Mining Software Repositories to Support Software Evolution

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A Thesis

In

The Department

of

Computer Science and Software Engineering

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Applied Science (Software Engineering) at
Concordia University
Montreal, Quebec, Canada.

March, 2009

Your file Votre référence
ISBN: 978-0-494-63201-7
Our file Notre référence
ISBN: 978-0-494-63201-7

Abstract

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Software evolution represents a major phase in the development life cycle of software systems. In recent years, software evolution has been recognized as one of the most important and challenging areas in the field of software engineering. Studies even show that 65-80% of the system lifetime will be spent on maintenance and evolution activities. Software repositories, such as versioning and bug tracking systems are essential parts of various software maintenance activities. Given the often large amounts of information stored in these repositories, researchers have proposed to mine and analyze these large knowledge bases in order to study and support various aspects of the evolution of a software system. In this thesis, we introduce a common ontological representation to support the mining and analysis of software repositories. In addition to this common representation, we introduce the *SVN-Ontologizer* and *Bugzilla-Ontologizer* tools that provide automation for both data extraction from remote repositories and ontology populations. A case study is presented to illustrate the applicability of the present approach in supporting software maintainers during the analysis and mining of these software repositories.

Acknowledgements

I am most grateful to my supervisor, Dr. *Juergen Rilling*, for his encouragement, support, and patience throughout this research. Without his help, advice and positive attitude, my studies in this area would not have been possible. I have collected many cherished moments and unique experiences from my supervisor and colleagues at *CONCEPT* (Comprehension Of Net-CEntered Programs and Techniques) *Concordia University.*

I express my deepest gratitude to my beloved wife, *Rozina* and my children, *Haris, Ammar* and *Omar,* for their enormous support, infinite patience, and unwavering belief towards me, as always. There is a litany of family members and friends who are not individually mentioned here, but they certainly made a difference.

I would also like to extend my appreciation and thanks to *Mr. Philipp Schugerl* and *Ali Asghar Sheikh* for their helpful comments and suggestions, they always helped me in times of great needs and deeds.

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1. Introduction

Software evolution represents a major phase of activities involved in the development, use, and maintenance of software systems. In recent years, software evolution has been recognized as one of the most important and challenging areas in the field of software engineering. Studies pointed out that 65-80% [LEH01] of a system's lifetime will be spent on maintenance and evolution activities. The majority of the costs of evolution of a software system are incurred in software comprehension, rather than in making the necessary corrections to the system. Available estimates indicate that the percentage of maintenance time consumed on software comprehension ranges from 50% up to 90% [COR89, LIV94, and STA84].

Software repositories, such as versioning systems and bug tracking systems are essential parts of supporting various software maintenance activities. These tools not only support software maintenance activities, but they also store important information related to software development and maintenance history. Given the often large amount of information stored in these repositories, researchers have proposed to mine and analyze these large knowledge bases in order to study and support various aspects of the evolution of software systems, such as impact analysis, software architecture, development process, software reuse, product reliability, and artifact traceability.

One of the key challenges in analyzing these software repositories is that they lack a common representation. These repository specific data models, often introduced as information silos, do not allow for a semantic rich integration of these resources and therefore limit the analysis support across repository boundaries. In order to address these challenges with respect to information integration and the analysis across repository boundaries, a common, semantic rich representation is needed to integrate information from various software repositories.

In this thesis we introduce a common ontological representation to support the mining and analysis of software repositories. In addition to this common representation, we introduce the *SVN-Ontologizer* and *Bugzilla-Ontologizer* tools that provide automation for both data extraction from remote repositories and automated ontology population. A case study is presented to illustrate the applicability of the approach in supporting the analysis and mining of the repositories in order to provide support to software maintainers.

The remainder of the thesis is organized as follows: Section 2 introduces a general background related to software evolution, software repositories, and ontologies. Section 3 details the motivation and objectives of our approach. Section 4 and 5 introduces the implementation of SVN and Bugzilla-Ontologizer tools respectively. An initial case study is presented in Section 6, followed by related work in Section 7. Section 8 presents conclusions and future work.

2. Background

In an attempt to make this thesis self-contained, we review some background relevant to the presented research. Background on software evolution and software comprehension process is presented in Section 2. 1. Section 2.2 introduces software repositories with a specific focus on *Subversion*, a version control system, and *Bugzilla*, a defect tracking repository. Section 2.3 provides a brief introduction to ontologies, semantic web technology, and their use as a modeling approach.

2.1. Software Evolution

Software evolution represents the cycle of activities involved in the development, use, and maintenance of software systems [WIKI09]. Software evolution includes software maintenance, which is defined as part of the IEEE Standard 1219[IEEE90] as, "the modification of a software product after delivery to correct faults, to improve performance or other attributes, or to adapt the product to a modified environment". The term 'software evolution' is now often preferred as a replacement for 'maintenance' [KHV00]. *Lehman* [LEH80] concludes the fact that maintenance is evolutionary development. Organizations have made large investments in their software systems. These systems become often critical business assets. In order to maintain the value of these assets to the business, the software must evolve. All software systems are subject to such an evolution, as these systems must evolve over time as new requirements emerge, or they have to adapt and extend the existing functionalities to meet changed requirements [LEH01]. As a result, the majority of software budgets in large organizations are devoted to evolve existing software in order to maintain the value of their software assets. Studies pointed out that 65 to 80% [LEH01] of a system lifetime will be spent on maintenance and evolution activities. Figure 2-1 shows the software life-cycle costs.

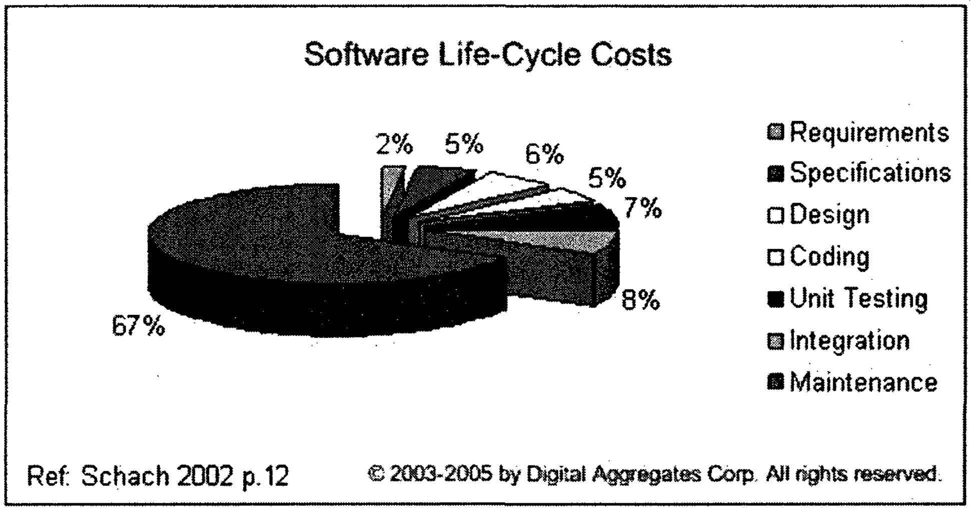


Figure 2- 1: Cost of the software life cycle [DAC01]

It has also been shown [LEH01] that the majority of the maintenance costs are related to enhancements of the existing software product, rather than corrections.

One of the major reasons for the overall significant effort and cost involved in software evolution is the need to comprehend systems that are either not well documented or have out of date and inconsistent documentation. Whenever a change is made to a piece of software, it is important that the maintainer gains some understanding of the structure, behavior and functionality of the system being modified. As a consequence, maintainers spend a large amount of their time reading the code and the accompanying documentation to comprehend its logic, purpose, and structure [GCM00]. Available estimates indicate that the percentage of maintenance time consumed on software comprehension ranges from 50% up to 90% ([COR89, LIV94, and STA84]). Software comprehension is necessary because the maintainer is rarely the author of the code (or a significant period of time has elapsed between development and maintenance) and a complete, up-to-date documentation is even more rarely available [CAG96].

Burd et al. [BUR98] define software comprehension as "the activity of understanding existing software systems". *Muller* [MUL94] defines software comprehension as "the task of building mental models of the underlying software at various abstraction levels, ranging from models of the code itself, to models of the underlying application domain, for maintenance, evolution, and reengineering purposes". The author further states that software comprehension is "a process whereby a software practitioner understands a software artifact using both knowledge of the *domain* and/or semantic and syntactic knowledge, to build a mental model of its relation to the situation" [MUL94]. Many software comprehension models (i.e. Mental and Cognitive Models) have been proposed. These models help to better identify what information needs to be provided to maintenance programmers, and when and how this information should be provided [LET86]. Software comprehension models normally consist of four common elements, namely, a knowledge base, external representation, assimilation process, and mental models [MPO03]. Figure 2-2 shows the common elements of comprehension models.

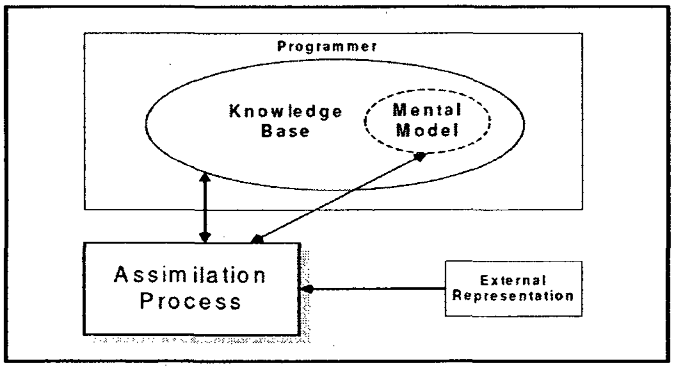


Figure 2- 2: Common elements of software comprehension models [MPO03]

An external representation corresponds to the external views available in assisting the maintainer comprehending a software system. This external support may be in the form of system documentation, the source code, expert advice from other maintainers familiar with problem domain or similar source code from the other system [MPO03]. A knowledge base can be defined as the maintainer's accumulated knowledge prior to the attempt to understand the software system. It may consist of an understanding of the domain and general information that may be pertinent to that domain, along with programming standards and practices [MPO03]. The knowledge base develops and expands as the level of maintainer understanding the changes [MPO03]. *Rouse et al.* [RWM85] defined a mental model as "mechanisms whereby the humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states". *Davis* [DSP93] defines an assimilation process as "the actual strategy, which the programmer employs to comprehend the source code". One method of assimilation is where maintainer's hypotheses are refined and elaborated during comprehension [BRK83]. *Storey* mentioned in [STO01] that a *mental model* describes a developer's mental representation of the program to be understood. A *cognitive model* describes the cognitive processes and temporary information structures in the programmer's mind that are used to form the mental model. In the past, several cognitive models have been developed to explain how maintainers comprehend the software system.

Letovsky [LET87] introduced a cognition model that consists of three main components: a knowledge base, a mental model, and an assimilation process. The first component contains the general knowledge that a programmer has about the programming discipline and the problem domain. It also includes rules of discourse, i.e. conventions in programming such as algorithm and data structure implementations and coding standards. The mental model is organized into three different levels of abstraction. First is the specification level, which describes the program goals. Second, the implementation level expresses the lowest level of abstraction, and contains the data structures and functions as entities. The third level of abstraction is the annotation level which links each goal in the specification level with its realization in the implementation level [CAG99].

Brooks [SOL84] proposed a model based on the top-down approach. The approach starts from the assumption that in the design phase a designer makes a number of decisions which will be reflected in the code. Comprehension involves recovering these decisions and mapping them onto the programming domain through the reconstruction of intermediate domains. The construction of the mental model happens through a top-down process that successively formulates and verifies hypotheses. At the top there is the primary hypothesis that expresses a high level description of the program function. Next, subsidiary hypotheses are formulated to support the primary hypothesis [CAG99].

Pennington [PEN87] proposed a bottom-up approach that starts by comprehending code line by line and discovering familiar patterns, called chunks, whose aggregation and next abstraction can bring to the identification of new patterns a higher level of abstraction. Pennington's model faces comprehension problems with the development of two different mental representations: the program model and the situation model. The first is a low level mental model of the program and its structure. Indeed, the first model that maintenance programmers build when dealing with unfamiliar code is typically a control flow abstraction. New and more abstract program models are then built by chunking code structures into more abstract structures. The situation model is developed after the program model. It creates a data flow/functional abstraction and requires knowledge of the application domain to mentally represent the code in terms of real-world objects organized as a functional hierarchy [CAG96].

Mayrhauser et al. [VMY93] proposed an integrated model that combines the models previously proposed. They start from the observation that a comprehension process proceeds either top-down, bottom-up, ***or*** a combination of the two. The integrated model consists of four main components: program model, situation model, top-down model, and knowledge base. The first three components are borrowed from the models already introduced. The integrated model exploits the top-down model when the code is familiar and the bottom-up model when it is completely new. By proceeding in a top-down way it can happen that an unfamiliar section of code is met, and a swap to the bottom-up investigation is required. The knowledge base is necessary for the construction of the other three components. Each model component consists of an internal representation of the code and the strategy to build this internal representation. The knowledge base furnishes related information and knowledge which has been previously acquired. During understanding, new information is developed and stored in the knowledge base for future usage. [CAG96].

2.2. Software Repositories

Software repositories help the users to manage the progress of software projects. A repository refers to a central place where data is stored and maintained within a persistent storage. Repository distributions can be either shared across a network or locally hosted on an individual computer. Software repositories such as version control and defect tracking systems are common examples of repositories used as part of modern software engineering and software development processes. These repositories provide shared understanding of the development processes of the software product.

Revision control (also known as version control) is the management of multiple revisions of the same unit of information. Version control systems (VCS) such as CVS [XMB09] and SVN [SVN09] are widely used examples of version control systems. These version control systems keep the development history of software projects in order to avoid modification conflicts among different revisions. Version control systems play also an important role during software evolution, since changes performed as part of maintenance requests can be traced and tracked (e. g. who made what changes and when.).

During the development of a software system certain problems may arise. Such problems can emerge from one revision to another and are referred to as "bugs. " Thus, bug tracking is a necessity in addition to a revision control system. When considering bug tracking we understand the storage and management of issues related to programmatic or even systemic instabilities, faults or conflicts during development. These issues are stored in a dedicated bug or issue tracking system. These systems mainly consist of a database (open source or proprietary) where the data pertinent to a specific issue is stored. The client and administrator side access layers (usually web based access, like *Bugzilla* [BUG09]).

2.2.1. Subversion (SVN)

Subversion (SVN) is a free/open-source version control system; it manages files and directories. Subversion places these files and directories into a central repository [SVN09]. The Subversion repository supports the tracking of changes to files and directories. SVN furthermore allows for the recovering of older versions of data, or examining the history how the data changed.

History of Subversion

CollabNet [CLB09] offers a collaboration software suite called CollabNet Enterprise Edition (CEE) [CL09A] of which one component is version control. Before August 2001, CEE used CVS (Concurrent Version System) as its initial version control system. CVS's limitations were obvious from the beginning. In early 2000, CollabNet planned to develop a new version control system from scratch which would match CVS's features and preserve the same development model but not duplicate CVS's most obvious flaws. It did not need to be a drop-in replacement for CVS. It should be similar enough that any CVS user could make the switch with little effort. After fourteen months of coding, the Subversion (SVN) became fully functional on August 31, 2001 by replacing CVS [SV09B].

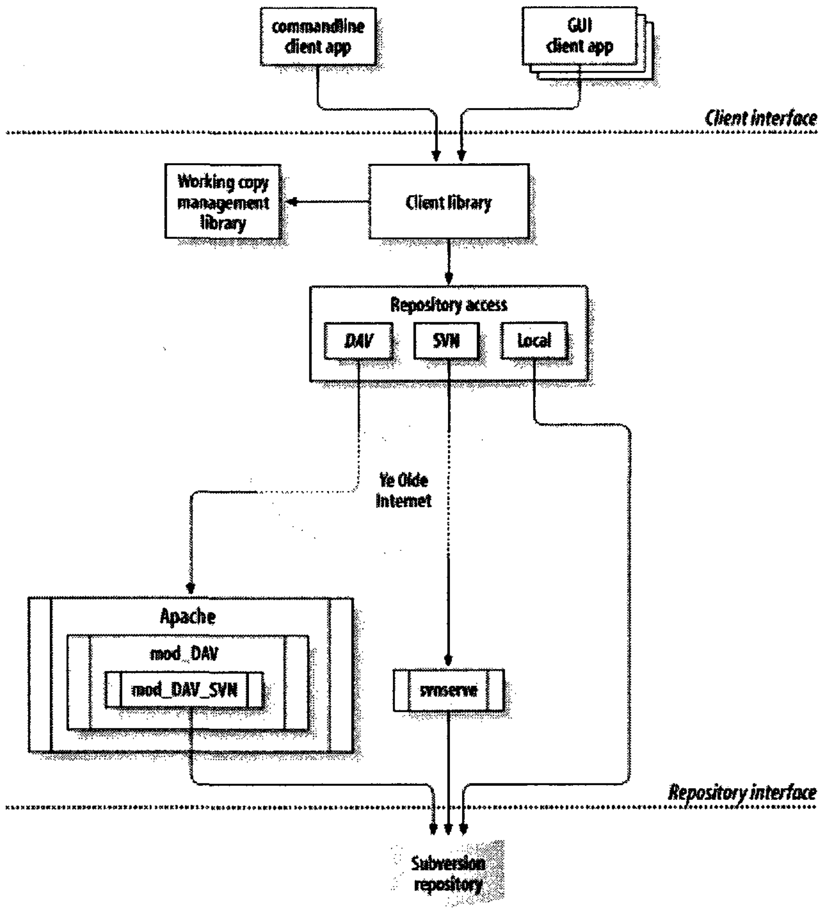


Figure 2- 3: SVN architecture [SV09A]

Architecture of Subversion

Subversion can access its repository across networks, enabling a collaborative environment for users where they can modify and manage the same set of data. Figure 2-3 shows the architecture of SVN repository. Subversion works in two ways. First, it provides repository that holds all of the versioned data. On the other end it works as a client program, which manages the local operations of the portions of that versioned data called *working copies*. Between these two ends there are multiple routes through various *Repository Access* (RA) layers. Some of these routes go across computer networks and through network servers that then access the repository. Others bypass the network altogether and access the repository directly.

Functions and Features

The basic functionalities provided by SVN are the same as in CVS, including the storage of file history information about users who checked out a working copy of a file to work locally on it. Users can easily compare the different versions of the file. In next paragraph we will discuss features exclusively supported by SVN.

SVN provides branching, tagging, and release concepts, where tags are common file metadata that are managed and kept in files or directories. Branches are separate directory trees made out of current main "trunk" directory. When a branch is made for a file, the revision enumeration continues on. The only property that changes is the path to the file or directory that moved from the main trunk to a branch. SVN tracks the changes made to both the main trunk and the branch as a log of the same file, telling the user where a particular change (main trunk or branch) was made and whether a revision corresponds to the main trunk or the branch. Figure 2-4 shows the example of SVN repository directory structure.

Releases are sets of revisions without explicit concepts or mechanisms corresponding to releases. Subversion creates branches and tags by simply copying the project, using a mechanism similar to a hard-link.

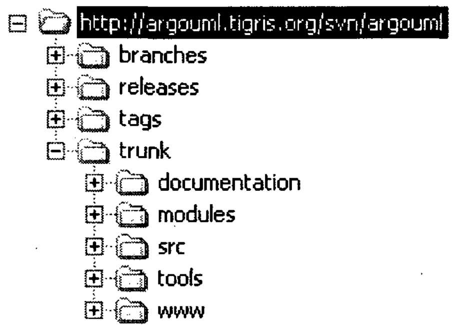


Figure 2- 4: An example of directory structure in SVN repository

Subversion supports add, delete, copy, and rename both files and directories. Every newly added file begins with a fresh and clean history of its own. Subversion provides consistent data handling by providing differences of the files in binary and human readable format. Subversion allows atomic commits; it stores complete collections of modification into repository.

Subversion uses a *copy-modify-merge* model as an alternative to locking. In this model, each user's client contacts the project repository and creates a personal working copy (i.e. a local reflection of the repository files and directories). Users then work simultaneously and independently to modify their private copies.

Finally, the private copies are merged together into a new, final version. The version control system provides support for merging, but ultimately, a human being is responsible for the final merging decisions.

Table 2-1 provides an overview of functionalities of some popular version control systems (including Subversion).

Features	Subversion	CVS	BitKeeper	Git
Atomic Commits	Commits are atomic.	CVS commits are not atomic.	need to verify	Commits are atomic.
Files / Directories Moves or Renames	Supported	Not supported.	Supported	Supported
Intelligent Merging after Moves or Renames	Partially supported.	Not supported.	Partially supported	Not supported
File and Directories Copies	Supported also utilized for branching.	Not supported.	Supported.	Not supported.
Remote Repository Replication	supported	supported	supported	very intrinsic feature of Git.
Propagating Changes to Parent Repositories	supported	Not supported	supported	supported
Repository Permissions	The WebDAV-based service supports defining HTTP permissions	Limited. "Pre-commit hook scripts"	FILL IN	No, but a single server can serve many repositories.
Change sets Support	Partial support. There are implicit change set that are generated on each commit.	Not supported Changes are file-specific.	Supported.	Supported
Branching and Merging	Sported	Not Supported	Supported	Supported
Tracking Uncommitted Changes	supported	supported	supported	supported
Command Set	A CVS-like command set.	A simple command set that includes (cvs commit, cvs update and cvs checkout) and several others.	A CVS-like command set	Command set is very feature-rich, and not compatible with CVS.
Portability	Excellent. Clients and Servers work on UNIX, Windows and Mac OS X.	Good. Client works on UNIX, Windows and Mac OS. Server	Very good. Binaries are available for most common UNIX systems and for Windows 98 and above.	The client works on most UNIXes, but not on native MS-Windows.
Web Interface	Supported verity of tools, more than any other version control system	Supported	Its own built-in web tool	Its own built-in web tool. Gitweb
Availability of Graphical User-Interfaces.	There are many available GUIs: RapidSVN (cross-platform), TortoiseSVN (Windows Explorer plug-in), Jsvn (Java), etc. development.	There are many available GUIs: WinCVS, Cervisia (for KDE), TortoiseCVS (Windows Explorer plug-in).	BitKeeper ships with several GUIs for performing common tasks.	Gitk is included in distribution. Qgit and Git-gui tools are also available.

Table 2- 1: Comparison of some version control systems [VEB09]

2.2.2. Bugzilla

Bugzilla [BUG09] is a bug or issue tracking system. Bug tracking systems allow individuals or groups of developers to keep track of outstanding problems with their product effectively.

History

Bugzilla was originally developed by Terry Weismann in a programming language called TCL to replace a rudimentary bug-tracking database used internally by Netscape Communications. Weismann later ported Bugzilla to Perl from TCL, and it remains in Perl to this day. Most of the commercial defect tracking software vendors at the time charged enormous licensing fees. Being an open source project, Bugzilla became a favorite of the open-source crowd (with its genesis in the open-source browser project, Mozilla) [BUG03]. Initially, Bugzilla was used to manage issues in the Mozilla Foundation projects. Now external projects (both open source and proprietary), can submit their bug reports too. It has become the de-facto standard defect-tracking system against which all others are measured.

Architecture and Functionality

Bugzilla is a web-based, open-source issue tracking tool. It is the most widely used web based tool to manage bugs. Bugzilla can also track enhancements, feature requests, and to-do items. Bugzilla allows individuals or groups of developers to keep track of outstanding problems with their product effectively.

The architecture of Bugzilla as a tool is rather simple. It requires an installed server and a database management system (PostgreSQL, MYSQL, etc.) to be operational. Further, Bugzilla requires a suitable release of Perl 5 along with a set of Perl modules for the installation and a mail transfer agent, such as Sendnote, qmail, Postfix or Exim.

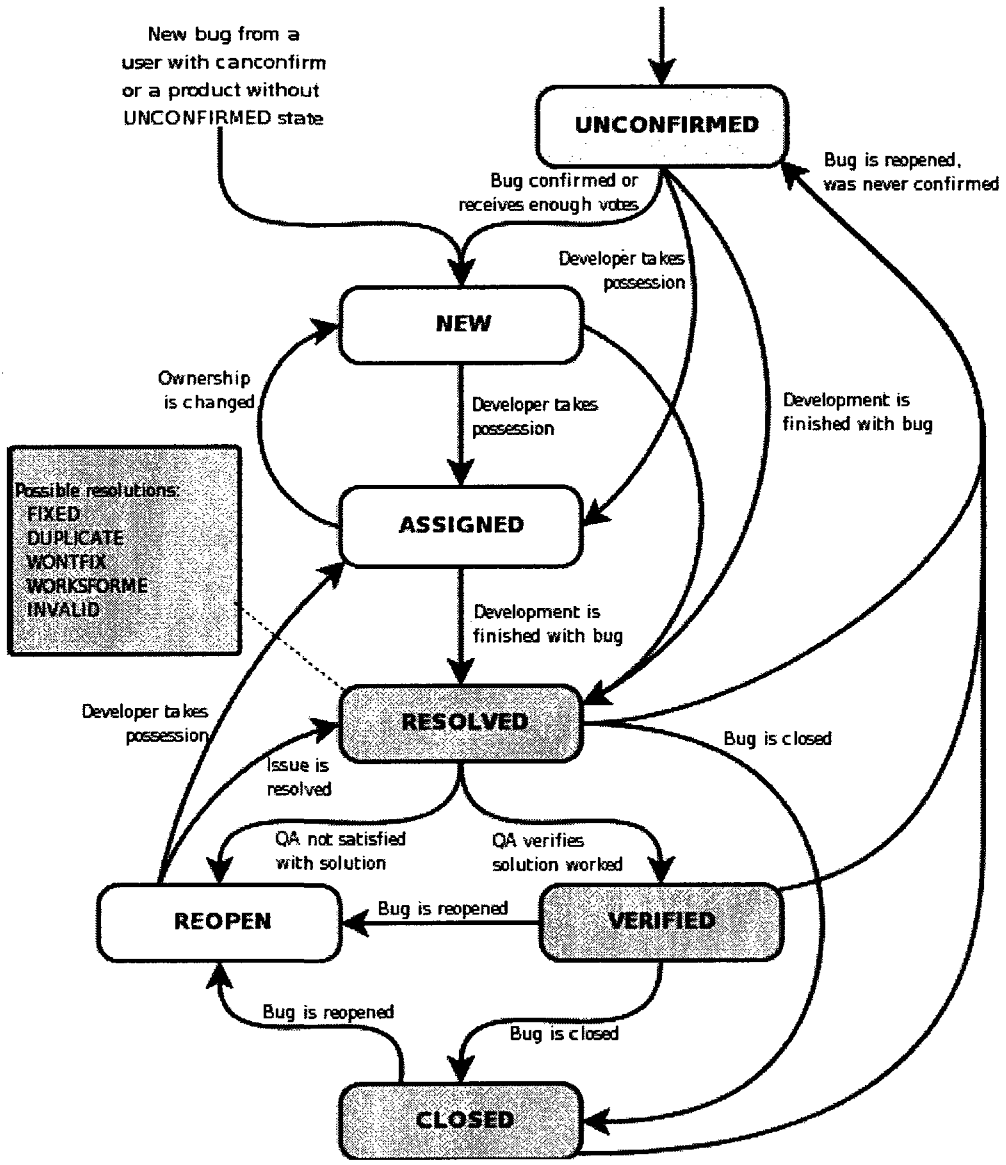

New bug from a user with canconfirm or a product without UNCONFIRMED state
UNCONFIRMED
Bug confirmed or receives enough votes
Bug is reopened, was never confirmed
Developer takes possession
NEW
Ownership is changed
Developer takes possession
Development is finished with bug
Possible resolutions: FIXED DUPLICATE WONTFIX WORKSFORME INVALID
ASSIGNED
Development is finished with bug
Developer takes possession
RESOLVED
Bug is closed
Issue is resolved
QA not satisfied with solution
QA verifies solution worked
REOPEN
Bug is reopened
VERIFIED
Bug is reopened
Bug is closed
CLOSED

Figure 2- 5: Life cycle of a bug [BU03A]

The central concept of the Bugzilla is the *issue*, all other information within the Bugzilla database being directly associated with an issue. As a result, issues cannot be merged, branched, or versioned. One issue can block another issue, which can be in a different state depending on the priority of bugs. Bugzilla is also used to file feature requests and enhancements.

Bugzilla follows the life cycle of the bug as shown in Figure 2-5. When a bug is submitted, it enters the state "new" as either confirmed or unconfirmed. Then it is assigned to a developer. When the developer has resolved the bug, it can either be verified, if the solution worked out, or it can be reopened if the solution was not satisfying. If a bug is verified it is closed.

This life cycle is currently hard-coded into Bugzilla. It manages the entire work-flow for a bug and defines clear states a bug goes through. Further, Bugzilla stores comments from different users, activities performed on the bug, and files attachments attached by users for the bug. Table 2-2 compares some popular bug tracking systems, including Bugzilla.

Bug Tracking System	**Integration with version control**	**Test Planning integration**	**Customizable Workflow**	**Unicode Support**	**LDAP user Authentication**
JIRA	ClearCase, AccuRev, Perforce, CVS, Subversion, Visual SourceSafe (beta)	Atlassian Bamboo (continuous integration & testing, via plug-in)	Supported	Supported	Supported
eTraxis			Supported, unlimited # of workflow templates	Supported	Supported
BugTracker. NET	Subversion	Supported	Supported	Supported	Supported
Debbugs	VCS Agnostic, DAK integration	Not Supported	Not Supported	Supported	N/A
Bugzilla	CVS, Subversion, Perforce, AccuRev	Testopia	Supported, as of Bugzilla 3. 2	Supported	Supported
Mantis	Supported, support for CVS, Subversion	Not Supported	Supported	Supported	Supported

Table 2- 2: Comparison of some bug tracking systems [WKB09]

2.3. Ontologies

Ontology is a specification of a conceptualization. In the context of computer and information sciences, ontology defines a set of representational primitives with which to model a domain of knowledge or discourse [GUR93]. The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members) [GUR93].

2.3.1. Why Ontology?

Ontologies have been widely used to conceptualize and define domains of interest. Ontologies include machine-interpretable definitions of basic concepts in the domain and relations among them. Why would someone want to develop an ontology?

Sharing common understanding of information structures among people or software agents is one of the more common goals in developing ontologies [MUS92, GUR93]. For example, several different web sites contain medical information or provide medical e-commerce services. If these web sites share and publish the same underlying ontology of the terms they all use, then computer agents can extract and aggregate information from these different sites. The agents can use this aggregated information to answer user queries or as input data to other applications.

Enabling reuse of domain knowledge was one of the driving forces behind recent development in ontology research. For example, models for many different domains need to represent the notion of time. This representation includes the notions of time intervals, points in time, relative measures of time, and so on. If one group of researchers develops such ontology in detail, others can simply reuse it for their domains. Additionally, if we need to build a large ontology, we can integrate several existing ontologies describing portions of the large domain.

Making explicit domain assumptions underlying an implementation makes it possible to change these assumptions easily if our knowledge about the domain changes. A hard-coding assumption about the world in programming-language code makes these assumptions not only hard to find and understand but also hard to change, in particular for someone without programming expertise. In addition, explicit specifications of domain knowledge are useful for new users who must learn what terms in the domain mean.

Separating domain knowledge from operational knowledge is another common use of ontologies. We can describe the task of configuring a product from its components according to a required specification and implement a program that does this configuration independent of the products and components themselves [MGW00].

Analyzing domain knowledge is possible once a declarative specification of the terms is available. Formal analysis of terms is extremely valuable for reusing existing ontologies and extending them [MGW98].

Ian [IAN07] illustrates some of the basic differences between ontologies and databases. Table 2-3 compares ontologies with databases observed by *Ian* [IAN07].

Ontologies	Databases
Open world assumption (OWA) • Missing information treated as unknown	Closed world assumption (CWA) • Missing information treated as false
No Unique name assumption (UNA) • Individuals may have more than one name	Unique name assumption (UNA) • Each individual has a single, unique name
Ontology axioms behave like implications (inference rules) • Entail implicit information	Schema behaves as constraints on structure of data. • Define legal database states
Ontology axioms play a powerful and crucial role • Answer may include implicitly derived facts • Can answer conceptual as well as extensional queries • Query answering amounts to theorem proving (i.e. logical entailment)	In Database querying, Schema plays no role • Data must explicitly satisfy schema constraints. • Query answering amounts to model checking (i.e. a "look-up" against the data).

Table 2- 3: Ontologies vs. databases [IAN07]

Uschold et al., [MUG04] also discuss some interesting differences between ontologies and databases. Table 2-4 describes the difference between databases and ontologies mentioned by [MUG04].

Ontologies	Databases
Ontologies have a range of purposes including interoperability, search, and software specification. One or more parties commit to using the terms from the ontology with their declared meaning.	The primary use of most DB schema is to structure a set of instances for querying a single database. This difference impacts heavily on the role of constraints.
For ontologies, constraints are called axioms. Their Main purpose is to express machine-readable *meaning* to support accurate automated reasoning. This reasoning can also be used to ensure integrity of instances in a knowledge base.	For databases, the primary purpose of constraints is to ensure the *integrity* of the data (*i.e.* instances). These 'integrity constraints' can also be used to optimize queries and help humans infer the meaning of the terms.
The main role for cardinality constraints in ontologies is to express meaning, and ensure consistency (either of the ontology, or of instances).	Cardinality and delete constraints are important Kinds of integrity constraints which have highly DBspecific uses those are outside the scope of most or all ontology systems.
support for taxonomic reasoning: it is fundamental for nearly all ontology applications	It is not supported by most DBMS.
Reasoning over ontologies normally is done by general logic-based theorem provers, specific to the language. The fundamental role of a reasoning engine is to derive new information via automated inference. Inference can also be used to ensure the logical consistency of the ontology itself.	Logical consistency through Reasoner is not supported by most DBMS.

Table 2- 4: Ontologies vs. databases [MUG04]

Robert et al. [RJS99] highlight some of the benefits of using ontologies as an enabling technology for interpersonal communication and inter-operability. For communication between people, an unambiguous but informal ontology may be sufficient. Inter-operability among computer systems can be achieved by translating between the different modeling methods, paradigms, languages, and software tools. The ontology is used as an interchange format.

Systems Engineering Benefits

Re-Usability: The ontology is the basis for a formal encoding of the important entities, attributes, processes and their inter-relationships in the domain of interest. This formal representation may be (or become through by automatic translation) a re-usable and/or shared component in a software system.

Search: Ontology may be used as meta-data serving as an index for a repository of information.

Reliability: A formal representation also makes possible the automation of consistency checking resulting in more reliable software.

Specification: The ontology can assist the process of identifying requirements and defining a specification for an IT system (knowledge based or otherwise).

Maintenance: The use of ontologies in system development, or as part of an end application, can render maintenance easier in a number of ways. Systems which are built using explicit ontologies serve to improve documentation of the software, which in turn reduces maintenance costs. Maintenance is also an important benefit if ontology is used as a neutral authoring language with multiple target languages - it only has to be maintained in one place.

Knowledge Acquisition: Speed and reliability may be increased by using an existing ontology as the starting point and basis for guiding knowledge acquisition when building knowledge-based systems.

Reasoning Services: Reasoning refers to the evaluation of ontologies according to their specifications, including:

- Checking consistency of the ontology
- Checking concept (and role) consistency
- Concept (and role) subsumption
- Instance checking
- Instance retrieval
- Query answering

2.3.2. Applications

Ontologies are part of the W3C standards stack for the Semantic Web, for which they are used to specify standard conceptual vocabularies to enable exchange of data among systems. Furthermore, they are the basis for providing services for answering queries, publishing reusable knowledge bases, and offering services to facilitate interoperability across multiple, heterogeneous systems and databases. The key role of ontologies with respect to database systems is to specify a data modeling representation at a level of abstraction above specific database designs (logical or physical), so that data can be exported, translated, queried, and unified across independently developed systems and services. Successful applications to date include database interoperability, cross database searches, and the integration of web services. Figure 2-6 shows an example of ontology.

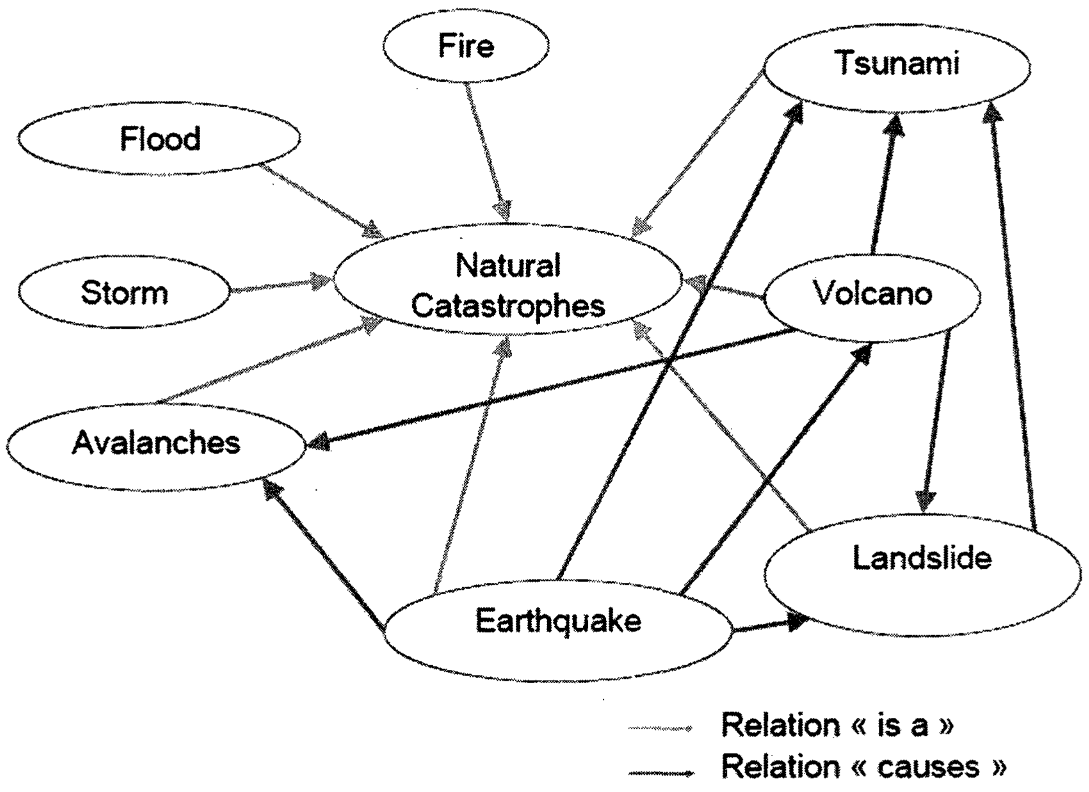


Figure 2- 6: An example of ontology [MAR09]

Robert et al. [RJS99] describe some ontology applications as follows:

Neutral Authoring: An information artifact is authored in a single language and is converted into a different form for use in multiple target systems. Benefits of this approach include knowledge reuse, improved maintainability, and long term knowledge retention.

Ontology as Specification: An ontology of a given domain is created and used as a basis for specification and development of some software. Benefits of this approach include documentation, maintenance, reliability, and knowledge re-use.

Common Access to Information: A piece of information is required by one or more persons or computer applications, but is expressed using unfamiliar vocabulary or in an inaccessible format. The ontology helps render the information intelligible by providing a shared understanding of the terms or by mapping between sets of terms. Benefits of this approach include inter-operability and more effective use and reuse of knowledge resources.

Ontology-Based Search: Ontology can be used for searching an information repository for desired resources (e. g. documents, web pages, names of experts). The chief benefit of this approach is faster access to important information resources, which leads to more effective use and reuse of knowledge resources.

2.3.3. Web Ontology Language OWL and SPARQL

OWL stands for Web Ontology Language. The OWL Web Ontology Language is designed for use by applications that need to process the content of information instead of just presenting information to humans [W3C09]. Following are the data formats supported by Web Ontology language.

- XML provides a surface syntax for structured documents, but imposes no semantic constraints on the meaning of these documents.

- XML Schema is a language for restricting the structure of XML documents and also extends XML with data types.

- RDF is a data model for objects ("resources") and relations between them. It provides simple semantics for this data model, and these data models can be represented in the XML syntax.

- RDF Schema is a vocabulary for describing properties and classes of RDF resources, with semantics for generalization-hierarchies of such properties and classes.

OWL is currently available in following three different types.

- OWL Full is the full specification of the language.
- OWL DL is a subset of OWL Full, making some restrictions to allow automated reasoning.
- OWL Lite is a subset of OWL DL as a simple-to-use, simple-to-implement version of OWL.

The OWL format has four major concepts to store information and its associations.

- Classes are abstract definitions of a single concept. Classes define possible associations and properties they can have. A class itself does not store concrete data. It only acts as a container concept.
- Individuals (also called instances) are the concrete realizations of a class. They can only have associations and store data in the defined manner of their respective class.
- Object properties define the associations between two classes (abstract) or two individuals (concrete). Object properties are directed associations and always

belong to a specific domain (i.e. the starting point of an association) and a range (i.e. the endpoint). Domain and range can both be a list of multiple Classes.

- Data type properties can be, like object properties, considered as associations. Unlike object properties, the range is not a list of classes but rather a predefined data type. Typically the data types of XML Schema [W3C, 2004b] are used.

SPARQL is the W3C standard query language for semantic web OWL/RDF data. In order to retrieve data using SPARQL, a triple template is defined in the query. The core idea is to leave the subject or object of a triple blank variable and the query engine will try to find all the triples matching this template.

It provides facilities to:

- Extract information in the form of URIs, blank nodes, plain and typed literals.
- Extract RDF sub graphs.
- Construct new RDF graphs based on information in the queried graphs.

2.3.4. Ontology editing tools

Protégé release 3.4

Protégé is a free, open-source platform that provides a suite of tools to construct domain models and knowledge-based applications with ontologies. Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protégé can be customized to provide domain-friendly support for creating knowledge models and entering data. Furthermore, Protégé can be extended by way of plug-in architecture and a Java-based

Application Programming Interface (API) for building knowledge-based tools and applications [PRG09].

TopBraid Composer (standard edition)

TopBraid Composer is an enterprise-class modeling environment for developing Semantic Web ontologies and building semantic applications. TopBraid Composer is implemented as an Eclipse plug-in. TopBraid Composer is a professional development environment for W3C's Semantic Web standards RDF Schema, the OWL Web Ontology Language, the SPARQL Query Language and the Semantic Web Rule Language (SWRL). Composer can be used to edit RDFS/OWL files in various formats and also provide scalable database back ends (Jena, AllegroGraph, Oracle 11g and Sesame) as well as multi-user support.

Composer provides a comprehensive set of features to cover the whole life cycle of semantic application development. In addition to being a complete ontology editor with refactoring support, Composer also can be used as a run-time environment to execute rules, queries, and reasoners. Based on Eclipse, Composer can also be extended with custom Java plug-ins. This supports the rapid development of semantic applications in a single platform.

2.3.5. Ontological Reasoners

An ontological reasoner is a piece of software able to infer logical consequences from a set of asserted facts or axioms. The notion of a semantic reasoner generalizes that of an inference engine by providing a richer set of mechanisms to work with. The inference rules are commonly specified by means of an ontology language, and often a description language. Many reasoners use first-order predicate logic to perform reasoning. The inference commonly proceeds by forward chaining and backward chaining [REA09].

Pellet reasoner

Pellet is an open source reasoner for OWL DL written in Java. It provides reasoning service for OWL ontologies. Pellet allows reasoning for semantically-enabled applications that need to represent and reason about information using OWL [PAL09]. Pellet is an OWL DL reasoner based on the tableaux algorithms developed for expressive Description Logics. It supports the full expressivity OWL DL including reasoning about nominal's (enumerated classes). The core of the Pellet reasoner is the tableaux reasoner that checks the consistency of a KB, (i.e. a pair of an ABox and a TBox). The reasoner is coupled with a data type oracle that can check the consistency of conjunctions of (built-in or derived) XML Schema simple data types. The OWL ontologies are loaded to the reasoner after a step of species validation and ontology repair. This step ensures that all the resources have an appropriate type triple (a requirement for OWL DL but not OWL Full) and missing type declarations are added using some heuristics. During the loading phase, axioms about classes (subclass, equivalent class or disjointness axioms) are put into the TBox component and assertions about individuals (type and property assertions) are stored in the ABox component. TBox axioms go through the standard preprocessing of DL reasoners before they are fed to the tableaux reasoner. Figure 2-7 shows the architecture of a Pellet reasoner.

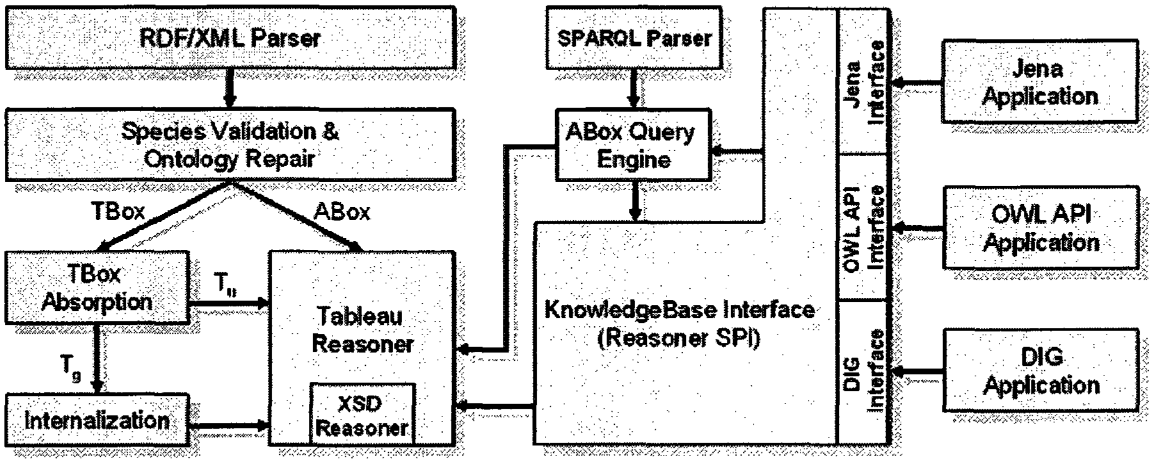


Figure 2- 7: Architecture of a Pellet reasoner [PL09A]

Jena Semantic Web Framework

Jena [JEN01] is an open-source Semantic Web framework developed in Java language. Jena framework is used to create and populate RDF models, to persist them to a database, and to query theses RDF models programmatically using SPARQ query language. Jena's reasoning service capabilities can be used to infer knowledge about models from ontology.

Table 2-5 compares some popular reasoners available.

	Pellet	KAON2	RacerPro	Jena	FaCT++	OWLIM
OWL-DL Entailment	Yes	Yes	Yes	No complete reasoner included with standard distribution	Yes	No
Supported expressivity for reasoning	SROIQ(D)	SHIQ(D)	?	varies by reasoner (incomplete for nontrivial description logics)	SROIQ(D)	R-entailment
Reasoning algorithm	Tableau	Resolution & Datalog	Tableau	Rule-based	Tableau	Rule-based
Consistency checking	Yes	?	Yes	Incomplete for OWL DL	Yes	No
DIG Support	Yes	Yes	Yes	Yes	Yes	No
Rule Support	Yes (SWRL -- DL Safe Rules)	Yes (SWRL -- DL Safe Rules)	Yes (SWRL -- not fully support SWRL)	Yes (Own rule format)	No	Yes (Own format)
Version	2. 0 RC5	Unknown	1. 9. 2	2. 5. 4	1. 1. 8	2. x/3. x
Licensing	Free/ open-source &	Free/ closed-source	Non-Free/ closed-source	Free/ open-source	Free/ open-source	Free/ open-source

Table 2- 5: Comparison of available reasoners [REA09]

2.3.6. Ontology Alignment

Aligning ontologies means "establishing links between two or more ontologies" and allowing the aligned ontologies to reuse information from one another [NFN07]. Aligning ontologies amounts to defining a distance between entities (which can be as reduced as an equality predicate) and computing the best match between ontologies, (i.e. the one that minimizes the total distance or maximizes a similarity measure) [JEP04]. Several methods are introduced by researchers to calculate distances between entities in ontologies [JEP04]:

- *Terminological* compares the labels of the entities.

- *String based* does the terminological matching through string structure dissimilarity (e. g., edit distance).
- *Internal structure comparison comparing* the internal structure of entities (e. g., the value range or cardinality of their attributes).
- *External structure comparison* compares the relations of the entities with other entities.
- *Taxonomical structure* compares the position of the entities within taxonomy.
- *Extensional comparison* compares the known extension of entities, i.e. the set of other entities that are attached to them (in general instances of classes).
- *Semantic comparison* compares the interpretations (or more exactly the models) of the entities.

The process of alignment creates a mapping between two input ontologies. The mapping is a set of anchors between the two ontologies (i.e. an edge connecting two elements of the ontologies).

3. Contribution

In this section we will first introduce the general motivation for our approach. We discuss the need for modeling and analysis of software repositories like bug trackers and version control systems. Next we will present the research hypothesis and the specific sub-goals which will be addressed as part of this thesis.

3.1. Motivation

According to Lehman, "a software system must evolve, or it becomes progressively less useful" [LEH97]. Software evolution involves both the comprehension and modification of existing software systems. Given the collaborative nature of software development, various software repositories like versioning systems and bug trackers are used to support the evolvability of the software system. When the software system evolves, changes made to source code and other documents are stored in software repositories. Software repositories contain valuable information about the development history of the software project. There is a great potential by mining and analyzing such historical information to support the evolution of software systems.

In recent years there has been a trend to use the information stored in these software repositories to provide the maintainers with additional support during the evolution of large software systems [CAC01, DTT05, GDM04, DMG04, TQG02, and HSK05].

For the detailed references we will discuss some efforts done in past to support software evolution.

As *Antoniol* [GIO04] states that, the software repositories like bug repositories and version control systems represent valuable sources of information to study software evolution. Version control systems can be mined to gain insights about the evolvability of a system by analyzing other properties like the size, complexity, and the amount of changes stored in the repository. Bug reporting systems on the other hand can provide additional insights on the reliability of a system, as well as the management of defects (e. g., average defect fixing rate and statistics about defect severity) [GIO04].

[AEH06] *Hassan et al.* came in their work to a similar observation, stating that mining historical information from software repositories can support both developers and managers in their endeavors to build and maintain complex software systems.

As pointed out in [JIM07], by mining and analyzing software repositories it is possible to recover traceability links among different repositories to support the evolvability of the software systems. Some of the potential applications for these traceability links are the support for impact analysis, software comprehension, and requirements assurance of high quality systems [JIM07]. Software repositories have also been analyzed in [BJM03, GHH98, DMG04VAR04, VR04S, ZTT05 and ZT05A] to support the prediction of software change.

Software repositories (i.e. SVN repository and Bugzilla repository) typically use different types of persistent storage and schemas, which makes it inherently difficult to share and link information among these repositories. The information gathered from these software repositories is not structured. It is not easy to interconnect traces related to the same artifact in different sources.

Among the challenges faced by researchers, one of the key challenges in mining and analyzing software repositories is that they lack a common representation. The lack of common representation does not allow for a semantic rich integration of these resources, and therefore limits the analysis support across the repository boundaries.

In order to address these challenges with respect to information integration and the analysis across repository boundaries, a common, semantic rich representation is needed to integrate the information from various software repositories. In this thesis we introduce a common ontological representation to support the mining and analysis of software repositories. The proposed common ontological representation will allow for efficient mining and analysis of software repositories (i.e. SVN and Bugzilla) to support software evolution.

Research Hypothesis

A common ontological representation can be established among software repositories to support the evolution of software systems.

3.2. Specific Contributions (Sub-goals) and Acceptance Criteria

The goal of our research is to provide a common ontological representation for software repositories for mining and analysis in order to support the evolution of software systems. We divide the general research goal into some more specific sub-goals to be addressed by this thesis:

Establishing a Common Ontological Representation

Software repositories, like versioning systems and defect tracking systems store valuable information for the evolution of a software project. The information stored in these repositories has a different format and representation. A user needs different tools to extract, integrate, and analyze the information stored in these repositories. For example, the SVN repository data can be retrieved through different client software available, such as *Tortoise SVN.* The Bugzilla repository information can be retrieved by the web interface tools provided by the Bugzilla installation. The information extracted from these repositories is in raw format. In order to process and analyze the raw data extracted from software repositories, as well as to identify the relationships and the dependencies between them, users require manual efforts and different types of analysis tools.

Nowadays, software development is a complex task; many large systems are interconnected with other systems. These systems produce a huge amount of information for software repositories. The process of extracting, combining, and analyzing such software repositories is more complex, time consuming, and requires much manual effort. In order to deal with the stated problems, we propose a common ontological representation based on the Web Ontology Language (OWL) in order to integrate the information from different software repositories.

The Web Ontology Language (OWL) provides a semantic rich and meaningful way to store the information extracted from the software repositories. Standard OWL processing tools allow for immediate processing of the information in terms of visualization, editing, querying, and debugging.

By using the OWL standard tools, there is no need to write the code or to use the complicated command line tools. Compared to other formats and tools, OWL enables treating of data based on its semantics.

A common representation for the software repositories allows analysis across software repository boundaries. Additionally, it allows analysis of the relationships and dependencies among different artifacts.

Automated Ontology Population

The process of connection, data extraction, and parsing raw data extracted from the different software repositories is a complex and a time consuming job. Since the software repositories store information in different formats, they need different types of connectivity profiles, as well as the tools for extraction and parsing the raw data.

We introduce an approach which automates the process of the connection, extraction, and refinement (i.e. the transformation of raw data) of the ontology population. The proposed automated approach will save the time consumed in the manual efforts, as well as provide a safe and error-free way to populate the ontology.

Implementation of an Automated Tool

In addition to a common ontological representation, we introduce the *SVN Ontologizer* and *Bugzilla Ontologizer* tools that provide automation for both data extraction from remote repositories and automated ontology population.

Mining and Analysis across the Repository Boundaries, in order to Support the Evolution of a Software System

As discussed earlier, software researchers have recognized the benefits of the mining software repository data. The information stored in software repositories is a valuable source to support the evolution of a software system. By mining the software repositories' information, we can improve the software design/reuse and recover the traceability links between different artifacts as well. The traceability links between the different artifacts can help to understand the relationships and dependencies among them.

As discussed in section 2, the one of the key aspects in software evolution is software comprehension. Our proposed common ontological representation supports bottom-up software comprehension. The bottom-up software comprehension approach is very useful for developers and maintainers, who have little or no knowledge of the existing software systems. The bottom-up approach helps the developers and the maintainers by gathering information from low level to abstract level. As mentioned in [BOT03], understanding is built from the bottom-up approach by reading the code and then mentally chunking or grouping these lines of code into higher-level abstractions. Analyzing software repositories across boundaries leads to better software comprehension.

The bottom-up approach to software comprehension primarily addresses situations where the developer or maintainer is unfamiliar with the domain. Several top-down models of software comprehension have been proposed to address the alternative situation, where the developer or maintainer has some previous domain exposure.

Analyzing the information stored in the software repositories also provides knowledge and understanding of:

- *Explicit concepts*, which are directly implemented in the source code as variables, executable code snippets, methods and classes.
- *Implicit concepts*, which are the assumptions that underlie parts of the code but are not directly implemented. For example, many applications assume that only one user is working with them; no specific code can be identified as the implementation of this single-user concept. If such an application is requested to support multiple users, programmers would have to change the implicit concept of the user to the explicit one, which requires substantial effort.

A common ontological representation allows for ease in the mining and analysis of the software repositories. Effective mining and analysis support the effective evolution of the software systems. Additionally, common ontological representation allows re-use of the information extracted from software repositories.

3.3. Acceptance Criteria

We expect our research hypothesis to hold if the following acceptance criteria can be validated:

- Establishing common ontological representation among software repositories
- Automated ontology population
- Implementation of SVN and Bugzilla Ontologizer tools
- Mining and analysis across the software repositories (i.e. SVN and Bugzilla repositories) in order to support the evolution of a software system.

4. Subversion Ontology

4.1. Subversion Ontology Design

For the design of the SVN ontology, we applied a three step development process. First, the existing schema of the SVN repository was extracted in order to identify and analyze the major concepts and their relationships modeled in the repository. Next, we applied a one-to-one mapping between the extracted relational SVN repository schema and an initial SVN ontology. In the last design step, we enriched and optimized our SVN ontology with new constraints and relations in order to be able to take advantage of ontology-specific modeling techniques and reasoning services.

4.1.1. SVN Repository Schema

Figure 4-1 provides an overview of the relational data schema extracted for the SVN repository. In what follows, we describe in more detail the modeled entities and relationships, since they are also going to be reflected in our ontological representation of the SVN repository.

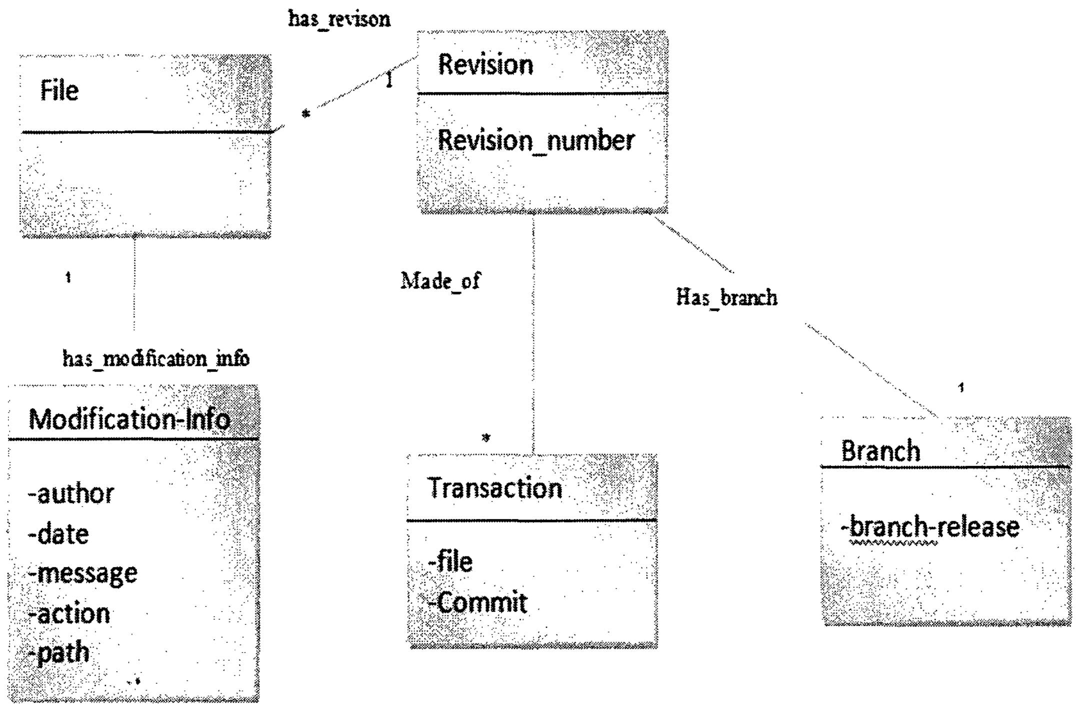


Figure 4- 1: SVN relational schema

The File-Revision Relation

The SVN repository manages both the directories (i.e. SVN branches/trunk) and the files that are committed to the repository. Within the relational data model, SVN does not distinguish between individual files or directories containing several files. Consequently, revisions, with revision number being the main attribute, are automatically associated through a many-to-one relation with the file entity. A file entity can have multiple revisions associated, whereby a particular revision belongs to a single file.

The Revision-Branch Relation

SVN supports the use of multiple parallel lines of development (branches). When a developer creates a branch in SVN, a new file is being created, yet the branch file remains invisible to the developer. Internally, SVN automatically creates a new sub-directory when a developer creates a branch. As a part of creating a branch, SVN creates first a transaction tree, then after a commit the transaction tree becomes a revision tree with the new branch as a sub-folder or file. The same procedure is applies for all commits performed.

The Revision-Transaction Relation

SVN defines what corresponds to a transaction as part of the relational schema. A transaction in SVN is used to distinguish uniquely a set of operations that lead to a new revision of a file. A transaction in SVN therefore represents a set of operations that apply to a file before the current revision number is updated.

The File-Modification-Info Relation

A modification report for a file in SVN can be extracted from the history log, which is available for each committed file. In SVN, a log corresponds to a listing of different modifications related to each revision of a file. SVN maintains the file and the modification information separately. As a result, the modification report log contains information about the particular action being performed (i.e. modified, added, deleted), the timestamps, the log message, the author, etc. for each revision.

4.1.2. Initial Mapping SVN Repository Schema to an Ontological Model

Description logic (DL) allows representing domain knowledge by defining relevant concepts called classes or *TBox [JRL06]*. As part of our ontological model for SVN, we define an initial *TBox* for our SVN ontology, which corresponds closely to a mapping of the existing SVN data repository schema. Figure 4-2 shows the resulting initial SVN ontology model. In order to define an initial TBox, we used Protégé release 3.4 ontology editor [PRG09]. The major entities are *files*, *releases*, and *revisions*. With every change to a file (commit) the revision- numbers increased to mark them as a new version. Older revisions of these files are still available and can be rolled back to. A revision represents the history of a specific file. A release combines a specific set of file revisions to a version that can be identified by its own unique name. For our initial ontological model we introduced three classes: revision, release, and file. We added a new concept, FileRevision, to our ontology model. The concept of a FileRevision is introduced to establish the relationship between File and Revision within a particular release.

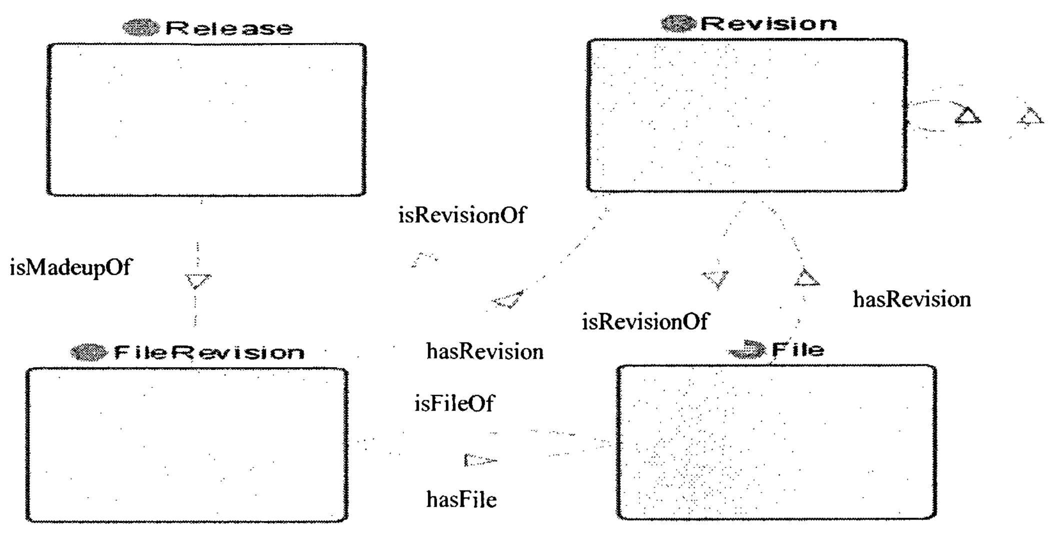


Figure 4- 2: An initial SVN ontology

Table 4-1 describes the main classes of our initial SVN ontology design.

Class Name	**Disjoint With**	**Description**
File	Revision, Release, FileRevision.	File from the file system
Revision	File, FileRevision, Release.	Revision denotes version of the file
Release	Revision, File, Release.	Tag with multiple Revisions and Files
FileRevision	Release, File, Revision.	Combination of File and Revision-number

Table 4- 1: Main classes of initial SVN ontology

Table 4-2 lists the various data properties modeled in the SVN ontology and a description of these properties. The data type properties allow the definition of the relations between instances of classes and RDF literals and XML Schema data types.

Name	Data Type	Domain	Description
State	String	File	The state describes the status of File in the Revision, (Added, Modified and Deleted)
creationDate	dateTime	Revision	Date when Revision was created
creationTime	dateTime	Revision	Time when Revision was created
fullPath	String	File	Full path of the File in SVN repository.
author	String	Revision	Name of the user who created this Revision
number	String	Revision	Revision-number
commitMessage	String	Revision	Text message entered at the time when Revision was created.
releaseDate	dateTime	Release	Time stamp for Release

Table 4- 2: Data type properties in SVN ontology

An object property is a binary relation between instances of two classes. In order to restrict the relation of an object property, we specified the domain and range for an object property. Table 4-3 illustrates the object properties introduced in the SVN ontology.

Name	Domain	Range	Inverse Property
hasFile	FileRevision	File	isFileOf
hasMadeRelease	FileRevision	Release	isMadeupOf
hasRevision	File or Release	Revision	isRevisionOf

Table 4- 3: Object properties in initial SVN ontology design

4.1.3. Enhanced SVN Ontology

As part of the ontological modeling approach, we further enriched and optimized our initial SVN ontology with additional constraints and relations in order to be able to take advantage of inference services provided by an ontological reasoner. The following enhancements to our initial SVN ontology were made: additional Object and Inverse Object Properties were introduced and we added new DL restrictions to existing concepts in order to allow us to take advantage of some reasoning services. Also, we added *functional* and *transitive* property types to the object properties and Inverse object properties.

Table 4-4 illustrates the additional object properties added in SVN ontology in order to take advantages of ontology reasoning services.

Name	Domain	Range	Inverse Property	Functional property	Transitive Property
hasLatestRevision	File	Revision	isLatestRevisionOf	Yes	Yes
hasNextRevision	Revision or File	Revision	hasPreviousRevision	Yes	Yes
hasFRevision	FileRevision	Revision	isFRRevisionof	Yes	
hasPreviousRevision	File	Revision			

Table 4- 4: Object properties added to enrich SVN ontology

Table 4-5 describes the main classes in SVN ontology and DL restriction applied on each class. The DL restrictions describe the relationships that must hold for members (individuals) of each class.

Class Name	Restrictions	Description
File	hasLatestRevision some Revision. hasRevision some Revision.	Existential restriction on class File necessarily hasLatestRevision some Revision and hasRevision some Revision.
Release	isMadeUpOf some FileRevision.	Existential restriction on class Revision necessarily isMadeupOf some FileRevision.
FileRevision	hasFile some File. hasFRevision some Revision.	Existential restriction on class FileRevision necessarily hasFile some File and hasFRevision some Revision.

Table 4- 5: DL restrictions applied to classes

Figure 4-3 provides an overview of the refined SVN ontology model including classes, data type properties, object properties, inverse object properties and their relationships.

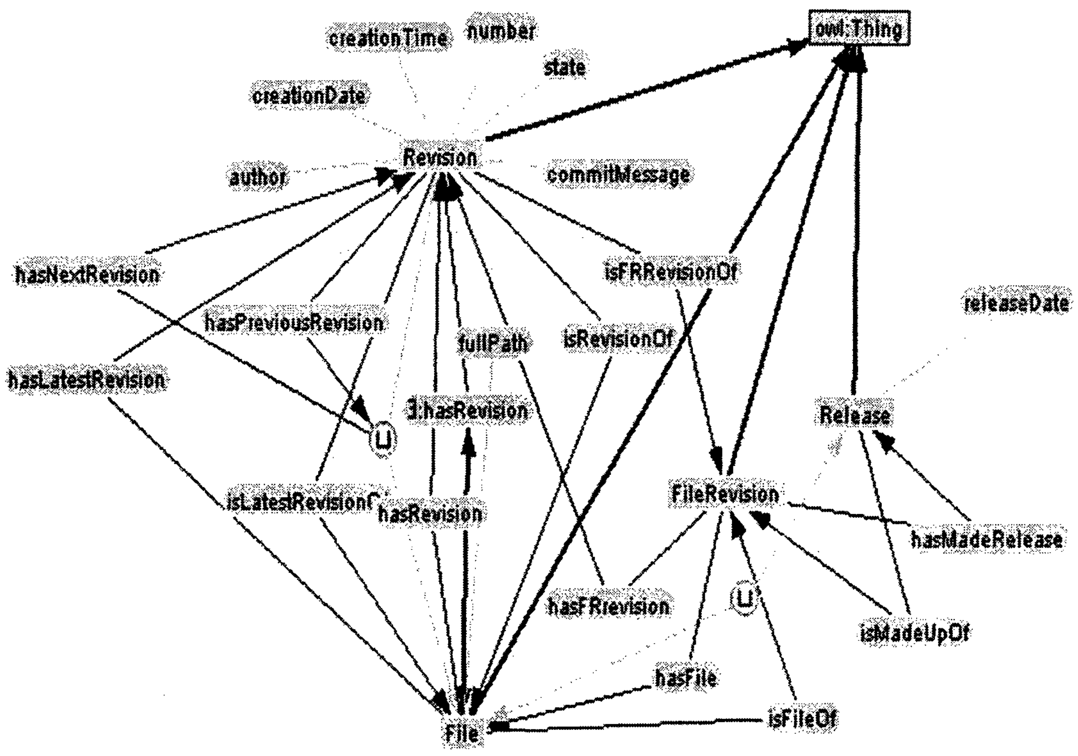
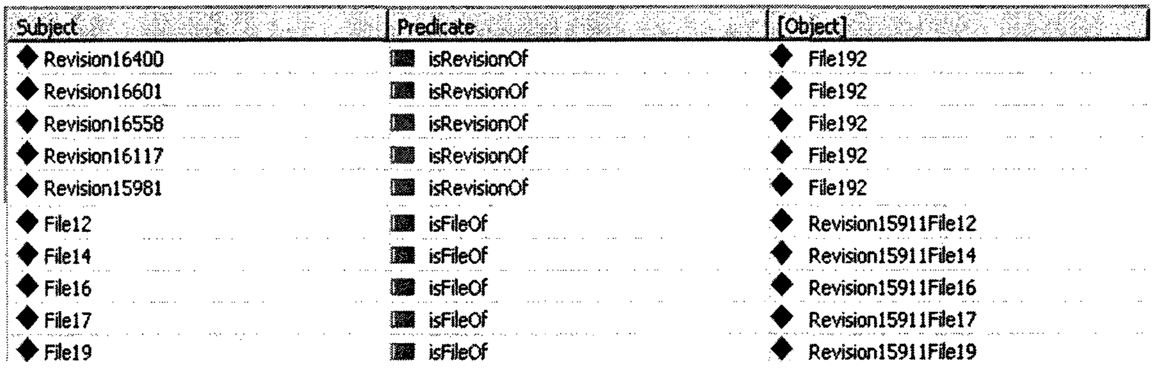


Figure 4- 3: Overview of an enhanced SVN ontology

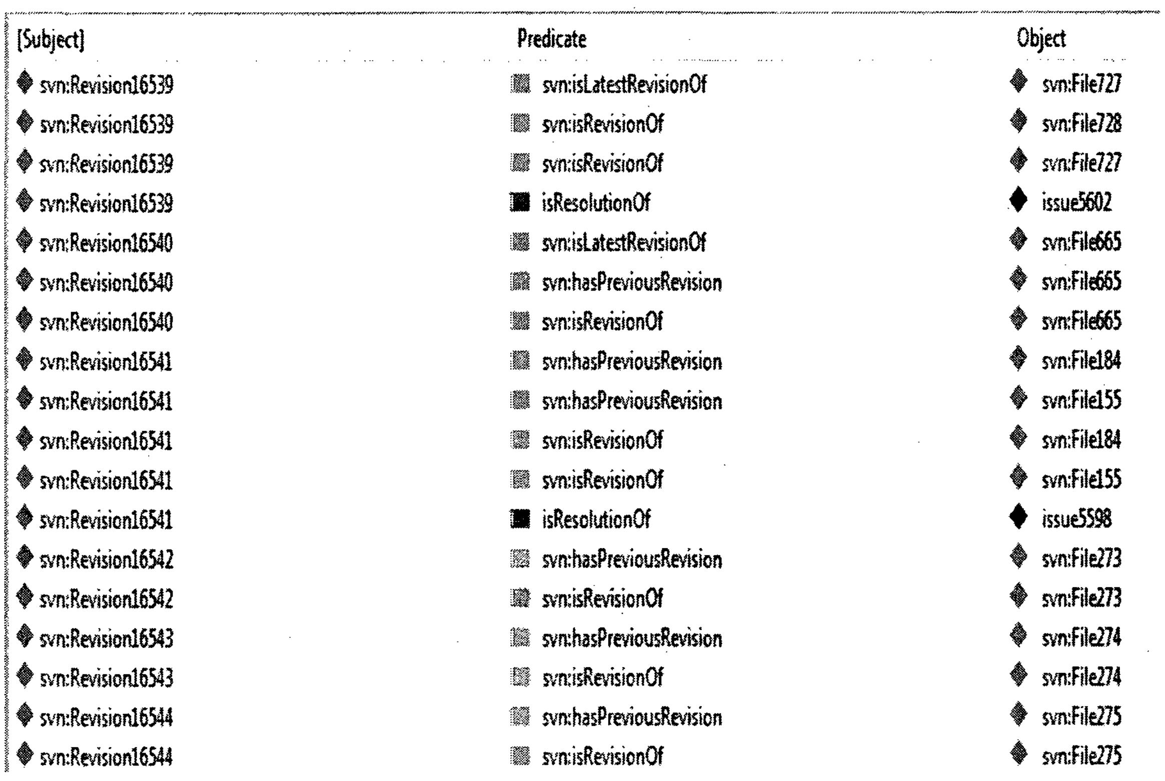
The DL restrictions on classes, the object and inverse object properties, and their types (i.e. functional property type and transitive property type) play a key role in reasoning, since some of the knowledge inference through the reasoner will be based on these object and inverse object properties. Our initial ontology design was almost one-to-one mapping with SVN repository schema. When we applied reasoning services to our initial ontology, the reasoner inferred no additional and /or interesting knowledge as shown in Figure 4-4.



Subject	Predicate	[Object]
◆ Revision16400	■ isRevisionOf	◆ File192
◆ Revision16601	■ isRevisionOf	◆ File192
◆ Revision16558	■ isRevisionOf	◆ File192
◆ Revision16117	■ isRevisionOf	◆ File192
◆ Revision15981	■ isRevisionOf	◆ File192
◆ File12	■ isFileOf	◆ Revision15911File12
◆ File14	■ isFileOf	◆ Revision15911File14
◆ File16	■ isFileOf	◆ Revision15911File16
◆ File17	■ isFileOf	◆ Revision15911File17
◆ File19	■ isFileOf	◆ Revision15911File19

Figure 4- 4: Reasoning services applied to initial SVN ontology model

After enriching and enhancing ontology models with new constraints, the reasoner inferred very useful knowledge like: links, relationship and dependencies of concepts as well as transitive relationships of the concepts. Figure 4-5 shows an example of inferred knowledge after enriching and enhancing initial SVN ontology model.



[Subject]	Predicate	Object
svn:Revision16539	svn:isLatestRevisionOf	svn:File727
svn:Revision16539	svn:isRevisionOf	svn:File728
svn:Revision16539	svn:isRevisionOf	svn:File727
svn:Revision16539	isResolutionOf	issue5602
svn:Revision16540	svn:isLatestRevisionOf	svn:File665
svn:Revision16540	svn:hasPreviousRevision	svn:File665
svn:Revision16540	svn:isRevisionOf	svn:File665
svn:Revision16541	svn:hasPreviousRevision	svn:File184
svn:Revision16541	svn:hasPreviousRevision	svn:File155
svn:Revision16541	svn:isRevisionOf	svn:File184
svn:Revision16541	svn:isRevisionOf	svn:File155
svn:Revision16541	isResolutionOf	issue5598
svn:Revision16542	svn:hasPreviousRevision	svn:File273
svn:Revision16542	svn:isRevisionOf	svn:File273
svn:Revision16543	svn:hasPreviousRevision	svn:File274
svn:Revision16543	svn:isRevisionOf	svn:File274
svn:Revision16544	svn:hasPreviousRevision	svn:File275
svn:Revision16544	svn:isRevisionOf	svn:File275

Figure 4- 5: Reasoning services applied to enriched and enhanced SVN ontology

The SVN ontology also needs to define its own namespace. A distinct namespace is required in order to be able to uniquely identify the ontology. This mechanism is a main pillar of the Semantic Web. In order to have multiple ontologies defined within the same domain, a complete URL is used to specify the namespace. The namespace for our SVN ontology is http://aseg.cs.concordia.ca/svn

4.2. SVN-Ontologizer

The SVN-Ontologizer tool was developed to support:

(1) The extraction of software version data from remote SVN repositories and

(2) The automated ontology population of the extracted SVN data into a corresponding SVN ontology.

Figure 4-6 provides a general overview of the SVN-Ontologizer tool and the steps involved in the SVN extraction and ontology population process.

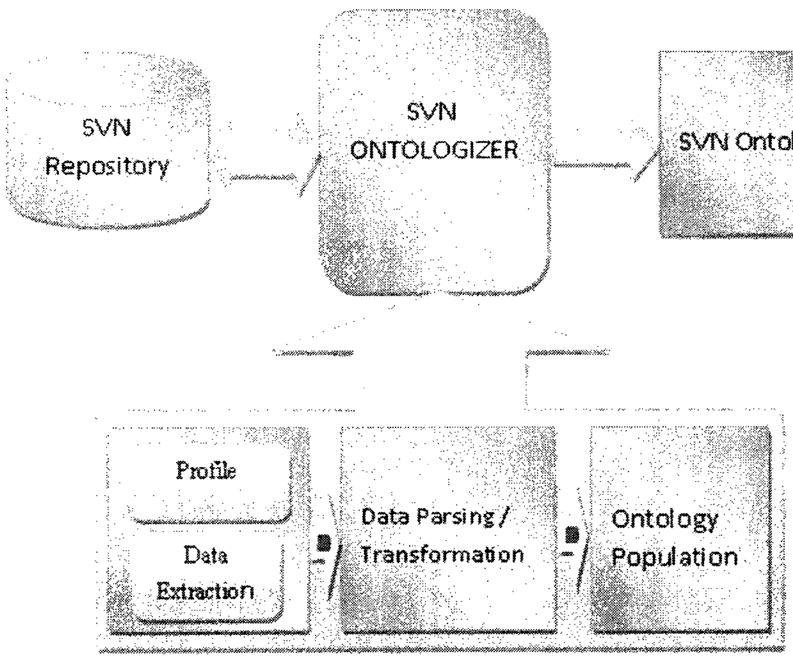
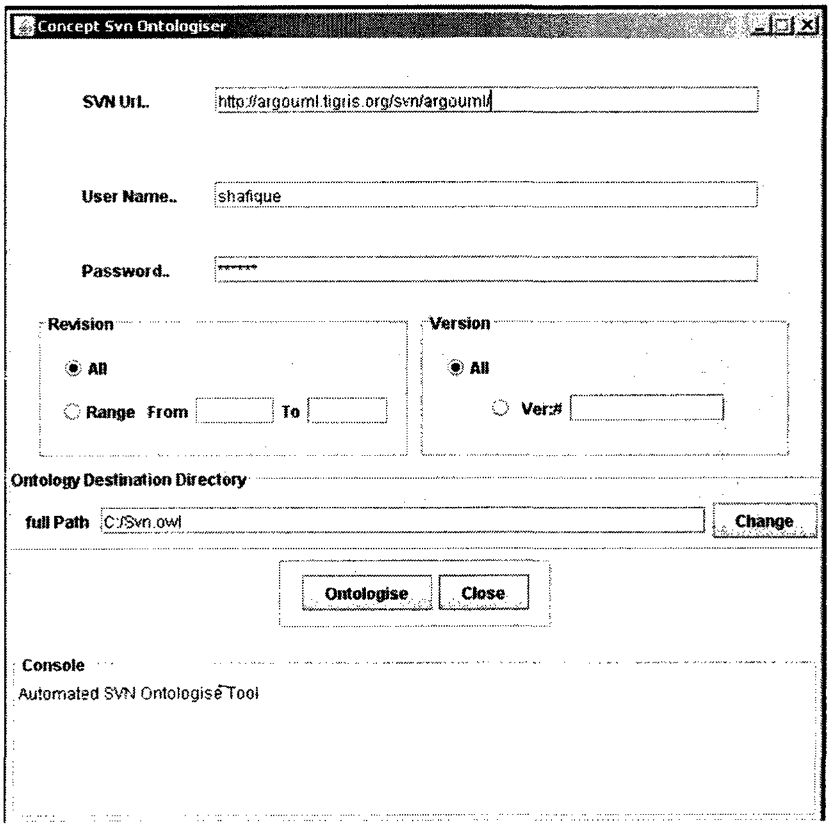


Figure 4- 6: SVN-Ontologizer tool overview

4.2.1. SVN Profile Setup

In order to establish a connection to a SVN repository, a user first has to set up a profile for the remote SVN repository (Figure 4-5). The profile includes the following information:

Repository location:	The repository location that is specified using one of two protocols: "svn://, svn+ssh://" or "http://, https://"
User credentials:	Required login and password information for the remote SVN repository server
Revision range:	A specific range of revisions to be extracted (optional all revisions)
Version range:	A specific range of versions to be extracted (optional all versions)
Ontology directory:	The user can also specify ontology name and directory where the ontology is going to be created



SVN Url.. http://argouml.tigris.org/svn/argouml/

User Name.. shafique

Password.. ******

Revision: [✓ All] Range From To

Version: [✓ All] Ver:#

Ontology Destination Directory

full Path C:/Svn.owl

Console

Automated SVN OntologiseTool

Figure 4- 7: SVN-Ontologizer main user interface

4.2.2. SVN Connection and Data Extraction

In the next step, access to the remote SVN repository is established by using the low level libraries provided by the SVNKit [SVK09]. The SVNKit provides an API to establish and manage remote access to a SVN repository. The SVN repository data can be accessed through the SVNKit using two different authentication protocols (shown in figure 4-8): (1) SVN specific protocols "svn/, svn+ssh" or (2) the standard "http and https" protocol [SV09A].

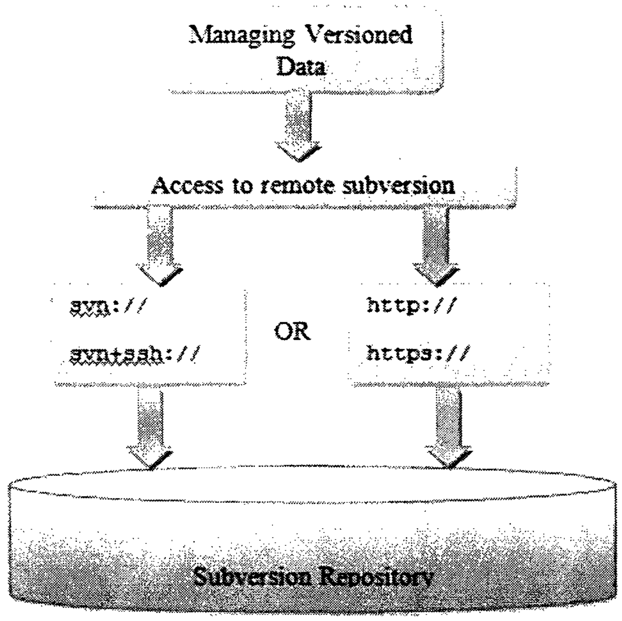


Figure 4- 8: SVN connection process

After a successful connection to the SVN server is established, the data extraction process for the *start revision* and *end revision* ranges specified in the profile is initiated. The raw data extracted from the SVN revision history consists of the following information:

revision: Denotes a revision number of the committed data

author:	Name of author or committer, who committed the revision
date:	Revision date when it was committed or created
log message:	Comments entered by author at the time of commit
changed paths:	Includes information with respect to:
	(a) The state of a file in the revision, denoted by the characters A, M or D, where "A" corresponds to Insertion, "M" to a Modification and "D" to a Deletion operation performed
	(b) The full file path, which could be either a change path within same branch or *copy path* from different branch

The following is an example of raw data extracted from the ArgoUML [ARG09] SVN repository.

```
revision: 1014
author: shafique
date: Wed Aug 03 21:19:55 NOV 2007
log message: upated panel view and input view
changed paths:
M /trunk/src/UI/interface. java
M /trunk/src/UI/input. html
M /trunk/src/main/new/org/Status. java
A /trunk/src/main/new/org/broad. java
```

The extracted data is stored in two binary files. The revision file contains information related to each revision (i.e. *revision number, author, date and log message*). The path file contains information related to the committed revision and actions performed on the file (i.e. *added, modified and deleted*), as well as the full path of the file in SVN repository.

4.2.3. Data Pre-processing

The extracted SVN data requires some pre-processing in order to support the automated population of the SVN ontology. The transformations are necessary to ensure that the extracted data can be represented in the OWL/RDF format.

Serialization

As part of the serialization process the following activities are performed:

- A unique identification is assigned to the paths associated with specific revisions.
- Revision numbers are serialized and duplicate entries of the same paths are eliminated.
- A memory model corresponding to the ontological representation is created to store serialized information.

Elimination of invalid characters

Some of the SVN data (in particular the SVN log messages) contains characters that are not supported by the OWL/RDF format; these invalid characters have to be removed. As part of the clean-up process, we replacing all invalid characters with characters supported by OWL/RDF format. Table 4-6 illustrates some of the substitutions that are performed as part of the data clean-up.

Non-valid characters	Replaced with
Ü	U
Ÿ	Y
<	-
>	-
Ö	O
Æ	a
&	and
Ï	I
Ñ	I

Table 4- 6: Substitution of invalid characters

4.2.4. Ontology population

In the last step the pre-processed and normalized SVN data in the memory will be used to automatically populate our SVN ontology. In order to populate our SVN ontology, first we write SVN ontology TBox into the RDF/OWL file. In the second step we write ABox containing instances (i.e. loaded in memory models) as per TBox specifications in the form of RDF triples.

The RDF triples consist of two pieces of data that are linked by a named relationship. The RDF triple is a simple statement about the truth of some proposition. RDF distinguishes two kinds of elements that can appear in triples, literals and resources. A *literal* is a piece of data which can be an integer, a string, a floating-point number, or even an XML structure. A *resource* in RDF identifies something (or someone) about which we make semantically meaningful statements.

5. Bugzilla Ontology

5.1. Bugzilla Ontology Design

For the design of our Bugzilla ontology, again a 3 step ontology design approach was applied. First we analyzed the Bugzilla repository relational data schema in order to identify the major concepts stored in the repository and the relationships among them. Secondly we created an initial ontological model for the Bugzilla repository by mapping existing tables and relations found in the Bugzilla repository to their ontological equivalents. This mapping resulted in an almost one-to-one mapping between the relational Bugzilla schema and our initial Bugzilla ontology. In the last step we enriched the Bugzilla ontology with new constraints and relations in order to be able to take advantage of the ontological representation and reasoning services.

5.1.1. Bugzilla Repository Schema

Figure 5-1 provides an overview of the relational data schema extracted from the Bugzilla repository [BUG03]. In what follows we provide a more detailed description of the major entities and their relationships in the Bugzilla schema.

Issue - Person (Many-to-Many Relationship)

The issue entity has a relation with three types of persons (i.e. reporter, assignee, and cc person). The *reporter* is the person who submits the bug to the bug repository. The assignee is the person responsible for the submitted bug. It is however possible that an *assignee* also submits a bug, which makes him/her a reporter as well. A *cc person* is the person to whom the bug was forwarded for resolution, review, or comment. The assignee, reporter and cc person types correspond to roles of the person, and can therefore be added to the entity person. The multiplicity of the relation between person and issue is many-to-many, with an issue having potentially multiple persons assigned to it. Likewise, a person can contribute to more than one issue.

Person - Comment, Attachment and Activity Relation (Many-to-One Relationship)

A person that contributes to a bug is a creator of a comment, attachment or an activity. The comment entity has a many-to-one relation with the person entity, since a person can write more than one comment, where as a comment can be written by only one person at a time. The same holds for the activity and attachment entities.

Issue - Comment (One-to-Many Relationship)

A *comment* entity contains information such as comment number, a time stamp, and the comment text. A comment provides additional information that is directly related to an issue. On the other hand, an issue can have multiple comments associated. The resulting relationship between issue and comment is therefore one-to- many.

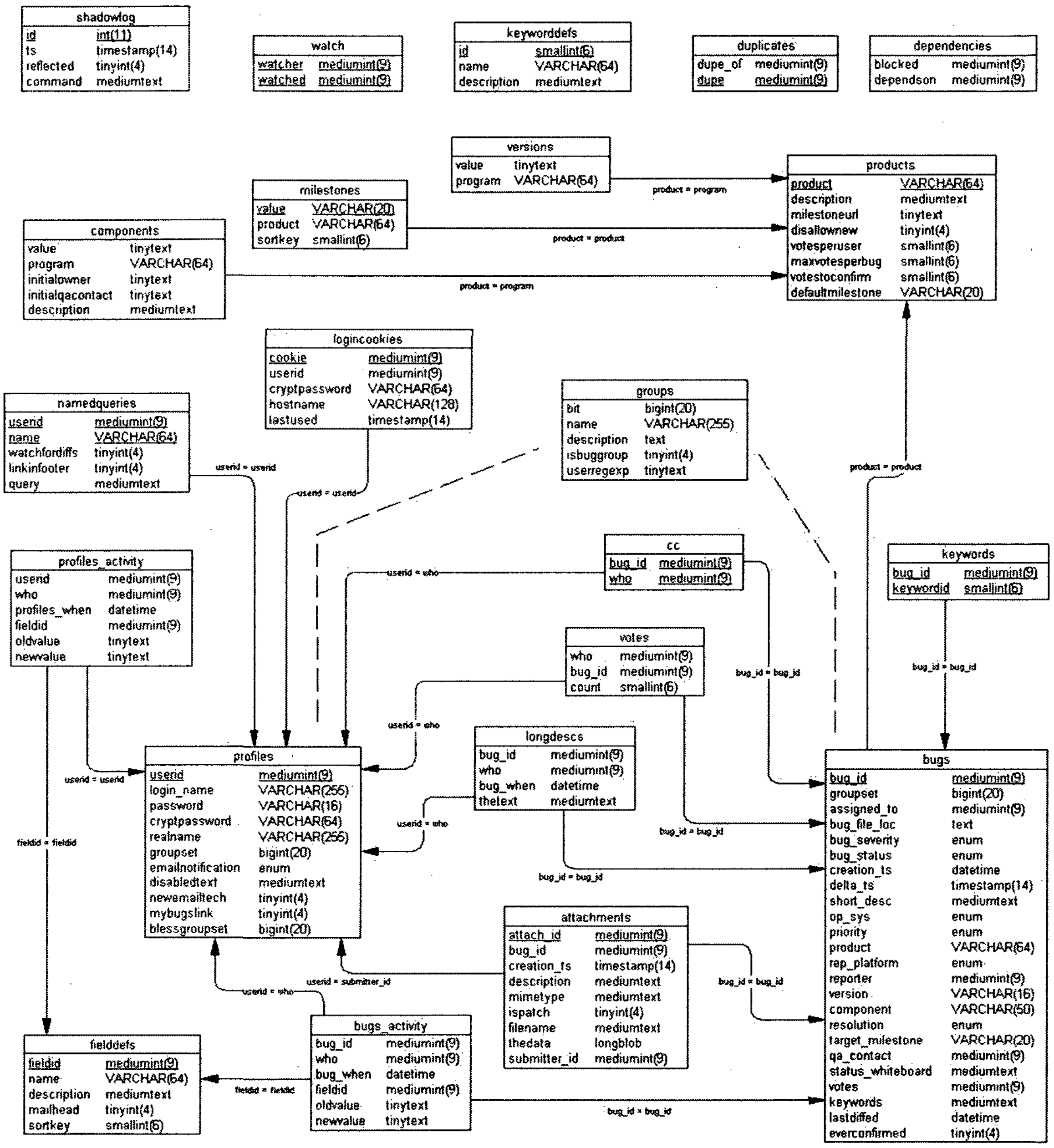


Figure 5- 1: Bugzilla repository schema

Issue – Attachment (One-to-Many Relationship)

An *attachment* (usually in the form of a file) provides additional information related to a particular issue. The attachment entity contains information such as the type of the attachment, the date of attachment, and a short description of the attached file. The relation between an issue and attachment is one-to-many, where an issue can have more than one file attachment associated but an attachment can only be linked to a single issue.

Issue - Activity (One-to-Many Relationship)

Issues in Bugzilla are strictly bound to bug life cycle. As part of the bug life cycle, each reported issue is required to have an *activity* associated with it. An activity relates to changes that modify the status of an issue. The activity provides a detailed record of all the changes and contributions to an issue including comments added, status changes, etc. An activity therefore provides relevant information with respect to the history of an issue. The multiplicity of the relation between issue and activity is one-to-many. An issue can have multiple activities associated, whereas an instance of an activity can only be linked to a single issue.

Issue - Dependency Relation

Some *issues* can depend on or block one another. The dependency relation is normally two sided (i.e. "Depends on" and "Blocks"). In order to illustrate such an issue dependency, we consider three issues (issue1, issue2, and issue3) shown in Figure 5-2. In this scenario, issue1 depends on issue2 and issue3. In other words, the resolution of issue1 depends on the prior resolution of issue2 and issue3. On the other hand, in this scenario, issue3 blocks issue2 and issue1.

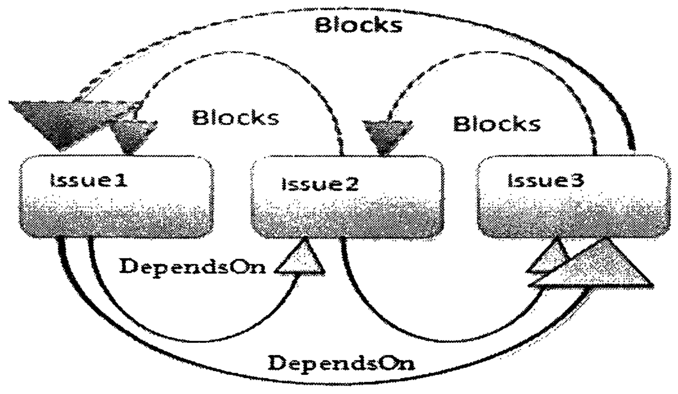


Figure 5- 2: An example of issue dependency

Issue- Milestone Relation (One-to-Many Relationship)

Milestones correspond to dates on which a developer plans to have a certain set of issue fixed. The multiplicity of the relation between issue and milestone is many-to-one, with a milestone typically involving more than one issue, whereas an issue has to be dealt with as part of a milestone.

Issue-ComputerSystem Relation (Many-to-Many Relationship)

The *ComputerSystem* contains hardware- and software-related information associated with a particular issue. The multiplicity of the relation is many-to-many; an issue can occur on different computer systems and a computer system can have different issues associated.

From the above schema description, one can identify that the issue entity plays a key role in the Bugzilla schema. A new instance of an issue is created each time, when a user reports a new bug or submits a feature request. The following information is always part of an issue to describe its details.

Issue number:	A unique issue identification number.
URL:	A location, where additional information about the bug can be found.
Summary:	A short description of the issue.
Priority:	Used by the assignee to prioritize the issue.
Date opened:	Timestamp when the issue was submitted.
Status:	Status of an issue in the bug lifecycle.
Resolution:	Indicates what happened to particular issue in bug lifecycle.

5.1.2. Mapping Bugzilla Repository Schema to an Ontological Model

As part of our ontological model for the Bugzilla repository, we define an initial TBox by mapping the Bugzilla repository entities to an initial set of concepts in the Bugzilla ontology. Figure 5-3 shows the resulting Bugzilla ontology model, which consists of eight classes: issue, comments, activity, attachment, ComputerSystem, milestone, component and product. The *product* refers to a component as disused earlier, and *component* refers to a subsection of the product.

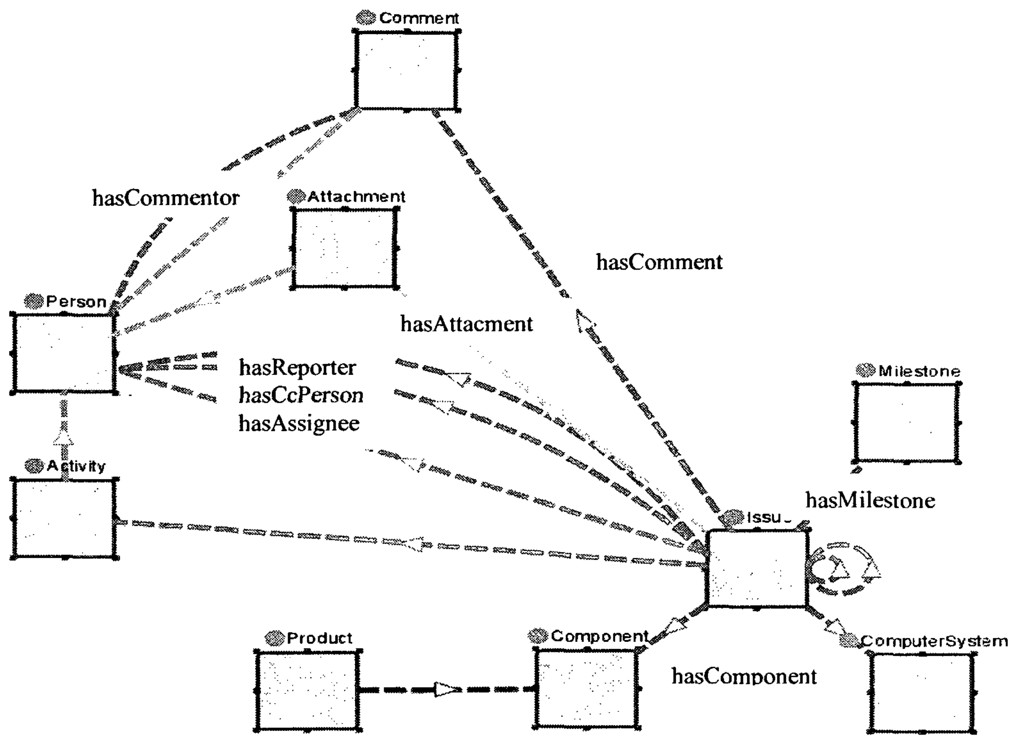


Figure 5- 3: Initial Bugzilla ontology model

Table 5-1 describes the main classes and their usage.

Class	Description
Issue	An Issue is an entity defining a certain topic concerning the development of a software system. An issue can be classified or discussed.
Activity	Activities form a certain kind of log, tracking the changes occurring to an Issue
Comment	A comment on a certain Issue
Attachment	Attachments are files sent in together with the Issue's text or a comment
Person	Person could be commenter, assignee of an issue, involved person in activity, cc person of an issue, reporter of an issue, an person attached file to issue
Component	A Component of the software system an Issue may refer to
Milestone	A Milestone refers to a planned version of a software system
Product	A Product is a functionally of a software system
Attachment	Attachments are files sent in together with the Issue's text or a comment
ComputerSystem	A ComputerSystem is the definition of an execution environment

Table 5- 1: Bugzilla ontology classes

Table 5-2 provides a description of data-type properties modeled in the Bugzilla ontology, their type, and associated domain.

Data Type Property	**Type**	**Domain**	**Description**
what	String	*Activity*	Element affected in Activity
performed	dateTime	*Activity*	Date and time when this activity took place
removed	String	*Activity*	The part that was removed during this activity
added	String	*Activity*	The part that was added during this activity
fileName	String	*Attachment*	The filename of the attachment
type	String	*Attachment*	The file type of this attachment. For example: gif, txt
text	String	*Comment*	Text part of comment
date	dateTime	*Comment*	The date when this comment was added
platform	String	*ComputerSystem*	A computer system's platform
OS	String	*ComputerSystem*	The operating system
status	String	*Issue*	The state of an issue
priority	String	*Issue*	The priority of the issues' fixing
dateOpened	dateTime	*Issue*	Date on which issue was reported
description	String	*Issue*	A description of the Issue
resolution	String	*Issue*	There can be different reasons why a bug is closed and therefore inactive
number	Integer	*Issue, Comment*	The number of an Issue an a comment describes its unique identifier
version	String	*Product*	Version of this Product

Table 5- 2: Data type properties in the Bugzilla ontology

Table 5-3 describes the *object properties* modeled as part of the Bugzilla ontology. The description includes the concept, the supported domain and range.

Object Property Name	Domain	Range
blocks	Issue	Issue
hasActivity	Issue	Activity
hasAssignee	Issue	Person
hasAttachment	Issue	Attachment
hasCcPerson	Issue	Person
hasComment	Issue	Comment
hasCommentor	Comment	Person
hasComponent	Product	Component
hasComputerSystem	Issue	ComputerSystem
hasCreator	Attachment or Comment	Person
hasInvolvedPerson	Activity	Person
hasMilestone	Issue	Milestone
hasReporter	Issue	Person
hasResolution	Issue	Revision (concept from Aligned SVN Ontology)

Table 5- 3: Object properties of Bugzilla ontology

5.1.3. Refining the Bugzilla Ontology

In order to take advantage of the ontological model and reasoning services, the Bugzilla ontology structure was refined with additional constraints and relations. The following tables (Table 5-4 to 5-6) list some of the major modifications made to the initial Bugzilla ontology:

(1) An additional Inverse Object Properties were introduced.

(2) New DL restrictions to concepts in our initial design were introduced.

(3) We added a functional property and transitive property type to both the Object Properties and Inverse Object properties.

Table 5-4 describes the additional constraints added in order to enrich and enhance Bugzilla Ontology.

Class	**Disjoints with**	**DL Restrictions**	**Description**
Issue	None	hasAssignee some Person hasComment some Comment hasReporter some Person	Existential restriction on class Issue necessarily hasAssignee some Person and hasComment some Comment.
Activity	Component, Product, Milestone, ComputerSystem, Attachment, Resolution, Comment	None	Disjoint classes
Comment	Component, Activity, Product, ComputerSystem, Milestone, Attachment, Resolution	hasCommnetor some Person isCommentOf some Issue	Existential restriction on class Comment necessarily hasCommentor some Person and isCommentOf some Issue
Attachment	Component, ComputerSystem, Activity, Product, Milestone, Resolution, Comment	hasCreator some Person isAttachmentOf some Issue	Existential restriction on class Attachement necessarily hasCreator some Person and isAttachementOf some Issue
Component	Activity, Product, Milestone, Attachment, ComputerSystem, Resolution, Comment	None	Disjoint classes
Milestone	Component, Activity, Product, ComputerSystem, Attachment, Resolution, Comment	None	Disjoint classes
Product	Component, Activity, Milestone, Attachment, Resolution	None	Disjoint classes

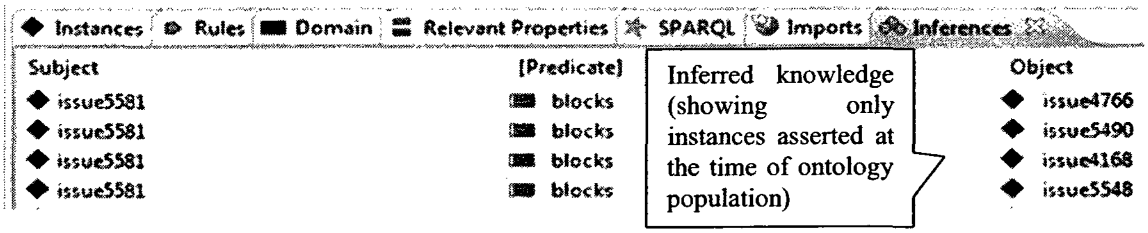
Table 5- 4: Bugzilla ontology classes

Table 5-5 describes the inverse object properties introduced for the object properties and property types (i.e. functional and transitive property type) as part of the Bugzilla ontology. The description includes the concept, the supported range, and their inverse property. The object properties and their types (i.e. functional property type and transitive property type) play a key role in order to utilize reasoning services.

Object Property Name	**Property Type**	**Inverse Property**	**Property Type**
blocks	Transitive Property	dependsOn	Functional Property Transitive Property
hasActivity	None	isActivityOf	Inverse Functional
hasAssignee	Functional Property	isAssigneeOf	Inverse Functional
hasAttachment	None	isAttachmentOf	Inverse Functional
hasCcPerson	None	isCcpersonOf	
hasComment	Functional Property	isCommentOf	Inverse Functional
hasCommentor	Functional Property	isCommentorOf	Inverse Functional
hasComponent	Functional Property	isComponentOf	Inverse Functional
hasComputerSystem	None	isComputerSystemOf	Inverse Functional
hasCreator	Functional Property	isCreatorOf	Inverse Functional
hasInvolvedPerson	Functional Property	isInvolvedPerson	Inverse Functional
hasMilestone	Functional Property	isMilestoneOf	Inverse Functional
hasReporter	Functional Property	isReporterOf	Inverse Functional
hasResolution	None	isResolutionOf	None
hasIssue	Functional Property Transitive Property	isIssueOf	Inverse Functional

Table 5- 5: Object properties of Bugzilla ontology

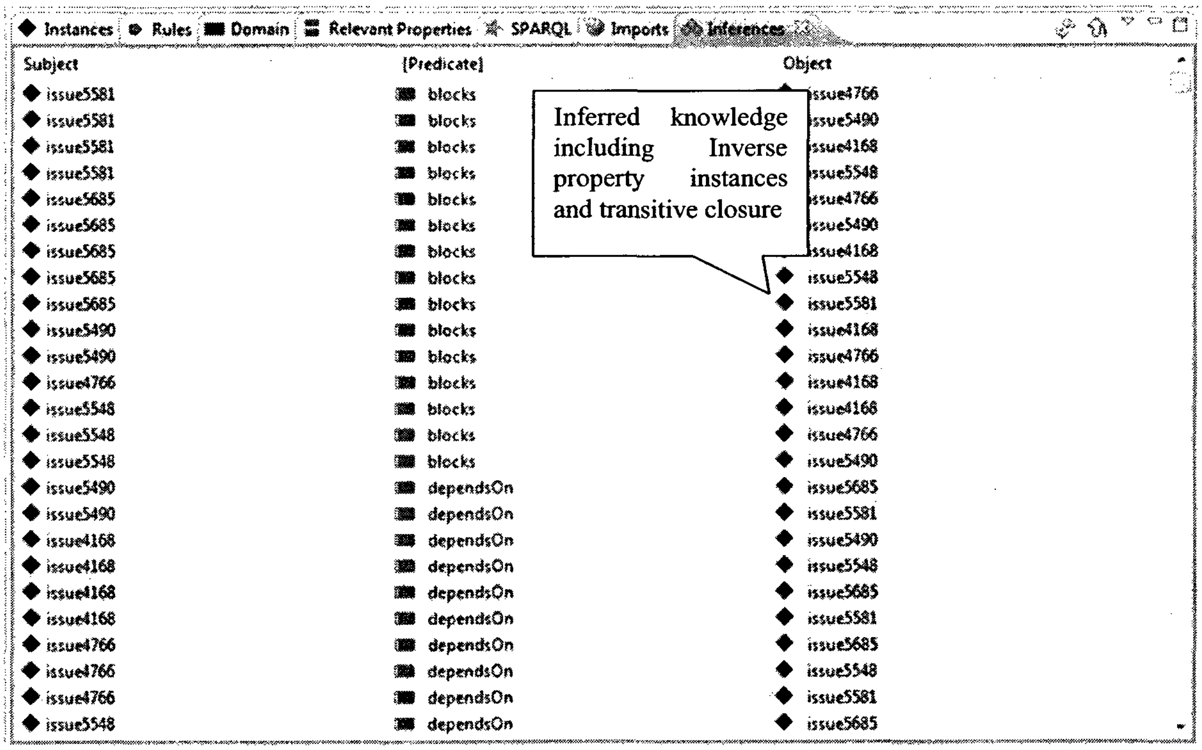
Figure 5-4 shows the example of reasoning services applied on initial Bugzilla ontology.


Instances
Rules
Domain
Relevant Properties
SPARQL
Imports
Inferences
Inferred knowledge (showing only instances asserted at the time of ontology population)

Subject	[Predicate]	Object
issue5581	blocks	issue4766
issue5581	blocks	issue5490
issue5581	blocks	issue4168
issue5581	blocks	issue5548

Figure 5- 4: Reasoning services applied to initial Bugzilla ontology

Figure 5-5 shows the knowledge inferred by the reasoner after enrichment and enhancement of an initial Bugzilla ontology design.


Instances
Rules
Domain
Relevant Properties
SPARQL
Imports
Inferences
Inferred knowledge including Inverse property instances and transitive closure

Subject	[Predicate]	Object
issue5581	blocks	ssue4766
issue5581	blocks	ssue5490
issue5581	blocks	ssue4168
issue5581	blocks	ssue5548
issue5685	blocks	ssue4766
issue5685	blocks	ssue5490
issue5685	blocks	ssue4168
issue5685	blocks	issue5548
issue5685	blocks	issue5581
issue5490	blocks	issue4168
issue5490	blocks	issue4766
issue4766	blocks	issue4168
issue5548	blocks	issue4168
issue5548	blocks	issue4766
issue5548	blocks	issue5490
issue5490	dependsOn	issue5685
issue5490	dependsOn	issue5581
issue4168	dependsOn	issue5490
issue4168	dependsOn	issue5548
issue4168	dependsOn	issue5685
issue4168	dependsOn	issue5581
issue4766	dependsOn	issue5685
issue4766	dependsOn	issue5548
issue4766	dependsOn	issue5581
issue5548	dependsOn	issue5685

Figure 5- 5: Reasoning services applied to enhanced Bugzilla ontology

Figure 5-6 provides an overview of the refined Bugzilla ontology. In addition to classes, object and data type properties, the Bugzilla ontology needs to define its own namespace. A distinct namespace is required in order to be able to uniquely identify the ontology.

This mechanism is a main pillar of the Semantic Web. In order to have multiple ontologies defined in the same domain name, a whole URL can be used to define a namespace more specifically. Although a URL usually hosts a web page, this is not necessary for a namespace. The namespace for our Bugzilla ontology is http://aseg.cs.concordia.ca/bug. As part of the ontology population, we populated the ABox. In order to populate the Bugzilla ontology, we assert instances of concept and their roles.

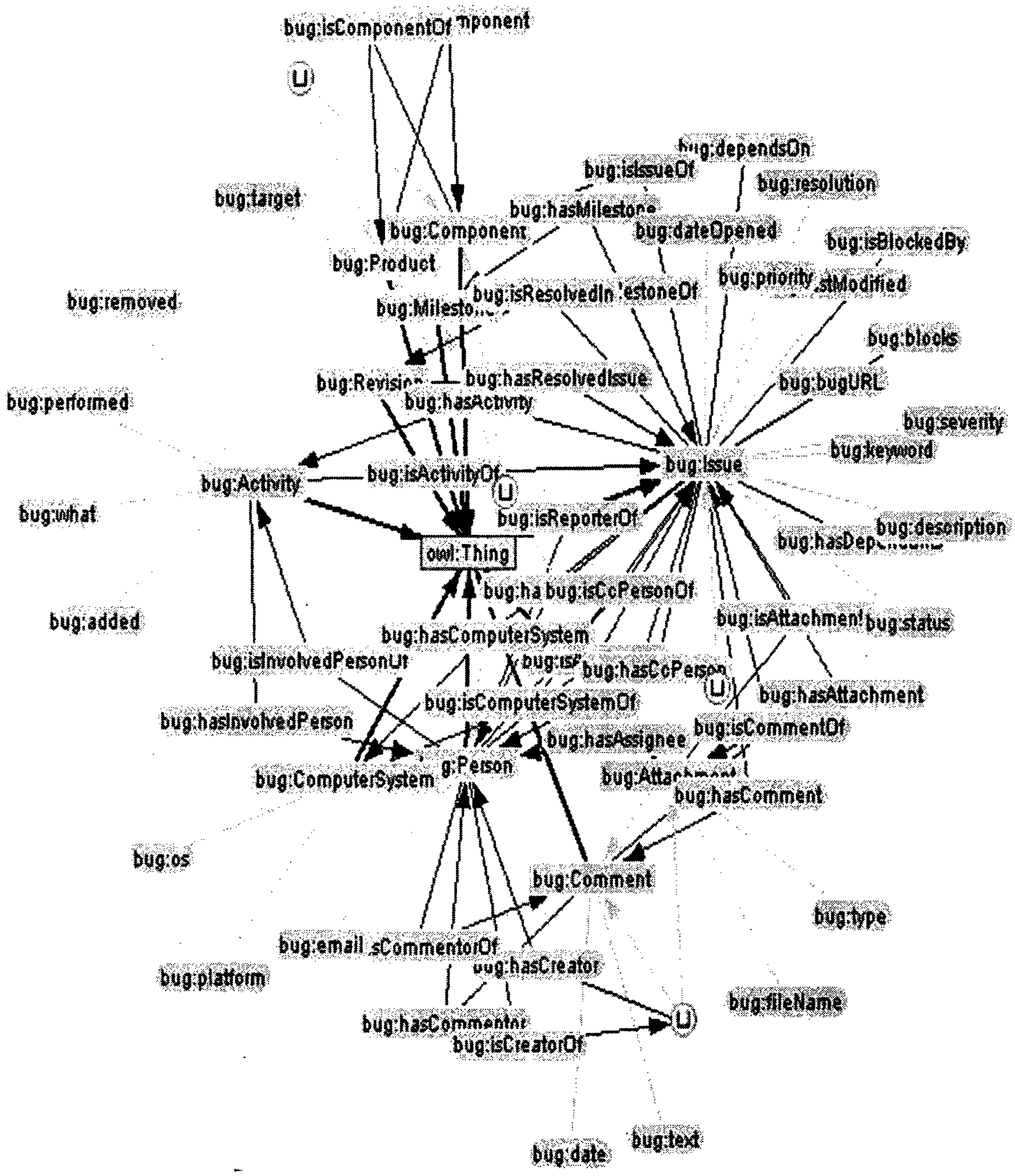


Figure 5- 6: Enriched Bugzilla ontology

5.2. Bugzilla-Ontologizer

In what follows, we discuss the initial Bugzilla-Ontologizer tool implementation in more detail. The Bugzilla-Ontologizer provides the follow functionalities:

(1) Establishing a remote connection to a Bugzilla repository

(2) Extracting and exporting raw data from a Bugzilla repository

(3) Transforming the raw data and providing for an automated ontology population

The next sections will describe in more detail implementation details of the Bugzilla-Ontologizer tool.

5.2.1. Connection to Bugzilla and Data Extraction

Bugzilla provides a *Common Gateway Interface* (CGI) to access its components. The following components are accessible through the CGI interface:

- Administration of a Bugzilla Installation can be accessed through editcomponents.cgi, editgroups.cgi, editkeywords.cgi, editparams.cgi, editproducts.cgi, editusers.cgi, editversions.cgi, and sanitycheck.cgi.
- Creating, changing, and viewing bugs features can be accessed through enter_bug.cgi, post_bug.cgi, show_bug.cgi, and process_bug.cgi.
- Query.cgi / Buglist.cgi, searching for the bugs and viewing the bug list (i.e. query.cgi and buglist.cgi).
- Generating reports from the Bugzilla repository. (i.e. reports.cgi and duplicates.cgi.)

For the implementation of the Bugzilla-Ontologizer, the API provided by the CGI was used to establish the remote access to the Bugzilla repository. In particular, the following CGI components were used for the Bugzilla-Ontologizer tool implementation (Figure 5-7):

- The *urlbase* Java utility, which uses as a parameter the fully qualified domain name of the web server path that hosts the Bugzilla installation. Also, show_bug.cgi was used to search through the HTML file (provided by the Bugzilla remote installation) to find the bug identification number associated with a bug.
- The buglist.cgi component is used to extract the bug list based on a string matching query. Component returns an XML file containing the matches.
- Bug details are accessed through the XML.cgi component.

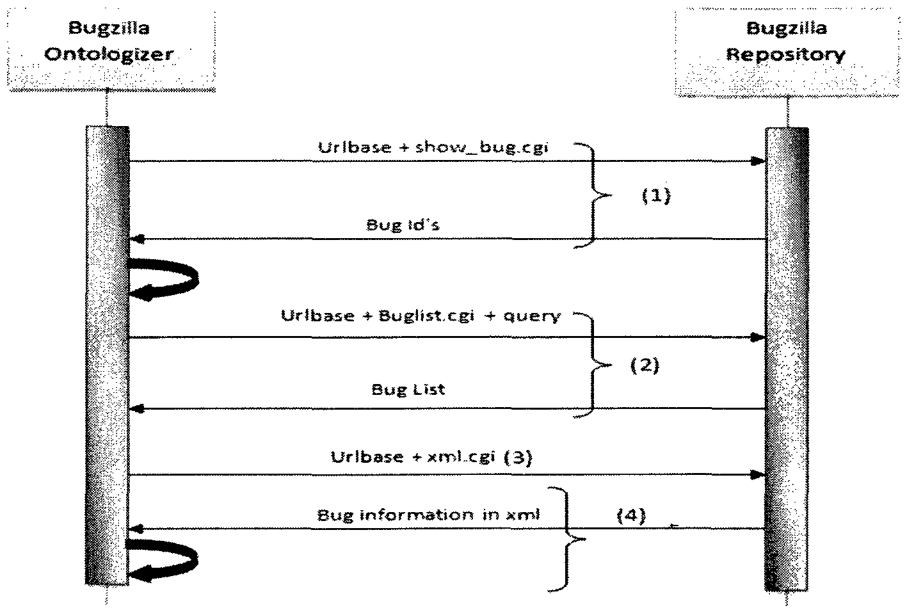


Figure 5- 7: Bug data extraction

5.2.2. Data Pre-processing

In what follows, we describe some pre-processing steps that are necessary in order to transform the raw data into a format suitable for automated ontology population. Figure 5-8 provides a general overview of the transformation process and the various steps involved.

Serializing

The first pre-processing steps involve the serialization of the exported Bugzilla raw data. The processing performed as part of this step includes:

- Assign a unique identification numbers to both, issues and related entities (i.e. *comments, activities and attachments*).
- Create an in memory representation of the data which corresponds close to the ontological model.

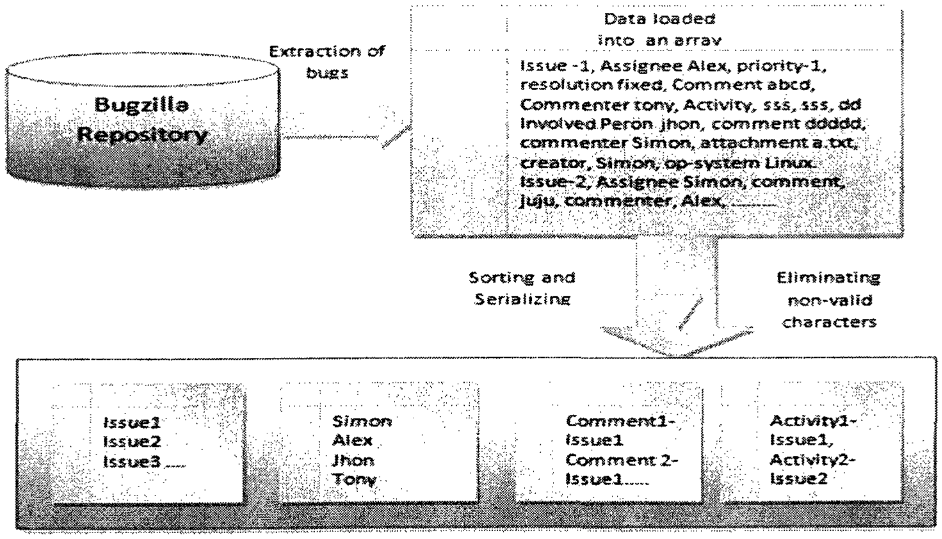

Bugzilla Repository
Extraction of bugs
Data loaded into an array
Issue -1, Assignee Alex, priority-1, resolution fixed, Comment abcd, Commenter tony, Activity, sss, sss, dd Involved Peron jhon, comment ddddd, commenter Simon, attachment a.txt, creator, Simon, op-system Linux Issue-2, Assignee Simon, comment, Juju, commenter, Alex, ...
Sorting and Serializing
Eliminating non-valid characters
Issue1 Issue2 Issue3 ....
Simon Alex Jhon Tony
Comment1-Issue1 Comment 2-Issue1......
Activity1-Issue1, Activity2-Issue2

Figure 5- 8: Overview of pre-processing steps

Elimination of invalid characters

In this pre-processing step a clean-up of the data is performed. In many cases the issue, activity, and text description of comments contain characters that are not supported by the OWL/RDF format. As part of the clean-up step, we replace invalid characters with characters supported by the OWL/RDF format. Table 5-6 provides some examples of the removal of non-valid characters and their replacements with valid ones.

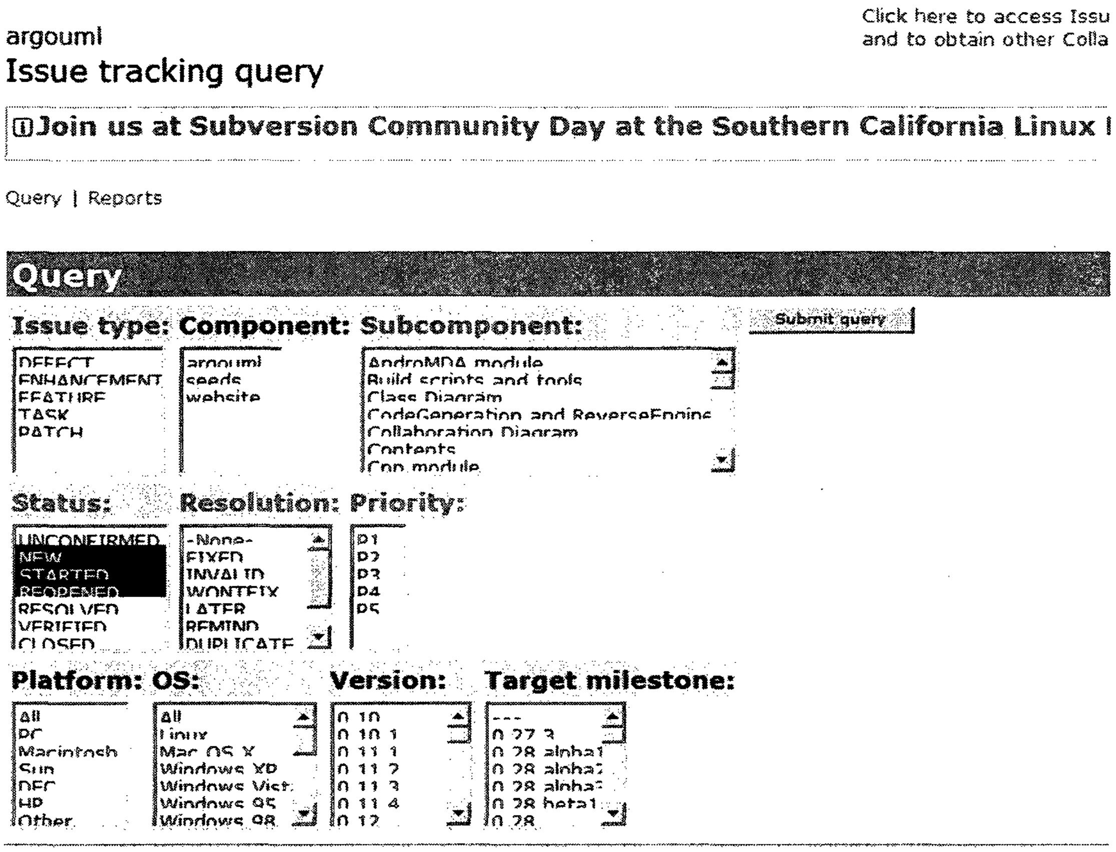
Non-valid characters	Replaced with
Ü	U
<	-
>	-
Ö	O
Æ	a
&	and

Table 5- 6: Substitution of invalid characters

In the last step, the pre-processed and normalized SVN data in the memory will be used to automatically populate our SVN ontology. In order to populate our SVN ontology, first we write SVN ontology TBox into the RDF/OWL file. In the second step we write ABox containing instances (i.e. loaded in memory models) as per TBox specifications in the form of RDF triples.

5.2.3. Bugzilla-Ontologizer User Interface

Common to most bug tracking systems is the provision of a web-based query interface. Figure 5-9 provides an example of the web-based query interface associated with the ArgoUML [ARG09] Bugzilla issue tracking system. In order to extract bugs from the underlying Bugzilla repository, users can specify various properties in order to filter and select the scope of the bug information to be extracted from the repository.



argouml

Issue tracking query

Click here to access Issu
and to obtain other Colla

Join us at Subversion Community Day at the Southern California Linux I

Query | Reports

Query

Issue type: DEFECT, ENHANCEMENT, FEATURE, TASK, PATCH

Component: argouml, seeds, website

Subcomponent: AndroMDA module, Build scripts and tools, Class Diagram, CodeGeneration and ReverseEngine, Collaboration Diagram, Contents, Cpp module

Submit query

Status: UNCONFIRMED, NEW, STARTED, REOPENED, RESOLVED, VERIFIED, CLOSED

Resolution: -None-, FIXED, INVALID, WONTFIX, LATER, REMIND, DUPLICATE

Priority: P1, P2, P3, P4, P5

Platform: All, PC, Macintosh, Sun, DEC, HP, Other

OS: All, Linux, Mac OS X, Windows XP, Windows Vist, Windows 95, Windows 98

Version: 0.10, 0.10.1, 0.11.1, 0.11.2, 0.11.3, 0.11.4, 0.12

Target milestone: ---, 0.27.3, 0.28.alpha1, 0.28.alpha2, 0.28.alpha3, 0.28.beta1, 0.28

Figure 5- 9: ArgoUML bug tracking system query interface

In order to reduce the need of context switching among interfaces, we adopted a similar GUI as the one implemented in Bugzilla, for our Bugzilla-Ontologizer tool (Figure 5-10). The user interface is divided into three main parts: query, remote directory, and ontology destination directory panel.

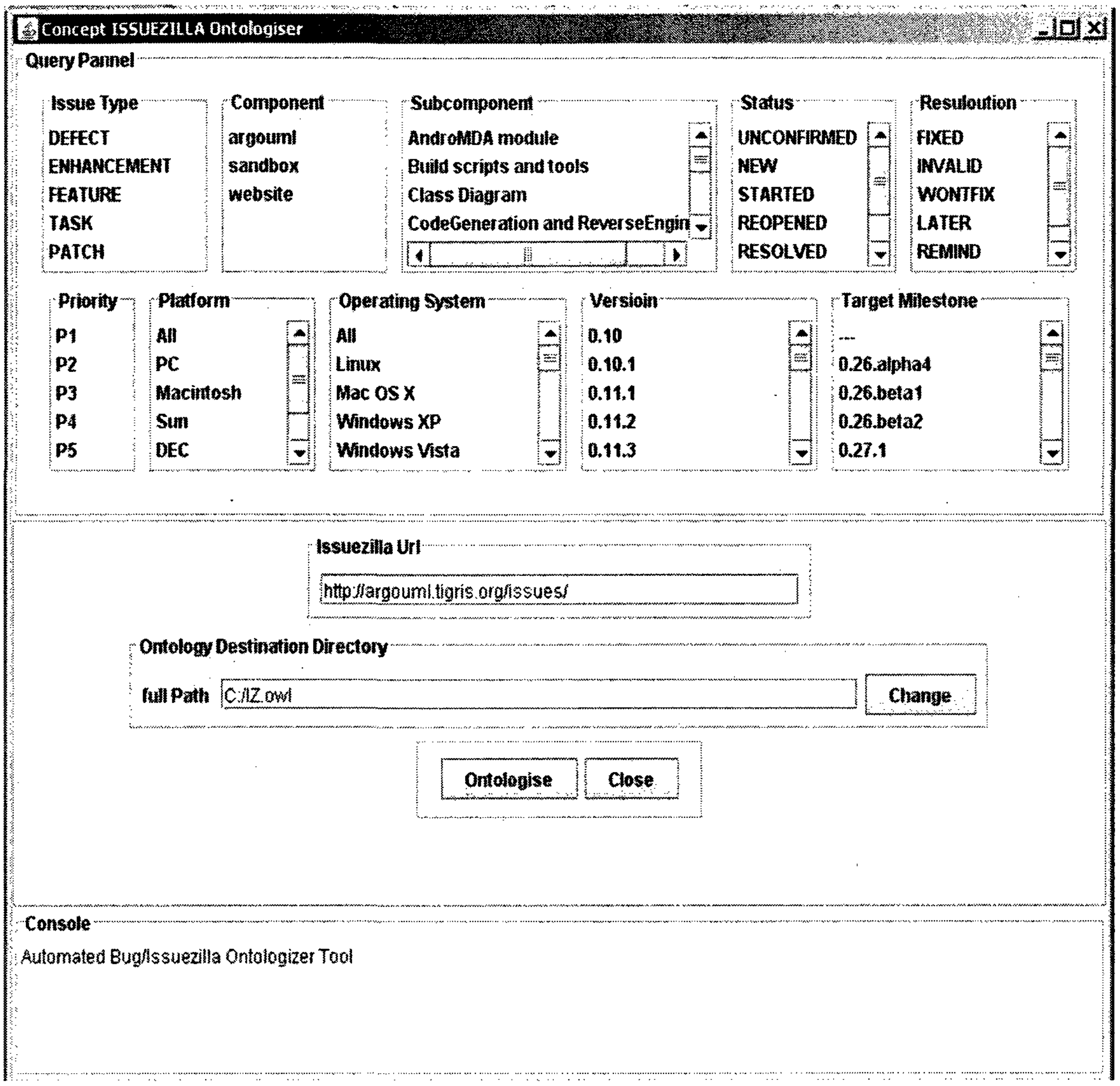


Figure 5- 10: Bugzilla-Ontologizer user interface

The query panel allows users to specify constraints in order to restrict the scope of the queries by filtering specific data. Among the supported filters are:

Issue type: Defines the type of issue the user wants to extract. Supported values are: DEFECT, ENHHANCMENT, FEATURE, TASK, and PATCH.

Component: Defines the product of a software project. The products are the broadest category in Bugzilla and tend to represent real-world shipping products. For example, if a company makes computer games it should have one product per game, perhaps a "Common" product for units of technology used in multiple games, and maybe a few special products (Website, Administration, etc.).

Subcomponent:	Defines the subsections of a component (product). For example, a company designing computer games may have a "UI" subcomponent, an "API" subcomponent, a "Sound System" subcomponent, and a "Plug-in" subcomponent, each overseen by a different programmer. It often makes sense to divide subcomponents in Bugzilla according to the natural divisions of responsibility within the component.
Status:	Defines the status of an issue in the bug lifecycle. Supported values are: UNCONFIRMED, NEW, STRTED, REOPEND, RESOLVED, VARIFIED and CLOSED.
Resolution:	Indicates that, what happened to a particular issue in the bug lifecycle. Supported values are: FIXED, WONTFIX, LATER, INVALID, REMIND and DUPLICATE.
Priority:	Describes the importance and order in which a bug should be fixed. The priority field is used by the developers to prioritize their work. Supported values are: *P1, P2, P3, P4,* and *P5* where *P1* indicates the most important issue and *P5* indicates the least important issue.

Platform:	Defines the hardware platform context in which the bug occurred. Supported values are: All, Macintosh, PC, Sun and HP.
Operating System:	Defines the operating system specific to a particular bug. Supported values are: All, Linux, Mac OS X, Windows XP, Windows Vista, Windows 95, Windows 98, Windows ME, Windows 2000, Windows NT, Mac System 7, Mac System 8.5, Mac System 9.0, BSD, HP-UX, IRIX, Solaris, SunOS and other.
Version:	Defines the release in which an issue or defect was found.
Target Milestone:	Defines the project designated milestones, this field can also be used to associate *issues* with those milestones, such as *version* and *releases.*

Based on user-specified filters, a SQL query will be executed to extract the information from the remote Bugzilla repository. The remote repository location itself is specified by the user within the remote directory panel. The query panel allows users to specify the output directory and name of the Bugzilla ontology.

6. Initial Experimental Evaluation and Ontological Queries

6.1. Case Study

We have selected ArgoUML 0.28 release [ARG09] as a case study. ArgoUML is a medium size open source UML modeling tool and includes support for all standard UML 1.4 diagrams. It runs on any Java platform and is available in ten languages. ArgoUML 0.26 and 0.26.2 have been downloaded over 80, 000 times and are in use all over the world. Table 6-1 shows some statistics of ArgoUML 0. 28 release.

Total number of attributes	2460
Total number of classes	18333
Total number of methods	14059
Total number of packages	144
Total number of interfaces	526
Total number of static methods	744
Total number of static attributes	1922
Total number of line of code	168516

Table 6- 1: Some statistics about ArgoUML 0.28

Table 6-2 shows some statistics of an ArgoUML project retrieved from SVN ontology.

Total number of concepts	4
Total number of Object properties	12
Total number of Data type properties	9
Total number of Instances	195591
Total number of Instances (reduced version)	103343
Total number of files used in different revision	56920
Total number of revisions	16793
Total number of Authors (developers /maintainers)	50

Table 6- 2: Statistics of an ArgoUML project from SVN ontology

Table 6-3 shows some statistics from an ArgoUML project retrieved from Bugzilla ontology.

Total number of concepts	9
Total number of Object properties	28
Total number of Data type properties	25
Total number of Instances	871
Extracted releases	8
Total number of Person	27
Total number Issues (as of February 4, 2009)	71
Total number Activities of related to an Issue	33
Total number of Comments on Issues	366
Total number of computer systems	10

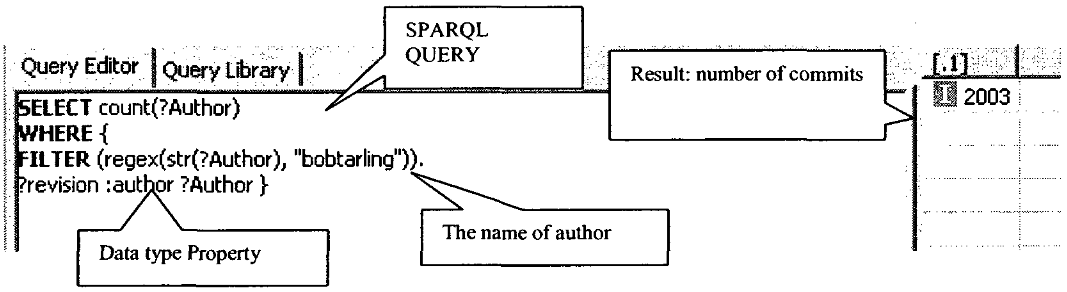
Table 6- 3: Statistics of an ArgoUML project from Bugzilla ontology

6.2. Ontological queries applied on SVN Ontology.

In this section, we present several SPARQL queries in order to illustrate information retrieval through the SVN ontology. The following queries discussed in more detail are applied to an SVN ontology that was populated with the SVN data extracted from the ArgoUML [ARG09] project. We will first identify the contribution of a developer/maintainer to the overall project. Next, we discuss the identification of releases and their commit dates. Finally, we treat the extraction of revisions and their associated files' information.

Contribution of a particular developer / maintainer to the overall project

In order to retrieve information about the contribution of a particular developer/maintainer, we defined the SPARQL query shown in Figure 6-1. The query identifies the overall contribution of a maintainer towards the project. We retrieve the number of revisions created by a specific author, in this case "bobtarling." The SPARQL query returns the total number of commits performed by "bobtarling." We can see that this author has made 2003 commits.

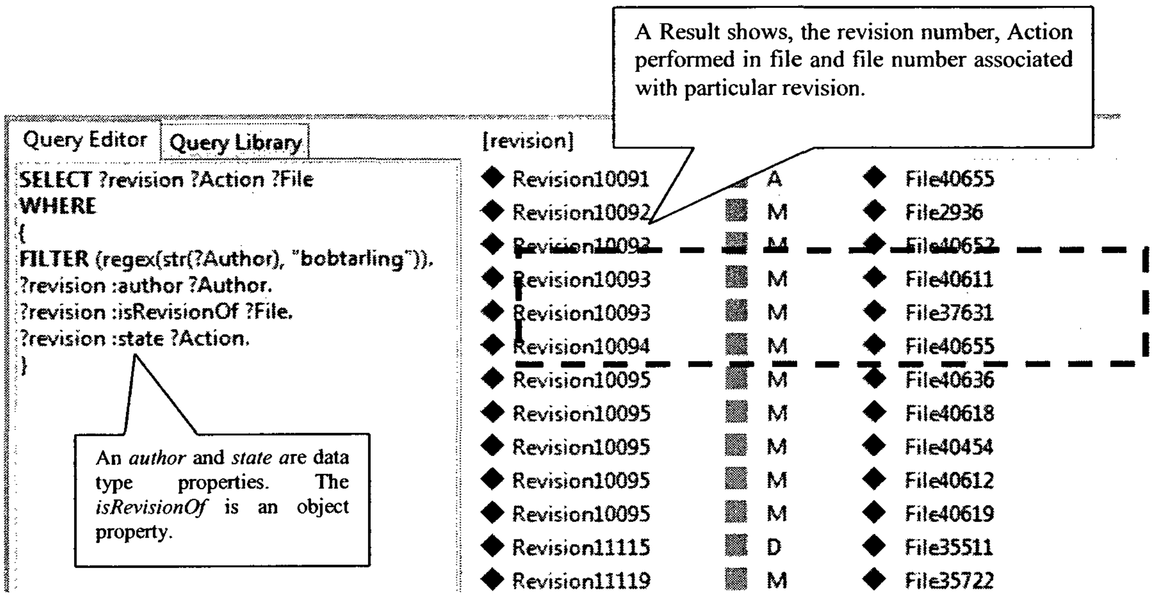


```
SELECT count(?Author)
WHERE {
FILTER (regex(str(?Author), "bobtarling")).
?revision :author ?Author }
```

```
2003
```

Figure 6- 1: Results of SPARQL query

For the next query, we extend the query as shown in Figure 6-2 in order to provide some additional insights regarding a developer's contribution towards each revision. In this query we have retrieved three pieces of information: the revision numbers of the revisions created by the specific author, the files associated with each revision, and the action performed on the file during each revision (i.e. added "A", modified "M" and deleted "D"). Figure 6-2 shows the results of this extended query. As a result, the query establishes a link between an author, revisions, files and actions performed by the author.


A Result shows, the revision number, Action performed in file and file number associated with particular revision.

```
SELECT ?revision ?Action ?File
WHERE
{
FILTER (regex(str(?Author), "bobtarling")).
?revision :author ?Author.
?revision :isRevisionOf ?File.
?revision :state ?Action.
}
```

An *author* and *state* are data type properties. The *isRevisionOf* is an object property.

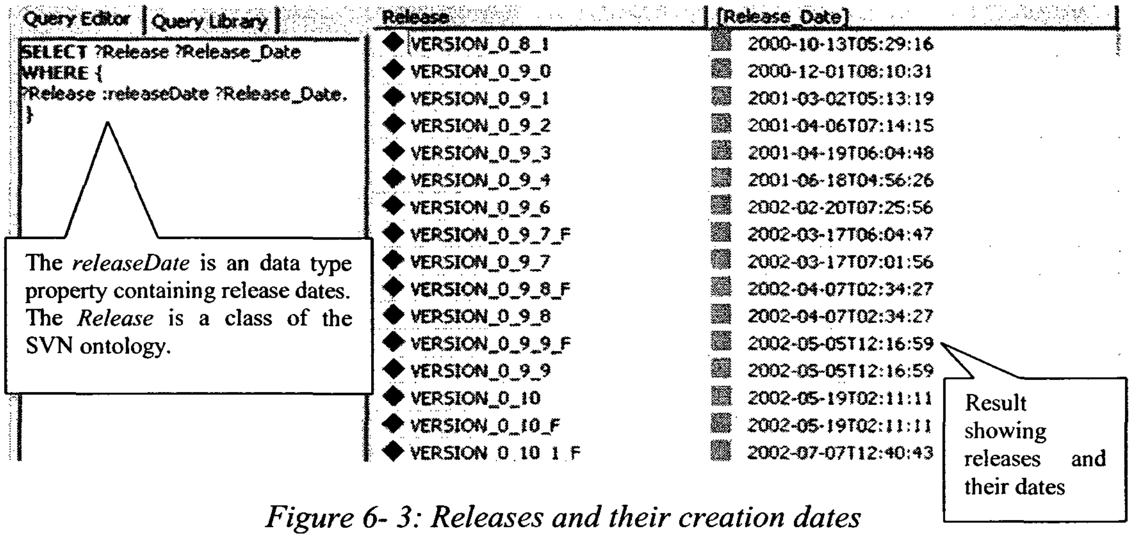
```
[revision]
◆ Revision10091    A   ◆ File40655
◆ Revision10092    M   ◆ File2936
◆ Revision10092    M   ◆ File40652
◆ Revision10093    M   ◆ File40611
◆ Revision10093    M   ◆ File37631
◆ Revision10094    M   ◆ File40655
◆ Revision10095    M   ◆ File40636
◆ Revision10095    M   ◆ File40618
◆ Revision10095    M   ◆ File40454
◆ Revision10095    M   ◆ File40612
◆ Revision10095    M   ◆ File40619
◆ Revision11115    D   ◆ File35511
◆ Revision11119    M   ◆ File35722
```

Figure 6- 2: Results obtained from extended query

The information retrieved through the SPARQL query is useful to evaluate the developer's contribution to a software project.

Releases and their commit dates

Release dates are stored within the SVN repository by creating release tags while committing a new revision. However, in SVN there is standard way of recording release information in the SVN repository. For example, releases in the ArgoUML SVN repository are stored as different branches. The branches are directories with no further information regarding the commits' history. During SVN data extraction and pre-processing, we extracted these release tags from the commit information and stored then within the SVN ontology. In order to retrieve the releases and their creation date, we applied the query shown in Figure 6-3. As a result, the query returns releases and their creation dates as shown in Figure 6-3.



```
SELECT ?Release ?Release_Date
WHERE {
?Release :releaseDate ?Release_Date.
}
```

The *releaseDate* is an data type property containing release dates. The *Release* is a class of the SVN ontology.

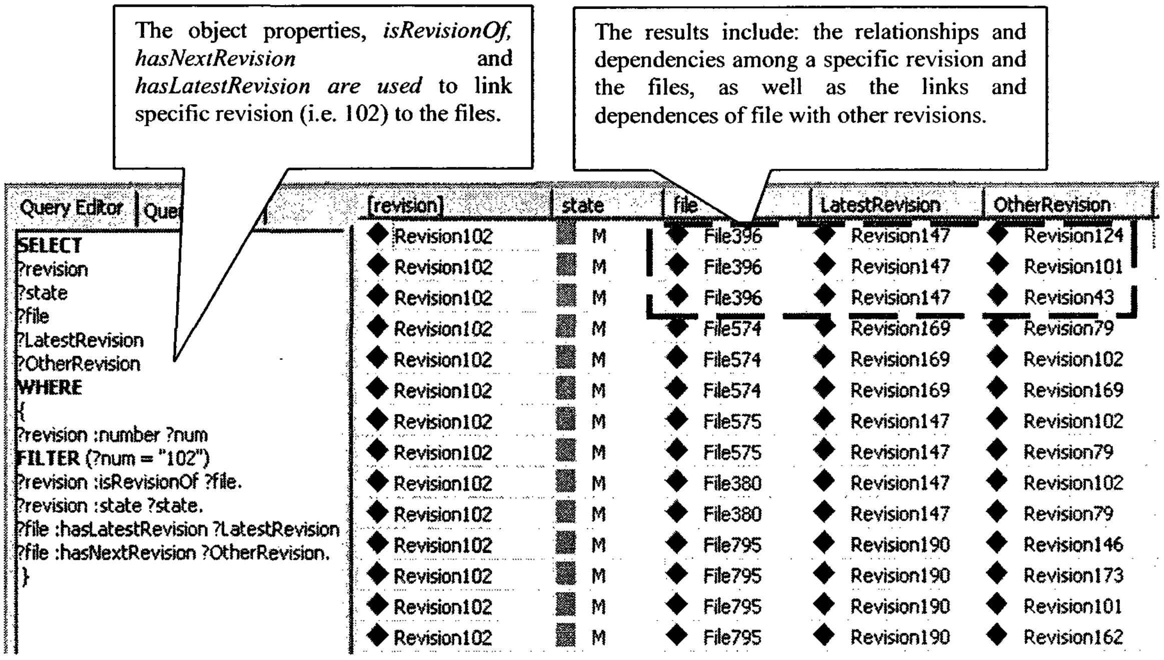
Release	Release_Date
◆ VERSION_0_8_1	▨ 2000-10-13T05:29:16
◆ VERSION_0_9_0	▨ 2000-12-01T08:10:31
◆ VERSION_0_9_1	▨ 2001-03-02T05:13:19
◆ VERSION_0_9_2	▨ 2001-04-06T07:14:15
◆ VERSION_0_9_3	▨ 2001-04-19T06:04:48
◆ VERSION_0_9_4	▨ 2001-06-18T04:56:26
◆ VERSION_0_9_6	▨ 2002-02-20T07:25:56
◆ VERSION_0_9_7_F	▨ 2002-03-17T06:04:47
◆ VERSION_0_9_7	▨ 2002-03-17T07:01:56
◆ VERSION_0_9_8_F	▨ 2002-04-07T02:34:27
◆ VERSION_0_9_8	▨ 2002-04-07T02:34:27
◆ VERSION_0_9_9_F	▨ 2002-05-05T12:16:59
◆ VERSION_0_9_9	▨ 2002-05-05T12:16:59
◆ VERSION_0_10	▨ 2002-05-19T02:11:11
◆ VERSION_0_10_F	▨ 2002-05-19T02:11:11
◆ VERSION 0 10 1 F	▨ 2002-07-07T12:40:43

Result showing releases and their dates

Figure 6- 3: Releases and their creation dates

In the following example, we retrieve all files associated with a particular revision. The query in Figure 6-4 returns the following information:

- A specific revision and its associated files (i.e. the files, which are modified to create a specific revision)
- The latest revision of each file.
- The links of a file with other revisions, in this case instances of *OtherRevision* are inferred by the Pellet reasoner
- Furthermore, the query establishes a link between the revisions and the files.


The object properties, *isRevisionOf, hasNextRevision* and *hasLatestRevision are used* to link specific revision (i.e. 102) to the files.

The results include: the relationships and dependencies among a specific revision and the files, as well as the links and dependences of file with other revisions.

```
SELECT
?revision
?state
?file
?LatestRevision
?OtherRevision
WHERE
{
?revision :number ?num
FILTER (?num = "102")
?revision :isRevisionOf ?file.
?revision :state ?state.
?file :hasLatestRevision ?LatestRevision
?file :hasNextRevision ?OtherRevision.
}
```

[revision]	state	file	LatestRevision	OtherRevision
◆ Revision102	▨ M	◆ File396	◆ Revision147	◆ Revision124
◆ Revision102	▨ M	◆ File396	◆ Revision147	◆ Revision101
◆ Revision102	▨ M	◆ File396	◆ Revision147	◆ Revision43
◆ Revision102	▨ M	◆ File574	◆ Revision169	◆ Revision79
◆ Revision102	▨ M	◆ File574	◆ Revision169	◆ Revision102
◆ Revision102	▨ M	◆ File574	◆ Revision169	◆ Revision169
◆ Revision102	▨ M	◆ File575	◆ Revision147	◆ Revision102
◆ Revision102	▨ M	◆ File575	◆ Revision147	◆ Revision79
◆ Revision102	▨ M	◆ File380	◆ Revision147	◆ Revision102
◆ Revision102	▨ M	◆ File380	◆ Revision147	◆ Revision79
◆ Revision102	▨ M	◆ File795	◆ Revision190	◆ Revision146
◆ Revision102	▨ M	◆ File795	◆ Revision190	◆ Revision173
◆ Revision102	▨ M	◆ File795	◆ Revision190	◆ Revision101
◆ Revision102	▨ M	◆ File795	◆ Revision190	◆ Revision162

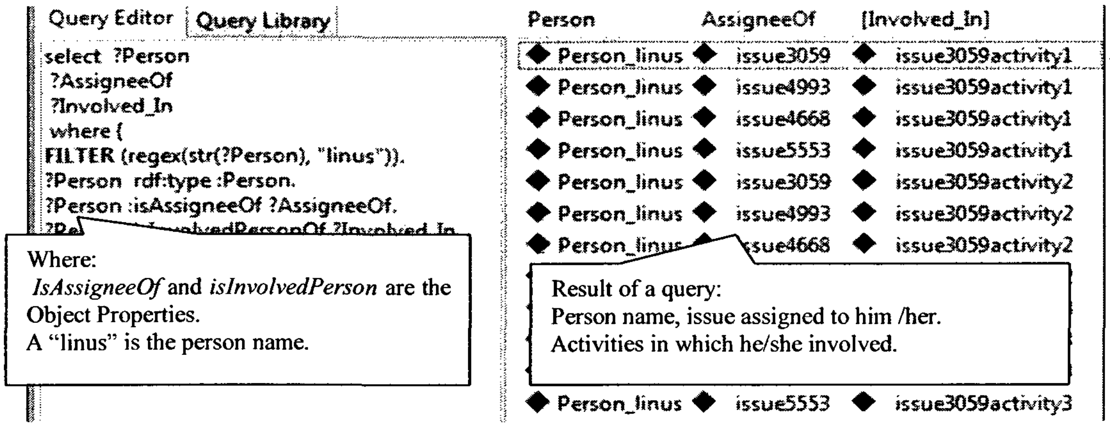
Figure 6- 4: Query results based on a revision and committed files

6.3. Ontological Queries Applied to Bugzilla Ontology

In the following examples, we apply SPARQL queries to extract information from the populated Bugzilla ontology. Among the queries we discuss in more detail are queries that identify the contribution of a specific programmer towards the Bugzilla repository, provide some general Bugzilla repository statistics, and illustrate the use of knowledge inference through reasoning services.

Identifying the Contribution of a Particular Person

In order to retrieve information about the contribution of a particular developer/maintainer, we defined the query as shown in Figure 6-5. In this query, we identify the contribution of a particular maintainer within the Bugzilla repository. The query retrieves all the assigned issues and the activities in which a specific person is/was involved. The query results can be used not only to identify the most active project members but can also analyze who worked on which issue in the past, etc.



```
select ?Person
 ?AssigneeOf
 ?Involved_In
 where {
FILTER (regex(str(?Person), "linus")).
?Person rdf:type :Person.
?Person :isAssigneeOf ?AssigneeOf.
?Pe[illegible]olvedPersonOf ?Involved_In
```

Where:
IsAssigneeOf and *isInvolvedPerson* are the Object Properties.
A "linus" is the person name.

Person	AssigneeOf	[Involved_In]
◆ Person_linus	◆ issue3059	◆ issue3059activity1
◆ Person_linus	◆ issue4993	◆ issue3059activity1
◆ Person_linus	◆ issue4668	◆ issue3059activity1
◆ Person_linus	◆ issue5553	◆ issue3059activity1
◆ Person_linus	◆ issue3059	◆ issue3059activity2
◆ Person_linus	◆ issue4993	◆ issue3059activity2
◆ Person_linus	◆ issue4668	◆ issue3059activity2
◆ Person_linus	◆ issue5553	◆ issue3059activity3

Result of a query:
Person name, issue assigned to him /her.
Activities in which he/she involved.

Figure 6- 5: Query results showing the contribution of a specified person

Inference knowledge by reasoning services

In addition to information retrieval through the SPARQL queries, reasoning services provided by ontological reasoners, such as Pellet in our case, can be used to infer additional knowledge. In what follows we illustrate the use of inference services to infer missing knowledge that was not available at the time of ontology population. For example, at the time of the Bugzilla ontology population, we were only able to assert the instances of the object property *DependsOn* but did not populate the inverse property *Blocks*.

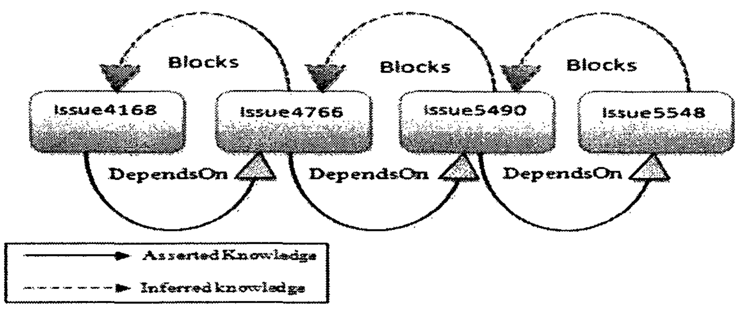
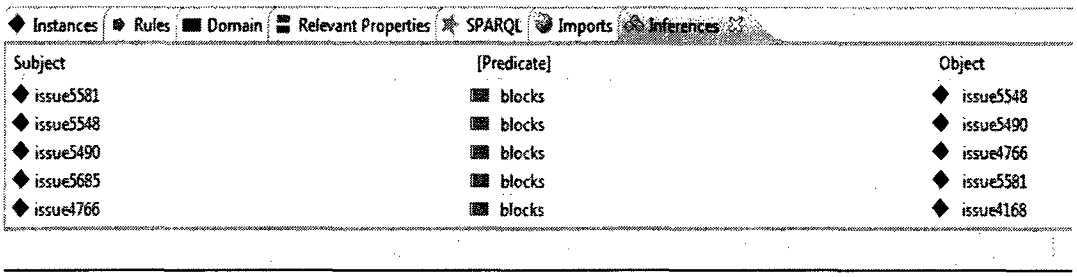


Figure 6- 6: Reasoning example

Figure 6-6 illustrates an example of such a SPARQL query that takes advantage of Pellet's reasoning services. In this example, we consider four issues: *issue4168, issue4766, issue5490, and issue5548.* From the asserted knowledge, one can identify that *issue4168* depends on issue4766, *issue4766* depends on *issue5490* and an *issue5490* depends on *issue5548.* Through reasoning, we can also infer that, *issue5548* is blocking *issue5490*, and *issue5490* is blocking *issue4766* (Figure 6-7).



Subject	[Predicate]	Object
◆ issue5581	■ blocks	◆ issue5548
◆ issue5548	■ blocks	◆ issue5490
◆ issue5490	■ blocks	◆ issue4766
◆ issue5685	■ blocks	◆ issue5581
◆ issue4766	■ blocks	◆ issue4168

Figure 6- 7: Knowledge inference based on property DependsOn

Furthermore, the reasoning services also allow us to resolve the transitive closure between the issues (Figure 6-8). In this case the reasoner infers that *issue4168* depends also on *issue5490* and on *issue5548.* Furthermore, *issue5548* blocks both *issue4766* and *issue4168.* Figure 6-8 illustrates this example that takes advantage of both asserted and inferred knowledge. The results are displayed in Figure 6-9.

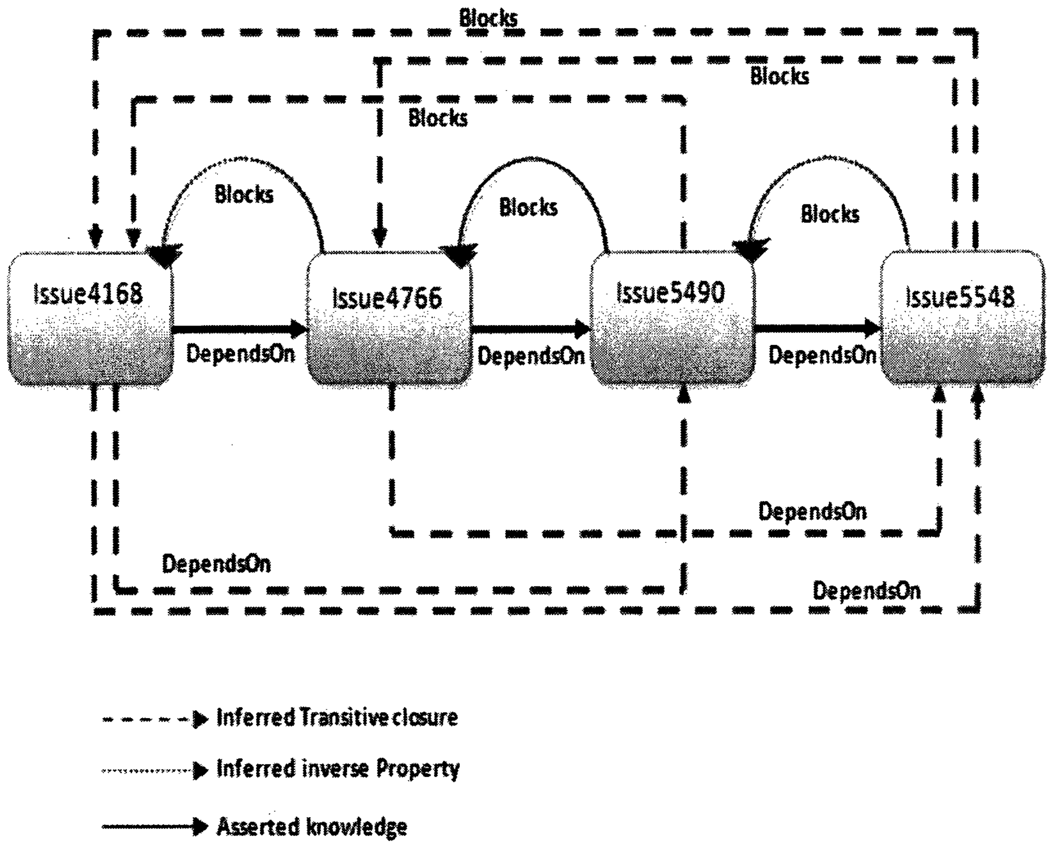
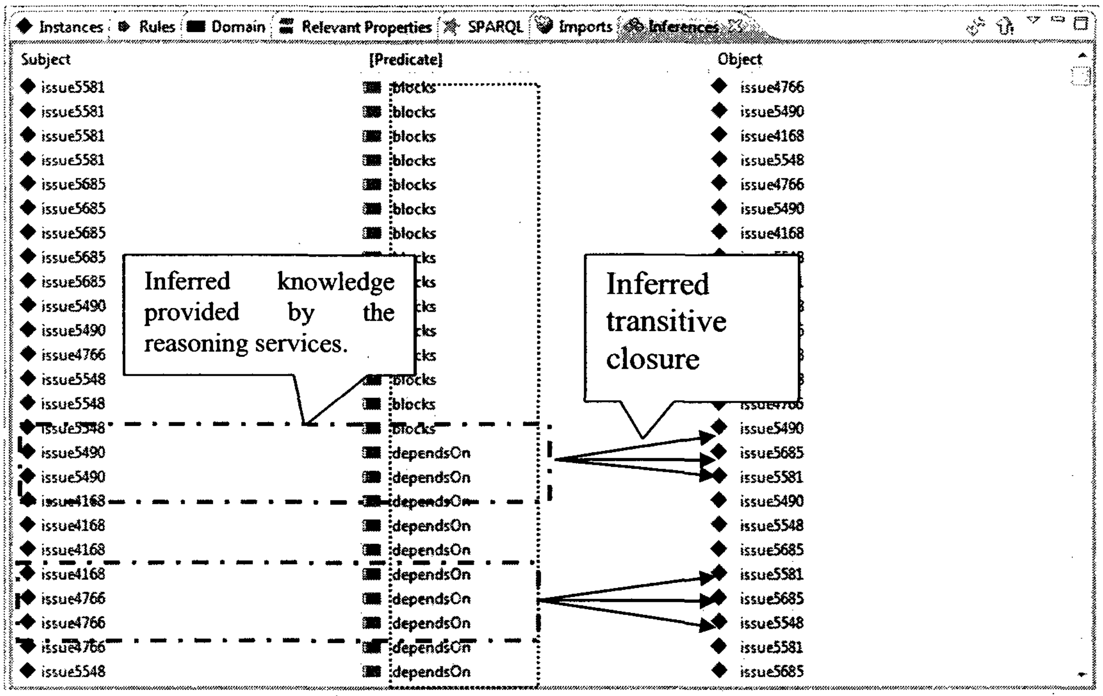


Figure 6- 8: Example of inferred transitive closure


Instances
Rules
Domain
Relevant Properties
SPARQL
Imports
Inferences
Inferred knowledge provided by the reasoning services.
Inferred transitive closure

Subject	[Predicate]	Object
issue5581	blocks	issue4766
issue5581	blocks	issue5490
issue5581	blocks	issue4168
issue5581	blocks	issue5548
issue5685	blocks	issue4766
issue5685	blocks	issue5490
issue5685	blocks	issue4168
issue5685	cks	[illegible]
issue5685	cks	[illegible]
issue5490	cks	[illegible]
issue5490	cks	[illegible]
issue4766	cks	[illegible]
issue5548	blocks	[illegible]
issue5548	blocks	issue4766
issue5548	blocks	issue5490
issue5490	dependsOn	issue5685
issue5490	dependsOn	issue5581
issue4168	dependsOn	issue5490
issue4168	dependsOn	issue5548
issue4168	dependsOn	issue5685
issue4168	dependsOn	issue5581
issue4766	dependsOn	issue5685
issue4766	dependsOn	issue5548
issue4766	dependsOn	issue5581
issue5548	dependsOn	issue5685

Figure 6- 9: Results derived from issue dependency

6.4. Linked SVN and Bugzilla Ontology Queries

In order to allow for queries to work across ontologies, our SVN and Bugzilla ontologies have to be linked.

Linking SVN and Bugzilla Ontologies

An interconnection between SVN and Bugzilla ontology is created through the entities sharing a common concept. The revision committed to an SVN repository may be referenced by its issue number. On the other hand, an issue reported in Bugzilla repository may be referenced by a revision number.

We linked our two ontologies through common shared instances with the help of the *isResolutionOf* and *hasResolution* object properties associations. As shown in Figure 6-

10, issue and revision concepts are linked through object properties *isResolutionOf* and *hasResolution*. The linking of the ontologies is bi-directional. The object property *hasResolution* contain revision numbers corresponding to the issue's resolution history in SVN ontology. The object property *isResolutionOf* contains an instance issue number, which refers the particular revision to an issue in the Bugzilla repository. During the SVN and Bugzilla ontology population phase we extracted revision numbers from issue comments and issue numbers from revision commit messages and stored them as instances of *isResolutionOf* and *hasResolution* object properties. Figure 6-10 shows the linked Bugzilla and SVN ontologies.

Evaluation of Links among SVN and Bugzilla Ontologies

In order to validate our approach of linking SVN and Bugzilla ontologies, we applied a SPARQL query. The query searches for all the issues that have an instance of *hasResolution* in the Bugzilla ontology. After retrieving the instances (i.e. the revision number related to an issue), the query retrieves the information related to the revision number from the linked SVN ontology (i.e. commit date). Table 6-4 shows the evaluation of the SVN ontology (i.e. revision number) links found in the Bugzilla ontology.

Total number of releases in Bugzilla Ontology (including Alpha-X and Beta X)	8
Total number of Bugs	71
Total Number of links to SVN repository	37
Total number of invalid links	2

Table 6- 4: Evaluation of links found in the Bugzilla ontology

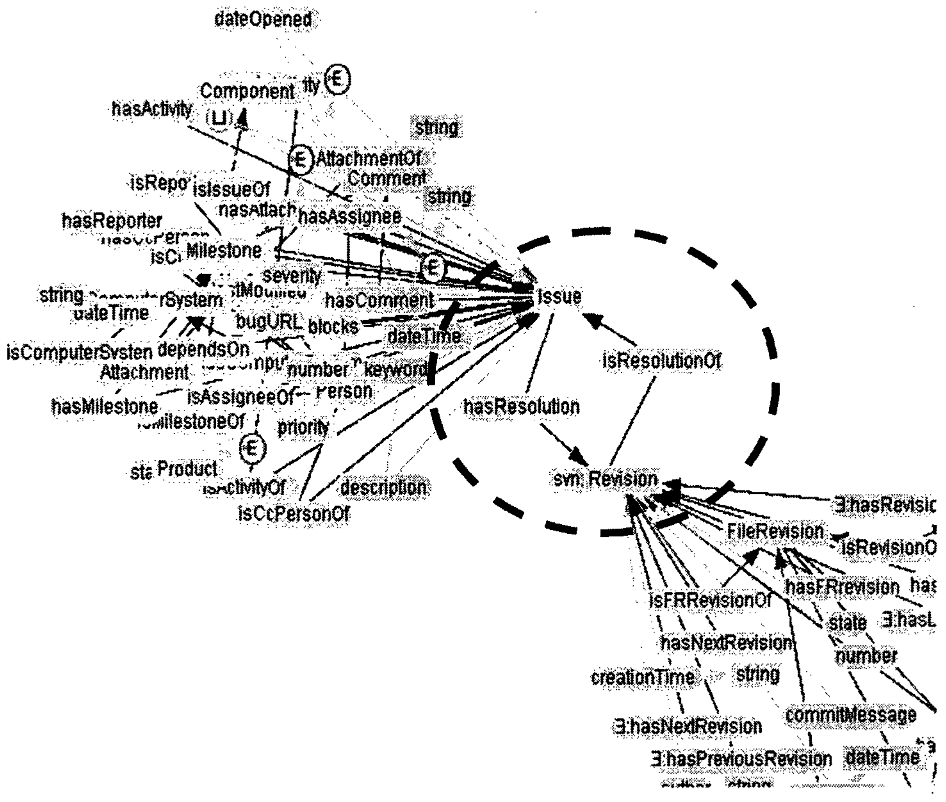
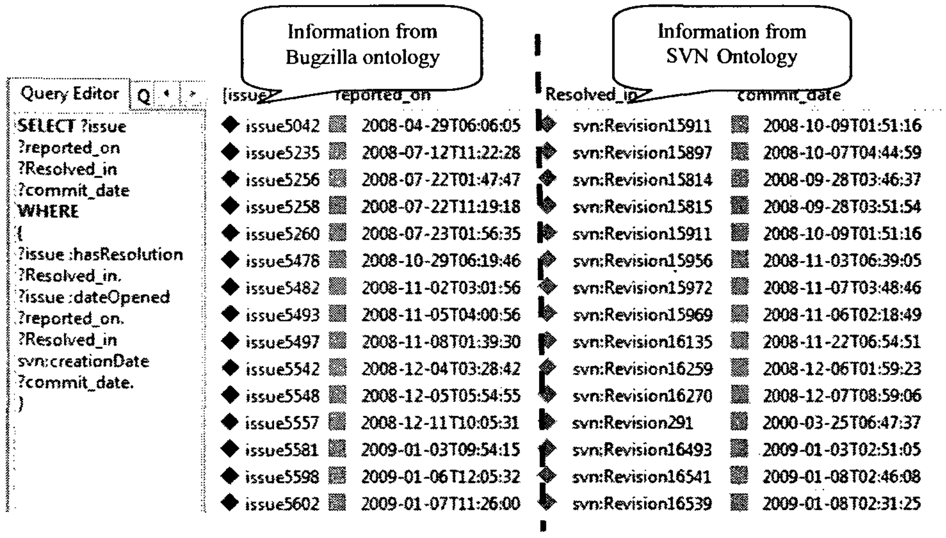


Figure 6- 10: Linked Bugzilla and SVN ontologies

In what follows, we present several SPARQL queries, which are applied to the linked SVN and Bugzilla ontology. Among the queries we discuss in more detail are the time spent to resolve an issue, the resolution history related to a particular issue, and the analysis of transitive relationships.

Time Required in order to Resolving a Reported Issue

In order to retrieve information related to the time required to resolve a reported issue, we define the query as shown in Figure 6-11, which retrieves the date and time an issue was first reported and the date and time of the commit corresponding to the resolution of the same issue. The query retrieves information in two steps. First, the query searches for all the issues that have an instance of *hasResolution* in Bugzilla ontology. Then, after retrieving the instances (i.e. the revision number related to an issue), the query retrieves the related information to the revision number from the linked SVN ontology (i.e. commit date). Figure 6-11 shows the query and results obtained from this query.



```
SELECT ?issue
?reported_on
?Resolved_in
?commit_date
WHERE
{
?issue :hasResolution
?Resolved_in.
?issue :dateOpened
?reported_on.
?Resolved_in
svn:creationDate
?commit_date.
}
```

issue	reported_on	Resolved_in	commit_date
issue5042	2008-04-29T06:06:05	svn:Revision15911	2008-10-09T01:51:16
issue5235	2008-07-12T11:22:28	svn:Revision15897	2008-10-07T04:44:59
issue5256	2008-07-22T01:47:47	svn:Revision15814	2008-09-28T03:46:37
issue5258	2008-07-22T11:19:18	svn:Revision15815	2008-09-28T03:51:54
issue5260	2008-07-23T01:56:35	svn:Revision15911	2008-10-09T01:51:16
issue5478	2008-10-29T06:19:46	svn:Revision15956	2008-11-03T06:39:05
issue5482	2008-11-02T03:01:56	svn:Revision15972	2008-11-07T03:48:46
issue5493	2008-11-05T04:00:56	svn:Revision15969	2008-11-06T02:18:49
issue5497	2008-11-08T01:39:30	svn:Revision16135	2008-11-22T06:54:51
issue5542	2008-12-04T03:28:42	svn:Revision16259	2008-12-06T01:59:23
issue5548	2008-12-05T05:54:55	svn:Revision16270	2008-12-07T08:59:06
issue5557	2008-12-11T10:05:31	svn:Revision291	2000-03-25T06:47:37
issue5581	2009-01-03T09:54:15	svn:Revision16493	2009-01-03T02:51:05
issue5598	2009-01-06T12:05:32	svn:Revision16541	2009-01-08T02:46:08
issue5602	2009-01-07T11:26:00	svn:Revision16539	2009-01-08T02:31:25

Figure 6- 11: Date/time between issue reporting and resolution

Resolution history related to an issue

Figure 6-12 illustrates an example of how to mine the linked Bugzilla and SVN ontologies in order to retrieve information related to the resolution of a reported issue. In our approach, the resolution history can be retrieved by applying the query across the linked Bugzilla and SVN ontologies.

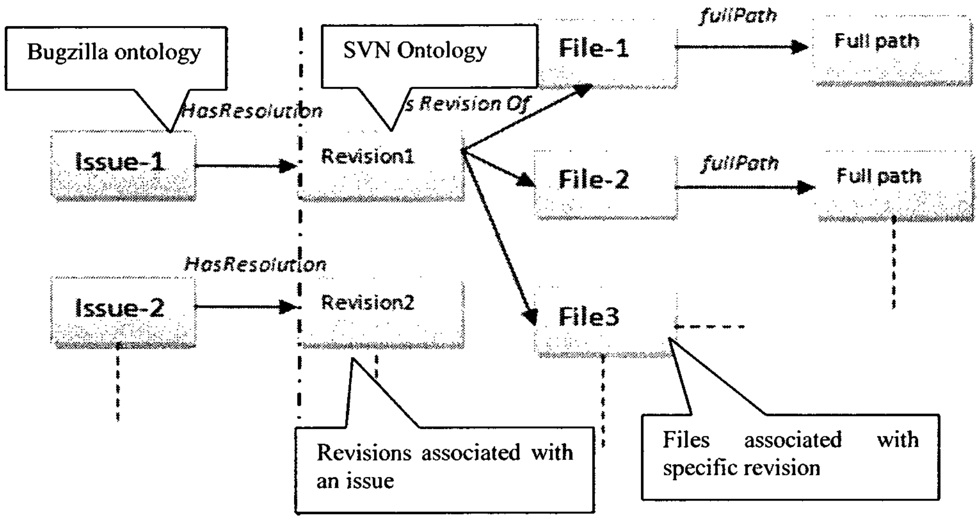
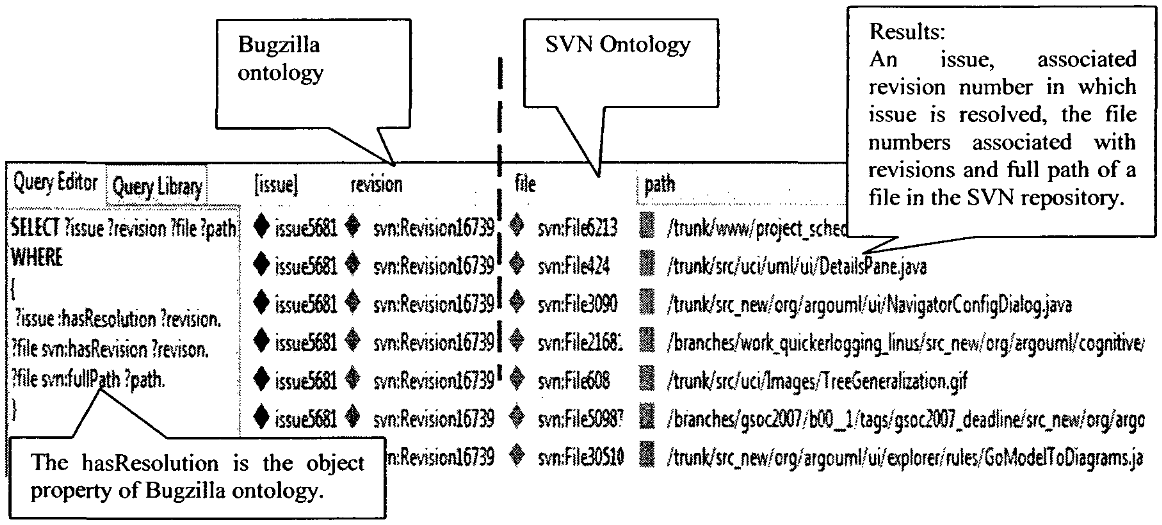


Figure 6- 12: Bug resolution history in SVN ontology

Figure 6-13 illustrates a detailed query and the results obtained from this query. After retrieving the revision related to a particular issue (through the Has Resolution property) the following additional revision information can be retrieved: the files modified in specific revision to resolve and issue, the full path of a specific file in SVN repository, and a traceability link between the issue and the its related resolution information stored in the SVN ontology.


Bugzilla ontology
SVN Ontology
Results: An issue, associated revision number in which issue is resolved, the file numbers associated with revisions and full path of a file in the SVN repository.
Query Editor
Query Library
The hasResolution is the object property of Bugzilla ontology.

```
SELECT ?issue ?revision ?file ?path
WHERE
{
 ?issue :hasResolution ?revision.
?file svn:hasRevision ?revison.
?file svn:fullPath ?path.
}
```

[issue]	revision	file	path
issue5681	svn:Revision16739	svn:File6213	/trunk/www/project_sched
issue5681	svn:Revision16739	svn:File424	/trunk/src/uci/uml/ui/DetailsPane.java
issue5681	svn:Revision16739	svn:File3090	/trunk/src_new/org/argouml/ui/NavigatorConfigDialog.java
issue5681	svn:Revision16739	svn:File2168:	/branches/work_quickerlogging_linus/src_new/org/argouml/cognitive/
issue5681	svn:Revision16739	svn:File608	/trunk/src/uci/Images/TreeGeneralization.gif
issue5681	svn:Revision16739	svn:File5098?	/branches/gsoc2007/b00_1/tags/gsoc2007_deadline/src_new/org/argo
	n:Revision16739	svn:File30510	/trunk/src_new/org/argouml/ui/explorer/rules/GoModelToDiagrams.ja

Figure 6- 13: SPARQL query and results for resolution history

Transitive relationships between entities

The query example in Figure 6-14 illustrates a case where inferred knowledge from the reasoner is combined with transitive relationships of entities to mine the two sub-ontologies.

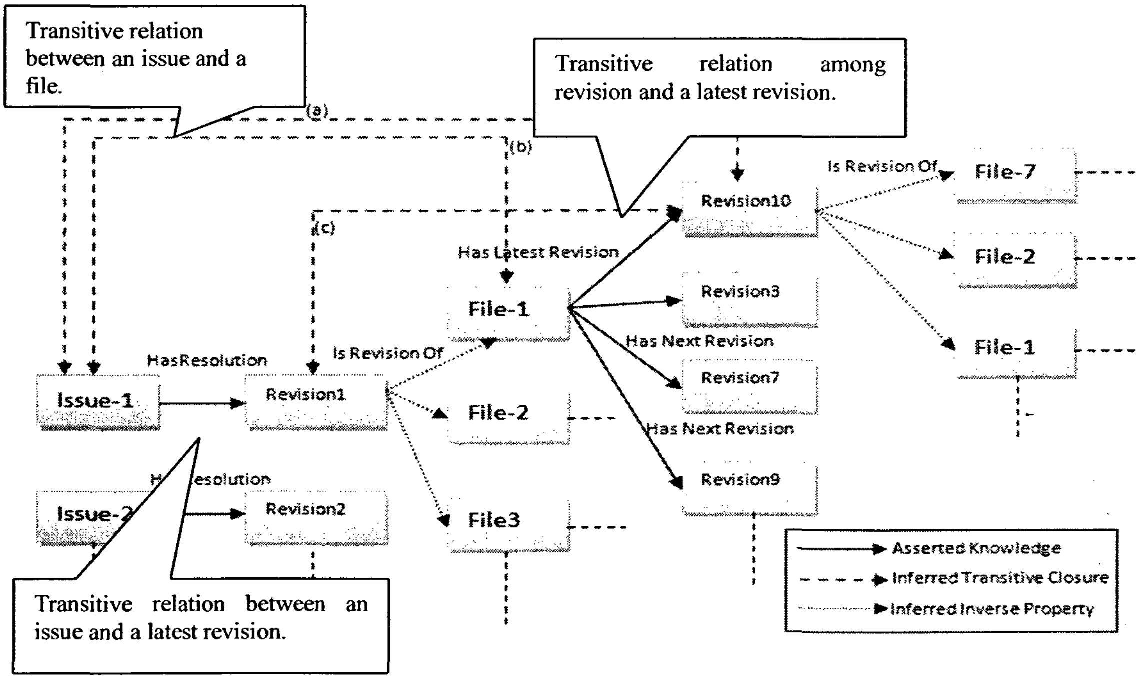
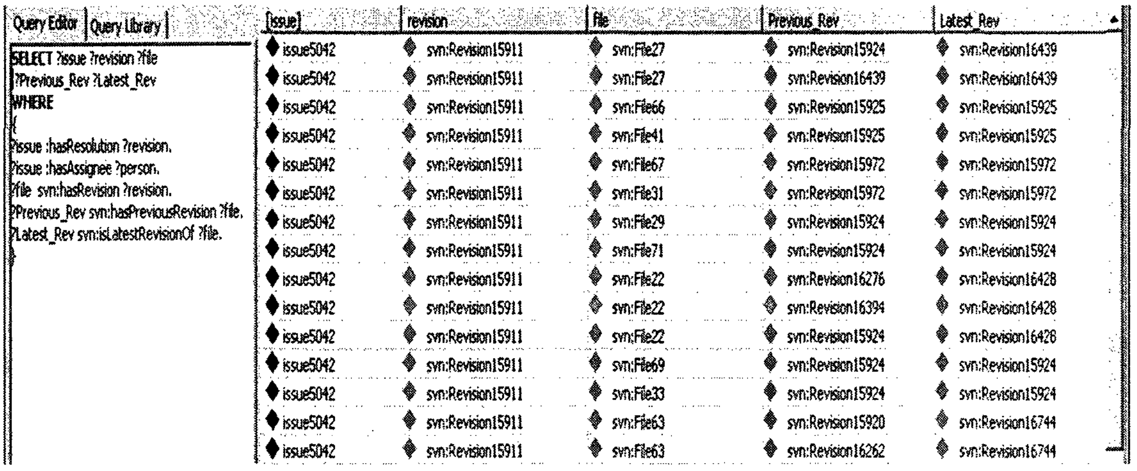


Figure 6- 14: Transitive relationships.

We note that revisions associated with a particular issue are identified. Also, files modified as part of a particular revision are retrieved. In addition, all previous revisions of a particular file are extracted using inferred knowledge (Figure 6-15).



```
SELECT ?issue ?revision ?file
?Previous_Rev ?Latest_Rev
WHERE
{
?issue :hasResolution ?revision.
?issue :hasAssignee ?person.
?file  svn:hasRevision ?revision.
?Previous_Rev svn:hasPreviousRevision ?file.
?Latest_Rev svn:isLatestRevisionOf ?file.
}
```

issue	revision	file	Previous_Rev	Latest_Rev
issue5042	svn:Revision15911	svn:File27	svn:Revision15924	svn:Revision16439
issue5042	svn:Revision15911	svn:File27	svn:Revision16439	svn:Revision16439
issue5042	svn:Revision15911	svn:File66	svn:Revision15925	svn:Revision15925
issue5042	svn:Revision15911	svn:File41	svn:Revision15925	svn:Revision15925
issue5042	svn:Revision15911	svn:File67	svn:Revision15972	svn:Revision15972
issue5042	svn:Revision15911	svn:File31	svn:Revision15972	svn:Revision15972
issue5042	svn:Revision15911	svn:File29	svn:Revision15924	svn:Revision15924
issue5042	svn:Revision15911	svn:File71	svn:Revision15924	svn:Revision15924
issue5042	svn:Revision15911	svn:File22	svn:Revision16276	svn:Revision16428
issue5042	svn:Revision15911	svn:File22	svn:Revision16394	svn:Revision16428
issue5042	svn:Revision15911	svn:File22	svn:Revision15924	svn:Revision16428
issue5042	svn:Revision15911	svn:File69	svn:Revision15924	svn:Revision15924
issue5042	svn:Revision15911	svn:File33	svn:Revision15924	svn:Revision15924
issue5042	svn:Revision15911	svn:File63	svn:Revision15920	svn:Revision16744
issue5042	svn:Revision15911	svn:File63	svn:Revision16262	svn:Revision16744

Figure 6- 15: Query results showing inferred knowledge

6.5. Discussion

The presented case study and the results obtained through queries illustrate the applicability of our approach in order to support various aspects of software evolution. The approach presented here is implemented as a part of the SE-Advisor framework. Section 6.5.1 introduces SE-Advisor framework functionalities and architecture.

6.5.1. SE-Advisor Framework

A common ontological representation (i.e. SVN and Bugzilla ontologies) and automated tools (i.e. SVN and Bugzilla Ontologizer tools) are designed and implemented as a part of SE-Advisor framework.

SE-Advisor provides a pro-active, ambient, knowledge-based environment that integrates users, tasks, tools and resources, as well as processes and history-specific information.

SE/Process Advisor provides an ambient semantic software maintenance environment. Its goal is to support developers throughout maintenance tasks by providing a context-sensitive knowledge base that can be queried either directly by a user or indirectly through supporting tools. The SE-Advisor framework supports maintainers by managing two knowledge-intensive aspects of the software evolution:

1. Collecting and maintaining semantic links, i.e., traceability links, between software artifacts, in particular those at different abstraction levels like source code and its associated documentation
2. Maintaining knowledge about available tools, software evolution processes, users, and their history of solving tasks with the available artifacts, to provide contextual guidance during complex maintenance tasks

SE-Advisor integrates available knowledge resources such as emails, wikis, bug trackers, source code, etc. This information is further automatically and/or semi-automatically analyzed and linked. The process of building knowledge repository ontology is also called ontologizing. Gathered information is presented to a maintainer in the form of a context-sensitive advisor tool which provides the ability to look beyond document boundaries while working on a process. Being aware of the process definition also allows one to guide users through a process. In a feedback loop, newly gained knowledge resources are used to constantly enrich the ontology. Figure 6-16 provides an overview of SE-Advisor framework.

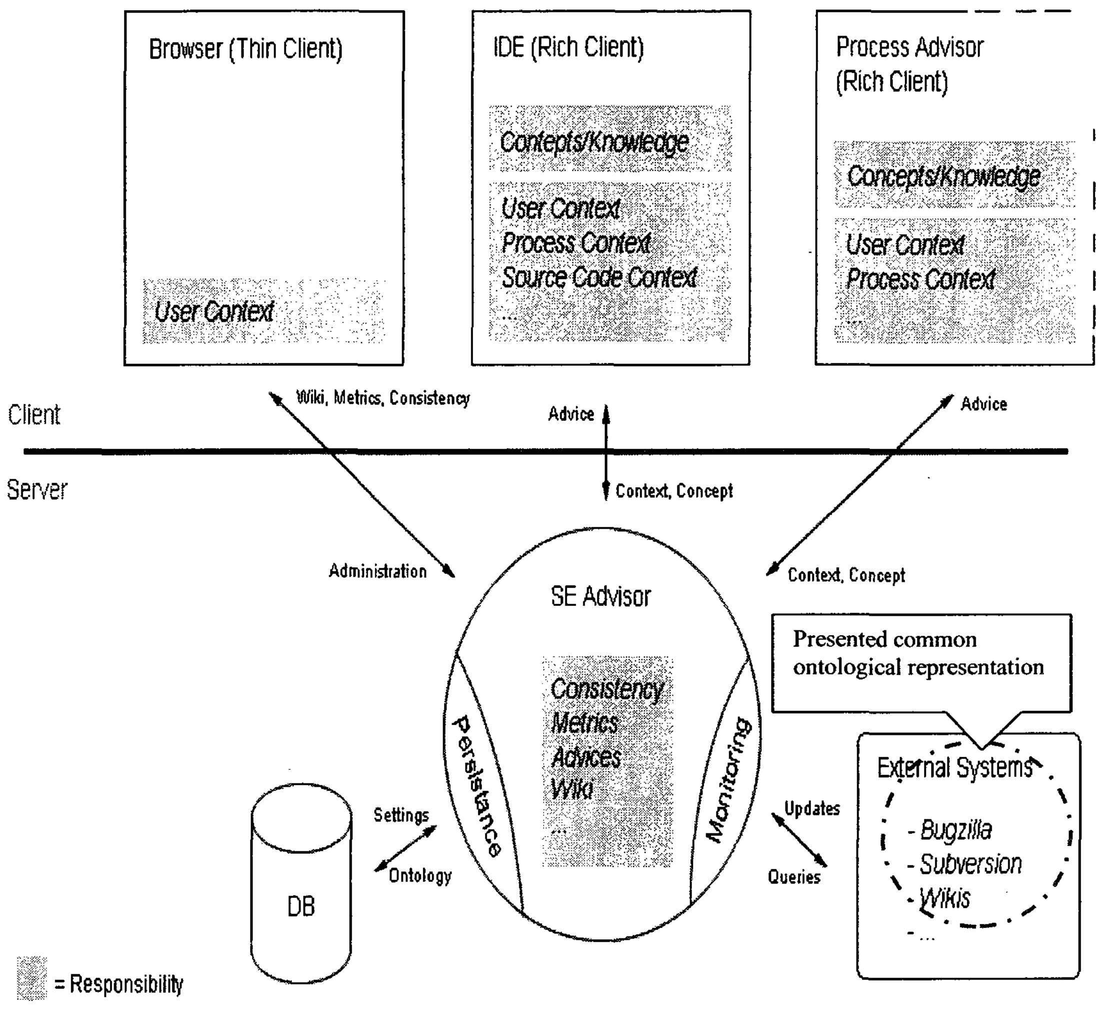


Figure 6- 16: Overview of SE-Advisor framework

7. Related Work and Limitations

In this section we will discuss and compare our work with existing approaches introduced by several researchers, which are closely related to our approach. Later we will discuss the limitations and challenges of our approach.

7.1. Related Work

The work most related to ours is by *Kiefer el al* [KAI07]. It also provided the foundation for the ontological models we used in this thesis. They introduced the *iSPARQL* query engine which is based on the SPARQL query language. They conducted four sets of experiments. The first was the *measurement of code evolution code* by visualizing changes between different releases. Secondly, they conducted *refactoring experiments* by the evaluation of the applicability of the iSPARQL framework to detect bad code smells. Their third experiment was a *metrics experiment*, performed by the evaluation of the ability to calculate software design metrics. Fourth and finally was their use of *ontological reasoning* as part of their software ontology models. However, the main focus of their work is on the source code model. In our approach, we enhanced and enriched the ontologies introduced by [KAI07] with two additional concepts: object and data type properties. We also applied DL restriction to our concepts to take advantage of reasoning services. Furthermore, we introduced the SVN and Bugzilla-Ontologizer tools to automate the process of extraction and ontology population.

Happel et al. [HAP06] presented their KOntoR project in which they focus on storing and querying meta-data about software artifacts to foster software reuse. The software components are stored in a repository and they present various ontologies for providing background knowledge about the components, such as the programming language and licensing models. Compared to our approach, their focus was mainly on conceptualization of the software domain, rather than on the analysis of specific artifacts, as in our case.

Antoniol et al. [GIA04] proposed a *multi-level concept navigation framework* that represents source code entities using the FAMIX meta-model compliant Rigi Standard Format (RSF). In their approach, the release history information from Release History and Bug Databases (RHDBs) were extracted using a set of different tools. The extracted information was stored as RSF files for further processing and analysis. Compared to the approach by [GIA04], we use an OWL/RDF format in order to provide a uniform and semantic rich ontological representation that allows us to take advantage of inference services provided by ontological reasoners. Another approach, presented by *D'Ambros et al.* in [IMB06], introduced a visualization technique to uncover the relationships between data from a versioning and bug tracking. In their approach they use a version of the *Release History Database.*

German [DMG04] proposed a tool called softChange. The main function of softChange is the extraction, enhancement and visualization of software repositories (i.e. CVS). SoftChange consist of three different sub tools: (1) the *trails extractor,* for retrieving the raw software trails from the CVS repositories. The extracted data is stored within a relation database. (2) The *fact enhancer* analyzes the raw data in the database in order to generate the new facts. (3) The *visualize* tool provides a visual representation of the extracted facts.

Main differences between the approach in [DMG04] and ours is that it focuses only on the analysis and visualization of CVS repositories. In our approach we are not limited to analyzing CVS but also include the bug tracking systems. Furthermore, within our approach we also promote the integration of various artifacts and cross-artifact analysis.

Rysselberghe [VR04S] introduced another visualization approach to visualize the changed frequency of files, using different charts.

Hyland-Wood [HLW06] introduced an ontology model for software code based on Java called *SEC*. *SEC* allows the recording and tracking of changes made to metadata. Our approach is similar to [HLW06] in the sense of an ontological format representation. However, *SEC* does not include the information from a versioning or bug tracking system. Our presented approach allows integration of the information from the versioning system and the bug tracking system and uses inference services across sub-ontologies. Other research in mining software repositories (i.e. [AEH06, JIM07, GCL05]) have also been focused on various types of analysis like impact analysis, traceability links, or guiding software development process. Our approach not only supports similar types of analysis, but also promotes the use of a common, semantic-rich ontological representation which allows for analysis across multiple repositories.

7.2. Limitations

During the evaluation phase, we found the following limitations of our presented approach.

Scalability

In order to evaluate our proposed approach with respect to reasoning services across multiple ontologies (i.e. SVN and Bugzilla Ontology), we used Protégé 3.4 ontology editor which provides a plug-in for the Pellet reasoner and SPARQL query editor. During the reasoning process, we experienced the memory overflow errors due to the size of our ontology. The initial size of the SVN ontology was 44 megabytes, causing memory overflow errors. We reduced our initial ontology size to 22 megabytes and were able to apply reasoning services and to apply SPARQL queries. The reason behind the memory overflow error was the consumption of memory by both the reasoner (Pellet Reasoner) and the ontology editor (Protégé 3. 4). Furthermore, the Protégé 3.4 and Pellet Reasoner use Java virtual machine in the background. During the reasoning process, these tools generate in-memory models too complex and too large to process ontologies in order to apply reasoning services. Another limitation is of the Java virtual machine, which only supports memory size up to 1 gigabyte.

Bug extraction

In order to extract all the bug information, we found the limitation of remote Bugzilla installation which does not allow for extraction of all the bug information at once. Due to this limitation we were only able to extract bug information of eight releases. This limitation meant that linking SVN and Bugzilla ontology (i.e. instances of *hasResolution* object property) is one-sided, from the Bugzilla ontology to the SVN ontology. In order to recover links from SVN to Bugzilla (i.e. instances *isResolutionOf* object property), we needed all of the issues to be stored in Bugzilla ontology.

Persistent Storage

Currently, our SVN and Bugzilla ontology is stored as plain RDF/XML format which has size (these are very large ontologies with many instances), performance, and management issues. In order to deal with size, performance, and management issues, there is a need to use database technology in order to provide persistence to the knowledge described by the ontologies, and scalability to the queries and reasoning on this knowledge.

Consistency (i.e. incremental updates)

One of the challenges and potential future work of this project is to manage incremental updates to software repositories such as SVN and Bugzilla ontology. Currently SVN and Bugzilla Ontologizer tools do not support incremental updates to SVN and Bugzilla ontologies.

8. Conclusion and Future Work

In this thesis, we discussed the importance of software repositories in supporting the evolution of software systems. We also discussed some of the challenges associated with extracting and modeling the information extracted from the software repositories.

In order to model the extracted information, we introduced a common ontological representation (based on the OWL/RDF format) to store the information extracted from SVN and Bugzilla repositories. In order to support the extraction process, we implemented two tools (SVN and Bugzilla-Ontologizer) to automate the data extraction and ontology population process. The two tools support the establishment of a connection between the Eclipse IDE and the software repositories, the extraction of raw data from the software repositories (namely SVN and Bugzilla), and the transformation and normalization of the extracted raw data in order to support automated ontology population. The approach we have presented is implemented as a part of our SE-Advisor framework. We presented a case study to evaluate our ontological model and its ability to mine and analyze data from these repositories to support the evolution of a software system. The case study was performed on ArgoUML [ARG09]. We used *SPARQL* queries to demonstrate how our ontological representation can support software evolution by mining and analyzing software repositories. The evaluation (case study) also shows the applicability of our presented approach as a part of SE-Advisor framework. SE-Advisor supports various aspects of the software evolution; our contribution of a common semantic rich ontological representation fulfils the key requirement of SE-Advisor framework. Furthermore, through the ontological queries, we also were able to illustrate some of the benefits of using an ontological reasoner.

As part of the future work, the SVN Ontology should be extended to include additional entities to support the modeling of file content differences (i.e. the difference of the file contents modified in each revision).

Furthermore, there is a need for additional analysis and evaluation of our approach. Also, additional data mining techniques can be applied to provide further insights and analysis of these repositories.

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Appendices

Appendix-I

Following Table (AP1) provides the details of the removal of non-valid characters and their replacements with valid ones in SVN and Bugzilla Ontology.

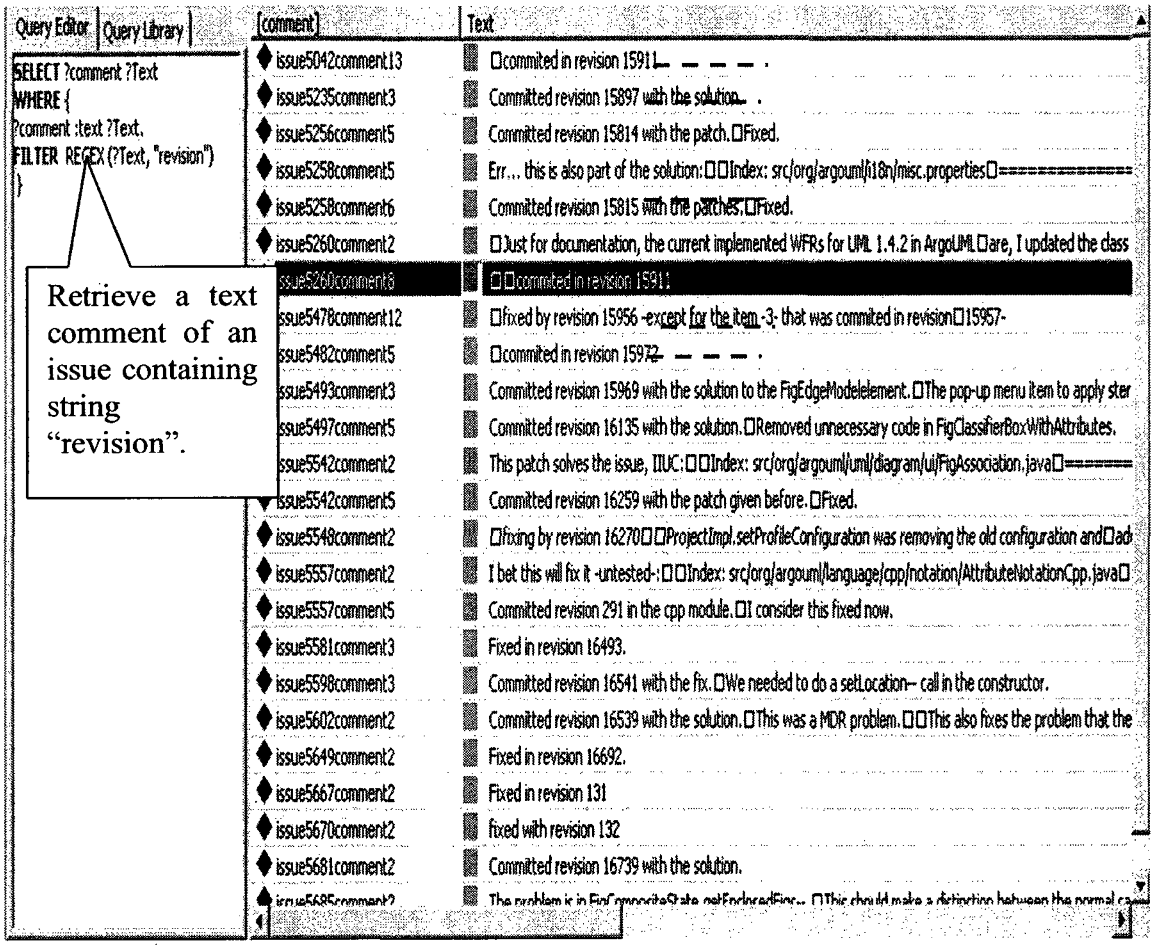
Non-valid character	Replacing character	Non-valid character	Replacing character	Non-valid character	Replacing character
—	-	«	«	Ó	o
!	Space	°	°	Ô	o
$	-	»	»	Õ	o
%	Percent	À	À	Ö	o
(	-	Á	Á	Ù	u
)	-	Â	Â	Ú	u
*	-	Ã	Ã	Û	u
<	-	Ä	Ä	Ü	u
>	-	Ç	Ç	Ÿ	Y
@	-at-	È	È	<	-
^	_	É	É	>	-
`	Space	Ê	Ê	Ö	O
{	-	Ë	Ë	Æ	a
|	-	Ì	Ì	&	and
}	-	Í	Í	‹	-
~	Space	Ï	Ï	Ž	Z
□	Space	Ñ	Ñ	Ú	Ú
€	-	Ò	Ò	Û	Û
ƒ	F	Ó	Ó	‘	Space
„	Space	Ô	Ô		
…	Space	Õ	Õ		
†	+	Ö	Ö		
ˆ	_	×	×		
‰	Space	Ø	Ø		
Š	S	Ù	Ù		

Non-valid character	Replacing character	Non-valid character	Replacing character	Non-valid character	Replacing character
‘	Space	Ü	Ü		
’	Space	Ý	Ý		
“	Space	ß	ß		
”	Space	À	À		
˜	Space	Á	Á		
Š	S	Â	Â		
›	-	Ã	Ã		
Ž	Z	Ä	Ä		
Ÿ	Y	Å	Å		
¡	I	Ç	Ç		
¢	Cents	È	È		
£	Sigma	É	É		
¥	Yen	Ê	Ê		
¦	:	Ë	Ë		
¨	-_	Ì	Ì		
©	Copy-rights	Í	Í		
		Î	Î		
		Ï	Ï		
		Ò	Ò		

Continued Table (AP1).

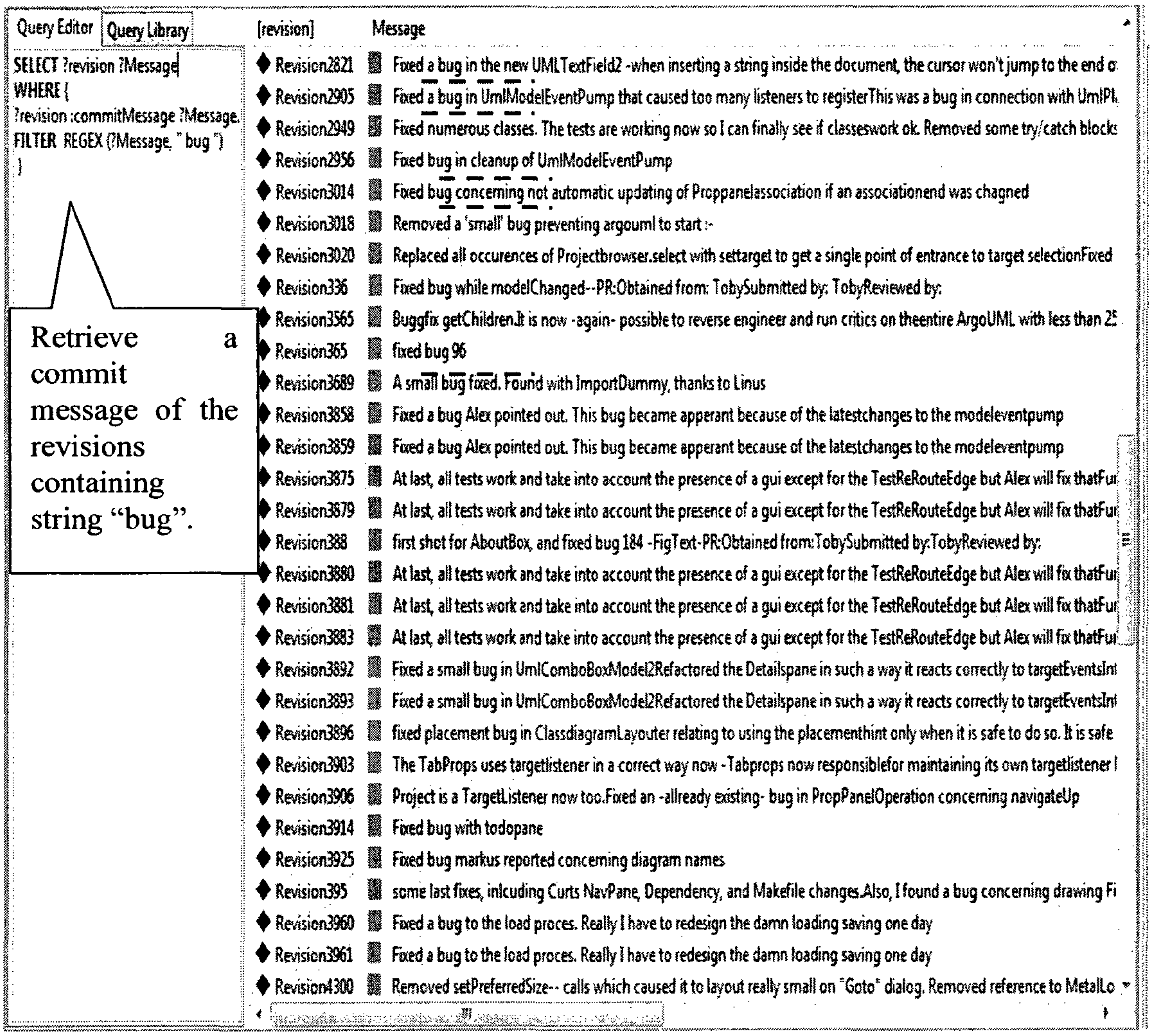
Appendix-II

Following are the SPARQL quires applied to retrieve results from SVN and Bugzilla Ontology by simple string matching.


Query Editor
Query Library
Retrieve a text comment of an issue containing string “revision”.

```
SELECT ?comment ?Text
WHERE {
?comment :text ?Text.
FILTER REGEX(?Text, "revision")
}
```

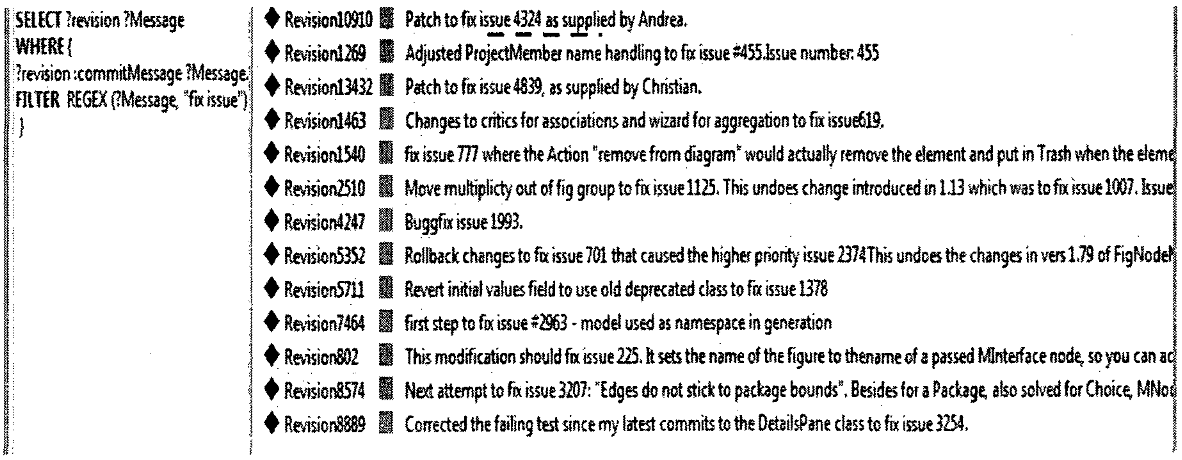
[comment]	Text
issue5042comment13	□commited in revision 15911
issue5235comment3	Committed revision 15897 with the solution.
issue5256comment5	Committed revision 15814 with the patch.□Fixed.
issue5258comment5	Err... this is also part of the solution:□□Index: src/org/argouml/i18n/misc.properties□=============
issue5258comment6	Committed revision 15815 with the patches.□Fixed.
issue5260comment2	□Just for documentation, the current implemented WFRs for UML 1.4.2 in ArgoUML□are, I updated the class
ssue5260comment8	□□commited in revision 15911
ssue5478comment12	□fixed by revision 15956 -except for the item -3- that was commited in revision□15957-
ssue5482comment5	□commited in revision 15972
ssue5493comment3	Committed revision 15969 with the solution to the FigEdgeModelelement.□The pop-up menu item to apply ster
ssue5497comment5	Committed revision 16135 with the solution.□Removed unnecessary code in FigClassifierBoxWithAttributes.
ssue5542comment2	This patch solves the issue, IIUC:□□Index: src/org/argouml/uml/diagram/ui/FigAssociation.java□=======
ssue5542comment5	Committed revision 16259 with the patch given before.□Fixed.
issue5548comment2	□fixing by revision 16270□□ProjectImpl.setProfileConfiguration was removing the old configuration and□ad
issue5557comment2	I bet this will fix it -untested-:□□Index: src/org/argouml/language/cpp/notation/AttributeNotationCpp.java□
issue5557comment5	Committed revision 291 in the cpp module.□I consider this fixed now.
issue5581comment3	Fixed in revision 16493.
issue5598comment3	Committed revision 16541 with the fix.□We needed to do a setLocation-- call in the constructor.
issue5602comment2	Committed revision 16539 with the solution.□This was a MDR problem.□□This also fixes the problem that the
issue5649comment2	Fixed in revision 16692.
issue5667comment2	Fixed in revision 131
issue5670comment2	fixed with revision 132
issue5681comment2	Committed revision 16739 with the solution.
issue5685comment2	The problem is in FigCompositeState.getEnclosedFigs-- □This should make a distinction between the normal ca



```
SELECT ?revision ?Message
WHERE {
?revision :commitMessage ?Message.
FILTER REGEX (?Message, " bug ")
}
```

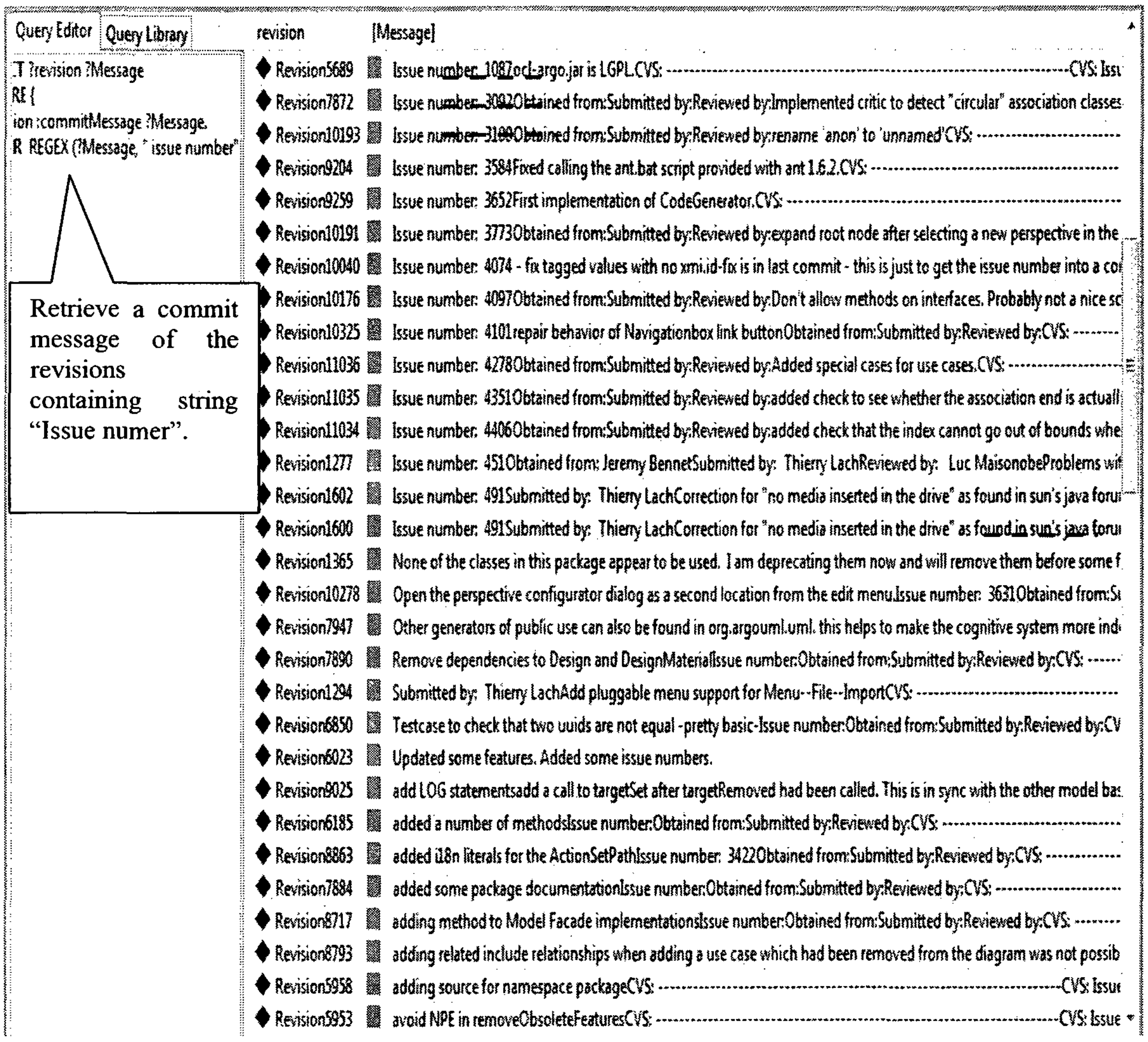
Retrieve a commit message of the revisions containing string "bug".

[revision]	Message
Revision2821	Fixed a bug in the new UMLTextField2 -when inserting a string inside the document, the cursor won't jump to the end o
Revision2905	Fixed a bug in UmlModelEventPump that caused too many listeners to registerThis was a bug in connection with UmlPl
Revision2949	Fixed numerous classes. The tests are working now so I can finally see if classeswork ok. Removed some try/catch blocks
Revision2956	Fixed bug in cleanup of UmlModelEventPump
Revision3014	Fixed bug concerning not automatic updating of Proppanelassociation if an associationend was chagned
Revision3018	Removed a 'small' bug preventing argouml to start :-
Revision3020	Replaced all occurences of Projectbrowser.select with settarget to get a single point of entrance to target selectionFixed
Revision336	Fixed bug while modelChanged--PR:Obtained from: TobySubmitted by: TobyReviewed by:
Revision3565	Bugfix getChildren.It is now -again- possible to reverse engineer and run critics on theentire ArgoUML with less than 25
Revision365	fixed bug 96
Revision3689	A small bug fixed. Found with ImportDummy, thanks to Linus
Revision3858	Fixed a bug Alex pointed out. This bug became apperant because of the latestchanges to the modeleventpump
Revision3859	Fixed a bug Alex pointed out. This bug became apperant because of the latestchanges to the modeleventpump
Revision3875	At last, all tests work and take into account the presence of a gui except for the TestReRouteEdge but Alex will fix thatFu
Revision3879	At last, all tests work and take into account the presence of a gui except for the TestReRouteEdge but Alex will fix thatFu
Revision388	first shot for AboutBox, and fixed bug 184 -FigText-PR:Obtained from:TobySubmitted by:TobyReviewed by:
Revision3880	At last, all tests work and take into account the presence of a gui except for the TestReRouteEdge but Alex will fix thatFu
Revision3881	At last, all tests work and take into account the presence of a gui except for the TestReRouteEdge but Alex will fix thatFu
Revision3883	At last, all tests work and take into account the presence of a gui except for the TestReRouteEdge but Alex will fix thatFu
Revision3892	Fixed a small bug in UmlComboBoxModel2Refactored the Detailspane in such a way it reacts correctly to targetEventsInt
Revision3893	Fixed a small bug in UmlComboBoxModel2Refactored the Detailspane in such a way it reacts correctly to targetEventsInt
Revision3896	fixed placement bug in ClassdiagramLayouter relating to using the placementhint only when it is safe to do so. It is safe
Revision3903	The TabProps uses targetlistener in a correct way now -Tabprops now responsiblefor maintaining its own targetlistener l
Revision3906	Project is a TargetListener now too.Fixed an -allready existing- bug in PropPanelOperation concerning navigateUp
Revision3914	Fixed bug with todopane
Revision3925	Fixed bug markus reported concerning diagram names
Revision395	some last fixes, inlcuding Curts NavPane, Dependency, and Makefile changes.Also, I found a bug concerning drawing Fi
Revision3960	Fixed a bug to the load proces. Really I have to redesign the damn loading saving one day
Revision3961	Fixed a bug to the load proces. Really I have to redesign the damn loading saving one day
Revision4300	Removed setPreferredSize-- calls which caused it to layout really small on "Goto" dialog. Removed reference to MetalLo



```
SELECT ?revision ?Message
WHERE {
?revision :commitMessage ?Message.
FILTER REGEX (?Message, "fix issue")
}
```

Revision10910	Patch to fix issue 4324 as supplied by Andrea.
Revision1269	Adjusted ProjectMember name handling to fix issue #455.Issue number: 455
Revision13432	Patch to fix issue 4839, as supplied by Christian.
Revision1463	Changes to critics for associations and wizard for aggregation to fix issue619.
Revision1540	fix issue 777 where the Action "remove from diagram" would actually remove the element and put in Trash when the eleme
Revision2510	Move multiplicty out of fig group to fix issue 1125. This undoes change introduced in 1.13 which was to fix issue 1007. Issue
Revision4247	Bugfix issue 1993.
Revision5352	Rollback changes to fix issue 701 that caused the higher priority issue 2374This undoes the changes in vers 1.79 of FigNode
Revision5711	Revert initial values field to use old deprecated class to fix issue 1378
Revision7464	first step to fix issue #2963 - model used as namespace in generation
Revision802	This modification should fix issue 225. It sets the name of the figure to thename of a passed MInterface node, so you can ac
Revision8574	Next attempt to fix issue 3207: "Edges do not stick to package bounds". Besides for a Package, also solved for Choice, MNo
Revision8889	Corrected the failing test since my latest commits to the DetailsPane class to fix issue 3254.

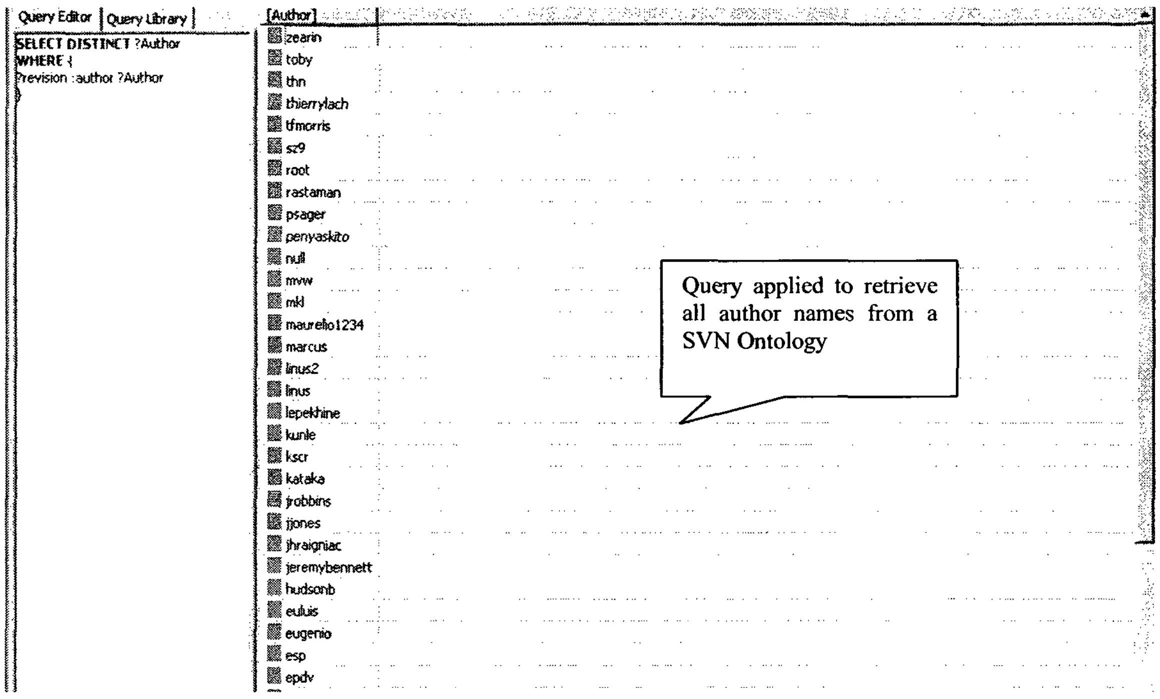


```
.T ?revision ?Message
RE {
ion :commitMessage ?Message.
R  REGEX (?Message, " issue number"
```

Retrieve a commit message of the revisions containing string "Issue numer".

```
revision          [Message]
◆ Revision5689   ▨  Issue number: 1087ocl-argo.jar is LGPL.CVS: ----------------------------------------------------------------CVS: Issu
◆ Revision7872   ▨  Issue number: 3092Obtained from:Submitted by:Reviewed by:Implemented critic to detect "circular" association classes
◆ Revision10193  ▨  Issue number: 3189Obtained from:Submitted by:Reviewed by:rename 'anon' to 'unnamed'CVS: ------------------------
◆ Revision9204   ▨  Issue number: 3584Fixed calling the ant.bat script provided with ant 1.6.2.CVS: ------------------------------------------
◆ Revision9259   ▨  Issue number: 3652First implementation of CodeGenerator.CVS: ----------------------------------------------------
◆ Revision10191  ▨  Issue number: 3773Obtained from:Submitted by:Reviewed by:expand root node after selecting a new perspective in the
◆ Revision10040  ▨  Issue number: 4074 - fix tagged values with no xmi.id-fix is in last commit - this is just to get the issue number into a co
◆ Revision10176  ▨  Issue number: 4097Obtained from:Submitted by:Reviewed by:Don't allow methods on interfaces. Probably not a nice sc
◆ Revision10325  ▨  Issue number: 4101repair behavior of Navigationbox link buttonObtained from:Submitted by:Reviewed by:CVS: --------
◆ Revision11036  ▨  Issue number: 4278Obtained from:Submitted by:Reviewed by:Added special cases for use cases.CVS: -------------------
◆ Revision11035  ▨  Issue number: 4351Obtained from:Submitted by:Reviewed by:added check to see whether the association end is actuall
◆ Revision11034  ▨  Issue number: 4406Obtained from:Submitted by:Reviewed by:added check that the index cannot go out of bounds whe
◆ Revision1277   ▨  Issue number: 451Obtained from: Jeremy BennetSubmitted by:  Thierry LachReviewed by:  Luc MaisonobeProblems wi
◆ Revision1602   ▨  Issue number: 491Submitted by:  Thierry LachCorrection for "no media inserted in the drive" as found in sun's java foru
◆ Revision1600   ▨  Issue number: 491Submitted by:  Thierry LachCorrection for "no media inserted in the drive" as found in sun's java foru
◆ Revision1365   ▨  None of the classes in this package appear to be used.  I am deprecating them now and will remove them before some f
◆ Revision10278  ▨  Open the perspective configurator dialog as a second location from the edit menu.Issue number:  3631Obtained from:S
◆ Revision7947   ▨  Other generators of public use can also be found in org.argouml.uml. this helps to make the cognitive system more ind
◆ Revision7890   ▨  Remove dependencies to Design and DesignMaterialIssue number:Obtained from:Submitted by:Reviewed by:CVS: ------
◆ Revision1294   ▨  Submitted by:  Thierry LachAdd pluggable menu support for Menu--File--ImportCVS: --------------------------------
◆ Revision6850   ▨  Testcase to check that two uuids are not equal -pretty basic-Issue number:Obtained from:Submitted by:Reviewed by:CV
◆ Revision6023   ▨  Updated some features. Added some issue numbers.
◆ Revision9025   ▨  add LOG statementsadd a call to targetSet after targetRemoved had been called. This is in sync with the other model bas
◆ Revision6185   ▨  added a number of methodsIssue number:Obtained from:Submitted by:Reviewed by:CVS: ------------------------------
◆ Revision8863   ▨  added i18n literals for the ActionSetPathIssue number:  3422Obtained from:Submitted by:Reviewed by:CVS: ------------
◆ Revision7884   ▨  added some package documentationIssue number:Obtained from:Submitted by:Reviewed by:CVS: --------------------
◆ Revision8717   ▨  adding method to Model Facade implementationsIssue number:Obtained from:Submitted by:Reviewed by:CVS: --------
◆ Revision8793   ▨  adding related include relationships when adding a use case which had been removed from the diagram was not possib
◆ Revision5958   ▨  adding source for namespace packageCVS: ----------------------------------------------------------------------CVS: Issue
◆ Revision5953   ▨  avoid NPE in removeObsoleteFeaturesCVS: ---------------------------------------------------------------------CVS: Issue
```

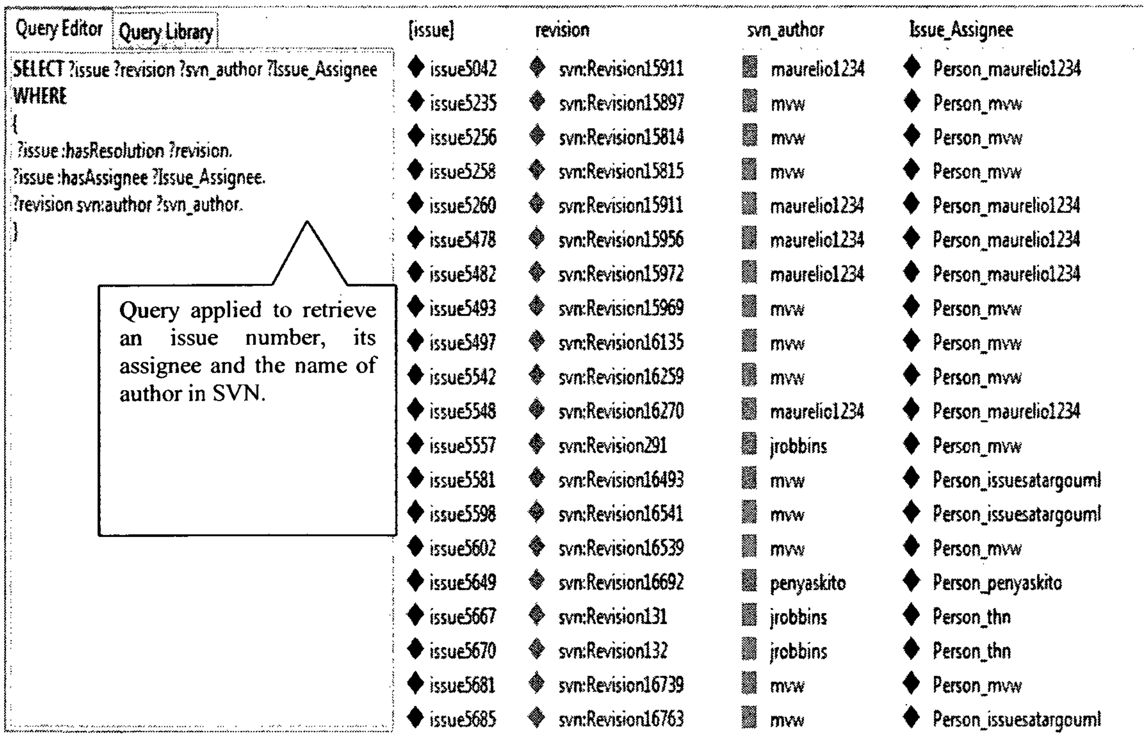
In what follows, several quires applied to retrieved information from the SVN and Bugzilla Ontology.



```
SELECT DISTINCT ?Author
WHERE {
?revision :author ?Author
}
```

```
[Author]
zearin
toby
thn
thierrylach
tfmorris
sz9
root
rastaman
psager
penyaskito
null
mvw
mkl
maurelio1234
marcus
linus2
linus
lepekhine
kunle
kscr
kataka
jrobbins
jjones
jhraigniac
jeremybennett
hudsonb
euluis
eugenio
esp
epdv
```

Query applied to retrieve all author names from a SVN Ontology

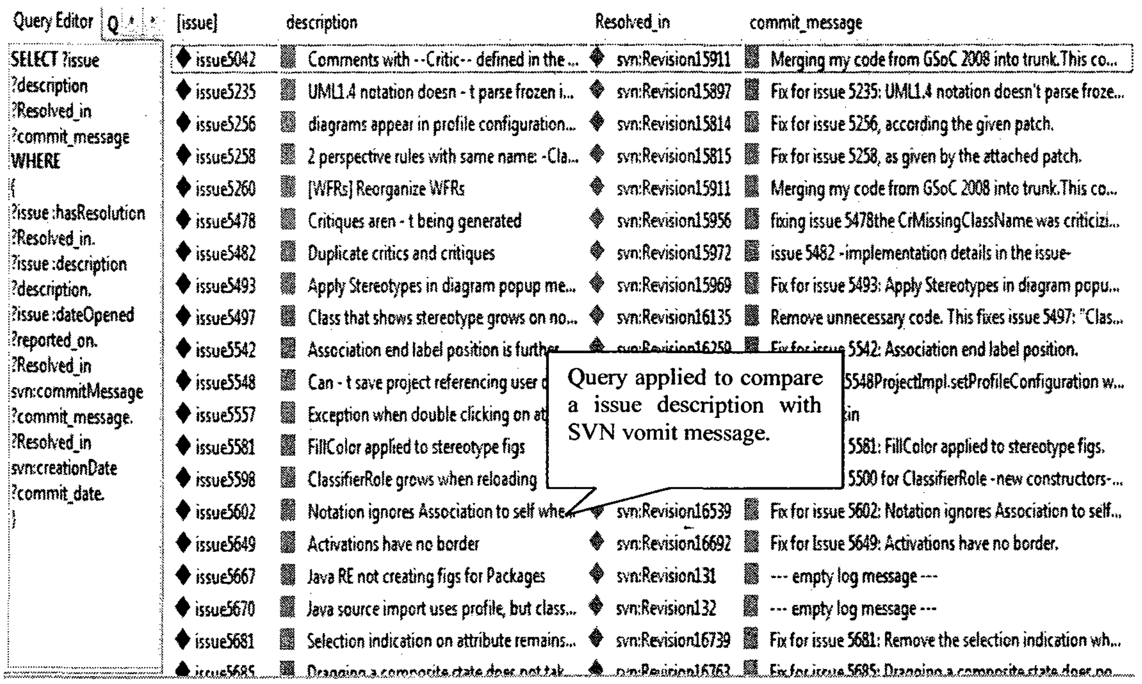


Query Editor | Query Library

```
SELECT ?issue ?revision ?svn_author ?Issue_Assignee
WHERE
{
?issue :hasResolution ?revision.
?issue :hasAssignee ?Issue_Assignee.
?revision svn:author ?svn_author.
}
```

[issue]	revision	svn_author	Issue_Assignee
issue5042	svn:Revision15911	maurelio1234	Person_maurelio1234
issue5235	svn:Revision15897	mvw	Person_mvw
issue5256	svn:Revision15814	mvw	Person_mvw
issue5258	svn:Revision15815	mvw	Person_mvw
issue5260	svn:Revision15911	maurelio1234	Person_maurelio1234
issue5478	svn:Revision15956	maurelio1234	Person_maurelio1234
issue5482	svn:Revision15972	maurelio1234	Person_maurelio1234
issue5493	svn:Revision15969	mvw	Person_mvw
issue5497	svn:Revision16135	mvw	Person_mvw
issue5542	svn:Revision16259	mvw	Person_mvw
issue5548	svn:Revision16270	maurelio1234	Person_maurelio1234
issue5557	svn:Revision291	jrobbins	Person_mvw
issue5581	svn:Revision16493	mvw	Person_issuesatargouml
issue5598	svn:Revision16541	mvw	Person_issuesatargouml
issue5602	svn:Revision16539	mvw	Person_mvw
issue5649	svn:Revision16692	penyaskito	Person_penyaskito
issue5667	svn:Revision131	jrobbins	Person_thn
issue5670	svn:Revision132	jrobbins	Person_thn
issue5681	svn:Revision16739	mvw	Person_mvw
issue5685	svn:Revision16763	mvw	Person_issuesatargouml

Query applied to retrieve an issue number, its assignee and the name of author in SVN.

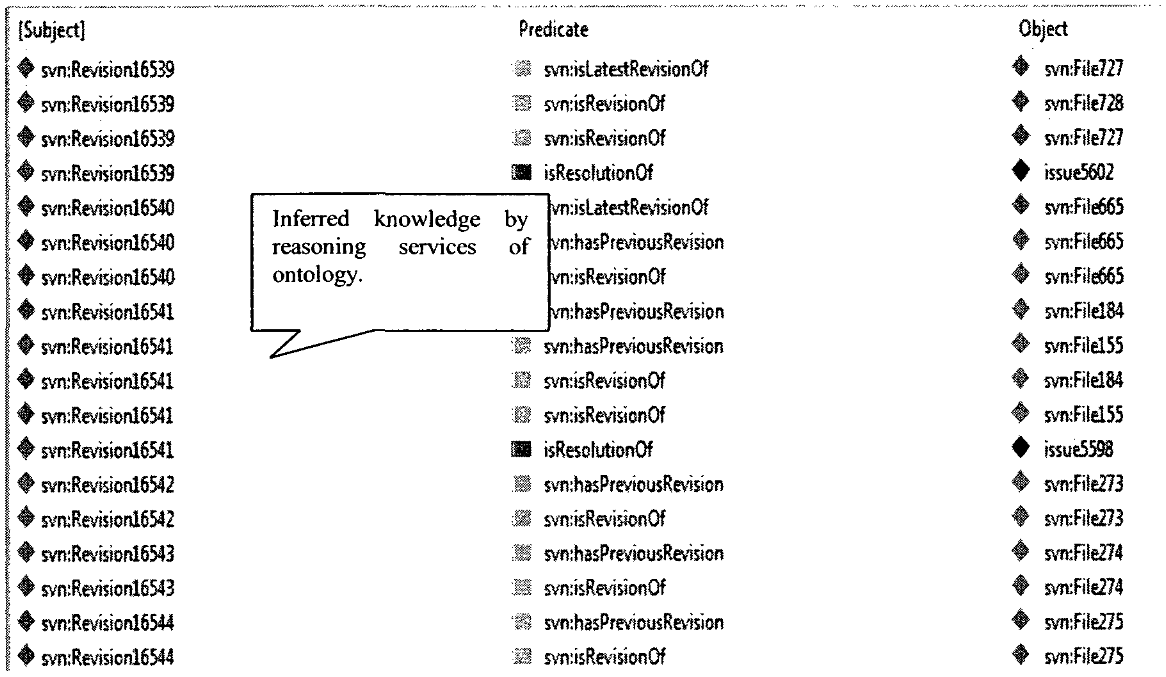


Query Editor | Q

```
SELECT ?issue
?description
?Resolved_in
?commit_message
WHERE
{
?issue :hasResolution
?Resolved_in.
?issue :description
?description.
?issue :dateOpened
?reported_on.
?Resolved_in
svn:commitMessage
?commit_message.
?Resolved_in
svn:creationDate
?commit_date.
}
```

[issue]	description	Resolved_in	commit_message
issue5042	Comments with --Critic-- defined in the ...	svn:Revision15911	Merging my code from GSoC 2008 into trunk.This co...
issue5235	UML1.4 notation doesn - t parse frozen i...	svn:Revision15897	Fix for issue 5235: UML1.4 notation doesn't parse froze...
issue5256	diagrams appear in profile configuration...	svn:Revision15814	Fix for issue 5256, according the given patch.
issue5258	2 perspective rules with same name: -Cla...	svn:Revision15815	Fix for issue 5258, as given by the attached patch.
issue5260	[WFRs] Reorganize WFRs	svn:Revision15911	Merging my code from GSoC 2008 into trunk.This co...
issue5478	Critiques aren - t being generated	svn:Revision15956	fixing issue 5478the CrMissingClassName was criticizi...
issue5482	Duplicate critics and critiques	svn:Revision15972	issue 5482 -implementation details in the issue-
issue5493	Apply Stereotypes in diagram popup me...	svn:Revision15969	Fix for issue 5493: Apply Stereotypes in diagram popu...
issue5497	Class that shows stereotype grows on no...	svn:Revision16135	Remove unnecessary code. This fixes issue 5497: "Clas...
issue5542	Association end label position is furth	svn:Revision16259	Fix for issue 5542: Association end label position.
issue5548	Can - t save project referencing user		5548ProjectImpl.setProfileConfiguration w...
issue5557	Exception when double clicking on at		in
issue5581	FillColor applied to stereotype figs		5581: FillColor applied to stereotype figs.
issue5598	ClassifierRole grows when reloading		5500 for ClassifierRole -new constructors-...
issue5602	Notation ignores Association to self whe	svn:Revision16539	Fix for issue 5602: Notation ignores Association to self...
issue5649	Activations have no border	svn:Revision16692	Fix for Issue 5649: Activations have no border.
issue5667	Java RE not creating figs for Packages	svn:Revision131	--- empty log message ---
issue5670	Java source import uses profile, but class...	svn:Revision132	--- empty log message ---
issue5681	Selection indication on attribute remains...	svn:Revision16739	Fix for issue 5681: Remove the selection indication wh...
issue5685	Dragging a composite state does not tak	svn:Revision16763	Fix for issue 5685: Dragging a composite state does no

Query applied to compare a issue description with SVN vomit message.



[Subject]	Predicate	Object
svn:Revision16539	svn:isLatestRevisionOf	svn:File727
svn:Revision16539	svn:isRevisionOf	svn:File728
svn:Revision16539	svn:isRevisionOf	svn:File727
svn:Revision16539	isResolutionOf	issue5602
svn:Revision16540	vn:isLatestRevisionOf	svn:File665
svn:Revision16540	vn:hasPreviousRevision	svn:File665
svn:Revision16540	vn:isRevisionOf	svn:File665
svn:Revision16541	vn:hasPreviousRevision	svn:File184
svn:Revision16541	svn:hasPreviousRevision	svn:File155
svn:Revision16541	svn:isRevisionOf	svn:File184
svn:Revision16541	svn:isRevisionOf	svn:File155
svn:Revision16541	isResolutionOf	issue5598
svn:Revision16542	svn:hasPreviousRevision	svn:File273
svn:Revision16542	svn:isRevisionOf	svn:File273
svn:Revision16543	svn:hasPreviousRevision	svn:File274
svn:Revision16543	svn:isRevisionOf	svn:File274
svn:Revision16544	svn:hasPreviousRevision	svn:File275
svn:Revision16544	svn:isRevisionOf	svn:File275

In order to retrieve some statistics of an ArgoUML project from the Bugzilla Ontology, we applied several queries on the Bugzilla Ontology. As a result, the queries retrieved following statistics. (1) The total number of persons involved in the Bugzilla Ontology (i.e. Person in the role of *Assignee, Commenter, Creator of an Attachment*, and *Involved Person*). (2) Total number of the issues reported in the current release. (3) Total number of activities related to the issues. (4) Total number of Comments. (5) Total number of computer systems (i.e. combination of an operating system and platform). Following table shows some statistics obtained from Bugzilla Ontology.

Total number of *Person*	27
Total number *Issues* (as of February 4, 2009)	71
Total number *Activities* of related to an *Issue*	33
Total number of *Comments* on *Issues*	366
Total number of *computer systems*	10

Some Statistics of Bugzilla Ontology.

In order to retrieve some statistics of an ArgoUML project, we applied several queries on the SVN ontology. As a result, the queries retrieved following statistics. (1) Total number of the files in SVN repository. (2) Total number of revisions. (3) Total number of authors (i.e. developers / maintainers). (4) Total number of releases tagged in SVN repository. Following table shows some statistics obtained from SVN ontology.

Total number of files used in different revision	56920
Total number of revisions	16793
Total number of Authors (developers /maintainers)	50
Total number of Releases tagged through revisions (i.e. including tags "ALPHA_1 to ALPHA_n", and "BETA_1 to BETA_n".	156

Some Statistics of SVN Ontology.