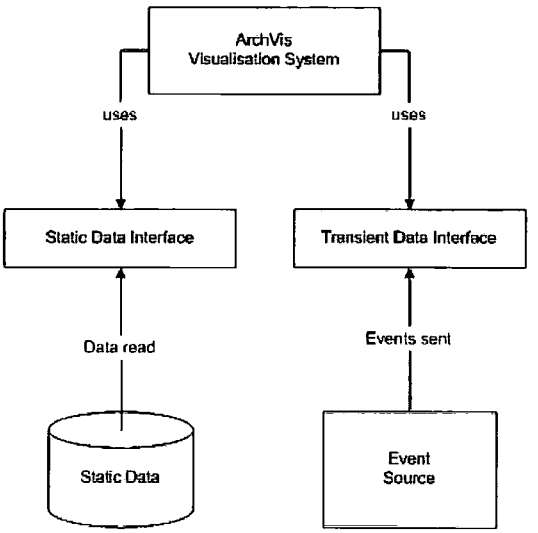


Figure 5-2 ArchVis data interfaces

The basic function of components that implement the static data interface and the transient data interface is to map real world entities to (entity, type) tuples, that is $f : W \rightarrow E$ where W is the set of real world entities and E is the set of all (entity, type) tuples. These components also extract the relationships and properties that are associated with these real world objects.

5.4.1 Static Data

Static data is placed into a repository that ArchVis can then use. The data model for ArchVis is an entity-relationship (ER) model along with properties associated with both entities and relationships. ArchVis provides an interface by which different storage mechanisms can be implemented, allowing for two distinct advantages.

Firstly, ArchVis can directly use existing data sources as part of its data set in an online fashion, without an explicit extraction and store process. A component can simply act as a gateway between ArchVis and the data source by translating the source data structures into a set of entities and relationships 'on the fly' (see Figure 5-3). In this approach, the design of the component will determine the resulting ER data set.

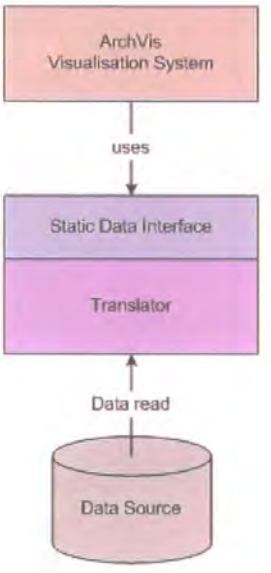


Figure 5-3 ArchVis data gateway

Secondly, ArchVis can take advantage of different storage technologies available. This is important as the number of entities and relationships can become large, performance may increasingly be an issue. For example, an implementation that uses a flat file structure can be replaced with a database implementation, or even an implementation that uses RAM only.

Fundamentally, the ER model also provides a very simple model that many different extractors can operate with.

Figure 5-4 ArchVis static data server

In order to allow for a wide array of input sources to be used, the mechanism used for extracting and retrieving data utilises a client-server architecture. The server (Figure 5-4) is responsible for listening for connections from clients and receiving data sent by those clients. A simple rolling graph indicates an impression of the activity of the server in terms of numbers of entities and relationships and properties added. Once received, the data is stored using the selected ER Store, which can be one of a number of implementations (Figure 5-5).

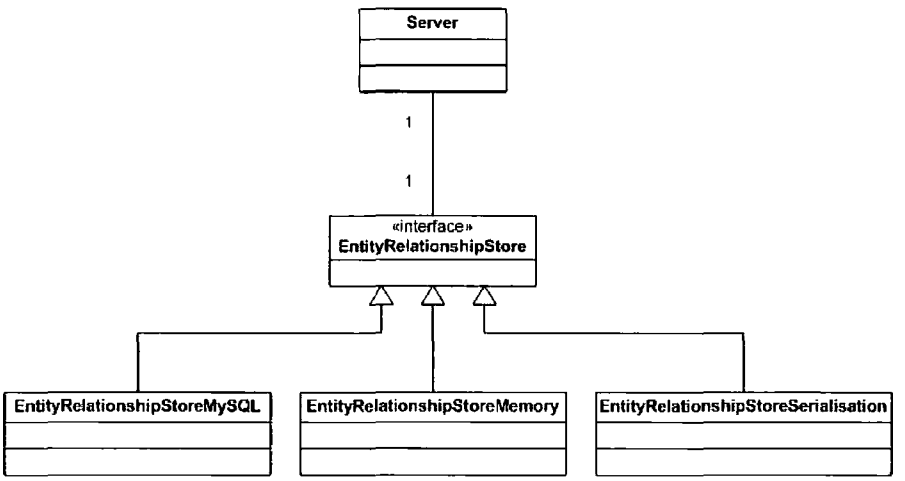


Figure 5-5 EntityRelationshipStore static UML diagram

Utilising a common client with a well-defined interface, many different extractors can interface to the server. Figure 5-6 shows how this is achieved. Each extractor is linked to an implementation of the 'Client' interface. This client exposes a simple interface for adding entities, relationships and properties, and it handles all communication with the server.

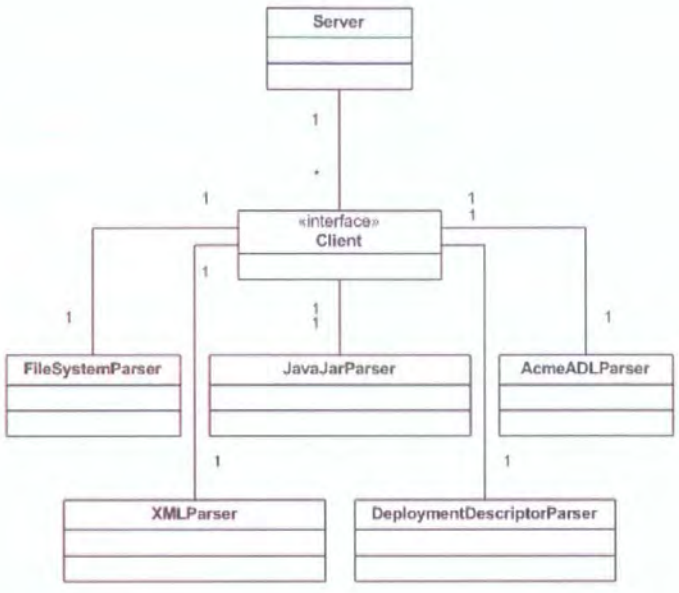


Figure 5-6 Data Extractors in ArchVis

A suite of tools exists to allow extraction of information from various sources. The data source types and the tools implemented are described below.

5.4.1.1 Architecture Description Languages

Chapter 2 includes a discussion on Architecture Description Languages (ADLs) and their application to software architecture. ADLs provide a useful mechanism for representing software architecture, and their formalism allows them to be manipulated with tools such as parsers. Many ADLs have been developed over the course of time. The Acme ADL was built to allow architecture descriptions written in these various ADLs to be translated so that a description in one ADL can benefit from the tools developed in another ADL. By supporting Acme, ArchVis can provide support to a wide variety of ADLs.

In ArchVis, an Acme description can be parsed using the Acme parser where the entities and relationships of the description are stored in the ER store.

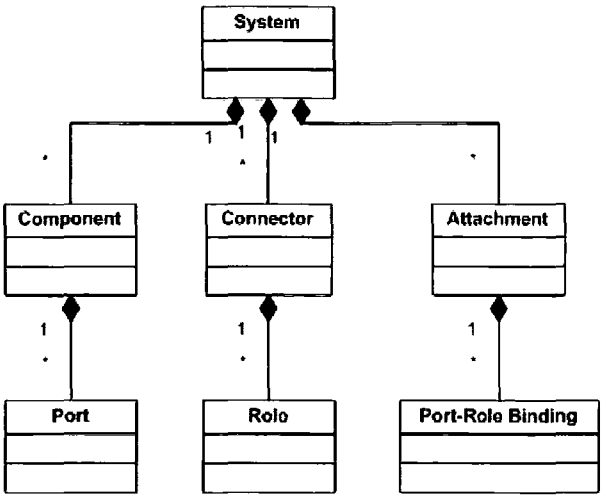


Figure 5-7 Acme ADL language structure

Figure 5-7 shows the main parts of the structure of the Acme ADL. The ArchVis Acme parser produces entities and relationships that follow this model.

5.4.1.2 Source Code

Perhaps the most well understood methods of extracting information about software systems come from traditional program comprehension and software visualisation research. Here, the source code for a software system is used as the input to the visualisation. In ArchVis, a source code parser can be used to parse a set of source files in order to populate the ER store. ArchVis and the source code parser are very loosely coupled, so the source code parser can be implemented in a number of ways. An obvious solution is for a custom parser to process the source files directly and populate the ER store accordingly. Figure 5-8 is a data-flow diagram of such a strategy.

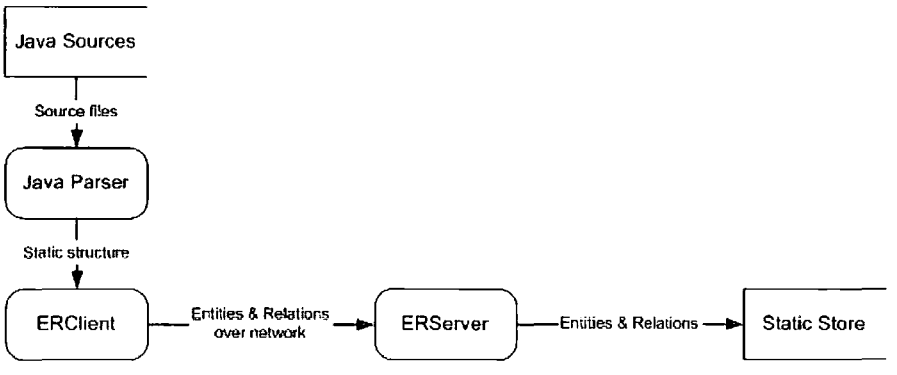


Figure 5-8 Data flow diagram of source code parsing

In another solution, an existing parser may have already created a database of information for which a separate tool can use that existing database as its input in order to populate the ER store. This is illustrated in the data flow diagram in Figure 5-9.

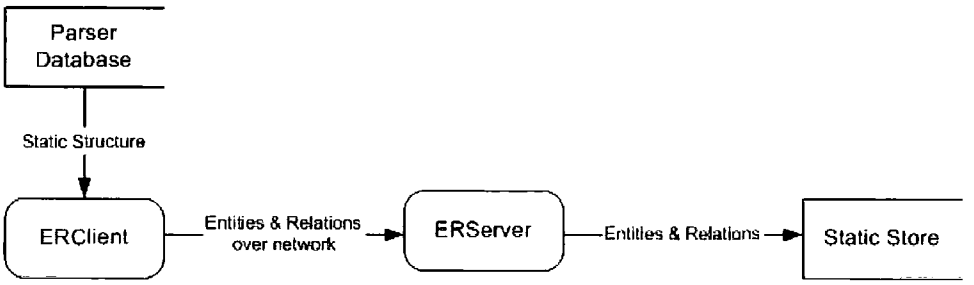


Figure 5-9 Data flow diagram of parser database extraction

5.4.1.3 Configurations

Another increasingly important source of persistent data is the configuration file. Two common examples of configuration files are key-value configuration files and extensible mark-up language (XML) documents. For the purposes of this thesis, key-value configuration files refer to properties files, initialisation files and system registry information. ArchVis makes use of a configuration file reader and XML document parser that can extract information from configuration files and place them in the ER store. XML use for defining the control structure of a software system is prevalent in enterprise environments such as in deployments of J2EE (Java 2 Enterprise Edition) applications. In particular, those applications that utilise the Struts framework where XML configurations define the flow of pages and also of intermediate actions.

5.4.1.4 Documents

Another type of information source is the document. Documents are widely used to describe many aspects of software systems in a multitude of ways. It is these documents that are invaluable to many stakeholders in a software system during all phases of the software lifecycle. Ideally, ArchVis would support the automatic parsing of natural language documents. Instead a tool can be used to help a stakeholder add information to the ER store. This tool is implemented such that any entity, relationship or property can be added to the store, and can therefore be used to capture document-based data.

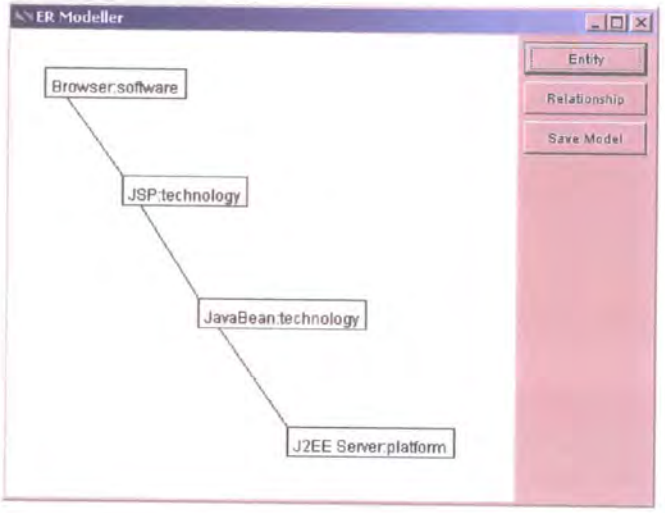


Figure 5-10 ArchVis modeller

Figure 5-10 shows an ER model based on information found in documentation of a software system. Once the model is has been successfully recorded, it is added to the ER store.

5.4.2 Transient Data

ArchVis retrieves transient data by acting as a server to a number of clients. Clients are able to initiate connections to the ArchVis service and begin to send event information (Figure 5-11).

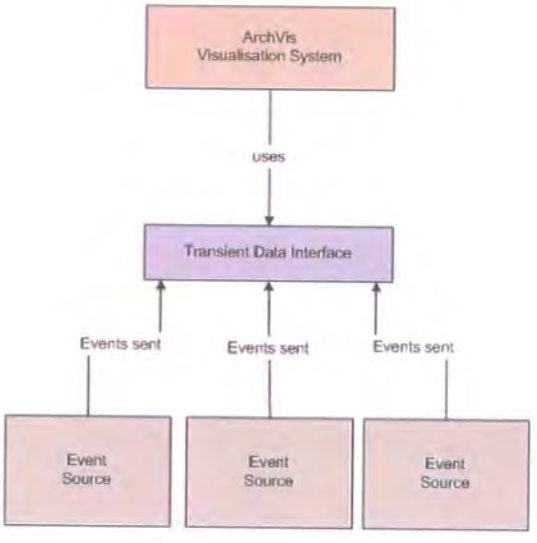


Figure 5-11 ArchVis transient data interface

Event information comprises of a set of key-values. This event information is then utilised within ArchVis in order to perform the following actions:

- Create a new entity or relationship
- Delete an existing entity or relationship.
- Change the properties of an entity or relationship.

An important aspect to mention here is that these operations are not performed over the original data in the ER store; they are operations over a temporary ER store used to generate views. This issue will become clear when views are discussed later in the chapter.

To facilitate re-running of a scenario, events can also be stored in a log to allow for playback.

5.4.2.1 Runtime Information

Some areas of program comprehension have used data gathered from a software system at runtime. The structure of software at runtime is very different to the static representation of that software in source code. There are two broad methods of extracting this information. The first is 'instrumentation' which involves changing the software itself to include statements that will record information about the running system. This is a directly intrusive approach. Some variants of this approach allow for pre-processing of source files in order to make the process less complex, but the resulting software is still modified. ArchVis supports this method of collection through the ArchVis Instrumentation interface (Figure 5-12).

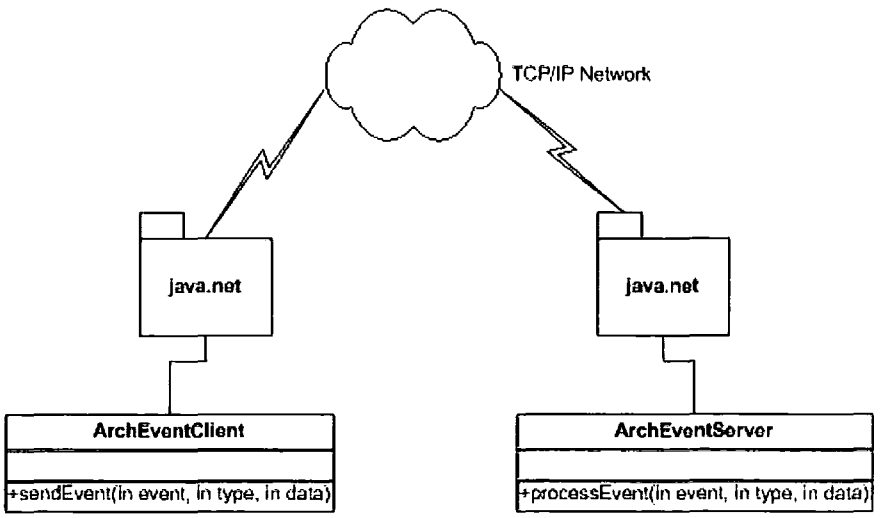


Figure 5-12 ArchVis client-server communication for transient data

The second method of extracting runtime information is applicable only to software that executes on a platform or virtual machine that supports that software. Perhaps most obvious is the debugging interface of the Java Virtual Machine (JVM). Using the debugging APIs, developers can build software that connects to the JVM in order to retrieve relevant information regarding runtime events [Smith02]. An advantage of some JVM implementations is that the debugger tool can be run remotely to the JVM, so the processor that drives the tool that uses the debugging information can exist on an entirely separate machine.

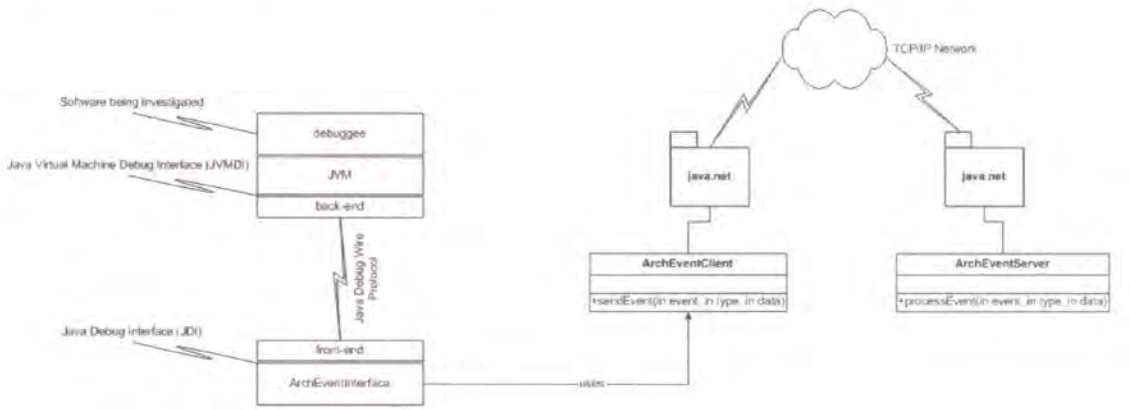


Figure 5-13 ArchVis and the Java debugger interface

Figure 5-13 shows how ArchVis can interface to the Java debugger interface.

Software architecture may also change during a program's execution. In some literature, this is referred to as 'dynamic architecture'. The ArchVis approach has limited support in that changes to the intermediate data store can cause the render model to change significantly. This largely depends on the implementation of the renderer.

5.4.2.2 Log Files

A common tool used in a running system is a log file. These log files are produced to help a system administrator or developer to determine a sequence of events. Log files contain varying levels of data from information-only entries to critical errors. One problem with log files is that they are often completely proprietary to the system that produces it, and they will often share no resemblance to any other log file. However, parsing log files is possible using a custom log file parser. One implementation of the Log File Parser allows the replay of event information that has been stored in a file.

5.4.2.3 Network Traffic

Another source of data of a running system is the network. For web based applications it is often useful to be able to monitor HTTP traffic. Figure 5-14 shows the ArchVis HTTP network sniffing tool in operation.

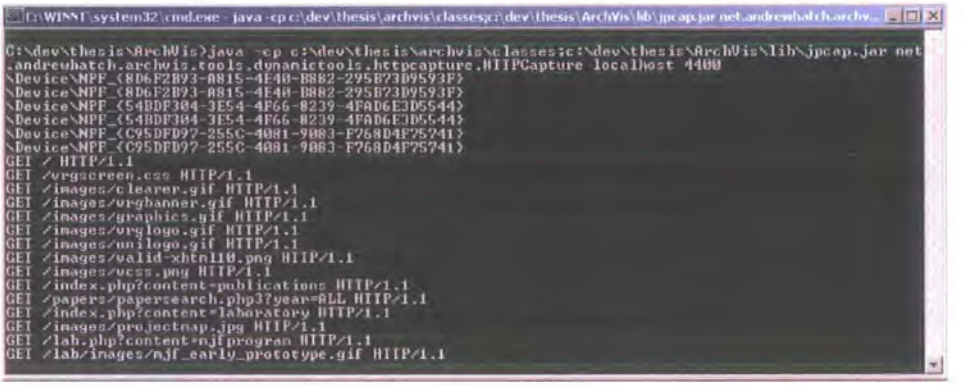


Figure 5-14 HTTP network sniffing tool

This can be configured in a variety of ways in order to capture different types of information, including:

- Source address
- Destination address
- URL
- Method (GET/POST)

Another common network protocol used in enterprise software systems is the Simple Network Management Protocol (SNMP). ArchVis can retrieve SNMP information from a variety of devices on the network including routers, switches and computers.

5.4.2.4 Consolidation

It is the responsibility of the individual who is building the visualisation to ensure that the different data extraction tools produce data that will be coherent once consolidated. Each tool that produces entity-relationship data for the visualisation can be said to have a vocabulary. If W is the set of all real world objects (within the domain of the data source), and E is the set of all (name,type) tuples, then the vocabulary mapping function v relates real world objects to (name,type) entities $v : W \rightarrow E$. Both static data providers implementing the Static Data Interface and transient data providers implementing the Transient Data Interface are components that perform function v.

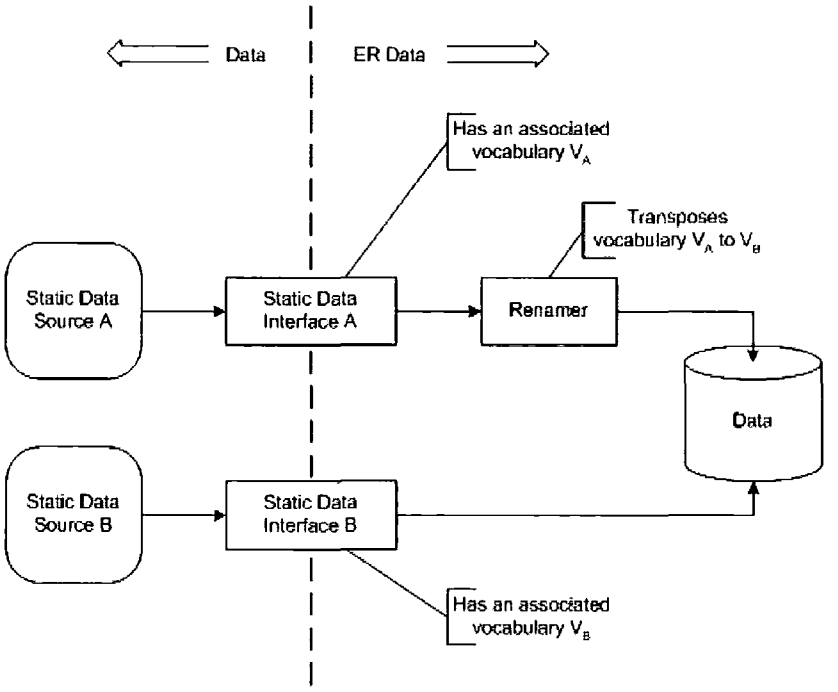


Figure 5-15 Consolidation process

A vocabulary, associated with a static data provider, is a subset of entities: $V \subset E$. A renaming function r will translate an entity $e \in E$ to another entity $e' \in E$. The intention of a renamer component, which implements a renaming function, is to map entities of one static data provider to another static data provider such that their vocabularies match. That is to say for all real world objects, w, a renamer function r should translate a vocabulary function v such that the resulting entities are the same as using another vocabulary function on the same real world object: $r(v(w)) = v'(w)$.

5.5 ArchVis View Model

So far, the data extraction process has been discussed. Once all the static data is available in an ER store, it is ready to be visualised. The ArchVis view model describes how this data is used to provide views on the architecture.

In a similar manner to IEEE 1471, ArchVis allows the definition of a multitude of architectural views. Frequently, research into software architecture identifies the need for more than one view of the software architecture. A model for how views are used in ArchVis is required, and is called a 'view model'. The view model utilised by ArchVis allows the definition of a vocabulary, model and graphical representation of architectures. Figure 5-16 is a class diagram of the view model. It shows that a visualisation profile has

exactly one ER store, but defines a number of views. Each of these views can have a number of data filters associated with it, and exactly one renderer.

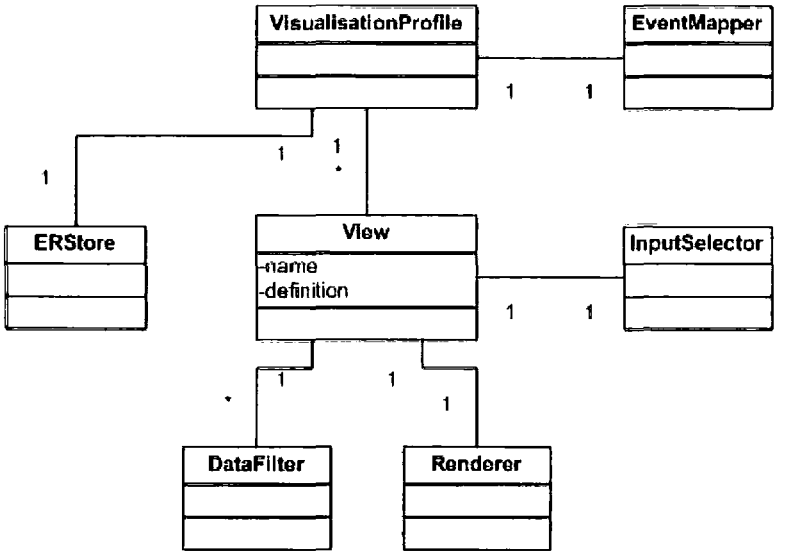


Figure 5-16 ArchVis view model

A visualisation profile consists of a number of views, and an entity relation store. The ER store is common across all views as each view is a representation of that underlying data. Each view has its own set of data filters and a render component. Data filters are defined to be an ordered list of filter components that take an entity-relation store as input, and output an ER store. In this way, the filters can be concatenated to achieve various functions. Also, each view has an associated definition in accordance with IEEE1471 [IEEE1471]. This definition will typically be a textual definition, or link to a document that contains the definition. Other aspects of the view model shown in Figure 5-16 are described elsewhere in the thesis.

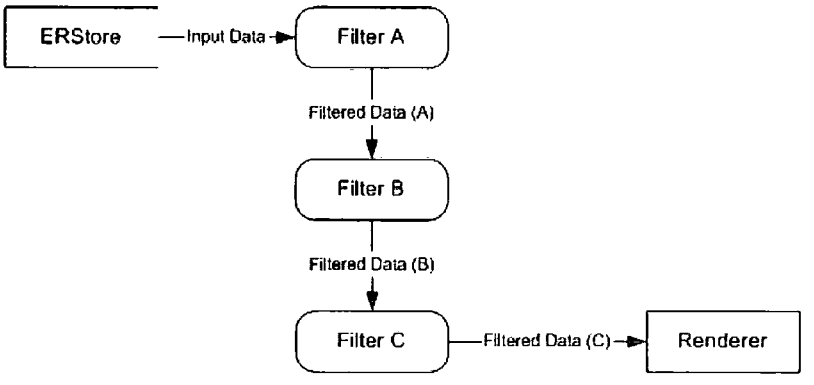


Figure 5-17 ArchVis static data filters

Figure 5-17 illustrates a view that consists of three filters. Data is retrieved from the ER store defined for the visualisation profile, and is passed to the first filter in the list. This filter then outputs an entity-relation store which is received by the next filter, B, and then again through to C. Finally, the entity-relation store that is output from C is passed directly to the renderer. For example, Filter A may remove entities of a certain type, Filter B may consolidate some related entities, and Filter C may factor some relationships into properties of entities.

A renderer takes an entity-relation store as input, and generates a render model. This render model is of a different structure to an entity-relation store, and is suitable for drawing.

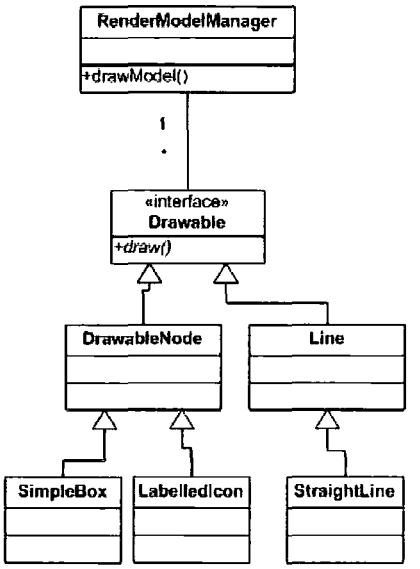


Figure 5-18 ArchVis' render model

The render model, shown in Figure 5-18, is controlled by a render model manager. It is the responsibility of the render component to take an entity-relation store and construct an appropriate render model. A key capability of this model is that it will support any number of filter configurations and renderers.

This approach to views means that any number of views can be created, catering for different view models found in research, such as the 4+1 view model described in chapter 2.

5.6 Render Models and Renderers

As shown earlier in this chapter, a view utilises a renderer in order to generate a visual representation of architecture. This renderer creates a render model, which is comprised of a set of graphical components along with a mechanism for organising those components.

5.6.1 The Render Model

The organisation of a render model is undertaken by the 'ModelManager', which is responsible for keeping a collection of 'Drawable' graphical components, and preparing them ready for rendering to a display.

The key to the power and flexibility of the visualisation lies in the graphical components that can be utilised by renderers. By having a large library of graphical components, more sophisticated visualisations can be achieved using the right renderer implementation. The following sections give core graphical elements that can be used in architecture visualisation.

5.6.1.1 Components and Connectors

Many ADLs use components, connectors, ports and roles as the entities that represent software architecture. The render model includes two graphical elements that represent these entities. Components are represented by large boxes and have smaller port boxes associated with them. Connectors are represented as vertical boxes, and have horizontal role boxes associated with them.

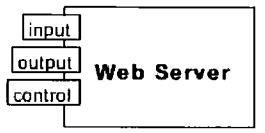
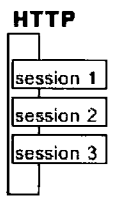
Example	*Description*
	An architectural component with three ports.
	An architectural connector with three roles.

Table 5-3 Render model component-connector elements

Table 5-3 gives an example of a component and connector with a number of ports and roles.

5.6.1.2 UML

The Unified Modelling Language (UML) is a de-facto standard for the design of software architecture, so the render model includes graphical elements to represent various aspects of the UML.

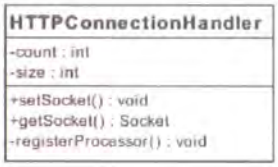
Example	*Description*
	A UML package, indicating a collection of classes and interfaces.
	A UML Class showing attributes and methods.
	A UML Interface showing methods.

Table 5-4 Render model UML elements

Table 5-4 gives an example of a package, class and interface. The class shows detail of the attributes and methods of the class, and the interface shows the methods associated with it.

5.6.1.3 Physical Elements

In the modelling of a software system, especially one that is distributed, the physical location of various components, and the configuration of the network between them are important.

Example	*Description*
	A computer deployed in a server-room environment that executes some software components of the architecture.
	Client computers and devices that are users of the software system whose architecture is being represented.
	Network devices that describe the topology of the network of computers in the software architecture.

Table 5-5 Render model physical elements

Table 5-5 shows a set of commonly used graphical elements that represent various physical hardware.

5.6.1.4 Utility

This section describes other graphical elements that are fundamental to displaying software architecture, but do not fit any of the categories identified above.

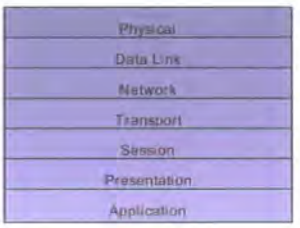
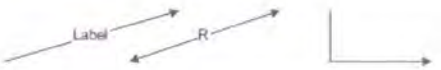
Example	*Description*
	Simple geometric shapes: rectangle, ellipse and triangle, which can be labelled.
	Abstract representations by using 3D-effect images such as spheres, which can be labelled.
	A collection of related entities, where the relationships between them are layered. This graphical component removes the need to show the inter-entity relationships as lines, but instead uses visual proximity. This example is showing the OSI network model.
	Simple straight lines with labels, and angled lines. Both may have arrowheads at each end of the line.
	Lines that have an association with the real world in the domain of pipes and filters.

Table 5-6 Graphical components in ArchVis

Table 5-6 lists some of the more commonly used graphical elements, including lines. As shown, further advantages can be made when graphical components are composite, such that one graphical component is composed of more graphical components (see OSI network model). Composition can happen with any graphical element, although the visual appeal of the resulting composite graphical element may vary depending on what elements are chosen.

Note that more graphical components can be added to the render model library, if the appropriate renderer is able to utilise them.

5.6.2 Architectural Style

ArchVis conveys architectural style in the selection and composition of graphical elements. It is the responsibility of renderers to present architectural style in the appropriate manner by utilising graphical elements that conform to the style in use. Possible graphical elements for architectural styles given in section 2.4.1 are shown below (Table 5-7). Note that these are images rendered from 3D models, and their use in ArchVis is as a 2D image.

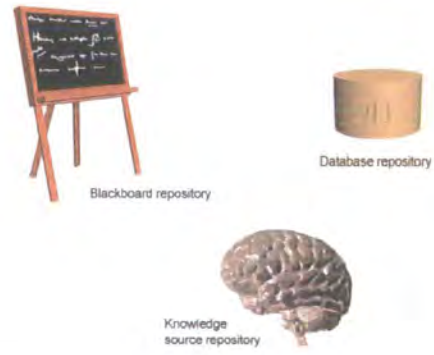
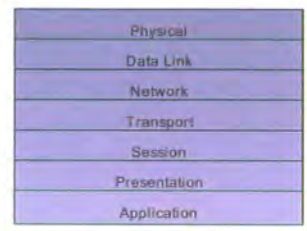
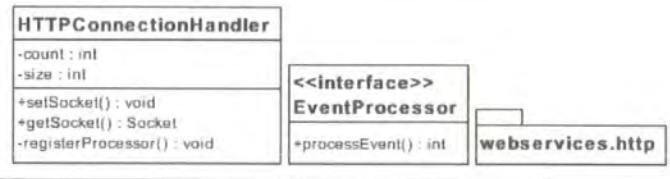
Style	*Example Graphical Elements*
Pipes and filters	
Repositories	
Layered	
Object oriented	

Table 5-7 Graphical elements as a representation of architectural style

Heterogeneous styles (2.4.1) can be represented through a graphical element allowing other graphical elements to become part of it. A good example is the layered style. Each of the layers may be implemented using a different architectural style, and thus the layer could be represented using a graphical item that follows a different style also.

5.6.3 Renderers

A renderer is a component whose function is to create a render model and populate it with instances of graphical elements. It does this by creating a render model manager, and then by creating the appropriate graphical elements to add to it, depending on the input to the renderer. Input to a renderer takes two forms.

The first and primary input is the ER store that the renderer is to act over, and the renderer recomposes entities, relationships and properties that it finds in the ER store, and recomposes them back into composite structures that are then represented by graphical elements.

The second input is an entity, or set of entities, that can be used to drive the renderer. For example, the user of the visualisation may be viewing a 'package view' that displays the contents of a chosen package. In order for this view to display the appropriate information, the user is required to select a package. The package that is selected is an entity that is input to the renderer, and causes the appropriate view to be rendered. This feature is described in more detail in section 5.10.1.

A renderer can also add associations with graphical elements. An association is a mechanism by which a graphical entity can be temporarily associated with another graphical entity. This temporary association is useful in situations where the user wishes to know some information about an entity, but then can hide that information later. The removal of associations can occur as a result of user action, or by the passing of time.

Examples of renderers are given in 'Example Views' below.

5.7 Transient Data Extraction and Use

Along with the visualisation of static data, ArchVis can also use transient data as input to the visualisation. Transient data can be important and useful for visualisation as it allows a stakeholder to visualise the activity of a system during its execution.

In a similar manner to the input of static data, the ArchVis approach allows a multitude of transient data sources to be used. Event Client components capture the dynamic data in the form of discrete events. These events are passed to the Event Server. The interface between client and server is network-based, so the transient data sources can be located on remote machines. Figure 5-19 illustrates the use of transient data in ArchVis.

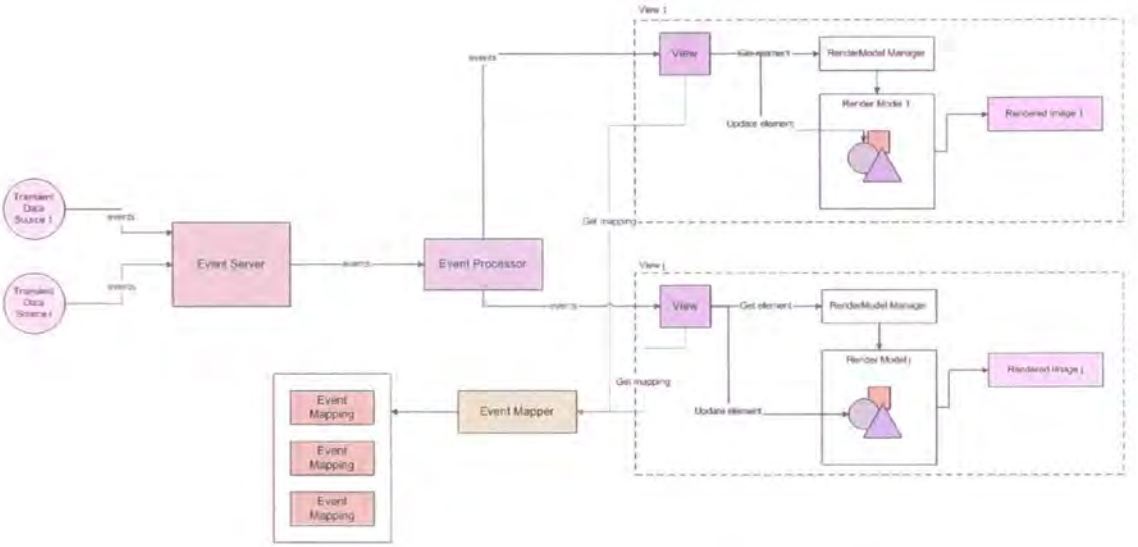


Figure 5-19 Transient data extraction

Each event that the Event Server receives is passed to the Event Processor from where the event is passed on to each view defined in the visualisation. The visualisation profile defines a number of event mappings that are supplied to an Event Mapper. When events arrive at a view, the view can then request the appropriate mapping from the Event Mapper, matching on the event type and the entity or relationship type.

Event Mapping components determine how an element of the RenderModel should be modified in order to visually represent the event that occurred. For example, an EventMapping object may describe that a failure event associated with an entity of type 'machine' should cause the relevant RenderModel element to be drawn with a failure warning icon.

In order to achieve this flexible approach to how to represent transient data events, elements in the RenderModel must have a set of associated capabilities. These capabilities indicate how the element can be changed over a period of time. Table 5-8 identifies such capabilities.

Capability	*Effects*
Label	Allows an element to have a label. This label is a string and is positioned over the top of the underlying element.
Transparency	Allows an element to have its transparency set from 0 percent to 100 percent. It also allows for effects over time such as fading out or fading in.
Flag	Allows an image to be overlayed in some position over the element. The image can be displayed for a fixed period of time if the flag is temporary.
Rotate	Allows the element to be rotated around its centre. This rotation can be to a fixed angle, or the element can be set to spin at a particular speed. Spinning can be limited to a fixed period of time.
Resize	Allows an element to be resized.
Brightness	Allows an element to have its brightness multiplied by a fixed amount.
Border	Allows an element to have a border set around its edges. The border width and colour are parameters to this capability.

Table 5-8 Graphical capabilities associated with elements of the render model

Graphical elements will have differing capabilities, so a particular visualisation should ensure that implementations of the EventMapping interface result in the correct requests to graphical elements in the RenderModel.

5.8 ArchVis Architecture

ArchVis, like all software has an architecture, and this has been described in this chapter. This section presents an overview of the logical view of the architecture. In this view, the focus is on the major components in the software and how they are connected to each other.

Figure 5-20 illustrates the logical view of ArchVis, showing the principle computation components and data flow.

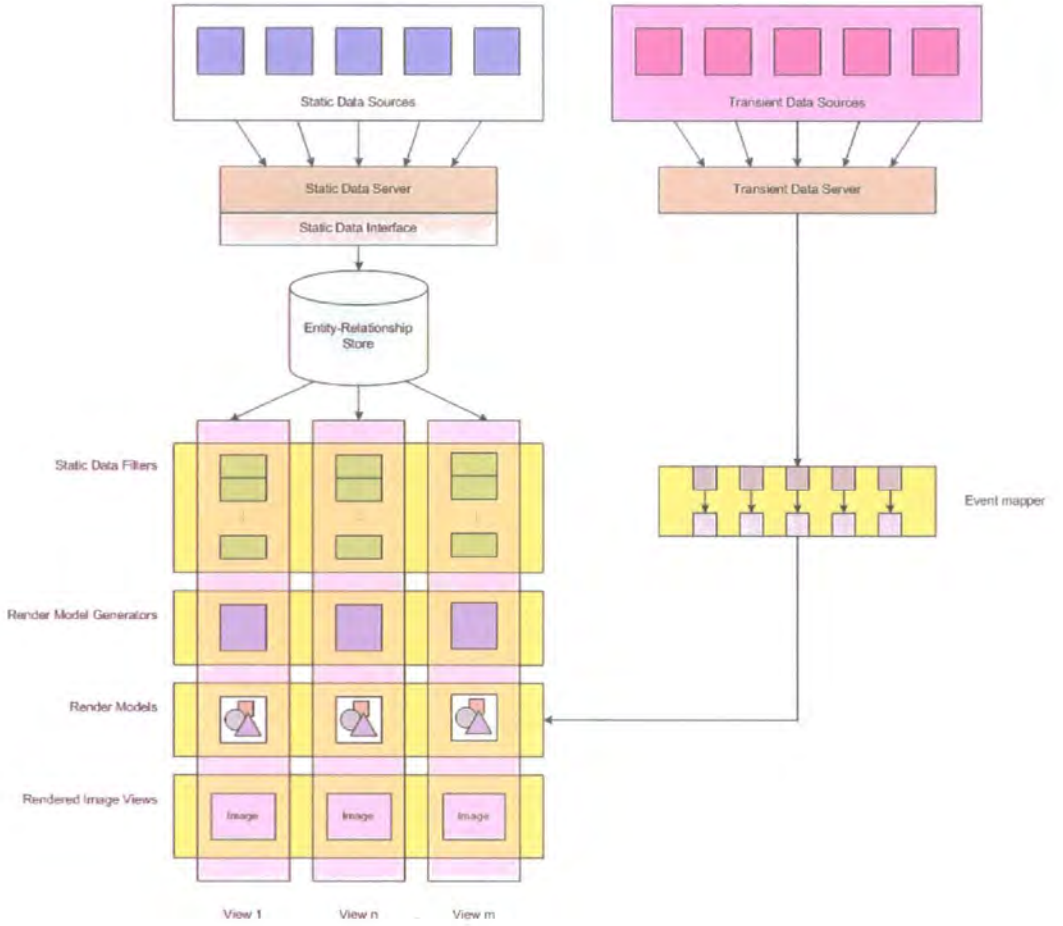


Figure 5-20 ArchVis logical architecture

Overall, the logical architecture consists of two instances of a client-server style and a pipeline.

The collection of static data from multiple sources is achieved through a client-server architecture, and results in a populated Entity-Relationship store. This store is then used by a number of views. Each of these views is a pipline, starting with filtering of the ER store, generation of a render model and the production of a rendered image.

Similarly, collection of transient data from multiple sources is the result of a client-server architecture. Output from the transient data server is pushed through an event mapper which causes modifications to the render models, which in turn results in the modification of the final rendered image.

5.9 Example Views

The following sections describe a set of typical views that may be found in an architectural description.

5.9.1 Component Views

Component views provide high-level views of the software system. From this high level view, the stakeholder has a broad perspective of the major components and connectors that the system is comprised of. The stakeholders who would use component views would not expect visual complexity to be increased by using complex graphical representations, so these views would remain simple and clean – using boxes, lines and other geometric shapes rather than icons and photographic imagery.

Unlike language-level views of a system, component views treat Components and Connectors as first class entities. Systems, components, connectors, ports, roles and attachments are the entities that are frequently used in architectural description languages. The data repository that is used to form this view must contain these entities and other entities that are relevant for this class of view. If an architecture description language has been used to build the data repository, then the repository would contain these entities. If not, data filters must be used to formulate these entities as required.

Component views are concerned with the high level logical entities. Figure 5-21 shows an online shopping system being comprised of four functional components. In this example, the components are represented as simple boxes with lines.

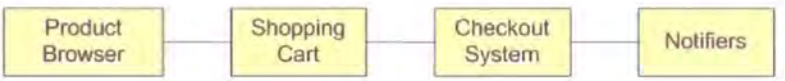


Figure 5-21 Online shopping system

These four components are linked together, indicating a logical relationship. This relationship can be presented in a number of ways, and architectural style plays an important role here. Figure 5-22 shows the same four components in the same system, but using a 'layered style'.

Figure 5-22 Layered style

By using a graphical representation of the layered style in this way, the user is able to see that the checkout system cannot be accessed by the product browser directly, and that the notifiers can only be accessed by the checkout system.

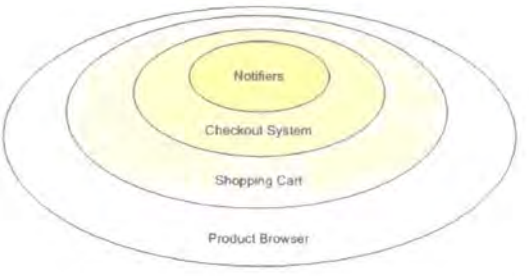


Figure 5-23 Onion-skin style

Figure 5-23 accentuates this relationship by using the onion-skin style. The latter two variations in showing these four components are not particularly suitable if the view is to contain more detail (Figure 5-24).

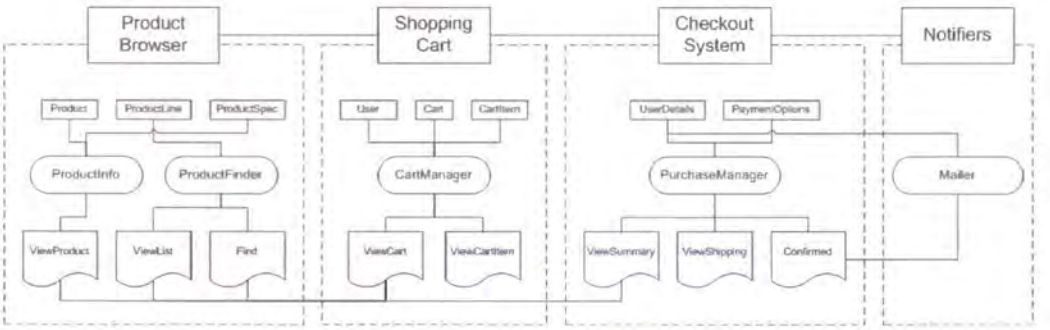


Figure 5-24 Detailed view of shopping cart system

Figure 5-24 shows the four components with a higher level of detail, showing the constituent parts. Table 5-9 is a key for this diagram.

Graphical Element	*Meaning*
	Component
	Entity Bean
	Bean
	JSP
	Component Boundary
	Uses relation

Table 5-9 Key of symbols used in component views

In order to generate component views, the 'PatternFilter' data filter is configured as shown in Table 5-10.

Rule	*Object*	*Match on*	*Value*
Include	Entity	Entity type	Component
Include	Entity	Entity type	Entity Bean
Include	Entity	Entity type	Bean
Include	Entity	Entity type	JSP
Include	Relation	*	*

Table 5-10 PatternFilter configuration for component views

Note that the '*' indicates 'all', so this filter will include all relationships in its output. The Renderer takes the resulting data and draws the view, with the configuration shown in Table 5-11.

Object	*Entity Type*	*Graphical Component*	*Configuration*
Entity	Component	SimpleRectangle	Fill=yellow; label=Entity Name
Entity	Entity Bean	SimpleRectangle	Fill=red; label=Entity Name
Entity	Bean	Capsule	Fill=green; label=Entity Name
Entity	JSP	Document	Fill=blue; label=Entity Name
Relationship	*	SimpleLine	<none>

Table 5-11 Renderer configuration for component views

The renderer will also evaluate, for each component, the boundary of all entities it is related to in order to draw a dashed boundary rectangle.

Components can be represented with their ports, and connectors represented with their roles (). Connecting lines between ports and roles indicate bindings between the two.

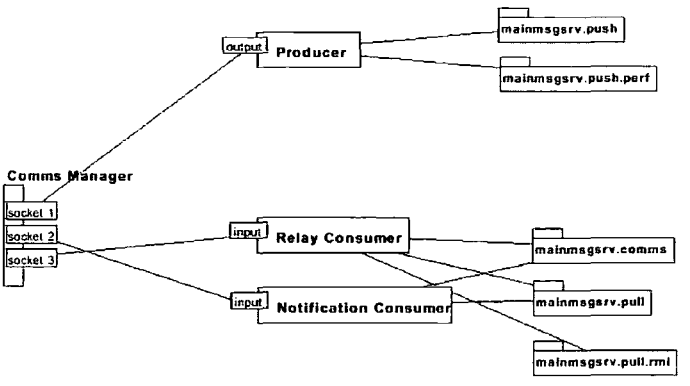


Figure 5-25 Component and connector view with ports, roles and packages

In Figure 5-25 the component and connector view shows package assignment to components.

5.9.2 Developer Views

The aim of developer view is to provide developers with all the information regarding the software system in a way that allows them to effectively develop and maintain that software. In many organisations, the UML is becoming the de facto standard for representing software systems in documentation that developers use.

In developer views, UML static representations can be related back to architectural components. This allows developers to gain an understanding as to their responsibility within the architecture of the system. Knowing the impact that a change to a particular method in context of the architecture can be beneficial.

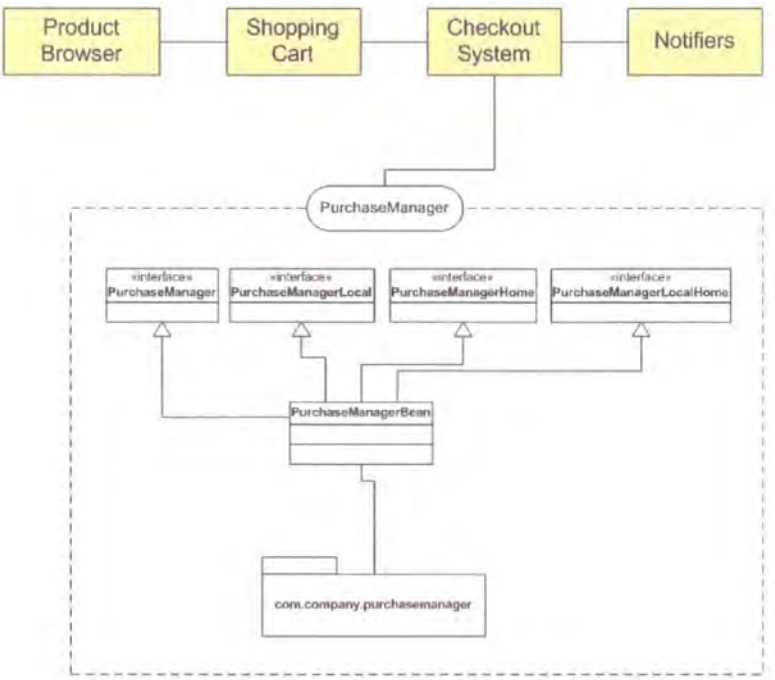


Figure 5-26 UML static model of an architectural component

Figure 5-26 shows a part of a UML static model of an architectural component, showing one bean only. It indicates that if a change were made to the interfaces or classes within that component, then the architectural impact can be seen to affect adjacent components directly.

In order to generate the view in Figure 5-26, the 'PatternFilter' data filter is configured as shown in Table 5-12.

Rule	*Object*	*Match on*	*Value*
Include	Entity	Entity type	Component
Include	Entity	Entity type	Bean
Include	Entity	Entity type	Interface
Include	Entity	Entity type	Class
Include	Entity	Entity type	Package
Include	Relation	*	*

Table 5-12 PatternFilter configuration for a developer view

To achieve a higher depth of information, the filter could add rules to include method and variable information. A renderer used in developer views may have the configuration shown in Table 5-13.

Object	*Entity Type*	*Graphical Component*	*Configuration*
Entity	Component	SimpleRectangle	Fill=yellow; label=Entity Name
Entity	Bean	Capsule	Fill=green; label=Entity Name
Entity	JSP	Document	Fill=blue; label=Entity Name
Entity	Interface	UMLInterface	Label=Entity Name
Entity	Class	UMLClass	Label=Entity Name
Entity	Package	UMLPackage	Label=Package Name
Relationship	Implements	SimpleLine	DstArrowHead=Unfilled
Relationship	*	SimpleLine	<none>

Table 5-13 Renderer configuration for developer views

Graphical components UMLInterface and UMLClass are subclasses of a generic StaticUML graphical component. ArchVis utilises actions (see later in this chapter) to facilitate the relationship between graphical representations of source files and the source files themselves.

5.9.3 Project Manager Views

Project managers may operate at different levels of abstraction when managing a project, so the definition of the project manager view will depend on preference. The primary difference will be at what level the project manager operates at – either at a component, connector, port and role only level, or whether they are interested in individual package, class, or interface level.

Some of the primary tasks that the project manager will perform are:

- Allocating resource to develop components in the system
- View the inter-dependencies on components in the system (if any)
- View milestones, and observe how these change when task timings are changed.

In project manager views, the project manager will be able to view the architecture of the system along with resource allocations, completeness and timing information.

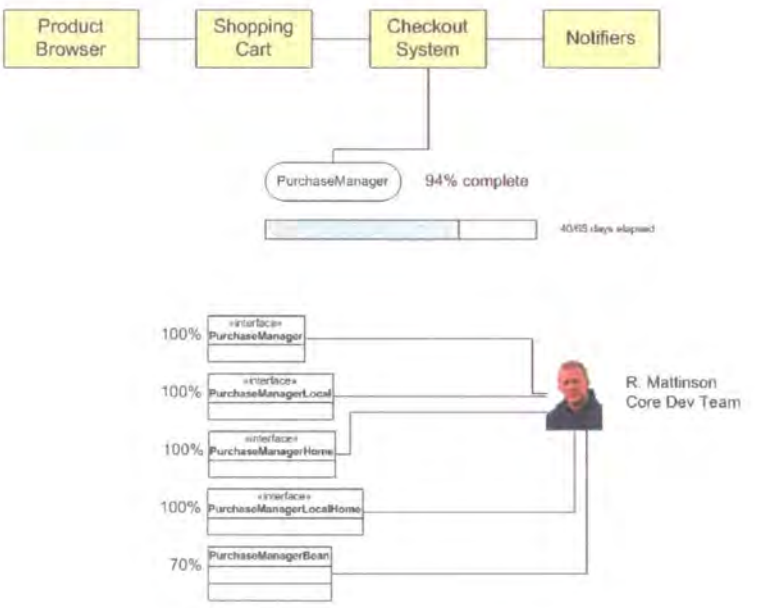


Figure 5-27 Development assignment to classes and interfaces of a component

Figure 5-27 depicts a project manager view, showing a bean within an architectural component along with respective completion statistics and closeness to deadline for individual classes, interfaces, and the bean component itself.

Rule	*Object*	*Match on*	*Value*
Include	Entity	Entity type	Component
Include	Entity	Entity type	Bean
Include	Entity	Entity type	Interface
Include	Entity	Entity type	Class
Include	Entity	Entity type	Person
Include	Relation	*	*

Table 5-14 Static data filter configuration for project manager views

Table 5-14 shows the rules that the static data filter is configured with in order to make the correct data available for these views.

Object	*Entity Type*	*Graphical Component*	*Configuration*
Entity	Component	SimpleRectangle	Fill=yellow; label=Entity Name
Entity	Bean	CapsulePM	Fill=green; label=Entity Name; Tag=Entity.property.complete; Bar=Entity.property.start + Entity.property.end + Today
Entity	Interface	UMLInterfacePM	Label=Entity Name; Tag=Entity.property.complete
Entity	Class	UMLClassPM	Label=Entity Name; Tag=Entity.property.complete
Entity	Person	LabelledPhoto	Photo=namedphoto; Label=Entity Name + Entity.property.Team
Relationship	*	SimpleLine	<none>

Table 5-15 Renderer configuration for a project manager view

Table 5-15 shows the configuration for the renderer. This utilises graphical elements that have specific capability for project management (note the use of PM in their name). These elements can take property values as input in order to generate the appropriate graphical output. In this case, this is percentage complete.

5.9.4 Technology and Deployment Views

The aim of technology and deployment views is to indicate the types of technologies that are used to construct the system. Stakeholders in this view would include:

- System administrators
- Purchasing department
- Customers
- Network engineers

The intention of these views is to indicate how components of the architecture are deployed – what operating systems, virtual machines and software platforms are intended for the component or connector. In enterprise environments, this may also extend to the type of network or network fabric, storage system, storage capacity and physical location.

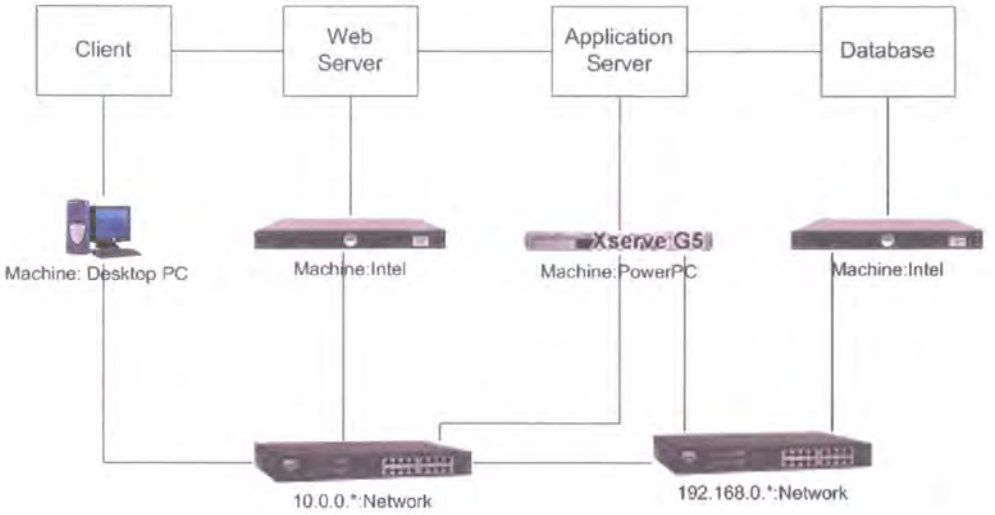


Figure 5-28 A physical deployment view

Figure 5-28 is a physical deployment view generated from a static data configuration that is given in Table 5-16.

Rule	*Object*	*Match on*	*Value*
Include	Entity	Entity type	Platform
Include	Entity	Entity type	Machine
Include	Entity	Entity type	Network
Include	Relation	*	*

Table 5-16 Static data filter configuration for physical deployment views

This view considers platforms, machines (computers) and networks to be of primary concern.

Object	*Entity Type*	*Graphical Component*	*Configuration*
Entity	Platform	SimpleRectangle	Fill=white; label=Entity Name
Entity	Machine	LabelledIcon	Label=Entity Name; Icon=Entity.property.processorarch
Entity	Network	LabelledIcon	Label=Entity.property.iprange + Entity Type; Icon=Entity.property.manufacturer
Relationship	*	SimpleLine	<none>

Table 5-17 Renderer configuration for a physical deployment view

Table 5-17 shows the renderer is configured for a physical deployment view.

Another important aspect of the architecture is the technology used to develop the system. Most of today's software is built on top of application frameworks, application programming interfaces (APIs), platforms and technologies.

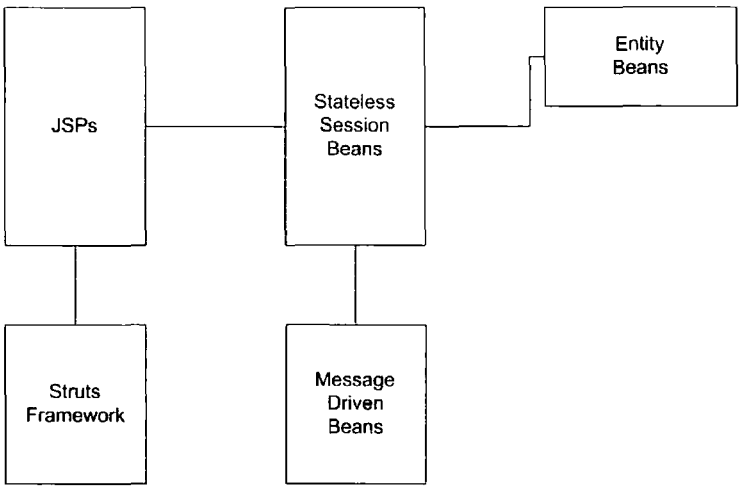


Figure 5-29 Framework and Technology View

Figure 5-29 shows an example of a framework and technology view on the software's architecture – showing generic interactions between them.

5.9.5 Sales and Marketing Views

Software architecture is often a fundamental aspect of the pre-sales process, with acquirers often wanting to see how a system will integrate with existing systems and infrastructure. As the sales process is closely related to the marketing function of a software-producing organisation, diagrams and images used as part of the sales process are often of very high quality.

Whilst some customers will wish to see much higher levels of detail, this section deals with sales views intended to give a high graphical quality without a large amount of detail. Other views can be used to present higher levels of detail to customers.

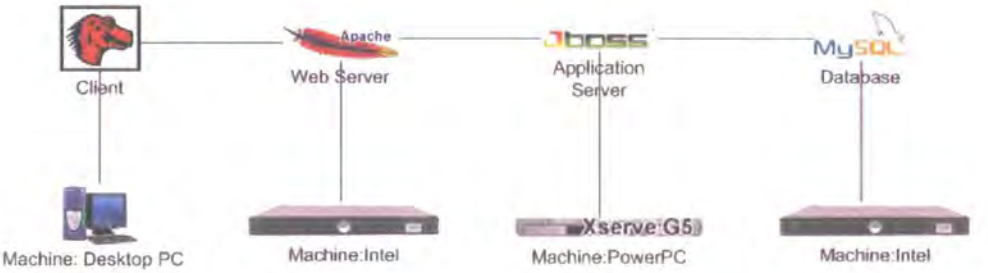


Figure 5-30 A technology view

Figure 5-30 illustrates a typical web application structure, showing the interconnections between the major architectural components along with technology choices. Logos are used here to illustrate the technology used as brand often plays an important role in the qualification part of the sales process. This view is a variation on a view presented in technology and deployment above.

Rule	*Object*	*Match on*	*Value*
Include	Entity	Entity type	Platform
Include	Entity	Entity type	Machine
Include	Relation	*	*

Table 5-18 Static data filter configuration for a technology view

Table 5-18 shows the data filter configuration required to build this view.

Object	*Entity Type*	*Graphical Component*	*Configuration*
Entity	Platform	LabelledIcon	Label=Entity Name; Icon=Entity.property.vendor
Entity	Machine	LabelledIcon	Label=Entity Name; Icon=Entity.property.processorarch
Relationship	*	SimpleLine	<none>

Table 5-19 Renderer configuration for a technology view

Table 5-19 shows how the renderer is configured for this view.

5.10 Activities

In order to facilitate comprehension of software architecture, a number of activities are supported. Here, some of the more fundamental activities are described.

5.10.1 Querying

ArchVis query support is provided by two mechanisms. The first is by setting the input to a view, a feature mentioned briefly in section 5.6.3. This mechanism relies on an input selection component that is associated with a view (Figure 5-31).

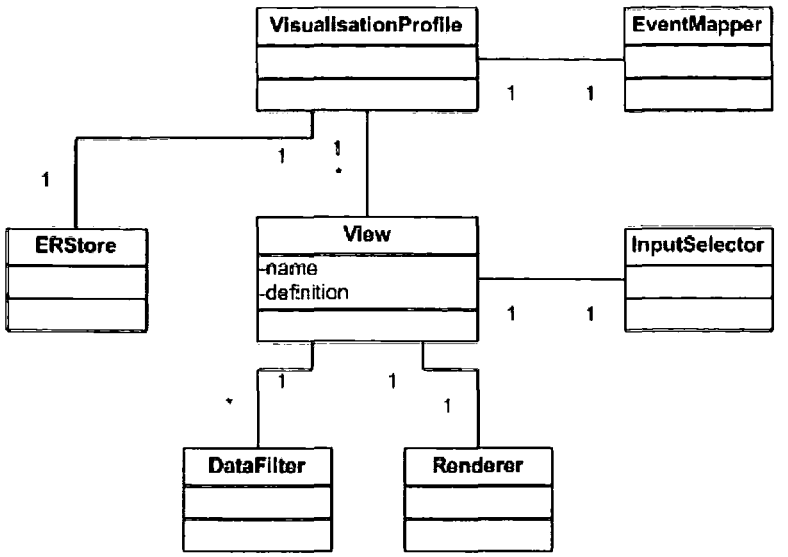


Figure 5-31 Input selection for a view

The input selection component allows users to set the input to a view. The input selector component determines, by configuration, what entities can be selected to be input to a view. For example, if the view is to display the contents of a package, the input selector will allow the user to select a package from the ER store. The act of selecting a package will then cause the view to be re-drawn with that particular package as input.

The second mechanism by which querying is supported is the use of an explicit query view. A query view is a very similar concept to input selection, but results in a new view being generated. A typical action that would cause a query view to be created would be that a user identifies an entity of interest, and requests the creation of a query view on it. This would then add a new view to ArchVis, showing the results of that query. Query views a particularly useful for showing all entities that are related to a particular entity.

5.10.2 Layout

Layout is an operation that operates over graphical elements in the render model of a view, and can be activated or deactivated by the user. Any available graph layout algorithms can be applied to the render model, and it is the responsibility of the layout component to determine whether it can operate over the render model given to it. Graphical elements in the render model have a type associated with them that determines if they correspond to entities or relationships. This information is used by a graph layout component in order to position those elements.

5.10.3 Browsing

Most of the activities that a user will perform whilst using the ArchVis visualisation can be labelled as browsing. As described earlier, browsing is the assimilation of understanding that is achieved by following concepts. In the ArchVis visualisation, a user can browse from one entity to another via relationships that link them. Visually, this is achieved by the Graphical Components that make up the rendered model, and that are displayed in the view. For example, an entity linked to another entity by a straight line indicates visually that the two are linked. Visual browsing is this act of following the relationships that are presented visually.

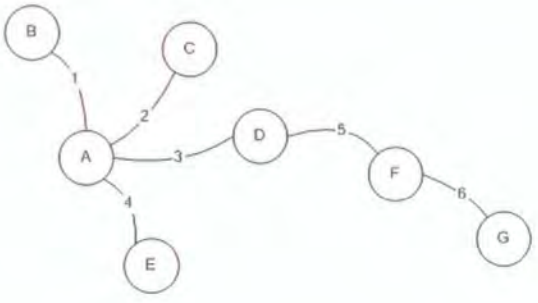


Figure 5-32 Browsing

Figure 5-32 shows how a user can browse objects in the visualisation by their visual association. A is related to D, is related to F, is related to G. This relationship is represented very clearly, and the user can 'browse' to G by following the visual chain from A.

A second method of browsing is to see a list of all relationships associated with an entity. By enumerating this list of relationships, the user can see what entities are linked at the other ends of those relationships. Another form of enumeration is the list of properties that are associated with the entity or relationship. Browsing via enumeration is a particularly important activity to support, as defined views may not present all the entities related to a particular entity that is the current focus.

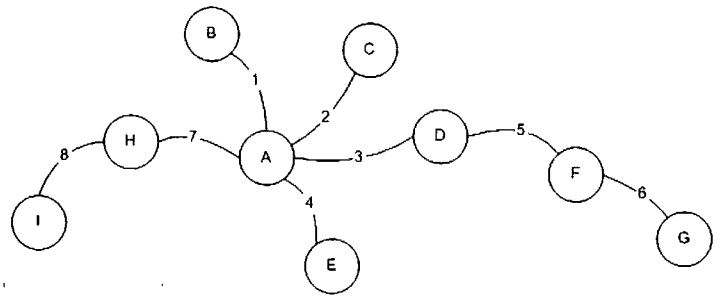


Figure 5-33 Browsing

Figure 5-33 illustrates this clearly in that entity J may not be visible in the current view, but is related to A via relationship 10.

When an entity is selected as the focus, the ArchVis visualisation system permits a number of useful browsing aids. All relationships that contain the currently selected entity can be calculated and presented for the user to examine. These relationships can be restricted to only those that appear in the current view, but can also include all relationships – even from other views.

5.10.4 Searching

Searching is complementary to browsing, and is considered very important by some visualisation researchers [Sim99]. The search capabilities offered by the ArchVis visualisation are extensive. Simple searches can be performed that are based on regular expressions on entity name, entity types, relationship names and relationship types. As ArchVis uses the entity-relationship model, more complex searches can also be performed by matching entities and relationships on their properties.

5.10.5 Annotation

Annotating a view is important when recording hypothesis about understanding. ArchVis separates annotations from the underlying data model. This is important, as the data model should remain independent of any visualisations that utilise it in order to allow multiple visualisations of the same data. Therefore, annotations are stored separately, but are related to the original data source by pointers. When the visualisation is resumed, annotations are retrieved from a separate data store. When entities, relationships and properties are selected, the appropriate annotation can be displayed and made available for editing.

5.10.6 Consolidating Views

As ArchVis is comprised of a number of views, it is important to be able to maintain context when switching between views. This is achieved in a number of ways. The entity or relationship in question can be highlighted such that the user can quickly identify the same entity in different views. In some instances, depending on the configuration of the data filters and the renderer, the entity may not exist in all views, so ArchVis will not display the entity, but provide a visual reference that indicates that the entity is not present in the view.

5.10.7 Context Sensitive Actions

When stakeholders are using the visualisation, they may wish to perform an action associated with an Entity or Relationship. Context Sensitive Actions (CSAs) is the ArchVis mechanism provided to support this. CSAs are components that can be associated with entities and relationships in three ways: name, type or property. Whenever the user selects an entity or relationship, they are able to view a list of CSAs available.

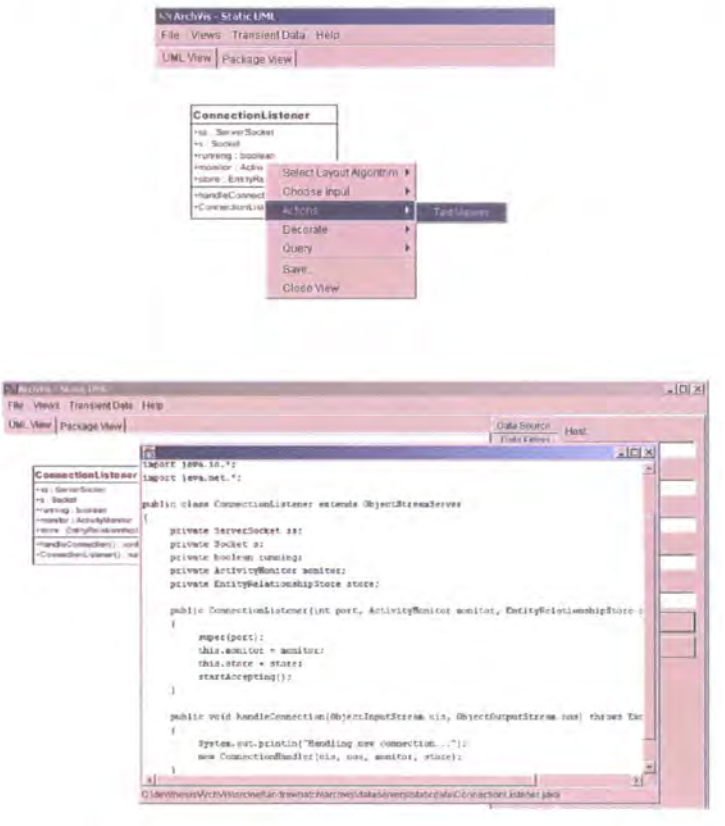


Figure 5-34 Context sensitive action

Figure 5-34 shows the selection of an entity. The 'Text Viewer' action is associated with the property 'sourcefile', and so shows in the list of actions available. Selecting this would execute the 'Text Viewer' CSA that opens the file using an operating system defined text editor.

Each CSA can be associated with names, types and properties. The format for this configuration is (name,value) pairs. This list of pairs can be extended prior to running the visualisation. This list is parsed in order to determine whether an entity or relationship is associated with the CSA or not. If it is, then the CSA is added into the menu hierarchy as appropriate, otherwise it is not.

CSA Class	**Typically Associated With**	**Description**
TextViewer	Property: sourcefile Property: textfile Property: configfile	Launches an external text editor that is set for the operating system using the value of the sourcefile property.
XMLViewer	Property: xml Type: xml	Launches an external XML viewer, with the value as the input file.
ImageViewer	Property: icon Property: image	Opens a window, showing the image along with basic information regarding size, colour depth and file type.
DirectoryViewer	Property: directory Type: file	Launches a file explorer, showing the location of the file or directory.
NetworkTools	Type: network	Launches a set of tools that can operate on the ipaddress property if it exists.

Table 5-20 Context Sensitive Actions

Table 5-20 shows a set of CSAs that may be associated with entities and relationships in an architecture. Each context sensitive action inherits from an abstract base class such that further implementations are possible.

5.11 Conclusions

ArchVis' approach to software architecture visualisation can be delineated into phases. The first phase is the extraction of appropriate architectural information. At the beginning of this chapter, the data model was identified and an approach to data extraction was described. The next phase concerns the filtering of data ready for a renderer. The final phase is for the renderer to produce a render model based on the filtered data and for that render model to be drawn. This chapter also describes the ArchVis view model, indicating the way in which multiple views are defined in a visualisation profile that then determines the behaviour of the visualisation as a whole. Finally, this chapter describes the operation of ArchVis at runtime, indicating how a stakeholder may use the system; how the user can perform essential activities and actions; and how runtime information can be represented in the views.

Chapter 6: Implementation

6.1 Introduction

This chapter deals with the construction of a set of prototype tools that implement the ArchVis visualisation system.

6.2 Architectural Data Capture

Several tools were implemented in order to obtain data that relates to software architecture. These tools were selected to cover those data sources that are commonly used to encode architectural information as well as providing an impression as the flexibility of the data model. As described earlier, the data model is represented by the EntityRelationshipStore interface, of which three implementations were created. Table 6-1 identifies the purpose of each of the implementations of the EntityRelationshipStore interface.

Class	*Purpose*
EntityRelationshipStoreMySQL	Provides a persistent store of architectural information.
EntityRelationshipStoreMemory	Provides a high performance non-persistent store of architectural information. Primarily used as output to the application of data filters.
EntityRelationshipStoreManager	Provides a wrapper to a persistent store, acting as a cache and improving performance.

Table 6-1 Implementations of the EntityRelationshipStore interface

Many techniques already exist to recover architectural information from data found at lower level of abstraction. Table 6-2 below shows the level of abstraction that the implemented data capture tools operate at.

Class	*Abstraction*	*Static/Transient*
ArchVisAcmeParser	Architecture Description	Static
ModelBuilder	Design	Static
ReflectionParser	Implementation Language	Static
PropertiesReader	Software Configuration	Static
INIFileReader	Software Configuration	Static
FileSystemReader	Filesystem	Static
ArchLog	Instrumentation	Transient
HTTPCapture	Network	Transient
ArchVisJDI	Class/Method/Variable (VM)	Transient

Table 6-2 Level of abstraction data extraction tools operate at

All of the static capture tools communicate in a client-server mode of operation, where the server is connected to an implementation of the EntityRelationshipStore, typically the EntityRelationshipStoreMySQL class. When the ArchVis system is to be used in an environment where it is to receive transient data, the ArchVis visualisation system opens a server ready for external tool connections.

6.2.1 ArchVisAcmeParser

Architectures described in the Acme language are parsed using the ArchVisAcmeParser tool. It utilises the AcmeLib, a Java library for the Acme language developed by the ABLE Group at Carnegie Mellon University (http://www.cs.cmu.edu/~acme). Its operation involves reading an Acme specification, parsing it, and then traversing the object model and retrieving entities and relationships between Systems, Components, Connectors, Ports, Roles and Attachments.

6.2.2 ModelBuilder

When a modeller of an architecture wishes to add entities, relationships and their properties to the ER store, and no other tool will allow them to add them automatically, then they may use the ModelBuilder. This tool allows the user to graphically define entities, relationships and properties, and then commit them to the ER store. This tool was developed in Java using the Swing libraries for the graphical user interface.

6.2.3 ReflectionParser

If source files are not available, then the ReflectionParser tool can be used. This allows classes to be loaded into the Java virtual machine and inspected using Java's standard reflection package. This package allows the recovery of information about a class's modifiers, fields, methods, constructors and super-class. It also allows an interface's constants and method declarations to be recovered, amongst other information.

6.2.4 PropertiesReader

Properties files are frequently used in Java applications for the storage of configuration information, and other useful runtime variables. Properties files are human-readable ASCII documents that can be read using Java's Properties class. The PropertiesReader class simply adds key-value pairs to the ER store, relative to the property file location.

6.2.5 INIFileReader

The INI file is a Microsoft Windows configuration file that is used in many Windows based applications, and consists of categorised key-value pairs. The operation of this tool is to parse these files in much the same way as the PropertiesReader utility, but also retains the categories used.

6.2.6 FileSystemReader

When information regarding the location of files is required, the FileSystemReader can be configured to locate files that conform to a specific filter. For example, the absolute path of all files that end in .java can be added to the ER store and then be associated with entities that are derived from it.

6.2.7 ArchVisJDI

ArchVisJDI provides the capability of analysing any Java program during its execution. It is able to do this by utilising the JDI packages provided as part of the Java language (com.sun.jdi). The tool can be configured

to monitor for class loading, method entry and exit, and also for variable changes. When these events occur, they are passed over the network to the ArchVis visualisation system for processing.

6.2.8 ArchLog

ArchVisJDI represents a relatively non-invasive approach to recovering runtime information. ArchLog, however, uses an 'instrumentation' approach to recovering information from software. This requires the addition of static calls to the sendEvent() method of the ArchLog class. The benefit of this approach is that arbitrary events can be sent at any stage of the program's execution. For example, when several objects that represent a component have been constructed, a 'component constructed' event can be sent. This overcomes ArchVisJDI's limitation of sending only predefined types of events.

6.2.9 HTTPCapture

When the visualisation requires information regarding hits on a website, the HTTPCapture tool can be used. This tool utilises a Jpcap java library developed by Keita Fujii (http://netresearch.ics.uci.edu/kfujii/jpcap/doc/) that allows Java access to a packet capture native library. The tool will listen on the network for HTTP requests, and can filter and send these back to ArchVis for processing in the visualisation.

6.3 Static Data Filter Library

Static data filters, as described earlier, are components that take EntityRelationshipStore objects as their input, perform some processing, and then output a new EntityRelationsihpStore object. The output is then either used as input to another static data filter, or used as input to a renderer. Filters are defined by the classes that extend the StaticStoreFilter class. Those implemented are listed in Table 6-3.

Class	Description
CopyFilter	Directly copies all entities, relationships and properties from the source to the destination.
PatternFilter	Excludes or includes entities and relationships depending on input rules. The ruleset defines the global directive to either include as default or exclude as default. The remaining rules are exceptions to the global rule.

Table 6-3 Implemented static data filters

A discussion on the limitations of these filters is described in a later section.

6.4 Renderers

Renderers take an EntityRelationshipStore as its input, and generates a model suitable for rendering, as managed by the RenderModelManager class. Table 6-4 lists those renderers that have been implemented.

Class	View Category	Description
AcmeRenderer	Component and Connector	Generates components and connectors with connecting lines for attachment bindings.
PackageRenderer	Developer	Generates the contents of a package using UML style graphical elements.
UMLRenderer	Developer	Generates packages, classes and interfaces with variables and methods as required.
TaskAssignmentRenderer	Project Manager	Generates a view of the assignment of people to UML entities with progress statistics.
SimpleFilter	Generic	Generates an icon for each entity, and draws lines for all relationships.
IconAssigner	Sales and Marketing, Technology and Deployment	Generates a suitable icon for each entity, depending on rules given in its configuration. It generates lines for all relationships.

Table 6-4 Implemented renderers

Two layout algorithms were implemented: a random layout, and a force-directed layout algorithm. No emphasis was placed on layout algorithms.

6.5 ArchVis Prototype Implementation

The prototype tool was written in Java, utilising features of the Java Standard Developers Kit version 1.4. ArchVis is entirely written in Java and is comprised of eight implementation areas:

- Entity-relationship and properties storage system.
- Client-server system for static data extraction.
- Client-server system for transient data events.
- Visualisation profile and view creation.
- Static data extractors
- Static data filters
- Renderers
- Supporting UI framework.

Much of the basic user interface was implemented using the Java Swing libraries, but the visualisations were created using graphics primitives such as BufferedImage and Graphics2D on JPanel objects.

6.6 Use of the Prototype Tools

There are several tools associated with this visualisation system. This section briefly describes how to use each of the tools.

6.6.1 Static Data Server

The static data server is very simple to operate, it simply takes as arguments the location and authentication information for the mysql database to be populated, for example:

```
java net.andrewhatch.archvis.gui.staticserver.StaticDataServer jdbc:mysql://localhost:3306/archvis root mysql
```

This launches the server with an activity monitor graph. (Figure 6-1).

Figure 6-1 Static data server activity monitor

The graph gives an impression as to the frequency by which objects are being added to the store.

6.6.2 Modeller

The Modeller is a utility that will allow a user to add a set of entities and relationships to a database. It has two modes of operation: add entity or add relationship. Clicking in the canvas will allow the creation of the entity or relationship – single click to add an entity, or click and drag between two entities to create a relationship.

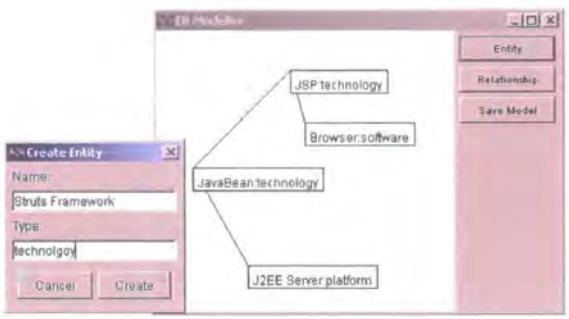


Figure 6-2 ArchVis modeller

Figure 6-2 shows an entity being created. Once the model is complete, the 'Save Model' will add the entities and relationships to data source that was selected on the command line.

6.6.3 ArchVis Browser

The ArchVis Browser is the tool that actually generates the visualisation views, and displays the resulting rendered displays to the user. Its operation is simple.

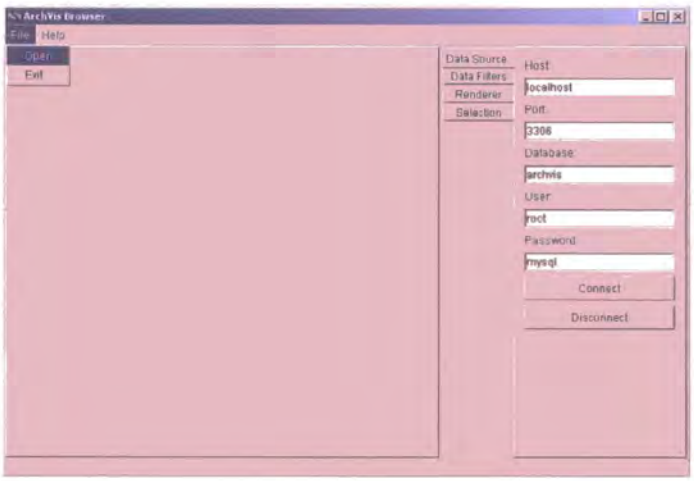


Figure 6-3 ArchVis browser

Firstly, select File->Open (Figure 6-3)

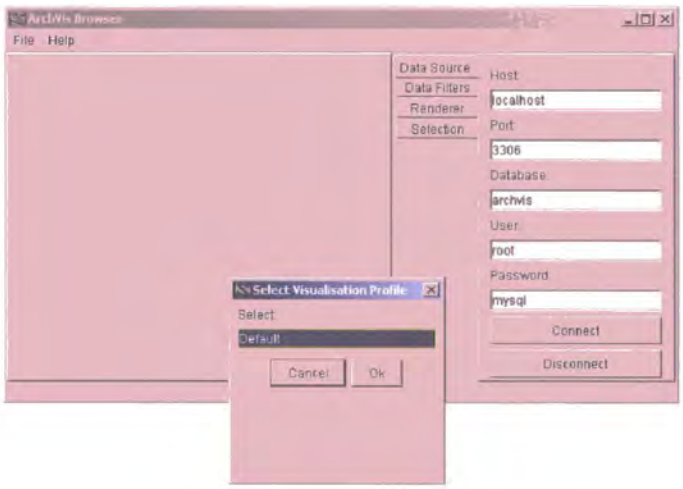


Figure 6-4 ArchVis browser's visualisation profiles

And then choose from the list of visualisation profiles defined (Figure 6-4). These visualisation profiles are configured in via text files located in the 'Profiles' directory of the ArchVis Browser directory.

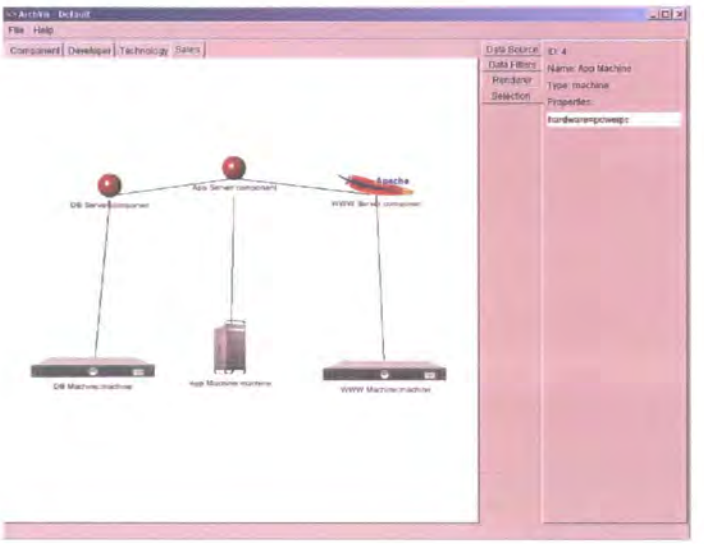


Figure 6-5 ArchVis rendered view

This will then create the view windows, and the visualisation is ready for the data to be input. Clicking on the 'Connect' button within the Data Source tab will load the data and pass it through the filters in each view. The views can be selected using the tabs on the upper portion of the display. The resulting rendered view is shown in the centre (Figure 6-5).

6.7 Conclusions

This chapter has presented some of the implementation detail of the components that comprise the ArchVis software architecture visualisation system. This chapter also describes some of the limitations of the implementation. Finally, the chapter has illustrated how some of the prototype tools can be used.

Chapter 7: Evaluation Approach

7.1 Introduction

In order to successfully evaluate this thesis, an approach to evaluation is required. As this research is strongly related to software visualisation, this chapter describes some of the strategies that are used in software visualisation. Following this, the chosen evaluation strategy is given. The evaluation strategy chosen in this chapter is then applied in chapter 8.

7.2 Software Visualisation Evaluation Strategies

There are several strategies adopted when evaluating software visualisations. This section identifies five strategies, giving an overview of how they can be used [Hatch01].

7.2.1 Design Guidelines

When a visualisation approach is evaluated, a set of design guidelines may sometimes be produced. These guidelines indicate important issues that the visualisation has uncovered. Guidelines are typically informal statements about aspects of a field of visualisation that are intended to assist further research. Formal feature-based evaluation frameworks also have a tendency to be used as design guidelines.

These informal statements promote reasoning about aspects of the visualisation in order to quickly determine their value in a new visualisation system. For example, guidelines can identify the relative merit of cognitive issues that the visualisation raises, navigation support, performance requirements and so on. This early stage evaluation that guidelines support helps to filter out the development of bad ideas early on in their inception and can therefore lead to more efficient development of visualisation ideas.

A mis-use of design guidelines is to use them as an evaluation framework in the analysis of a visualisation. The primary use of design guidelines is to help in early stage evaluation, not for complete evaluation of the fully developed visualisation. Application of guidelines as an evaluation framework may lead to self-measurement in that the system is being designed against the evaluation, rather than the original requirements. Guidelines are often open-ended and are designed to be applicable in a broad sense, and evaluating against them can lead to problems. Consider Shneiderman's relate property [Shneiderman98] that states that the visualisation should be able to "view relationships among items". This statement can be taken in a very broad sense and applied to any number of visualisation functions. Further, by taking guidelines out of context and applying them in areas to which they are unsuited an evaluation can also be erroneous. Whilst there is not a

problem in demonstrating that a visualisation adheres to good guidelines, it should not be presented as an evaluation, especially in the cases where the guidelines are generic and open to differing interpretations.

Identifying areas in which guidelines are used as evaluations can help in identifying where there is a lack of evaluation frameworks. It is important that the research community develops new guidelines to address this deficiency, especially where new branches of software visualisation are emerging. Guidelines do exist for information visualisation as a whole, but it is useful to have specific task-related guidelines.

7.2.2 Feature-Based Evaluation Frameworks

Feature-based evaluations frameworks are popular evaluation strategies. Perhaps a key driver for their success is the ease by which they can be applied. Feature-based frameworks often take on the form of multiple-choice questions which can be answered comparatively quickly. The application of an evaluation framework imposes no prerequisites on infrastructure or target system [Kitchenham96] and allow for evaluation of a system at multiple levels of detail. Frameworks therefore facilitate an evaluation capability with low overhead and investment.

Despite the simplicity of applying a feature-based framework, there are problems inherent in this style of evaluation. Here, the style of question used is of critical importance. Framework questions that result in simple 'yes' or 'no' answers may be too open ended. For example, Storey et al. [Storey99] suggests that a visualisation should 'indicate maintainer's current focus'. It is easy to argue that the current focus could always be the object at the centre of the screen, despite this not being the original intention of the question. Further, a question to be answered on a sliding scale may then become too subjective. This can introduce subtle problem in some aspects of evaluation. What may happen is that the answer to the question can depend very much on the experience that the user has had with similar visualisations. For example, the answer to a question asking whether a three-dimensional visualisation was easy to navigate would depend greatly on the previous experience that the user had working within such environments. Finally, some questions are simply too vague to be answered accurately. An illustration of this is where Wiss and Carr [Wiss98] asked users whether a visualisation was simply 'good' and 'easy to use' where the required response was on a defined sliding scale.

Current frameworks also fail to consider 'negative features' - unwanted features within the visualisation that have a detrimental effect overall, such as those considered by Globus and Uselton [Globus95]. Gestalt effects are significant, and can distort the mental view that the user has of the visualised data. Similar distortions may arise through the use of animation, colour, size and many other features. Failure to consider such features when evaluating using a framework can lead some visualisations to be considered acceptable, when they are fundamentally flawed in practice. Other important features currently not covered by most frameworks include issues of scalability and accuracy. Many current frameworks do not consider aspects highlighted by Tufte

[Tufte92], such as complexity, density and beauty. If these properties are important to the visualisation then other methods of evaluation such as guidelines or user study should be used.

7.2.3 User and Empirical Studies

Empirical studies are often sought after by researchers in the software engineering community in order to provide hard evidence to support hypotheses. The strength of empirical studies is the resulting statistical analysis of data collected during the study. There are instances of the successful application of empirical studies to information visualisation, but there are comparatively few good attempts at their use for evaluation of software visualisation. Where empirical studies have strength is in situations where time-based measurements are important. Statements such as 'the use of the visualisation enables the task to be completed in one third of the time taken to complete the task without the visualisation'. Statements like these lend themselves to statistical analysis rather than statements that describe properties of a visualisation such as 'it allows the user to maintain focus and context'.

User studies can be carried out independently or as part of an empirical study. By using questionnaires and user observations, user studies record individual and collective user-experience, as applied by Storey et al. [Storey99] for example. These kinds of studies are useful in contrast to empirical studies with users as they highlight individual issues that might be overlooked when combining results of a number of users. Nevertheless care must be taken in generalising individual user-experience.

User studies and empirical studies reduce the bias of self-evaluation at the expense of overheads such as user training. Lack of training for participants in the evaluation can produce results that are confounded. Other influences cause confounding in results of which user experience is significant. Differences in the knowledge of a domain, familiarity with the task at hand, and environmental knowledge have significant effects on experimental results. Users often bring bias to visualisations, especially when they are based on 3D interfaces where the ability to learn, openness to new interfaces and spatial awareness can all make some impact on results. Common sources of error lie with the type and scale of tasks being set, and also subject selection problems. For example, students are frequently used in studies rather than experienced programmers for the SV domain. A critical mistake is to then generalise the results of the study beyond the experimental conditions. Applying results from student-based studies to professional programmers and applying results from academic environment-based studies to industrial organisations is not an appropriate step. In order to counteract the problems highlighted here and conduct a successful study, considerable investment in time and organisation is required. This can make such studies unattractive for some situations, particularly small or short-term projects.

A pre-requisite of the application of user studies and empirical studies is a partial or full implementation of the visualisation system – evaluation of a concept is difficult for these evaluation strategies.

7.2.4 Scenarios and Walkthroughs

Scenarios and walkthroughs provide a showcase for the demonstration of features of a visualisation and are becoming a useful tool in evaluation [Chi98] [Knight00] [Smith02]. A walkthrough takes the reader through a particular aspect of the visualisation, and leaves the evaluation of the system to the reader. By doing this, it evaluation is conducted in terms of the reader's own experiences and requirements. Results of this reader-centric type of evaluation cannot be generalised. For this reason other methods of evaluation are presented. For example, work by Knight [Knight00] shows how information on determining the impact of a change to the type of a class variable can be found in the Software World visualisation, alongside a feature-based evaluation framework.

As with any evaluation strategy, scenarios and walkthroughs have their relative merits along with problems. They do offer a more concrete example of how a visualisation system is used for a particular task and does so in a more natural way than describing a visualisation in terms of its mappings, metaphors and representations. They often include many screenshots as evidence, giving the reader an overview of the visualisation's user-interface, technology and visual quality. As noted previously, results of this evaluation technique are applicable only to the individual readers. This individual evaluation cannot be propagated back to the wider research community.

Scenarios and walkthrough's visual presentation is primarily a storyboard of images that can provide the user with a visual impression of the system, but it is still very difficult for the reader to gain a feel for issues such as navigation. This is especially true in 3D visualisations. Scenarios and walkthroughs can illustrate aspects of the visualisation in more detail than frameworks, however, the features demonstrated will often only show the visualisation in a positive light, highlighting well supported tasks with favourable data and conditions.

Scenarios and walkthroughs should not be the primary focus of an evaluation, due to the large possibility of bias by the researcher, and the limited subset of the visualisation demonstrated. However, they are relatively easy to produce and can offer a way to check the visualisation, from the initial idea to the final visualisation, against support for required tasks.

Future effort could be invested in increasing the use of specific tasks by basing task selection on research into information requirements for specific activities, such as those on program comprehension by Mayrhauser and Vans [Mayrhauser98]. These requirements can then be verified more appropriately than by using a framework, as scenarios and walkthroughs show the process by which the information can be found, which can be just as important as showing that it is actually present.

7.3 Chosen Evaluation Approach

Earlier in the chapter, four evaluation strategies were described. Design guidelines are not intended for post-development evaluation, but for use during the visualisation design process. User and empirical studies are difficult to perform with limited time and resource and are more suited to numerical measurement of various aspects of a visualisation. For these reasons, an empirical approach has not been taken here.

Therefore, the evaluation of this thesis will be divided into three approaches. Firstly, there will be a feature based evaluation framework that extends existing evaluation frameworks that are more applicable to lower level software visualisation. Secondly, there are to be a set of scenarios that are applicable to the domain. Lastly, there is an informal discussion of the benefits and disadvantages of the ArchVis visualisation.

7.3.1 Evaluation Framework

7.3.1.1 Justification for the Evaluation Framework

As software architecture visualisation is in its infancy, specific reference to it in existing software visualisation literature is scarce. Evaluation of visualisations from the viewpoint of program comprehension cannot suffice for higher-level representations of software where the task to be supported is radically different. For these reasons, this chapter has several goals.

Reading literature that introduces new visualisations for software, frequently the choice is either for empirical evaluation involving participants, or the invention of a new framework against which the visualisation is evaluated. A new framework is required when considering the evaluation of visualisations that explicitly address software at an architectural level. As identified previously, most software visualisation has occurred at a lower level and as an obvious result the evaluation frameworks available reflect this. Many of the major frameworks that have been used to evaluate software visualisations were not directly applicable to software architecture visualisation as they address different problems. They do, however, capture several aspects of visualisation that are directly applicable to software architecture visualisation.

Whilst the framework described here is new, it is not without a strong basis, as software architecture visualisation evaluation is rooted in disciplines with a history of evaluation frameworks, some of which draw on earlier work on related work in software visualisation, psychology, aesthetics and usability. Where applicable, the framework identifies previous work that has contributed to the respective component of the framework.

By breaking down an evaluation framework into the structure proposed below gives benefits and disadvantages. A modular structure allows individual concerns to be addressed in comparative isolation, and

so the application of the framework need not be performed in its entirety. Guidelines are presented which direct the use of the framework and oversee the selection of framework components. A downside to this structure is that such a rigid division causes areas to be strictly divided when they might otherwise not be. As far as possible, these are identified in the description of the evaluation components themselves.

Some instances of evaluation in software visualisation literature make no attempt to evaluate the implementation of a visualisation, but focus on the visualisation itself. On the surface, it appears that this approach results in the ability to reason about a visualisation without binding that visualisation to a particular implementation which might not fully support all the concepts, ideas and features identified in the visualisation concept. Clearly this has some benefit, but here the framework also considers implementation. One reason for this is that some properties of a visualisation can be better reasoned about in terms of its implementation. Secondly, the line that divides a visualisation from its implementation often becomes blurry, even in evaluations that attempt to keep the division distinct.

7.3.1.2 Description of the Evaluation Framework

The proposed framework is divided into seven sections: static representation, dynamic representation, data-space navigation, interaction, task support, implementation and visualisation. In this way, the framework segments distinct concerns.

Reference	*Framework Feature*
Static Representation (SR)	
SR1	Multiple software architectures
SR2	Types of software architecture
SR3	Recovery of software architecture information
SR4	Accommodate large volumes of information
Dynamic Representation (DR)	
DR1	Support dynamic data
DR2	Associate events with architectural elements
DR3	Non invasive approaches
DR4	Live collection
DR5	Replay data
Views (V)	
V1	Multiple views
V2	Representation of viewpoint definition
Navigation and Interaction (NI)	
NI1	Browsing
NI2	Searching
NI3	Query building
NI4	Inter-view navigation
NI5	View navigation
Task Support (TS)	
TS1	Represent anomalies
TS2	Comprehension
TS3	Annotation
TS4	Communication
TS5	Show evolution
TS6	Construction
TS7	Planning and execution
TS8	Evaluation
TS9	Comparison
TS10	Show rationale
Implementation (I)	
I1	Automatic generation
I2	Platform dependence
I3	Multiple users
Visualisation (VN)	
VN1	High fidelity and completeness
VN2	Dynamically changing architecture

Table 7-1 Summary of evaluation framework

Table 7-1 presents a summary of the evaluation framework. Each section of the framework is presented below, showing the questions that they are composed of along with further information regarding the semantics of the question.

Static Representation (SR)

SR1: Does the visualisation support a multitude of software architectures?

It is possible that a visualisation system will be restricted to a small number of possible architectures. For example, the architecture visualisation may be designed explicitly for a particular subclass or domain of software architectures. It is important to recognise that a visualisation need not support a multitude of software architectures if that is not the intention of the visualisation. This question merely qualifies the intent. This question relates directly to Price *et al* [Price93] and the discussion on 'generality'.

SR2: Does the visualisation support the appropriate types of static software architecture data sources?

In some cases, the software architecture is clearly defined, and a single data source exists from which the visualisation can take its input. The visualisation should be capable of accessing the data source.

Sometimes architectural data often does not reside in a single location. Instead, architectural information can be extracted from a multitude of sources. An architecture visualisation would benefit from the ability to support the recovery of data from a number of disparate sources. More importantly, if multiple data sources can be used, then there should be a mechanism for ensuring that this disparate data can be consolidated into a meaningful model for the visualisation.

SR3: Does the visualisation support the recovery of architectural information from sources that are not directly architectural?

In some cases, architectural information is not available directly, but is recovered from sources that are non-architectural. For example, file-systems may not be directly architecturally related, but they can contain important information that relates to architecture. Even more so, packages, classes, methods and variables can all contribute to a view of the software architecture, and so a visualisation system may be able to support these data types.

SR4: Can the visualisation accommodate large amounts of architectural data?

Depending on the size and level of detail of a software system, there is a potential for large volumes of architectural data. If architectural data is to be retrieved from non-architectural data (see later), there is a potential for the data repository to contain large amounts of data from lower levels of abstraction. Architectural information is sometimes recovered from method and variable information. If this is the

strategy employed by the visualisation, then the visualisation should be able to deal with large volumes of information. Price *et al* [Price93] discusses this in their section on 'scalability'. Visualisation systems should be able to cope with large volumes of data and have the appropriate mechanisms to be able to present this in a suitable manner.

Dynamic Representation (DR)

DR1: Does the visualisation support an appropriate set of dynamic data sources?

The realisation of software architecture is at runtime, and runtime information can indicate a number of aspects of the software architecture. Visualisations may support the collection of runtime information from dynamic data sources in order to relay runtime information. Typically, for smaller software systems, this runtime information will only be available from one source, but for larger distributed software systems, the visualisation may need the capability of recovering data from a number of different sources. These data sources may not reside on the same machine as the visualisation system, so the ability to use remote dynamic data sources is useful. Some sources may produce data of one type, where another source produces different data. In this case, the visualisation should provide a mechanism by which this data is made coherent.

DR2: Does the visualisation support association of dynamic events with elements of the software architecture during the execution of the software?

When dynamic events occur, the visualisation should be able to display these events appropriately, and within the context of the architecture. The visualisation must therefore be able to associate incoming events with architectural entities.

DR3: Does the visualisation support relatively non-invasive approaches to retrieving dynamic data sources?

Any method of recovering dynamic information from a software system will affect that software system in some way. This thesis has identified a number of mechanisms for recovering this data. At one extreme, there is the directly invasive approach of adding lines to the software source code. At the other extreme is by retrieving information from the virtual machine. The visualisation system should support a suitable approach to recovery of dynamic architecture data in the least-invasive way as Price *et al* [Price93] state that disruptive behaviour is not desirable.

DR4: Does the visualisation allow the live collection of dynamic data?

By visualising the dynamic data as it is generated, there may be an ability to affect the software being visualised in order to see the generated data live. This is a popular method of visualising dynamic data.

DR5: Does the visualisation allow the collection of dynamic data for replay at a later time?

Sometimes called 'post mortem style' visualisation [Price93], this approach has the benefit of knowing the period of time over which the visualisation occurs. This is useful to a visualisation in that it can render a display for a particular instance in time whilst knowing what will occur next.

Views (V)

V1: Does the visualisation allow for multiple views of the software architecture?

Research in software architecture indicates a general consensus that software architecture is represented in a number of ways. These are called views of the architecture. Kruchten [Kruchten95] identifies four specific views of software architecture, whereas the IEEE 1471 [IEEE1471] standard allows for the definition of an arbitrary number of views. A visualisation may support the creation of a number of views of the software architecture, and may wish to allow simultaneous access to these views.

V2: Does the visualisation display a representation of the viewpoint definition?

In the IEEE 1471 standard [IEEE1471], architectural views have viewpoints associated with them. A viewpoint defines a number of important aspects about that view including the stakeholders and concerns that are addressed by that viewpoint, along with the language, modelling techniques and analytical methods used in constructing the view based on that viewpoint. A visualisation may choose to make this information available to the user in order to assist in their understanding of the view they are using.

Navigation and Interaction (NI)

NI1: Can users browse through the visualisation by following concepts?

An important part of the comprehension process if the formulation of relationships between concepts. Having the ability to follow these relationships is fundamental. Storey *et al* [Storey99] indicate that a software visualisation system should provide directional navigation, and describe this as supporting the traversing of software structure in hierarchical abstractions and by allowing the user to follow links in the software. The visualisation should support the user being able to follow concepts in order to gain an understanding of the software architecture.

NI2: Can users search for arbitrary information relating to the architecture?

Another mechanism in the comprehension process is the arbitrary location of information. Searching is the data-space navigation process that allows the user to locate information with respect to a set of criteria. Storey *et* al label this as arbitrary navigation – being able to move to a location that is not necessarily

reachable by direct links. Sim *et al* [Sim99] identifies the need for searching architectures for information, so the visualisation should support this searching for arbitrary information.

NI3: Can the user build queries in order to locate information they need?

Query building is a hybrid combination of browsing and searching. It allows a user to find a set of information, and then continually expand on a search in a particular direction by repeated searching from a related result. Visualisations may also support this style of data-space navigation.

NI4: Can users navigate between views easily?

Architecture is often comprised of a number of views. Moving between views is essential in order to understand an architecture from different viewpoints. Context should also be maintained when switching between views so as to reduce disorientation.

NI5: Can users navigate through a view in an appropriate manner?

Along with data-space navigation, the movement within a view is also important. Shneiderman's mantra for visualisation is overview first, zoom and filter, and then show details on demand [Shneiderman98]. A visualisation system should support this strategy for visualising information. Also, the visualisation should allow the user to move around so as to focus on and see the information they are looking for. Typical navigational support would be pan and zoom. Whilst allowing the user to navigate, the visualisation should provide orientation clues in order to reduce disorientation [Storey99].

Task Support (TS)

TS1: Does the visualisation support the representation of anomalies?

This question relates to whether the visualisation be used to identify areas in which the architecture has been broken or misused. The visualisation should be able to cope with data anomalies that are unexpected and may cause unwanted behaviour. Also, the visualisation may wish to report these anomalies to the user if they can be detected.

TS2: Does the visualisation support the comprehension of the software architecture in the appropriate manner?

Comprehension strategies are task dependent. For example, top-down comprehension might be associated with a design change task, whereas a bottom-up comprehension task is associated with gaining an understanding of unfamiliar components before making a change. Architecture visualisations may support

either of these two strategies, or a combination of the two, depending on the tasks for which the visualisation is intended.

TS3: Can users annotate the visualisation?

The ability to tag graphical elements in a visualisation is important for various activities. Adding notes to a graphical element is called 'annotation'. Annotation can allow users to tag entities with information during the formulation of a hypothesis.

TS4: Does the visualisation support the communication of the architecture to the appropriate stakeholders?

Software systems have a number of associated stakeholders [IEEE1471]. Visualisations can support any number of these stakeholders. In order to facilitate the communication of the architecture to a stakeholder, the visualisation must represent the architecture in a suitable manner. Stakeholders may require very different views from other stakeholders.

TS5: Does the visualisation show the evolution of the software architecture?

Software architecture can evolve over time. Subsystems may be redesigned; components replaced, new components added, new connectors added and so on. An architecture visualisation may provide a facility to show the evolution. This support may be basic, showing architectural snapshots, or the support may be more advanced by illustration using animation.

TS6: Does the visualisation support the construction of software architecture?

Visualisations may offer the capability for the users to create, edit and delete objects in the visualisation. When the visual editing is supported, the visualisation can be called a 'visual editor'. In order to be able to fully support the construction of software architecture, the visualisation must be able to allow the user to create objects in the domain of the supported viewpoint. Of course, the visualisation should also then support the editing and deleting of those objects.

TS7: Can the visualisation support planning and then executing the development of a software system?

Architectural descriptions can be used for the planning, managing and execution of software development [IEEE1471]. In order for the visualisation to support this task, it should provide rudimentary functionality of a project management tool – or have the ability to communicate with an existing project management tool.

TS8: Does the visualisation support evaluation of the architecture?

Software architecture evaluation allows the architects and designers to determine the quality of the software architecture and to predict the quality of the software that conforms to the architecture description [IEEE1471]. To support this, a visualisation should have some mechanism by which quality descriptions can be associated with components of the software being visualised.

TS9: Does the visualisation support the comparison of software architectures?

A typical use of software visualisation is in the comparison of as-implemented with as-designed architecture. The visualisation should be able to support the display of these two architectures and allow users to make meaningful comparisons between them. Software built from a software product line is a typical scenario where comparison of architectures is particularly useful.

TS10: Does the visualisation allow for rationale to be shown?

Rationale for the selection of architecture, and the selection of the individual architectures of the components of that architecture, are included in architectural descriptions. Rationale can also be associated with each viewpoint of an architecture. By showing rationale for elements of the architecture, and the architecture as a whole, a visualisation will allow a user to have an insight into the decision making process. This detail will be useful for some tasks.

Implementation (I)

I1: Can the visualisation be generated automatically?

Some visualisations are demonstrable theoretically, but are pragmatically infeasible. Visualisations, in order to find use, need to be able to be generated automatically.

I2: Can the visualisation be run on appropriate platforms?

Price et al [Price93] include a 'generality' section in their taxonomy. Here, they identify several issues regarding the platform on which a visualisation can execute on, and the types of software that it will be able to operate over. A visualisation should be able to execute on a platform suitable for the types of software it is intended to visualise. For example, a visualisation that is implemented for a particular platform is unsuitable for visualising programs written for another platform.

I3: Does the visualisation support multiple users?

As there are many stakeholder roles in a software system, there may also be a one-to-one mapping of role to physical users. Therefore the visualisation may support multiple users. It may support multiple users concurrently, or asynchronously.

Visualisation (VN)

VN1: Does the visualisation achieve high fidelity and completeness?

Eisenstadt et al [Eisenstadt90] ask the question as to whether the visualisation uses visual metaphors that represent true and complete behaviour. For software architecture visualisation, the visualisation must present the architecture accurately, and represent all of that architecture if the visualisation purports to do so.

VN2: Does the visualisation support the representation of dynamically changing software architecture?

During its execution, software may change its configuration in such a way that its architecture has changed. Software that changes its architecture in such a way is labelled as software that has a dynamic architecture. If the visualisation is able to support architectural views of the software at runtime, then it may be capable of showing the dynamic aspects of the architecture. In order to do so, the visualisation may either support snapshot views of the progression, or animate the changes.

7.3.2 Scenarios

A set of scenarios is identified that represents a broad range of activities in which software architecture descriptions are used. For each scenario, tasks are identified that stakeholders will be undertaking, along with a description of the information that they would require in order to successfully complete the task. Then, the capability of the ArchVis visualisation to assist in those tasks is described.

These scenarios are intended to show both the strengths and weaknesses of the ArchVis visualisation, and will provide a benchmark for other Architecture Visualisations. These scenarios will be chosen from existing literature, and from architecture in practice today.

7.3.3 Informal Evaluation

In order to give further detail on the design and implementation of the visualisation, there will be an informal evaluation. This informal evaluation will highlight some of the features of the visualisation that are not well represented in the chosen scenarios. It will also identify some of the issues that are associated with the visualisation.

7.4 Conclusions

Software visualisation evaluation is a relatively small area of visualisation research, and the first half of this chapter has presented some of the current approaches to software visualisation evaluation. The latter half of the chapter identifies the fact that there is very little published research that deals with the specifics of software architecture visualisation evaluation, and proposes one method by which software architecture visualisations might be evaluated. This method is divided into three elements. The first is a feature-based framework; the second is evaluation by scenarios; and the third is an informal discussion.

Chapter 8: ArchVis Evaluation

8.1 Introduction

An evaluation strategy has been chosen in chapter 7. This chapter applies the evaluation strategy to the ArchVis approach. Firstly, the software architecture visualisation feature based framework is applied to ArchVis. A number of scenarios are then identified and applied. Finally, and informal evaluation is used to expand on some areas of the approach that are not covered by the first two evaluation sections.

8.2 Application of the Framework to ArchVis

Applying the framework identified in chapter 7 requires responding to each of its questions. The response structure used in Smith [Smith00] is applied here also. Smith defines the following responses:

Response	*Meaning*
Yes	The feature is fully supported.
Yes?	The feature is mainly supported.
No?	The feature is mainly not supported.
No	The feature is not supported at all.
NA	The feature is not applicable.

Table 8-1 Responses to framework questions

The response to each question is accompanied by a discussion of the reasons for the value of the response given.

Static Representation (SR)

SR1: Does the visualisation support a multitude of software architectures?

Yes.

Evidence for the support of a multitude of software architectures can be seen in several areas of the design of ArchVis. Firstly, the data model is an entity-relationship (ER) model along with properties. ER models are flexible, and allows for the modeling of a very broad range of software architectures. Secondly, ArchVis is capable of extracting architecture information from a multitude of sources. A number of static and transient data extraction tools exist that pass information to the ArchVis visualisation. Finally, the ArchVis render model is extensible, allowing for new graphical primitives to be added. Components that create render models can also be added in order to provide support for a number of different architectures.

SR2: Does the visualisation support the appropriate types of static software architecture data sources?

Yes.

As an ER model is used within ArchVis, a large number of software architecture data sources can be supported. ArchVis utilises a single data repository that is populated by a number of extraction tools. These extraction tools operate in a client-server mode allowing for the data sources to be remote from the data repository and visualisation.

SR3: Does the visualisation support the recovery of architectural information from sources that are not directly architectural?

Yes.

ArchVis uses a number of data extraction tools, and provides a number of these tools as default. ArchVis can also be extended to use new tools. Examples of ArchVis' extraction tools that extract data from non-architectural sources include its packet sniffer, and file-system extraction utility. ArchVis can then display non-architectural information alongside architectural information as required. For example, the location of source code files can be shown for an architectural component.

SR4: Can the visualisation accommodate large amounts of architectural data?

Yes

Each view in ArchVis uses a set of data filters to pass data over to the render model. These filters can perform various transformations on the data, including removal and aggregation. By using these data filters, each view can have only relevant information presented to it, avoiding the need to process irrelevant information.

Navigational capability of pan and zoom also means that each view can accommodate large volumes of information.

Dynamic Representation (DR)

DR1: Does the visualisation support an appropriate set of dynamic data sources?

Yes?

Dynamic data is retrieved by ArchVis in the form of Events. These events are represented by a 4-tuple: (event, entity name, entity type, user data). ArchVis is able to map an event of a particular entity type to an action within ArchVis. Support in ArchVis is limited to operations over the render model. This means that events can cause elements of the render model to change, but it does not support the addition, removal and alteration of elements.

DR2: Does the visualisation support association of dynamic events with elements of the software architecture during the execution of the software?

Yes.

As noted above, dynamic events are mapped onto actions that operate over the render model. This is an association between the events and the software architecture.

DR3: Does the visualisation support relatively non-invasive approaches to retrieving dynamic data sources?

Yes.

ArchVis supports both invasive and non-invasive approaches to retrieving data from dynamic sources. The primary non-invasive approach utilises the Java debugger interface. This allows retrieval of information from the virtual machine of software that is executing on it.

The JDI interface is suitable only for systems implemented in the Java language, however, ArchVis can be extended to utilise other technologies for different languages and platforms. This can be achieved if the dynamic data can be encoded in the 4-tuple of (event, entity name, entity type, user data).

DR4: Does the visualisation allow the live collection of dynamic data?

Yes.

When the ArchVis visualisation begins execution, it creates the ArchEventServer data server that awaits for the connection of clients. Clients can connect to this server, and events sent are pushed through to each view currently open in ArchVis.

DR5: Does the visualisation allow the collection of dynamic data for replay at a later time?

Yes.

As ArchVis uses an event model for capturing transient data, each discrete event can be recorded. These events can then be played back to ArchVis at any time in order to recreate the sequence of events.

Views (V)

V1: Does the visualisation allow for multiple views of the software architecture?

Yes.

The ArchVis model of views is shown in Figure 8-1.

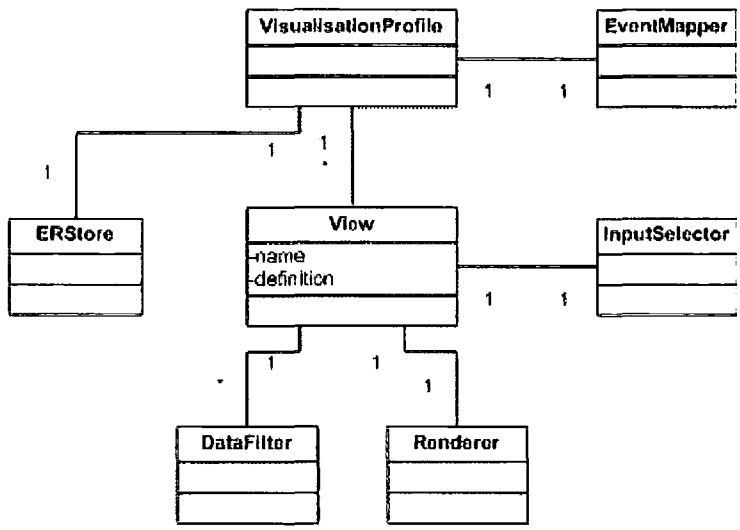


Figure 8-1 ArchVis view model

This shows that the VisualisationProfile that defines a visualisation contains a number of named views with associated definition. Each of these views contains data filters and a renderer.

V2: Does the visualisation display a representation of the viewpoint definition?

Yes?

Architectural representations should have a viewpoint definition associated with every view [IEEE1471]. ArchVis is able to associate a textual representation of the viewpoint definition, but does not cater for a visualisation of that definition.

Navigation and Interaction (NI)

NI1: Can users browse through the visualisation by following concepts?

Yes.

Browsing in ArchVis is achieved through the relationships that link elements of the architecture. Browsing is achieved both by the relationships visually represented within a view and also by following relationships into other views that contain the same element.

NI2: Can users search for arbitrary information relating to the architecture?

Yes.

Entities can be searched by both name and type, and can be restricted to any number of the open views. Searching also extends to external text-based sources such as source code, configuration files and logs.

NI3: Can the user build queries in order to locate information they need?

Yes.

Queries are supported in two ways within ArchVis. Every view in ArchVis, along with the filtered data, can have a set of inputs. This set of inputs can drive the resulting view rendered. The second manner in which queries can be built is that each graphical element in the render model can be selected to create a query view from. Query views then operate in the same manner as an ordinary view, except that the input ER store is affected by which graphical element was chosen.

NI4: Can users navigate between views easily?

Yes?

ArchVis presents all defined views to the user, allowing them to switch between them with ease. However, ArchVis may not always be able to retain current focus when switching between views. 'Current focus' is the element in the view that the user is currently interested in, and may be represented by a highlight, or other graphical distinguisher. When the user switches to another view, the current focus may not exist in that view, so focus is lost.

NI5: Can users navigate through a view in an appropriate manner?

Yes.

Navigation within a view consists of panning across the display, zooming in to view detail and zooming out to show more elements. It also consists of selection, examination and graph layout. ArchVis supports all of these navigational mechanisms at the render-model level.

Task Support (TS)

TS1: Does the visualisation support the representation of anomalies?

No?

ArchVis is not able to automatically identify anomalies in the architecture. ArchVis has no 'intelligence' or engine by which elements in the architecture can be identified as anomalies. However, ArchVis will faithfully represent any entity or relationship in accordance with the renderer.

TS2: Does the visualisation support the comprehension of the software architecture in the appropriate manner?

Yes.

Support of this is largely attributed to ArchVis' support of multiple views. These views are intended to satisfy the comprehension requirements of particular stakeholders. The design of individual views will determine what comprehension approach is most suited to the data it shows – either bottom-up, top-down or both. ArchVis supports top-down comprehension of the architecture through high-level views such as component and technology views. Bottom-up comprehension is supported through developer views. Users can switch between views, so ArchVis can simultaneously support both approaches.

TS3: Can users annotate the visualisation?

Yes?

ArchVis supports the addition of notes to graphical elements in the visualisation, but it does not support the addition of these notes to the underlying data source.

TS4: Does the visualisation support the communication of the architecture to the appropriate stakeholders?

Yes.

ArchVis facilitates the use of multiple views. By supporting multiple views, the visualisation is able to cater for the informational requirements of different stakeholders in the system.

TS5: Does the visualisation show the evolution of the software architecture?

No.

In order to show the evolution of software architecture, a visualisation must be able to at least be able to show snapshots of that architecture at points in time. ArchVis is capable of representing the architecture of a system at a particular point in time, but would have to treat an architecture at a different point in time as a completely different architecture. As ArchVis is not able to show the architecture of more than one system simultaneously, it is not capable of directly showing the evolution of a software architecture.

TS6: Does the visualisation support the construction of software architecture?

No?

As ArchVis has the clearly distinct phases of a visualisation pipeline of data extraction, data filtering and rendering, the implementation of this pipeline is important when considering construction support. It is fair to say that the data model supports the construction of software architecture in that the ER store does not preclude an editor from contributing data to this store. However, this kind of process is divorced from the main visualisation process.

Considering this in terms of a model view controller architecture, ArchVis is implemented in a uni-directional manner. When the visualisation is constructed, data flows strictly from the model to the view. Any control over the data cannot be updated in the view in sufficient time as to make the process worthwhile.

TS7: Can the visualisation support planning and then executing the development of a software system?

Yes?

ArchVis provides direct support for planning in its Project Management view, and for development in developer views. ArchVis only provides support for visualising aspects of planning and execution, but does not support some of the basic functions that would be found in other CASE tools, naturally. In order to provide greater support planning and execution, ArchVis would have to have a mechanism by which the visualisation can be integrated with such CASE tools. It currently does not have this integration mechanism.

TS8: Does the visualisation support evaluation of the architecture?

Yes?

In order to be able to support the evaluation of software architecture the visualisation should have some means by which quality descriptions can be associated with components of the software being visualised. ArchVis can support this due to the entity-relationship data model, and the flexibility of the renderer framework. Typically these quality descriptions will be textual, and basic visualisation would be to represent these as text. More advanced representation can be achieved where the quality is described in a more formal manner such as clearly defined categories with scores.

The use of associations in the render model means that graphical elements can be tagged with other graphical elements. These elements can be drawn from the same library, and so can be as flexible and detailed as the library supports.

TS9: Does the visualisation support the comparison of software architectures?

No.

As noted earlier, ArchVis does not support the visualisation of more than one software architecture at any one time. This is a key pre-requisite for supporting comparison.

TS10: Does the visualisation allow for rationale to be shown?

Yes?

ArchVis supports the display of rationale information, but does not require this information to be included in the visualisation. The support for visualisation of rationale is limited to displaying the text of notes or diagrams that describe the rationale behind an element of the architecture.

Implementation (I)

I1: Can the visualisation be generated automatically?

Yes

ArchVis is capable of visualising the architecture of a variety of software systems automatically, and can do so without any additional extension of its capabilities. However, one of the key features of ArchVis is its extensibility. As software architecture is encoded in many sources, and can be represented in many different ways, ArchVis has been designed to explicitly allow customisation and extension.

Data extraction of Acme, Java source code and file systems, amongst other sources, means that ArchVis can generate visualisations of software architectures of software systems written in Java, or described in an Acme compatible ADL.

I2: Can the visualisation be run on appropriate platforms?

Yes.

Implemented in Java, ArchVis can run on any hardware/operating system platform that has the appropriate Java Virtual Machine (JVM) and display capability. The proliferation of JVMs to date means that there are few platforms that do not support a JVM.

Further, the visualisation is broken down into components that can execute on different platforms. Data extractors of both static and transient data can reside on remote machines to the visualisation system.

I3: Does the visualisation support multiple users?

Yes?

Views and viewpoints relate directly to different stakeholders. ArchVis supports a theoretically infinite number of views that is limited only by the practicality of implementation. This support is limited in that only one physical user can access the ArchVis visualisation tool at any one time.

One simple means by which ArchVis can support multiple simultaneous users is by implementing a variation of the data access interface EntityRelationshipStore such that the store can be located remotely, and accessed by more than one ArchVis implementation. This would mean that multiple instances of ArchVis can operate over the same data-set. This is possible as the repository is effectively read-only after the data extractors have populated it.

Visualisation (VN)

VN1: Does the visualisation achieve high fidelity and completeness?

Yes?

ArchVis has the capability of representing true and complete behaviour, but is not required to. It is the design of the static filters and renderer that determine whether the visualisation will be high-fidelity and complete. Also, there is no mechanism by which the stakeholder can be informed if the view is intended to be complete.

VN2: Does the visualisation support the representation of dynamically changing software architecture?

No?

Support for dynamism in ArchVis is encapsulated in its utilisation of transient data events. In its implementation, ArchVis maps events to changes in the render model, not the underlying data store. This means that if components, connectors and other such architectural elements are added, changed, removed or reconfigured, these can only be represented by changing the render model. Support for dynamically changing architecture will therefore be limited to very simple changes and does not currently include the addition of new graphical elements.

8.2.1 Summary

Table 8-2 summarises the results of the application of the framework.

Reference	*Framework Feature*	*Result*
Static Representation (SR)		
SR1	Multiple software architectures	Yes
SR2	Types of software architecture	Yes
SR3	Recovery of software architecture information	Yes
SR4	Accommodate large volumes of information	Yes
Dynamic Representation (DR)		
DR1	Support dynamic data	Yes?
DR2	Associate events with architectural elements	Yes
DR3	Non invasive approaches	Yes
DR4	Live collection	Yes
DR5	Replay data	Yes
Views (V)		
V1	Multiple views	Yes
V2	Representation of viewpoint definition	Yes?
Navigation and Interaction (NI)		
NI1	Browsing	Yes
NI2	Searching	Yes
NI3	Query building	Yes
NI4	Inter-view navigation	Yes?
NI5	View navigation	Yes
Task Support (TS)		
TS1	Represent anomalies	No?
TS2	Comprehension	Yes
TS3	Annotation	Yes?
TS4	Communication	Yes
TS5	Show evolution	No
TS6	Construction	No?
TS7	Planning and execution	Yes?
TS8	Evaluation	Yes?
TS9	Comparison	No
TS10	Show rationale	Yes?
Implementation (I)		
I1	Automatic generation	Yes
I2	Platform dependence	Yes
I3	Multiple users	Yes?
Visualisation (VN)		
VN1	High fidelity and completeness	Yes?
VN2	Dynamically changing architecture	No?

Table 8-2 Summary of the results of the framework evaluation

Colouring the results in Table 8-2 gives a visual impression as to which areas of ArchVis score well, and which areas do not. Data representation is strong in ArchVis, with both static and dynamic representation showing highly positive results. ArchVis also scores well in views, navigation and interaction. It is in the category of task support that ArchVis shows weakness in four of the ten features. This, and the results in the visualisation category show the ArchVis is weakest in the area of representing evolution and change. Whilst ArchVis strongly supports wide and varied data sources as the informational input to ArchVis, the configuration of data filters and the view model means that showing fundamental changes to an architecture presents a challenge.

A point of note is that no responses were 'NA'. The reason for this is that the framework supports the evaluation of software architecture visualisation, and does so in such a way as to maximise the scope by which visualisations can be evaluated. For example, 3D architecture visualisations can be evaluated against the framework in much the same way as 2D architecture visualisations.

8.3 Scenarios

ArchVis is evaluated against a number of scenarios. Each scenario is described along with how ArchVis supports the task involved in the scenario.

8.3.1 Analysis of Architectures of Existing Systems

Scenario

Sometimes, system development takes place without an architectural description. The implemented system will have an architecture, but will not have an architectural description associated with it [IEEE1471]. As every implemented system has an architecture, whether known or not, an architectural representation can be recovered. Once recovered, this architectural representation can be used in the development of a new system based on the old one, or for maintenance or evolution of the existing system.

In this scenario, an architect has a piece of open-source software that is very poorly documented. This software is a stand-alone application but contains a set of functionality that they wish to incorporate into a larger piece of software. In order to determine feasibility the architect wants to analyse its architecture and therefore make a decision regarding its suitability.

Application

The first phase of the visualisation process is to extract information about the software system. As this software is written in Java, the ArchVis JavaParser can be used to extract the following static information:

- Packages
- Classes
- Methods
- Class Variables
- Method call and usage
- Import relations

The ArchVis JavaParser tool will then copy over relevant information to the ER store. This process can involve a further step of filtering, but the architect in this case copies all information available.

In order to preserve directory structure information, the architect uses ArchVis' directory parser in order to relate files on the file system to file entries related to the java source files. During this process, a number of other filename entries are also added to the ER store – a set of properties files and a number of images.

The architect then uses the ArchVis PropertiesParser to add the properties file into the ER store. In order to determine which parts of the software use the various properties and image files, the architect uses a text scanner that relates the java source file with the filename of the properties files and image files.

Now the architect has the relevant information, they can define a number of views that they wish to have on the architecture. For this, they edit a visualisation profile configuration file and a number of associated configurations. The views that the architect decides on are:

- Package View
- UML View
- Import relations
- Call Graph

This choice reflects the goal of the analysis exercise, which is to determine if the relevant part of the software can be 'disconnected' from the rest of the software and used directly in the system that the architect is building. In order to determine this, the architect is looking to see how tightly or how loosely coupled the relevant components are, and also to see if the architecture is of sufficient quality. The package and UML view allow the architect to see the structure of the software system, and the import relation and call graph view help the architect to see how tightly coupled the components are.

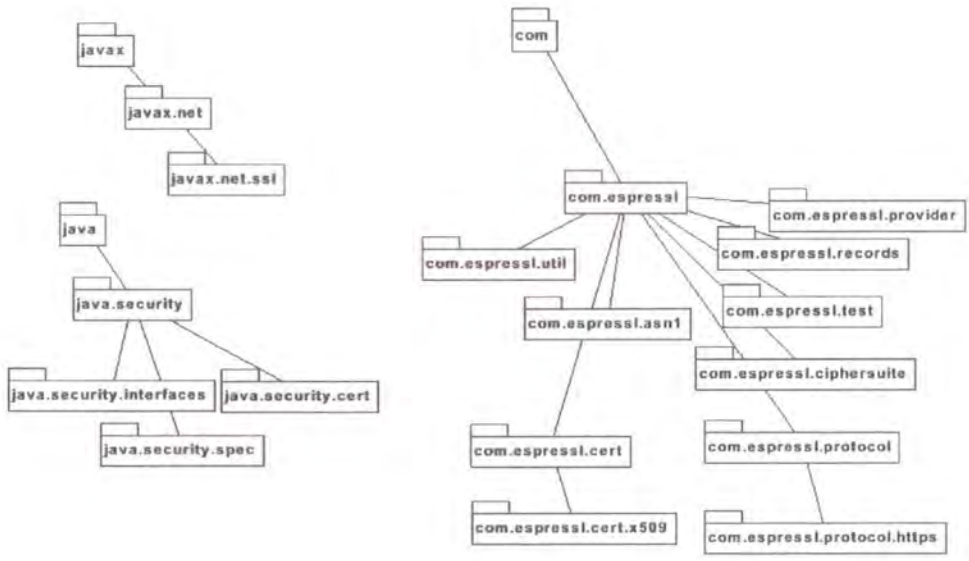


Figure 8-2 Package Structure view

Package structure visualisation (Figure 8-2) helps the stakeholder to quickly gain an impression as to how the software is organised. From here they can identify the parts of the software that they wish to inspect in more detail.

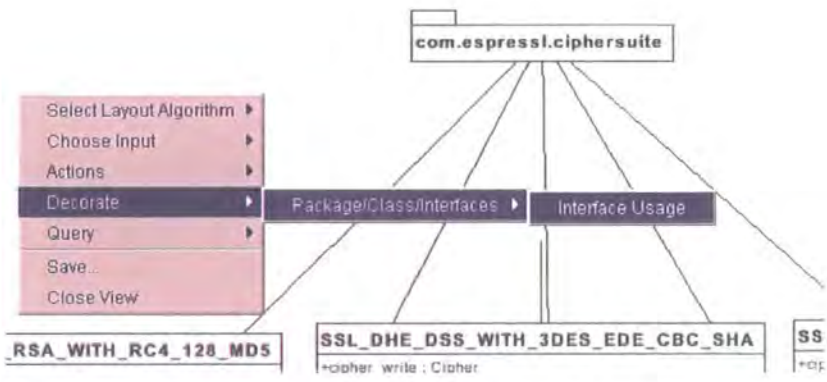


Figure 8-3 Selecting interface usage decoration

The stakeholder can then use the Package View in order to see the contents of a particular package. Decorations can be added to the view by selecting the appropriate option. In this case, the stakeholder may wish to see how tightly coupled a class is by measuring the number of non class variables used as class variables, and as parameters to methods (Figure 8-3).

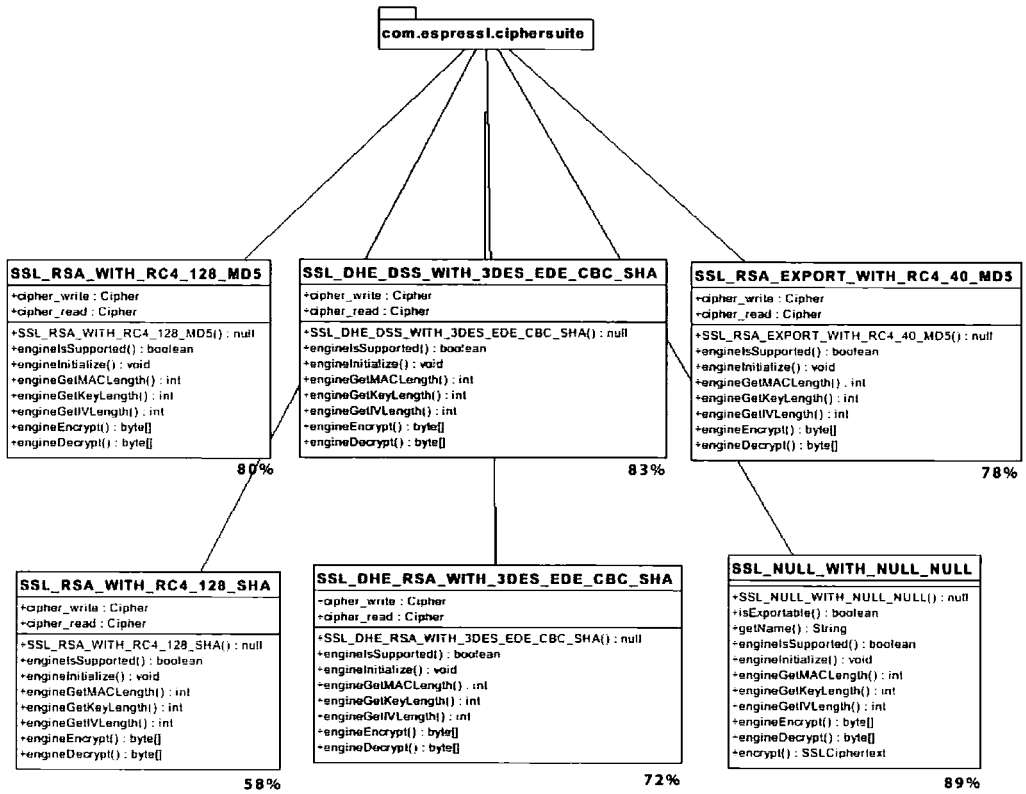


Figure 8-4 Package view

The resulting view (Figure 8-4), along with the other views describe previously, can allow the architect to determine from the software's structure whether the software is suitable for further investigation.

8.3.2 Analysis of Alternative Architectures

Scenario

When building a new software system, an architect may consider the architecture of previous systems in a similar domain. There are several advantages to be gained by looking at existing architectures. Firstly, they provide a useful reference for construction of new architectures, and they may also have an associated set of metrics concerned with the implementation of software systems that use that architecture.

The primary task associated with this scenario is the systematic comparison of software architectures against a set of criteria. An architect will look at a number of architectures, and perform a comparison against a number of criteria. For example, they may look at the selection and configuration of the major components, and focus on the performance metrics of each. If customisability is a key criterion for the architecture, then the architect will consider the architectures against this non-functional requirement.

In order to successfully make comparisons of different architectures, the architect will need to gain a level of understanding of those architectures. That level of understanding can vary from a high-level component view, down to a low-level understanding of the architectures of individual components with some implementation-specific information.

One mechanism by which an architect can make high-level comparisons between architectures is to show a visualisation of those architectures side-by-side. The architect should be able to view similar sets of information regarding common elements of those architectures, if that information is available. If required, detailed information should be available regarding the architectures of individual components of the architecture, along with implementation information should that be required by the architect.

For this scenario, an architect has three systems to compare before deciding on which architecture to use when building a new system. The first system has a well-documented architecture that includes a description of that architecture in the Acme architecture description language. The second system is well documented, but is in hard copy and not in a format that is directly parseable. The third system does not have an architectural description at all, but the source code is available.

Application

In order to compare these architectures, the architect wishes to have views of those architectures directly available side-by-side. ArchVis does not have direct support for multiple systems in one instance of ArchVis, but it does have the capability of persistently storing a render model. This means that once a view of a system has been created and rendered, the render model can be saved to disk and loaded at a later stage. Data stored includes position information, so once an appropriate layout has been achieved, the view can be stored with positional information intact. Also, when a view is loaded, layout algorithms can again be applied to the view. The disadvantage for ArchVis is that whilst views from different systems can be loaded from a persistent store, there may be a danger that the view becomes mentally associated with the current system. ArchVis does not currently have a mechanism by which to adequately distinguish views from other systems.

In order to compare the architectures, the architect decides that a comparison across a component-connector view is appropriate, and so begins a process of obtaining such a view from each system.

For the first system, the architect is able to use the description of the architecture as encoded in the Acme architecture description language. ArchVis' AcmeParser processes the Acme description file and populates the ER store. In the case of the second system's architecture, the architect has to decide how best to capture the architecture as described in the document. One route would be to re-write the architecture in an architecture description language, or the architect could use the ArchVis modeller tool in order to define the entities and relationships of the system. If the modeller tool is used, then a data filter should ensure that the vocabulary used to describe the system is translated into the vocabulary used in the Acme language. For the third system, the architect can use a language parser, similar to the method described in the first scenario. An additional step is required for the third system. A component data filter is required to aggregate classes into defined components, or to treat each class or package as an individual component. To achieve this, the OOAggregate static filter can be used, with an appropriate configuration.

The second stage of this process is to define a number of appropriate views that are to be used to compare the two systems. In this scenario, the architect has decided on a component level view of this system. Each system is opened into ArchVis, and the view saved to disk. Once a view for each system has been created, the architect can then restart ArchVis and open up each view. From here, the architect can make comparisons against the architecture represented in each view.

The second stage of this process is to define a number of appropriate views that are to be used to compare the two systems. As noted previously, ArchVis does not support direct comparison of architectures, but does allow views to be saved and loaded, and so the architect must create loadable views of two systems. In this scenario, the architect has decided on a component level view of the system. One of the systems is represented as an Acme description, and so requires the use of the ArchVis Acme parser (Figure 8-5).

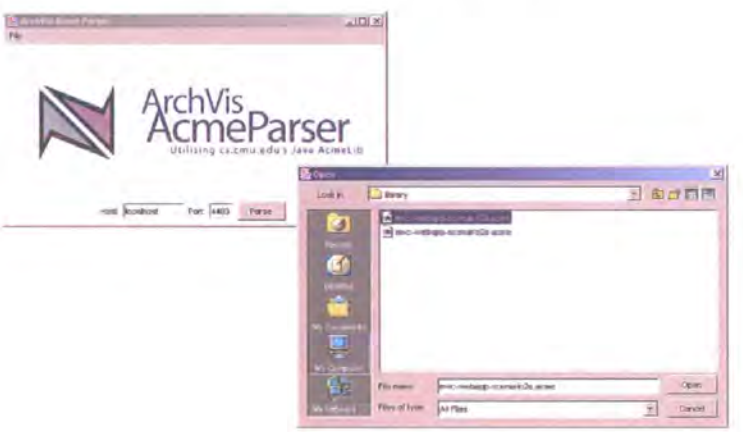


Figure 8-5 The ArchVis Acme Parser using AcmeLib

This allows the ER store to be populated with the entities and relationships that are found within the Acme description. The stakeholder can then use a Component Connector view in order to view this information. Once a satisfactory layout is achieved, the view can be saved (Figure 8-6).

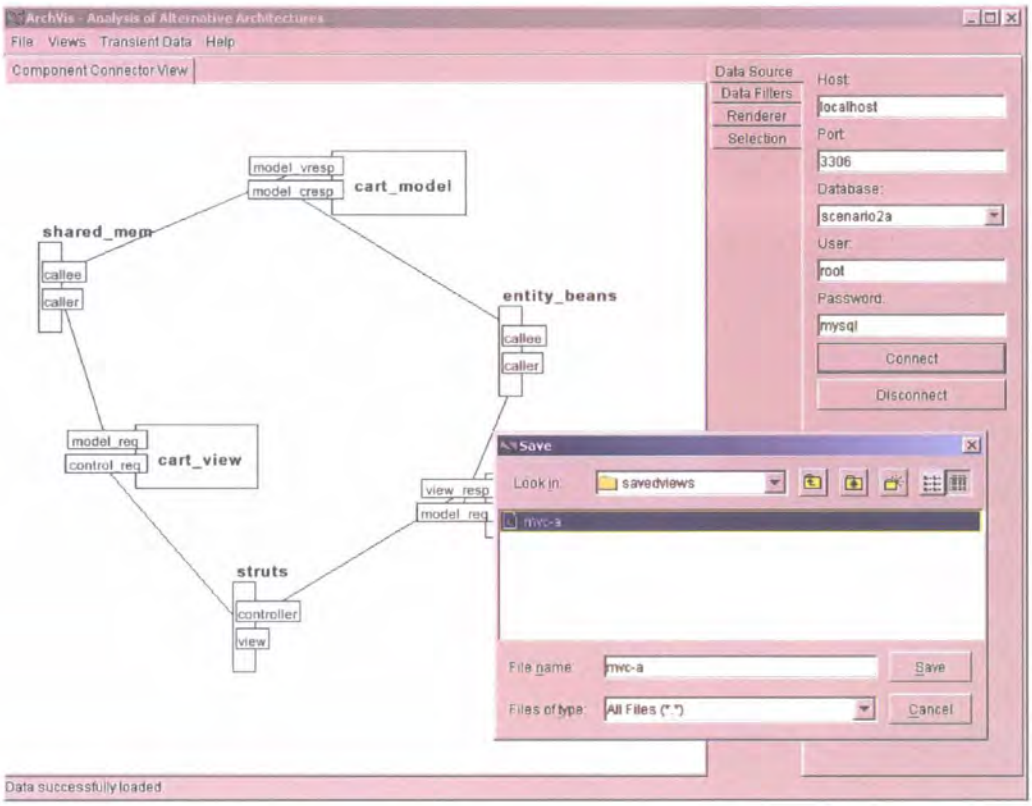


Figure 8-6 Saving a component-connector view

For the second system, the architect will use source code parsers and aggregation techniques in order to produce a component connector view of the second system. A similar process is used to create a view of the third system. Once these views are defined and saved, they can be loaded side-by-side (Figure 8-7).

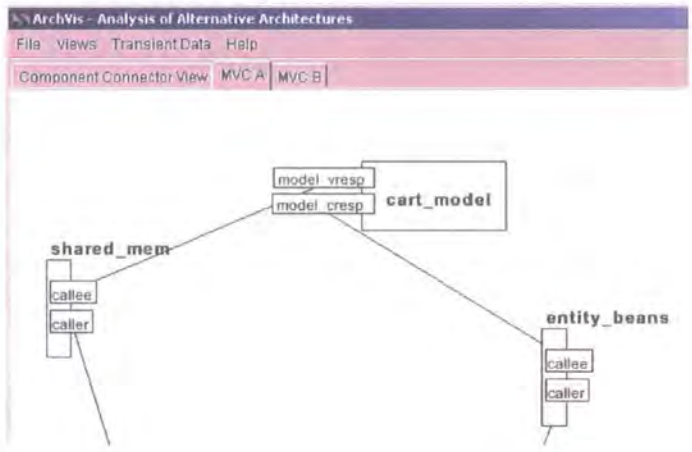


Figure 8-7 Loading a saved architectural view

One of the problems with this approach to comparison is that by saving only the render model of the view, the underlying data set is lost. In this case, only visual comparisons between views are possible. Tools that use the underlying data set, which include searches and queries, do not apply in this case. ArchVis' support for architecture comparison is, therefore, quite limited.

8.3.3 Specification of Single System Architecture

Scenario

In this scenario, taken from IEEE 1471-2000 [IEEE1471], the stakeholder who procures the system (acquirer) is the stakeholder who uses the system. Along with this user-acquirer stakeholder are the system developers. A software system is architected in response to this user-acquirer's needs and constraints. The architecture description will evolve throughout the life cycle of the system, and is used to predict the fitness for use of a system that conforms to the architectural description, and provides the means for assessing changes to that system.

The main task here is the construction of the architecture description. Architects will create a description of the architecture by identifying key views of the architecture and develop a model of the system with respect to each of those views.

Application

As the developers are the primary stakeholders in this scenario, the architect decides on the following views:

- Component and connector view
- UML developer view
- Deployment view with technology choices

In the construction of the architecture description, the architect uses an XML editor to produce two sets of XML documents. The first set of XML documents describes the system in terms of packages, classes and interfaces and even includes a number of methods and variables that are required. The second set of XML documents describe the major components and connectors of the architecture along with information that links these elements to the underlying implementation defined by packages, classes and so on (Figure 8-8).

```
<?xml version="1.0" encoding="UTF-8"?>
<architecture>
    <system>
        <name>Shopping Cart</name>
        <component>
            <name>Web Server</name>
            <implementation>
                <resource>w3serv.server</resource>
                <type>package</type>
                <path></path>
            </implementation>
        </component>
        <component>
            <name>Data Store</name>
            <implementation>
                <resource>StorageManager</resource>
                <type>class</type>
                <path>w3serv.storage</path>
            </implementation>
        </component>
    </system>
</architecture>
```

Figure 8-8 Implementation XML document

Finally, the documents describe deployment information. This maps the high-level components and connectors onto physical devices and geographic locations (Figure 8-9).

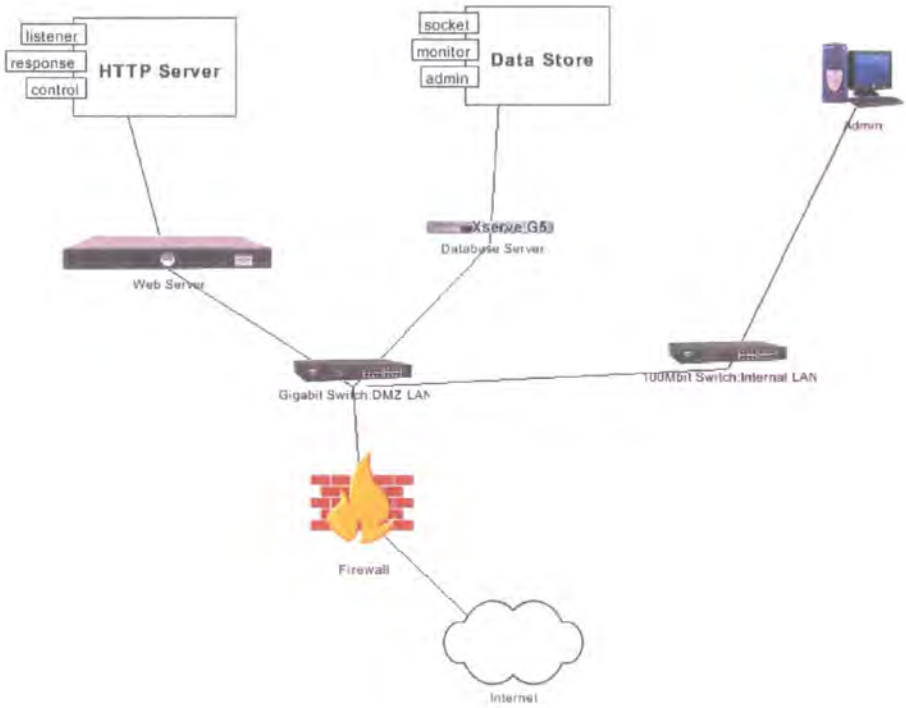


Figure 8-9 Deployment View

During development, the architect frequently updates the XML architecture descriptions. ArchVis is used as a tool to check the changes from one version to the next, and to ensure that architecture quality has not degraded from one version to the next. This can be achieved by saving each view to disk, naming it with a version number. At any point during the architects work, they can open up previous views of the architecture in order to compare the current view with previous versions.

8.3.4 Communication Between Stakeholders

Scenario

Stakeholders in the architecture of a system can be and individual, a team or organisation with interest in or concern about that system. Representations of the system's architecture are used in facilitating communication between those stakeholders. These representations include architectural descriptions and architecture visualisations.

In order to enable effective communication between stakeholders, architectural representations should have a set of viewpoints that contains one or more viewpoints that are suitable for each stakeholder. Views that are then based on those viewpoints should be readily understandable. Each stakeholder will have differing concerns of that system, from very basic knowledge (for example, in sales and marketing), to highly detailed

in-depth knowledge (for example, that required by developers). Finally, these architectural representations should provide for inter-view cohesion such that stakeholders have a common reference with which they can communicate with each other. One typical situation where this becomes obvious is when the language used to describe the system is different when the organisation communicates internally from when it communicates externally.

In this scenario, a company has an enterprise-class software product that they are selling to other companies. This product has been built as a J2EE compliant application, using EJB and JSP technology. As such, the application can be deployed in a number of ways, and this has helped the product to gain market advantage. This organisation intends to sell this application as a full product, but also extol the product's capability to be customised to suit the individual needs of the client. The company has a number of stakeholders in the architecture:

- The architect
- Developers
- Sales and Marketing
- Support
- Professional Services

The visualisation should cater for these stakeholders.

Application

ArchVis can support any number of views. The following matrix (Table 8-3) identifies the views to be used in ArchVis against the stakeholders that might use those views.

		Views				
		Product Component	Component and Connector	Static UML	Physical Deployment	Technology
Stakeholders	Architect	✓	✓	✓	✓	✓
	Developers	×	✓	✓	×	×
	Sales & Marketing	✓	×	×	✓	✓
	Support	✓	×	×	✓	×
	Professional Services	✓	✓	✓	✓	✓

Table 8-3 Stakeholder Communication View matrix

ArchVis is then configured for each of the five views identified. By using ArchVis, the stakeholders have a single reference point for the architecture, and this reference will allow each stakeholder to gain an appreciation of other stakeholders' views.

8.3.5 Conformance Checking

Scenario

Once a system has been implemented, the as-implemented architecture of the system is checked against the as-designed architecture of that system to determine if the implementation is faithful. For this conformance checking to be feasible, an automatic or semi-automatic process is required by which the as-implemented architecture can be extracted. Once extracted, this extracted architecture is represented in some way such that comparison can be made to the representation of the as-designed architecture. Once these representations can be compared, checks are made between them to see if the implementation is true to the design. If there are discrepancies, then these can be further investigated.

Application

In this scenario, a company prescribed a software system's architecture in the Acme architecture description language, and began development. Development of this software is in the Java language, and so is comprised

of packages, classes and interfaces. Each package that is developed has an associated mapping with an architectural component (Figure 8-10).

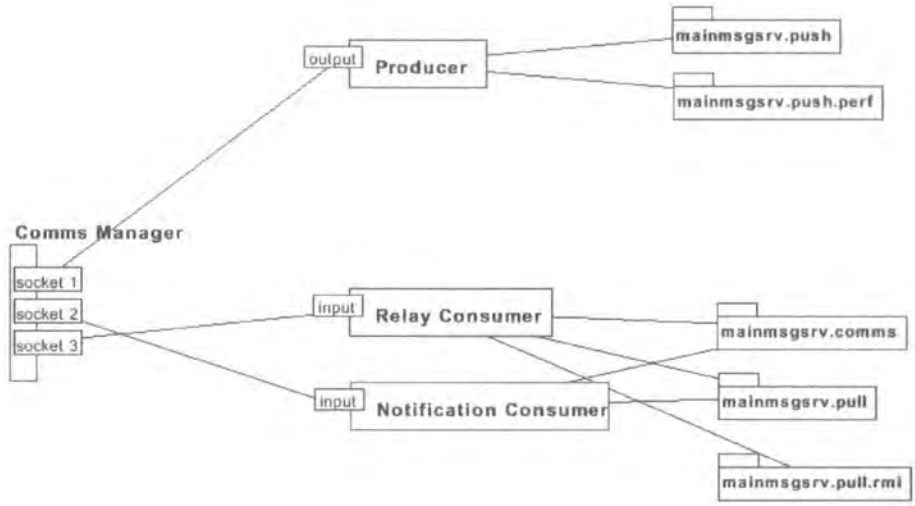


Figure 8-10 As designed package assignment to architectural components

This mapping is captured in an XML document that simply records this relationship. At major milestones in the project, they wish to check that the as-developed architecture matches the as-prescribed architecture. When a conformance check is required, the source of the software is parsed, ready to be used by ArchVis. The XML component-mapping document is also parsed. Finally, a 'component implementation' view is defined that shows this graphically (Figure 8-11).

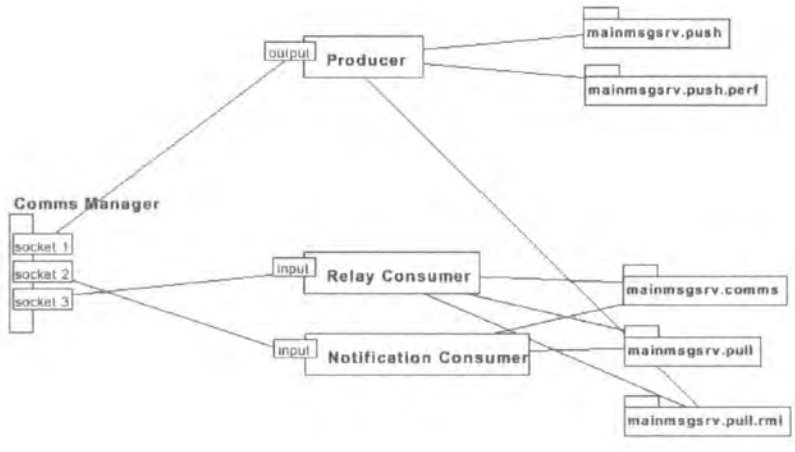


Figure 8-11 As implemented package assignment to architectural components

The architect is able to compare the two views together, and can see that in this example the package mainmsgsrv.pull.rmi is incorrectly being used in the Producer component. From this information, the architect is able to determine why the architecture has not conformed to the specification.

8.3.6 Operational and Infrastructure Support

Scenario

At some point during the life cycle of a system, it will be deployed. Depending on the scale of the system, this may occur during development, but is more typically deployed onto a testing platform during testing phases. Eventually, the system will be released and deployed in its target environment.

Operational, infrastructure and support stakeholders use architectural representations to ensure that the appropriate operational infrastructure is in place. Information that they require include:

- Computing hardware platforms
- Operating systems
- Software platforms
- Network infrastructure
- Telecommunications
- Human infrastructure

Architectural representations should contain information pertaining to the above. This can then be used to make acquisition decisions and to provide the appropriate environment for deployment. Those who are responsible for this aspect of deployment can use architectural representations in order to communicate with other stakeholders, including the architect in order to feed information back into the design process.

A typical scenario is when a large system is comprised of a number of components, and these components are distributed across a number of physical platforms and geographic areas. One such system is a company's intranet portal. Portals consist of a number of components, listed below:

- Portal home system
- Customer database.
- Contact database.
- Customer support system
- IT helpdesk
- Enterprise Resource Planning application
- Web-based e-mail access

The components are distributed across an internal network.

Application

ArchVis requires information about each component, and about the network infrastructure of the company. From diagrams of the network topology, a stakeholder can input network topology information into the ArchVis ER store. From the architectural descriptions, the physical deployment characteristics of each of the components can be determined and input into the ER store. Along with the above information, human resource data can also be added that indicates which groups are responsible for the operation, maintenance and support of each of the components.

Once this information is available, ArchVis can show a number of views:

- Network topology of the portal
- Physical location of components of the portal
- Support responsibility

In order to show real-time information regarding the operation of the portal, several transient data capture components can be deployed to various sub-components of the portal. For example, the ArchVis HTTP sniffer can be deployed at the portal home system and web-based e-mail access system (Figure 8-12).

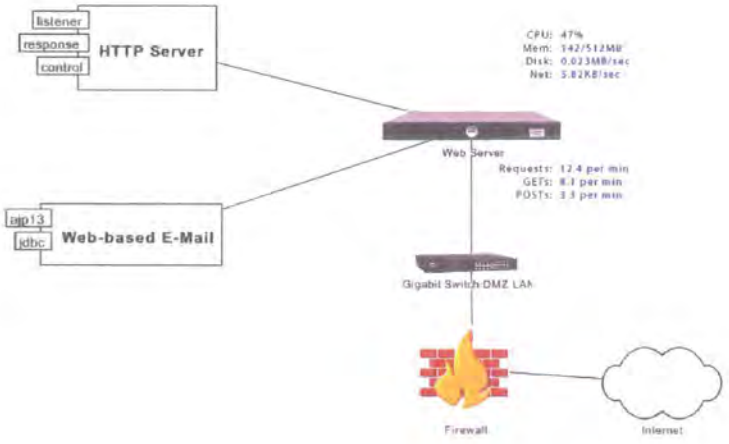


Figure 8-12 Real-time deployment information

Each machine that the portal system is deployed on can have an appropriate ArchVis activity monitor deployed on it that will communicate real-time CPU, disk and memory usage statistics (Figure 8-12).

8.3.7 Architecture Evaluation

Scenario

Evaluation of an architectural predicts the quality of systems whose architectures conform to that architecture. Quality measures for systems resulting from an architecture description are measured in terms of non-functional qualities such as efficiency, reliability, security and performance.

Application

In order for ArchVis to represent architecture quality, that information must be available in the ER store. Typically, components will have properties that record such quality measurements, and these can be used in any of the appropriate views.

Many of ArchVis' render model elements support the assignment of a quality rating measured as a percentage. It is the responsibility of the renderer to assign the appropriate entity property to the quality rating of the graphical element. ArchVis also allows stakeholders to view the properties of any selected element, however graphical elements support only one quality value, so if multiple quality measures are present, the renderer to determine which quality measure takes precedence, or combine the two quality measures in some way.

Figure 8-13 Quality shown as rust

Figure 8-13 indicates how a graphical element can have an association with a sphere that is at various stages of rusting. From left to right, the quality of the graphical element would be indicated as high quality to low quality.

8.3.8 System Development

Scenario

During the construction of the system, architectural representations are used in a number of ways in all areas of the life cycle. Designers will use the architecture in order to create interfaces between the major elements of the architecture such as the components and connects. Developers will use the architecture representation in order to gain an understanding of where their work fits into the system as a whole. Testers will use the architecture representation in order to determine test plans, impact analysis and integration testing. Maintainers will use the architecture in order to gain an understanding of the context of the changes they are to make. Managers can also use architectural representations in order to track development, development resources and plan budgets.

Application

ArchVis' support of a number of views over a single data store means that it can visualise a wide range of aspects of the development process. For this scenario, the following stakeholder-view matrix is applicable.

		Views			
		Component and Connector	Static UML	Project Management	Testing
Stakeholders	Architect	✓	✓	✓	✓
	Designer	✓	✓	✓	×
	Developer	✓	×	×	✓
	Maintainer	✓	×	×	✓
	Tester	✓	✓	✓	✓
	Project Manager	×	×	✓	×

Table 8-4 System Development Stakeholder-View Matrix

The information gathering process required to supply ArchVis with the appropriate information will need to be performed regularly. An appropriate time in which to populate the ER store with development-specific information would be during each system build, which can occur nightly in some instances. Project management and tester-specific information would need to be populated at the same frequency, but this information would be encoded in machine parseable documents, rather than encoded in the software source code.

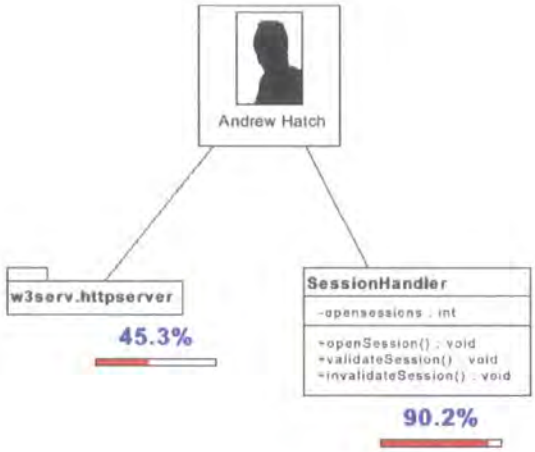


Figure 8-14 Developer task assignment

Figure 8-14 shows how developer assignments are represented along with progress information.

8.4 Informal Evaluation

The final part of evaluation is informal. The intention is to further explore both the potential of ArchVis along with some of its limitations. In order to comprehensively review ArchVis, this section is divided into several areas. Each of these areas represents a fundamental part of the ArchVis visualisation approach and are discussed below.

8.4.1 Static Data Support

ArchVis classifies data into two categories. Static data describes the static structures of the software system in terms of its elements and relationships. Static structures are those structures of the system that describe the software before its execution. Transient data, the second category, is data that relates to the system during its execution, and is described in the next section.

During the static data capture process, ArchVis static tools take data from static data sources and represents them in terms of entities, relationships and properties. This is a process of decomposition, taking complex structures and reducing them down into a set of entities and relationships with a number of associated properties. Whilst this data model of entities and relationships presents a very simple and flexible model to work with, it also means that the data volume increases, and that to work with the complex data structure

during later stages requires a re-composition process. This means that the visualisation has to work in order to be able to use a higher-level data structure for visualisation.

Data expansion is also necessary as a result of the definition of equality of two entities. Two entities are equal if and only if both their names and types are of equal value. Properties are not considered in this equality check. One scenario in which problems can arise is when two entities of a particular type may have the same name, but not be equal. One obvious example of this scenario is in the decomposition of classes in separate packages. Consider a package com.company that contains class A and class B, and both classes have a method do() that has the same signature in each class. One way to encode this would be to have the following entities shown (Table 8-5).

Entity name	*Entity type*
com.company	package
A	Class
do()	Method
B	Class
do()	Method

Table 8-5 Entity equality problem

The obvious problem is that there are two entities that are now equal when they should not. In order to overcome this problem, ArchVis uses a fully qualified path approach, meaning that the encoding would in fact be as shown in Table 8-6.

Entity name	*Entity type*
com.company	package
com.company.A	Class
com.company.A.do()	Method
com.company.B	Class
com.company.B.do()	Method

Table 8-6 Solution to entity equality problem

This solution to the entity equality problem means that there is a considerable amount of data expansion due to the pre-pending of 'path' information.

Another feature of the ArchVis approach to data is that before the renderer begins its rendering process over an ER store, a number of data filters can be applied. These data filters can be used to perform a variety of functions, and the data filter's simple function is easily implemented. As described previously, the static data filter takes an ER store as input, and outputs a new ER store. The static data interface allows all static data filters to be configured using a properties file. During implementation, a number of static data filters were implemented very quickly and incorporated into the ArchVis visualisation by merely editing a number of configuration property files. It is this loose coupling that means that ArchVis can be extended and reconfigured very easily and very quickly. In order for changes to the configuration files to become effective, ArchVis requires reloading of the visualisation profile. One way in which ArchVis can be extended is to allow a visualisation profile to change dynamically as these configurations are changed, and therefore not require reprocessing of the entire data pipeline.

ArchVis is able to use several implementations of ER stores. Presently ArchVis has limited capability for the selection and initialisation of new ER stores. This process is a step that currently requires running a separate set of tools. If a user begins to populate an ER store with information, there are no checks that ensure that the user is populating the correct store for the system they are processing.

8.4.2 Renderers and Render Model Capability

ArchVis clearly separates out the elements that make up a visual rendering, and the renderer that produces it. This separation allows for many different implementations of the renderer interface, and each renderer can use any of the graphical elements defined in the render model.

The render model uses a number of interfaces by which two classes of graphical element can be built. They are DrawableNode and DrawableRelationship. From these interfaces, any number of implementations can be derived. Again, this provides a mechanism by which ArchVis can easily be extended, and implementations of new graphical elements are easily achieved.

Renderers are reliant on having the appropriate data presented to them. The configuration of a view in the visualisation profile should be designed with the renderer in mind. The choice of data filters is crucial in order to present the correct data to the renderer. ArchVis' render pipeline does not provide a mechanism by which a renderer can publish its data requirements to the static data providers that supply it.

8.4.3 Views

Views are designed with a number of stakeholders in mind. ArchVis does not enumerate which stakeholders are to be associated with a particular view. Stakeholders therefore do not have an easy means by which they can determine which views are appropriate for them to use.

Further to this, views that may be related are not shown to be related – there is no means by which those views can be shown as associated. As an example, consider a system that has its architecture defined in a number of views modelled in the UML. It would be useful to relate these views together.

When a view is asked to perform a render to generate a render model, ArchVis passes the source data to the first data filter, and then each filter in turn receives the output ER store from the previous data filter. Relational information is not kept from one ER store to the next such that an entity in one ER store does not have a direct and formal relationship to the same entity in a previous ER store. This information is particularly useful when linking views together. If an element is selected in one view, and it is composed of a number of elements in another view, this should be shown. However, as the relationship between the composed element and its constituents is lost, this cannot easily be shown.

8.4.4 Implementation

The ArchVis prototype tool is successful in demonstrating a system by which architectural information can be successfully extracted from a variety of sources, and be consolidated into a repository that can then be used to

visualise the system. Much of the focus of this tool has been to demonstrate a great degree of flexibility in this approach to visualising software architecture. As such, much of the implementation has been on the data extraction and view creation mechanisms rather than generating refined views of software architecture.

Several implementations of static data filters and renderers were given in order to demonstrate how these components could be built in order to generate more refined and complete visualisations. Given further work, the full potential of this visualisation system could be realized.

8.5 Conclusions

This chapter has evaluated the research presented in the thesis, and has taken the evaluation approach described in section 7.3 and applied it to ArchVis. There are three distinct areas of evaluation. Firstly, software architecture visualisation evaluation framework was applied to ArchVis. Secondly, a number of scenarios were used in order to identify how ArchVis supports various tasks in the life cycle of a software system. Finally, ArchVis is described and evaluated informally. This informal evaluation explores some areas of ArchVis that are not uncovered in the first two evaluation methods.

The feature-based evaluation framework applied to ArchVis yields interesting results, indicating both positive and negative aspects of the visualisation approach. The scenarios were most suited to showing how ArchVis performs in supporting various tasks that stakeholders in software architecture perform during the life cycle of that software system. The results of these scenarios show that ArchVis does perform well in certain areas of architecture visualisation, but is less suited to situations where architectures change dynamically, or when multiple software architectures are to be shown.

An empirical study would be useful in order to demonstrate how useful ArchVis is to real stakeholders in real software systems where factors that are not able to be recreated in scenarios come in to play.

Chapter 9: Conclusions

9.1 Introduction

Software architecture is increasingly being recognised as of fundamental importance to the success of software engineering projects. Computer science has a history of abstraction, from machine code, to high-level languages, to design methods and design patterns. Software architecture forms part of this move in abstraction, and is a high-level abstraction of software design. For a software system, there are a number of stakeholders in the software architecture. The stakeholders reflect all aspects of the life cycle of that software, from its inception by the architect to the purchase by the customer and deployment by technicians.

Software visualisation has very much concentrated its efforts on supporting developers and maintainers. This is a feature of the fact that software visualisation has its roots in program comprehension. Software architecture brings more stakeholders, and many existing software visualisations are not currently capable of dealing with this. Many of the software architecture visualisation does not explicitly cater for stakeholders other than architects and developers.

Architecture visualisations often have a limited capability to retrieve architectural information from the array of sources that contain such data. Source code is the typical means by which architectural information is retrieved, but in modern applications architectural information can be found more readily in other places.

9.2 Summary of Research

This research presents a new approach to software architecture visualisation that addresses issues and challenges raised through the analysis of software visualisation research and the current use of software architecture.

Taking a practical approach to software architecture, this thesis identifies key ways in which architecture is used, why it is used and who uses it. It is important to consider these pragmatic issues in software architecture in order to ensure that the research would yield results that can be applicable to real world software engineering problems. This philosophy also extended to consideration of how software architecture is represented. Present day enterprise software has architectural information specified in places other than the software source code, and recovery of this information is vital in being able visualise the architecture of these classes of software systems.

This result of this research is an approach to software architecture visualisation that enables a number of stakeholders to access the visualisation, and to see views of the software architecture that are relevant and

comprehensible by them. In this way, inter-stakeholder communication can be improved. In order to support multiple stakeholders, the approach was designed to support a number of different representations of the software architecture. This meant that the render pipeline had to be flexible and customisable at the appropriate stages of data recover, filtering and render model construction.

A prototype tool has been developed to demonstrate the applicability of the visualisation approach. This tool demonstrates a significant proportion of the concepts and strategies associated with the ArchVis approach. Development of the tool facilitated the application of the visualisation approach to real world software systems and enabled an evaluation process.

To successfully evaluate the ArchVis approach to software architecture visualisation, a new feature-based evaluation framework had to be developed. Whilst software visualisation research has a number of evaluation frameworks, none were particularly well suited to software architecture visualisation. This research presented a new framework that inherits many characteristics from previous visualisation frameworks, and added features that are particular to software architecture.

Evaluation of the visualisation approach took on three forms. The software architecture visualisation evaluation framework was applied to the ArchVis visualisation approach. This results in a rating for each feature. In order to explore how ArchVis might be used in real world situations, a number of scenarios were used and the way in which ArchVis would support these tasks was described. Finally, an informal evaluation described some aspects of ArchVis that the framework and scenarios did not uncover.

9.3 Criteria for Success

At the beginning of this thesis, a set of criteria was given by which this research can be judged in terms of its success. This section examines each criterion and discusses the degree to which it has been achieved.

9.3.1 Identify the current use of architecture visualisation in practice by showing the tasks different stakeholders perform.

In chapter 2, the motivation and use of software architecture was introduced, including a discussion on the stakeholders in a system's architecture. Chapter 3 discusses the current research in software architecture visualisation and discusses how these might be applied to real world systems. One key finding in this thesis is that architecture visualisations are generally not suited for the broad range of stakeholders in an architecture. Typically, visualisations are suited to architects and developers only.

9.3.2 Address the visualisation issues of representing software architecture for different stakeholders.

Chapter 2 identifies several classes of stakeholder in software architecture. Chapter 4 introduces the concept of views of software architecture as much of software architecture literature discusses the necessity of having different views. The IEEE standard for architectural descriptions [IEEE1471] makes a strong link between views of software architecture and the stakeholders in that architecture and describes a model for maintaining an explicit connection between the two. The ArchVis approach, discussed in chapter 5, defines a view model by which multiple views can be represented in a visualisation of an architecture. In this way, different stakeholders can see the architecture from a viewpoint suited for them. Under evaluation, in section 8.2, ArchVis is partially successful in supporting multiple users simultaneously, but does score well in supporting the communication of software architecture to a large number of stakeholders in that architecture.

9.3.3 Identify a mechanism for providing architectural information to an architecture visualisation.

Architectural information can be found amongst a variety of collateral related to a software system, including software source code and configuration information. Some of these representations are identified in chapter 2, and ArchVis provides a mechanism by which many of these sources can be used for architectural visualisation. This mechanism is described in detail in chapter 5. The application of the evaluation framework in chapter 8 indicates that ArchVis rates well in terms of retrieving both static and dynamic data.

9.3.4 Develop visual representations of software architectures that are suited to the identified tasks.

Chapter 2 identifies the uses of software architecture in practice. Chapter 5 identifies five sets of views that will support those tasks (component views, developer views, project manager views, technology and deployment views, sales and marketing views). These views are developed within the ArchVis framework, showing how the relevant data is captured, filtered and how a render model is generated from this to produce the view. The evaluation of ArchVis (chapter 8) shows that whilst ArchVis provides good support for a number of different views to support tasks, there are some tasks that are not directly supported.

9.3.5 Develop a proof of concept prototype tool to demonstrate the visualisations.

The ArchVis proof of concept tool was developed in the Java language and demonstrates many of the key areas of the ArchVis approach as identified in chapter 5. Implementation specific detail is reviewed in chapter 6 for those features that were implemented.

9.3.6 Demonstrate that the visualisations can be generated automatically with minimal disruption to the software system itself.

The methods of static data extraction that ArchVis supports vary from invasive techniques such as instrumentation through to non-invasive techniques such as parsing the source using a language parser. Static data collection again varies from invasive approaches such as instrumentation through to the use of a virtual machine interface such as the Java debugger interface.

9.3.7 Create a feature based evaluation framework suitable for software architecture visualisation.

As research in software architecture visualisation has had little work carried out in evaluation, the only available frameworks are for software visualisation, and these have problems in application to software architecture visualisation. Chapter 7 introduces a new evaluation framework suited to software architecture that is based on the principles of software visualisation and cognitive psychology. This framework is then used in Chapter 8 in the evaluation of ArchVis.

9.4 Comparing ArchVis

Comparing ArchVis to the six other architecture visualisations identified in section 4.2, a number of observations can be made.

The areas in which ArchVis performs well, with respect to the evaluation framework described in section 7.3.1, are in its capability of supporting both static and transient data, views and navigation. Comparing these to existing architecture visualisations, no other performed as well in static data and transient data support. The closest tool to ArchVis in terms of views and navigation is Enterprise Architect, the system that also performed better in task support. Enterprise Architect, however, lacks in its support of static and transient data.

9.5 Future Work

Architecture visualisation is a relatively unexplored research territory. This thesis identifies several areas of future work.

9.5.1 Architecture Representations

For software engineering outside of a research lab, there are many non-ideal scenarios. When software architecture is considered, the use of ADLs in software projects is very much limited to a few documented cases. In order for architecture visualisation to be of significant use to software engineers, mechanisms must exist for retrieving architectural information from a multitude of sources and consolidate that into a repository of architectural information ready for visualisation. This thesis has presented an approach to this process, but can be improved in a number of ways.

Firstly, the mechanism presented requires decomposition followed by re-composition by individual views. This is computationally expensive, and could potentially be avoided. Secondly, the re-composition process uses individual filters that do not maintain context or history information from one filter to the next. This means that tracing a render element back to the original data source is difficult.

9.5.2 Architectural Views

Perhaps one of the easiest ways to take this research forward with respect to the views described, is to provide more implementations of renderers and to provide extensions to the library of graphical elements that can be used by those renderers. There are many views that are not developed through ArchVis that are frequently used by developers – particularly collaboration views in UML.

Another area of research would be to examine how viewpoint definitions can be better represented in the visualisation, and to explicitly map stakeholders and their concerns to the views that address those concerns. These issues are not currently addressed adequately in ArchVis.

In order to more effectively support some tasks such as choosing from alternative architectures, and evaluating as-implemented architectures against as-prescribed architectures, a visualisation should be able to support the visualisation of multiple architectures concurrently. ArchVis supports the concurrent visualisation of the render model produced by each architecture, but this is fundamentally different to having the full architecture on hand to retrieve information from.

Views presented here all rely on two-dimensional graphics in order to produce displays. As noted in chapter 3, some research in software visualisation has examined the use of three dimensions in order to convey new

perspectives on software, and to alleviate some of the problems posed by two-dimensional displays. This is an avenue that can equally be explored for software architecture visualisation.

9.5.3 Implementation

In terms of the implementation of ArchVis, there are two ways in which the work can be carried forward. The first is to examine a possible mechanism by which multiple stakeholders can use the visualisation concurrently. This would improve on the current support which is multiple stakeholders, but one at a time. The second direction would be to examine the transient data support in ArchVis. This is currently very limited to the model described in chapter 5 – which does not allow for the visualisation of changing architectures; it simply allows transient events to be associated with elements in the render model.

9.6 Conclusion

This thesis has examined the fundamental principles of software architecture visualisation by looking at software architecture, and software visualisation, and reported on the current state of research in these fields. It has also examined the state of research in software architecture visualisation to date. From this, this research then identifies the issues and challenges that face software architecture visualisation, and proposes a new approach. This approach, called ArchVis, is described in detail along with details on how a prototype tool was developed to demonstrate the principle concepts of the ArchVis approach. ArchVis demonstrates how architectural information that is relevant to a number of stakeholders can be retrieved and input into a view model in such a way as to present views that are appropriate to the stakeholders. An evaluation of ArchVis identified its relative merits, and the future work describes ways in which the work of this thesis can be carried forward.

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