2010-12-16

A Reusable Persistence Framework for Replicating Empirical Studies on Data from Open Source Repositories

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Computer Science

Brigham Young University

April 2011

ABSTRACT

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Empirical research is inexact and error-prone leading researchers to agree that replication of experiments is a necessary step to validating empirical results. Unfortunately, replicating experiments requires substantial investments in manpower and time. These resource requirements can be reduced by incorporating component reuse when building tools for empirical experimentation. *Bokeo* is an initiative within the Sequoia Lab of the BYU Computer Science Department to develop a platform to assist in the empirical study of software engineering. The *i3Persistence Framework* is a component of *Bokeo* which enables researchers to easily build and rapidly deploy tools for empirical experiments by providing an easy-to-use database management service. We introduce the *i3Persistence Framework* of *Bokeo* to assist in the development of software to replicate experiments and conduct studies on data from open-source repositories.

ACKNOWLEDGMENTS

First and foremost, to my wife Andrea, who never gave up even when I did.

To my children, Christopher, Samuel, Alexander, Daniela, and Dominik, for their patience when Papa was "too busy."

To my advisor, Dr. Charles Knutson, for lighting a fire under me and making sure I finished.

To my collegue Alex MacLean for his counsel and critique which have improved this thesis.

To Dr. Benjamin Gibbs whose orthogonal view added a new dimension to this thesis.

To my sister-in-law Beth for the time she spent to edit this thesis.

To my co-workers, Ben Wood and Jason Hill, without whose collaboration this project would not have been possible.

To my father who in his dying breath instructed me to pursue higher education.

Thank you.

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Chapter 1

Introduction

1.1 The Role of Replication in Empirical Research

Basili [4], Brooks [8], MacDonnell [32] and other researchers [23, 24, 40] state that empirical studies tend to be inexact and error-prone; thus, results need to be validated. Empirical experiments are fraught with potential errors: statistical procedures may be misapplied, the sample size may not be adequate to support the results, and/or the results may not justify the conclusion.

Because of such problems, researchers consider reproducibility of experimental results a prerequisite to establishing validity. Shull et al. state that one of the primary goals of replication is to *verify* the applicability of the results of the initial study [39].

One method of validating the results of an experiment is for multiple independent teams to conduct the same experiment concurrently [8]. The confirmation of two or more independently conducted experiments adds credibility to the results.

Another way to facilitate replication is to publish detailed reports on *how* to replicate the empirical experiment. When describing an experiment a researcher provides a recipe for others to verify results by documenting the type of equipment used and the precise procedure followed. Basili et al. suggest a project package structure which outlines the minimal information necessary to facilitate the external replication of an experiment [39].

A third way to facilitate replication is to use *experiment databases* (*ExpDB*) to store detailed information on numerous *learning* experiments [6, 7]. An *ExpDB* is a special kind of inductive database whose methodology consists of filling and then querying this database for patterns [37]. This methodology is useful for data mining and machine learning where insights into the behavior of *learning* algorithms are obtained by implementing the algorithms and studying their behavior on specific datasets. Although *ExpDB* has been successfully used in empirical experiments in various fields of study (i.e., biology, physics) where algorithms are applied to well-defined datasets, it is not as readily applicable in empirical studies of software evolution because such studies are exploratory in nature and are not as well-defined as *learning* experiments. Therefore, the *ExpDB* methodology is mostly applicable to software engineering empirical studies which optimize algorithms that work on well-defined datasets.

Experimental replication may require the researcher to invest substantial manpower and/or time to develop and maintain the software tools necessary to validate empirical experiments.

One technique to reduce the resources required to develop tools and increase experimental accuracy is to incorporate code reuse when implementing the tools. Studies have shown the positive effects of code reuse on reducing the time required to develop and maintain software projects [3, 11, 42]. We intend to apply similar principles to experimental replicability.

We present a reusable persistence framework to help implement and deploy tools for replicating empirical experiments.

1.2 *Bokeo*: A Framework for Conducting Empirical Experiments

Although tools are available to assist with empirical experiments, we are not aware of any tools with the extensibility and power to conduct a broad scope of empirical software engineering research on a large corpus of data. Most research tools are intended as proof-of-concept and are designed to test the hypothesis of a particular experiment. Such tools usually have limited functionality, applicability, and scalability. Other tools define a static workflow tailored to the specifics of an experiment, making them difficult to extend to new experiments.

Consequently, the Sequoia Lab at BYU is actively developing *Bokeo* to help researchers conduct empirical experiments on large corpora of open source software. *Bokeo* is an extensible framework with which users may extract, analyze and visualize derived metrics and data from software repositories. *Bokeo* follows a conceptual workflow-based model with four distinct areas of abstraction called phases, each comprised of one or more components and workflows.

In this section we present the overall architecture of *Bokeo* and describe the high-level functions of each phase (see Figure 1.1).

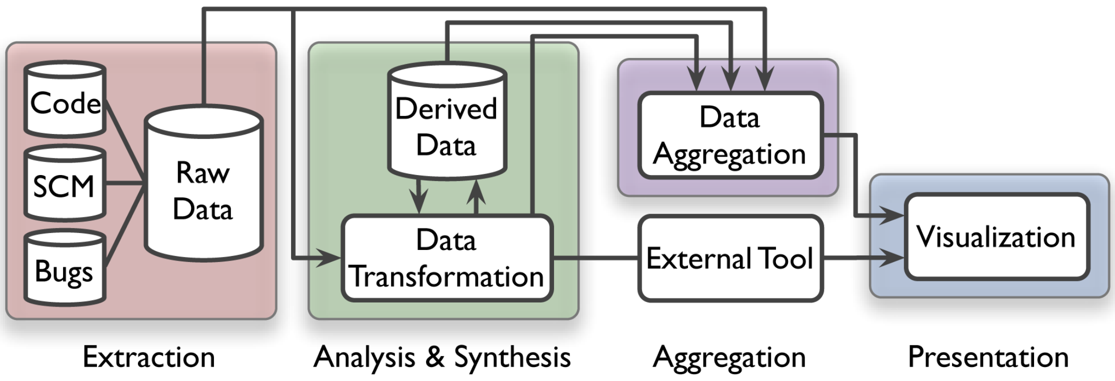


Figure 1.1: High-level Workflow Phases of *Bokeo*.

The first phase of *Bokeo* is the *Extraction Phase*, which extracts raw data from source code or other artifacts of software and bug repositories. Our goal is to aggregate, into a single repository, evolutionary data from many projects across multiple revision control systems to allow researchers to conduct a broad scope of experiments with varying sample sizes.

The second phase of *Bokeo* is the *Analysis and Synthesis Phase*, which analyzes and synthesizes raw data to generate new, more informative *derived* data. Unlike controlled experiments in which the variation in data is dictated by the design of the experiment, the data contained in software and bug repositories are historical and fixed. The variation in the data is extracted or derived in the *Analysis and Synthesis Phase* for the purpose of testing the hypothesis of the empirical experiment, validating the results of an experiment, or viewing a metric to gain insights into a complex data set. Therefore, the majority of the work for an empirical experiment will normally be carried out in the *Analysis and Synthesis Phase.*

The third stage of *Bokeo* is the *Aggregation Phase,* which performs the aggregation, correlation, and dissemination of both raw and derived data into forms consumable by the *Presentation Phase.*

The fourth stage of *Bokeo* is the *Presentation Phase*, which allows users to navigate and explore derived data in order to gain insights about large and complex data sets.

1.3 The Database Management System

The study of software engineering allows researchers to create better models of software processes, products, and environmental factors and to understand how these models interact. This knowledge, in turn, empowers practitioners to better control the development process by understanding what techniques work and what techniques do not work, and under what conditions.

Most artifact-based empirical studies of software engineering analyze one or more metrics extracted from the software or bug repository. As an example, in the case of software evolution, this metric may be compared at different points in the life of the software project to identify trends or patterns of behavior. For example, Gall et al. used software change version information, fine grained changed entities data and Concurrent Versions System (CVS) release history data to create models of (1) project growth and change behavior, and (2) the dependencies within the evolution of particular entities [15].

A central requirement when conducting artifact-based empirical experiments of open source software development for academic research is to share and store comparable data and analysis of software artifacts [22, 17]. The most common method of storing and organizing data is the use of a database management system (DBMS). *i3Persistence Framework* upon which *Bokeo* is being built, reflects the current state of the art in database ease of use and setup. This persistence framework will allow researchers to rapidly develop and deploy *Bokeo* plug-in modules.

The *i3Persistence Framework* was originally designed as a standalone technology to address the general need in the software development community to increase developer productivity and decrease the cost of software maintenance. However, in this industrial thesis, we focus on the applicability of the *i3Persistence Framework* in replicating artifact-based empirical experiments on data from open source repositories.

Chapter 2

Related Work

The analysis and synthesis of data from source code and bug repositories is an increasingly well-researched problem with tools emerging within the open source community. These tools support the extraction of data from repositories and the generation of high-order, derived metrics via analysis and synthesis techniques. In this section we present relevant related work.

Bonsai [21] and LXR [19], two commonly used CVS front-end tools, store the revision information for each file into a relational database. Both Bonsai and LXR consist of several PERL scripts that are run in succession. Although many researchers have managed to generalize Bonsai and LXR, their maintainers recommend using these tools with the repository for which they were originally designed, namely Mozilla and the Linux kernel respectively. Bonsai and LXR are characteristic of tools that are designed to work on a narrow group of repositories but which researchers have adapted for their particular empirical needs.

SoftChange tracks changed files in C/C++ or Java software projects by aggregating data from the CVS source repository, Bugzilla bug repository and mail archives [18]. This tool consists of several PERL scripts designed to run in sequence on a Linux platform. SoftChange requires the user to install an instance of the PostgreSQL database into which intermediary information is placed. SoftChange is not designed for use in an automated workflow scenario due to technology dependencies, as well as required human interaction.

Hipikat identifies relationships between documents by aggregating information from CVS source and Bugzilla repositories, newsgroups and archives of mailing lists [10]. The goal of Hipikat is to recommend to the user existing artifacts from a software project that are relevant to a task of interest. This tool is implemented as a plug-in to Eclipse, and hence cannot be used as a standalone contributor in an automated workflow.

Xia/Creole is an Eclipse plug-in which leverages the Eclipse CVS API and the Shrimp Visualization Tool [41] to create a visual architectural representation of CVS repositories [44, 30]. Since Xia/Creole is implemented as a plug-in, it cannot be used as a standalone component in an automated workflow.

The Google App Engine is an end-to-end Web application development and runtime environment. Developers build App Engine applications using the provided SDK and deploy them onto Google's infrastructure. For the App Engine datastore, the Java SDK includes implementations of the Java Data Objects (JDO) and Java Persistence API (JPA) interfaces. The current App Engine JDO implementation does not support inheritance, and only objects in the same group can be saved in one transaction. Additionally, the App Engine incorporates a pay-as-you-go fee model: the application resources used, such as storage and bandwidth, are measured and billed by the gigabyte.

Although analysis and data transformation tools have been developed, much work remains in improving the extensibility, reusability, and scalability of such tools. The most significant limitations of existing tools are that (1) they require complex setup rendering them difficult to utilize, (2) they enforce a static workflow which is not adequate for general use, (3) they are designed with non-standard interfaces, making them difficult to reuse in a larger tool context, and (4) they are generally not scalable under increased load.

Chapter 3

Thesis Statement

In this industrial thesis, we present a reusable persistence framework, called *i3Persistence*, to increase developer productivity in replicating data-centric empirical experiments by abstracting away from the user the complexity of data management, and facilitating ease of use and setup. We validate this framework by replicating the GNU gcc portion of German's study, *Mining CVS Repositories, the softChange Experience*, using the *Sliding-Time-Window* algorithm to rebuild Modification Requests from CVS revision logs.

Chapter 4

Project Description

4.1 Why Another Persistence Framework?

Given the plethora of relational database management systems (RDBMS) currently available, one may argue against the need for yet another persistence framework. We present our justification below in three parts:

1. The limitations of existing database management systems.
2. The deficiencies of data management in the current development model for empirical experiments of open source software.
3. The lack of support for *Bokeo*'s plug-in architecture requirements by the design-time static schema requirement of current RDBMSs.

4.1.1 Limitations of Existing Database Management Systems (DBMSs)

Although Database Management System (DBMS) technology has evolved from the tightly integrated systems of the mid 1960s to the cloud-based systems of today, the basic building blocks of general-purpose DBMSs continue to pose obstacles to the application developer. We outline these obstacles in the following subsections.

4.1.1.1 The Relational vs. Object-Oriented Impedance Mismatch

Most applications that rely on a database as a datastore use a RDBMS while employing an object-oriented programming language to implement business logic. Since RDBMSs store data in tables which is inconsistent with this programming model, business objects must be mapped to and from predefined database tables. This inefficiency, or "impedance mismatch," resulting from the need to map objects to tables and vice versa, has been a necessary complexity and performance penalty when using RDBMSs.

4.1.1.2 The Challenges of SQL

The use of RDBMSs requires proficiency in SQL (Structured Query Language), the most widely used computer language designed for managing data in RDBMSs. Unfortunately, the use of SQL poses several challenges to the developer.

First, although there is an accepted SQL standard, there are significant differences in DBMS implementations [2]. These differences are significant to the degree that SQL written for one DBMS will often not work on another DBMS. The reason for this can be traced to the fact that most modern database systems existed long before SQL was standardized and that there is still a business need to continue to support the legacy SQL written for these distinct environments. This uneven implementation of SQL and proprietary SQL extensions among RDBMS products makes migrating a sizable application from one RDBMS to another a significant effort.

Second, the grammar of SQL is based on *declarative programming* as opposed to *imperative programming* paradigm of traditional computer programming languages. In *declarative programming*, computation is described in terms of *what* the program should accomplish without prescribing the details of the actions to be taken. In contrast, *imperative programming* describes *how* to accomplish a task in terms of specific directions for the computer to perform. This difference in programming paradigms imposes another "impedance mismatch" for developers.

Third, although there have been great strides made in the development of database debuggers, these tools usually support a limited set of databases and require intimate knowledge of the particular flavor of SQL supported by each database. This results in an obtrusive “trial-and-error” development process which usually requires substantial time and resources (see Section 4.1.2). Additionally, a debugging solution for one RDBMS may not work for other vendors’ products. Such is the case for Oracle and MySQL.

For example, the accepted practice when debugging Oracle queries is to use the `DBMS_OUTPUT` package. This package is a corollary to `System.out.println()` in Java. The developer inserts output statements at strategic points in the code during design to evaluate the state of the executing query.

Additionally, in order to view the output at the command-line in Oracle without using a database-aware debugger such as SQL*Developer or Toad, the developer must first set a SQL*Plus environment variable from inside the SQL*Plus command-line environment (Listing 4.1). The developer can then test anonymous or named blocks (which is not supported in MySQL) with SQL statements such as in Listing 4.2.

Listing 4.1: Oracle Debugging Setup

```
SQL> SET SERVEROUTPUT ON SIZE 1000000
```

Listing 4.2: Oracle SQL Debugging Code

```
-- Create a procedure in Oracle.
CREATE OR REPLACE PROCEDURE hello_world IS
BEGIN
  -- Print a word without a line return.
  dbms_output.put('Hello ');
  -- Print the rest of the phrase and a line return.
  dbms_output.put_line('World!');
END;
/
-- Call the procedure.
EXECUTE hello_world;
```

The MySQL equivalent to calling the `DBMS_OUTPUT` package procedures is to simply `SELECT` a string as in Listing 4.3.

Listing 4.3: MySQL SQL Debugging Code

```sql
-- Conditionally drop the procedure.
SELECT 'DROP PROCEDURE hello_world' AS "Statement";
DROP PROCEDURE IF EXISTS hello_world;

-- Reset the delimiter to write a procedure.
DELIMITER $$

-- Create a procedure as in Oracle.
CREATE PROCEDURE hello_world()
BEGIN
  -- Print the phrase and a line return.
  SELECT 'Hello World!';
END;
$$

-- Reset the delimiter back to a semicolon to work again.
DELIMITER ;

-- Call the procedure.
SELECT 'CALL hello_world' AS "Statement";
CALL hello_world();
```

As can be seen in Listing 4.2 and Listing 4.3, the syntax of the SQL statements (as well as the APIs used for debugging) substantially differ between Oracle and MySQL. This example illustrates that debugging knowledge and efforts for Oracle are not transferable to MySQL and vice-versa.

4.1.1.3 The Challenges of Modern Object-Oriented DBMSs

An alternative to RDBMS is to manage data through object-oriented database management systems (OODBMS). There are many products currently available and most have semantics that are close to those of object-oriented programming languages, making it relatively easy to store, retrieve, and manage objects rather than rows of data. However, although the acceptance of OODBMS is growing, this solution also has its drawbacks.

While a standard exists for OODBMSs [5], in practice most products implement very little of that standard and vendors differ broadly on which portions of the standard they do implement. Additionally, most OODBMSs require knowledge of OQL, in addition to SQL, to manipulate the data. Due to the complexity of OQL, many OODBMS vendors implement only subsets of the standard, leading to the same diversity problem of SQL described in Section 4.1.1.2.

4.1.2 The Traditional vs. *i3Persistence* Development Process Model

Most existing DBMSs are designed for general use and are not optimized for computation-centric research. One of the building blocks of a general application DBMS is the Data Manipulation Subsystem, which helps the user to add, change, and delete information in a database and query it for valuable information. To maximize flexibility, most RDBMS Data Manipulation Subsystems support the use of a Data Query Language called SQL.

Complex computations are written in SQL and executed on the database server. SQL is complex to write and difficult to debug, thus increasing the likelihood of defects and prolonged development time.

The standard process for developing complex SQL logic is to implement the code in steps where the outputs of each coding step are saved to be analyzed at a later time for correctness. This process is repeated until the desired results are generated. This "non-runtime" debugging process, as depicted in Figure 4.1, usually involves the use of multiple tools and significantly more iterations than "runtime" debugging processes of modern programming languages.

The *i3Persistence Framework* alternative is to write the computations and business logic in Java and use a persistence-only optimized system to handle the storing and retrieving of data. This process is shown in Figure 4.2.

In this development model, computations are written in Java using tools with which the developer is familiar and which support a robust write-debug-modify cycle. The complexity of storing and retrieving data is abstracted behind an easy-to-use interface, freeing developers to focus on the solution to the research question instead of on the details of persistence implementation. Advanced Integrated Development Environments (IDE), such as

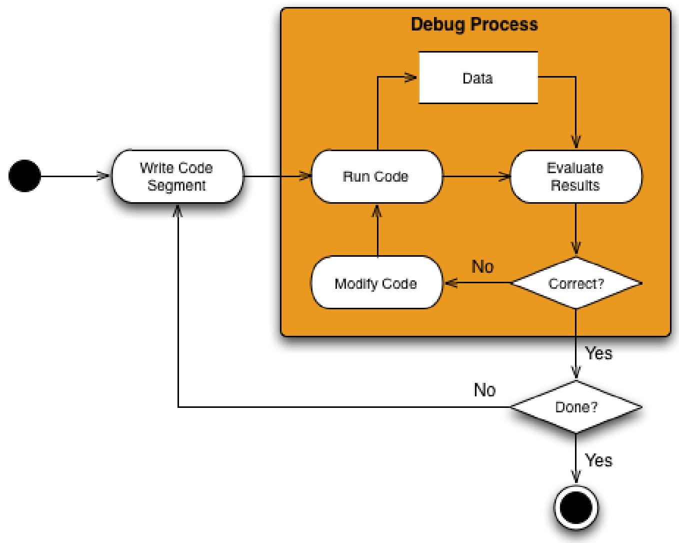


Figure 4.1: SQL-based Database Development Process

Eclipse, allow rapid implementation cycles by supporting code editing and debugging as a contiguous process within a single tool.

4.1.3 Static vs. Dynamic Database Schema

RDBMSs enforce the use of a design-time static schema, which is contrary to *Bokeo*'s plug-in architecture, in which each plug-in designer can specify persistence requirements. The RDBMS-persistence-based prototype-to-production development model usually requires database changes to be migrated from the prototype to production runtime environment at design time. This implies that the framework must be aware of each plug-in's persistence requirements.

The goal of *Bokeo* is to allow researchers to prototype their *Analysis and Synthesis Logic* outside *Bokeo* then migrate the modules into *Bokeo* by wrapping them in the plugin framework as shown in Figure 4.3.

Bokeo provides the same *i3Persistence* services used during the prototyping phase of development where the *Analysis and Synthesis Logic* is developed as a standalone application. By using *Dependency Inversion* (Appendix B), *Dependency Injection* (Appendix

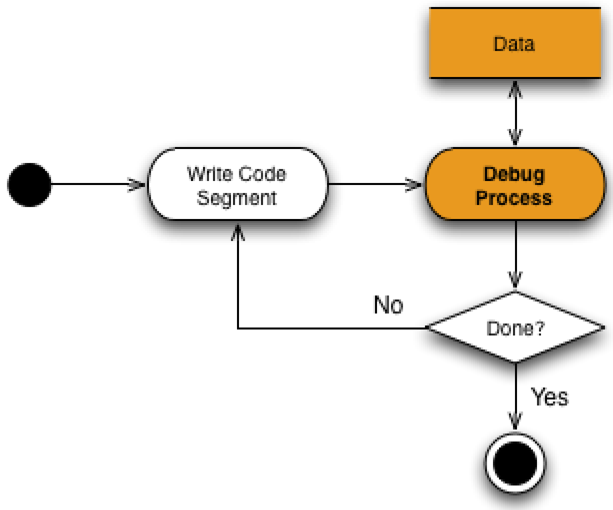


Figure 4.2: *i3Persistence*-based Database Development Process

C), and *Byte Code Manipulation* (Section 5.2.2), *Bokeo* seamlessly supports the persistence requirements of the plug-in. Therefore, an *i3Persistence Framework*-based standalone application can be converted into a *Bokeo* plug-in without any changes to the persistence logic.

4.2 *i3Persistence Framework* User Specifications

The *i3Persistence Framework* was developed over a period of 1.5 years. The primary product goals of the initial release of the *i3Persistence Framework* are three-fold:

1. Allow development teams of various skill levels to work concurrently on the project, but independent of each other.
2. Increase developer productivity by abstracting the complexity of data management away from the user.
3. Promote ease of use and setup.

The following sections describe features that were designed to address the product goals listed above.

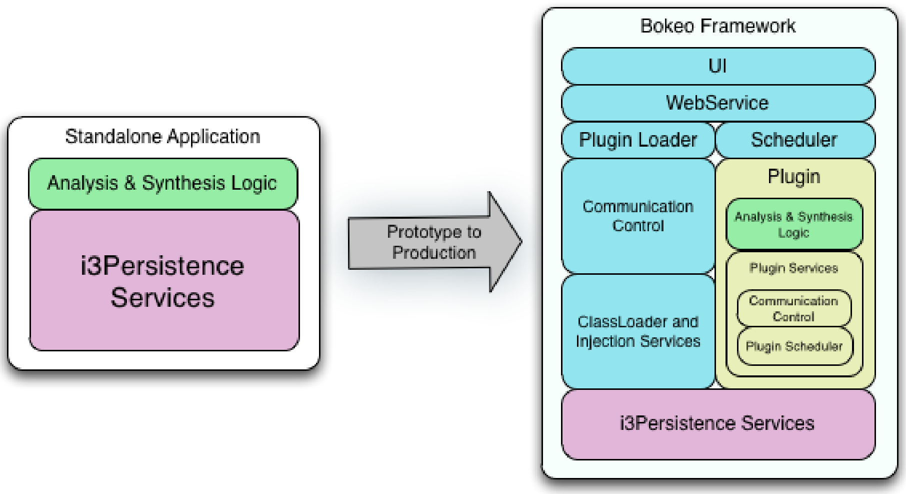


Figure 4.3: *i3Persistence*-based Plug-in Development Process

4.2.1 Decoupling via the *Dependency Inversion Principle*

In 1996, Robert Martin postulated the *Dependency Inversion Principle* (DIP) articulating the need to reduce the dependency of higher-level, more general layers to lower-level, more concrete layers in software systems [33]. This decoupling is achieved through the use of abstractions or, in the case of Java, `interfaces`.

The *i3Persistence Framework* achieves reduction in coupling by using a Component-Layered Architecture (see Appendix A). Each layer exposes a *Service Interface* which abstracts the layer's implementation details. This decoupling facilitates the independent, concurrent development of the *i3Persistence Framework* components and layers.

4.2.2 Further Decoupling via the *Dependency Injection Pattern*

Dependency Injection (DI) is a programming pattern that separates application code from the concrete implementation of the *Service Interface*. The main idea behind DI is that if an object relies on other "components" to help it accomplish its work, it should not be responsible for creating those components; rather, the components it depends on should be injected into it in the form of abstractions. Therefore, DI is based on the *Dependency Inversion* concept of programming to abstractions.

One benefit of using DI is the reduction of boilerplate code in the application objects since all work to initialize or set up dependencies is handled by a provider component [27].

Another benefit of DI is that it offers configuration flexibility because alternative implementations of a given service can be used without recompiling code. This means that service implementations can be easily changed by simply changing a configuration file.

The *i3Persistence Framework* uses DI to “glue” its services to application logic (see Appendix C).

4.2.3 Delegation via The *Factory Method Pattern*

One of the fundamental goals of software development, as stated by the open/close principle, is to design systems in which software entities (classes, modules, functions, etc.) are “open for extension, but closed for modification” [34]. Simply stated, software systems should be designed to change rapidly while reducing the negative impact these alterations can bring.

The *Dependency Inversion Principle* and *Dependency Injection Pattern* presented previously reduce coupling which in turn reduces the impact of changes to the system, but the use of abstractions introduces another problem. A module at runtime may only know when to instantiate a new object, but not the kind of subclass to create.

A solution to this problem is a creational design pattern called the *Factory Method Pattern* [16]. This pattern addresses the problem of creating objects without specifying the exact class of object that will be created. The classic definition of the *factory method* handles the problem of anonymous object creation by defining a separate method for creating the objects, of which subclasses can then override to specify the derived type of product that will be created.

Another definition of the term *factory method* refers to a method of a *factory* whose main purpose is the creation of objects. The *i3Persistence Framework* implements this definition by providing a mechanism to define an *object factory* with the use of the `@Service` annotation and by implementing the `Factory interface` (see Section 5.5). This delegation of responsibility increases application maintainability.

Another benefit of using the *Factory Method Pattern* is the reduction of boilerplate code in the application objects since all work to instantiate objects is handled by the *i3Persistence Framework*.

4.2.4 Reduce Complexity via Query By Filter vs. SQL

The *i3Persistence Framework* `Query` object eliminates the need for SQL by supporting query by filter. A `Filter Object` for a query is used to limit the results returned by a query based upon the return value of a *getter* method (see Section 5.5.3). For filtering on multiple properties, multiple `Filters` can be applied to a `Query` using a `FilterGroup`.

4.2.5 Reduce Code via Automatic Generation of `interface` Implementations

To reduce lines of code, the *i3Persistence Framework* provides a mechanism to automatically generate implementations for `interfaces` which adhere to the *JavaBeans* properties naming convention. *JavaBeans* is a framework for defining reusable modular software components. The class properties must be accessible using `get, set, is` (not that common) and other methods (so-called *getter* methods and *setter* methods), following a standard naming convention [12]. These conventions make it possible to develop tools that can use, reuse, replace, and connect *JavaBeans*. The *JavaBeans* properties naming convention is depicted in Table 4.1.

A bean defines a property *p* of type `T` if it has *getter* methods that follow these patterns (if `T` is boolean, a special form of *getter* method is allowed):

JavaBeans-compliant classes are used frequently as *Data Transfer Objects* (DTO). A DTO (formerly known as *Value Objects*) [14], is a design pattern used to transfer data between software application subsystems. DTOs are often used in conjunction with *Data Access Objects* (DAO) to retrieve data from a database. The difference between DTOs and

Property	Naming Convention
Getter	`public T getP()`
Boolean getter	`public boolean isP()`
Setter	`public void setP(T)`
Array getter	`public T[] getP()`
Element getter	`public T getP(int)`
Array setter	`public void setP(T[])`
Element setter	`public void setP(int, T)`

Table 4.1: *JavaBeans* Properties Naming Convention

DAOs is that a DTO does not have any behavior except for storage and retrieval of its own data (*getters* and *setters*).

In a traditional three-tiered architecture, DTOs serve dual purposes: first, they provide serializable solutions for objects which are not serializable; second, they implicitly define an assembly phase where all data to be used by the view are fetched and marshaled into the DTOs before returning control to the presentation tier. A benefit of controlling the synthesis of DTOs in the framework is that the object assembly phase can be optimized for a particular platform or database without affecting the client application.

The *i3Persistence Framework* implementation auto-generation mechanism creates a DTO class definition for an `interface` at runtime using the *Javassist* APIs. The fields of the generated DTO are based on the property name *p* and type `T` required by the *JavaBeans* naming convention for *getter/setter* methods.

This auto-generation mechanism reduces boilerplate code in the application since the framework generates the implementation for an `interface`. The usage details of this feature are described in Section 5.3.5.

4.2.6 Ease of Use via a Simple Persistence API

The *Persistence Layer* of the *i3Persistence Framework* is optimized for data storage and retrieval, leaving computations to be written at the *Application Layer* in Java. This optimization is manifested in the simplicity of the data management API, which consists of a

`PersistenceManager` to store data and a `Query` manager to retrieve data. These two API classes hide the complexity of data management and integrate seamlessly into native Java along with the object-oriented programming paradigm.

Because the *i3Persistence Framework* is written completely in Java, the framework functions as an extension to the Java language and is supported by the same IDE as is used to develop the *Analysis and Synthesis Logic.* This integral development allows for rapid write-debug-modification cycles.

4.2.7 Support for MySQL

MySQL is an RDBMS released as open source by MySQL AB in 2000. Since then, MySQL has emerged as the preferred open-source database choice for developers [1]. MySQL runs on more than 20 platforms including Linux, Windows, Mac OS, Solaris, HP-UX, IBM AIX, and is currently being used on every continent. The *i3Persistence Framework* supports MySQL.

Chapter 5

Implementation

5.1 Architecture Overview

The architecture of a software system is the highest-level breakdown of the system into its parts [14]. It embodies the design decisions that are difficult to change over the course of the software development cycle.

In this chapter, we present what we consider to be the important aspects of the *i3Persistence Framework* architecture.

5.1.1 Project Organization

The *i3Persistence Framework* is composed of two layers: the *Injection Layer* and the *Persistence Layer* (see Figure 5.1). As the names suggest, the *Injection Layer* encapsulates the DI functionality and the *Persistence Layer* encapsulates the Data Persistence functionality.

The *Injection Layer* is comprised of the following modules:

- `i3InjectionApi` – The service abstraction for the *Injection Layer* (see Section 4.2.1)
- `i3InjectionImpl` – The implementation of the `i3InjectionApi` services (see Section 4.2.1)
- `i3Agent` – An implementation of the *Java Agent* module required by the Java Instrumentation mechanism (see Section 5.2.1)
- *Javassist* – A third-party library for byte-code manipulation

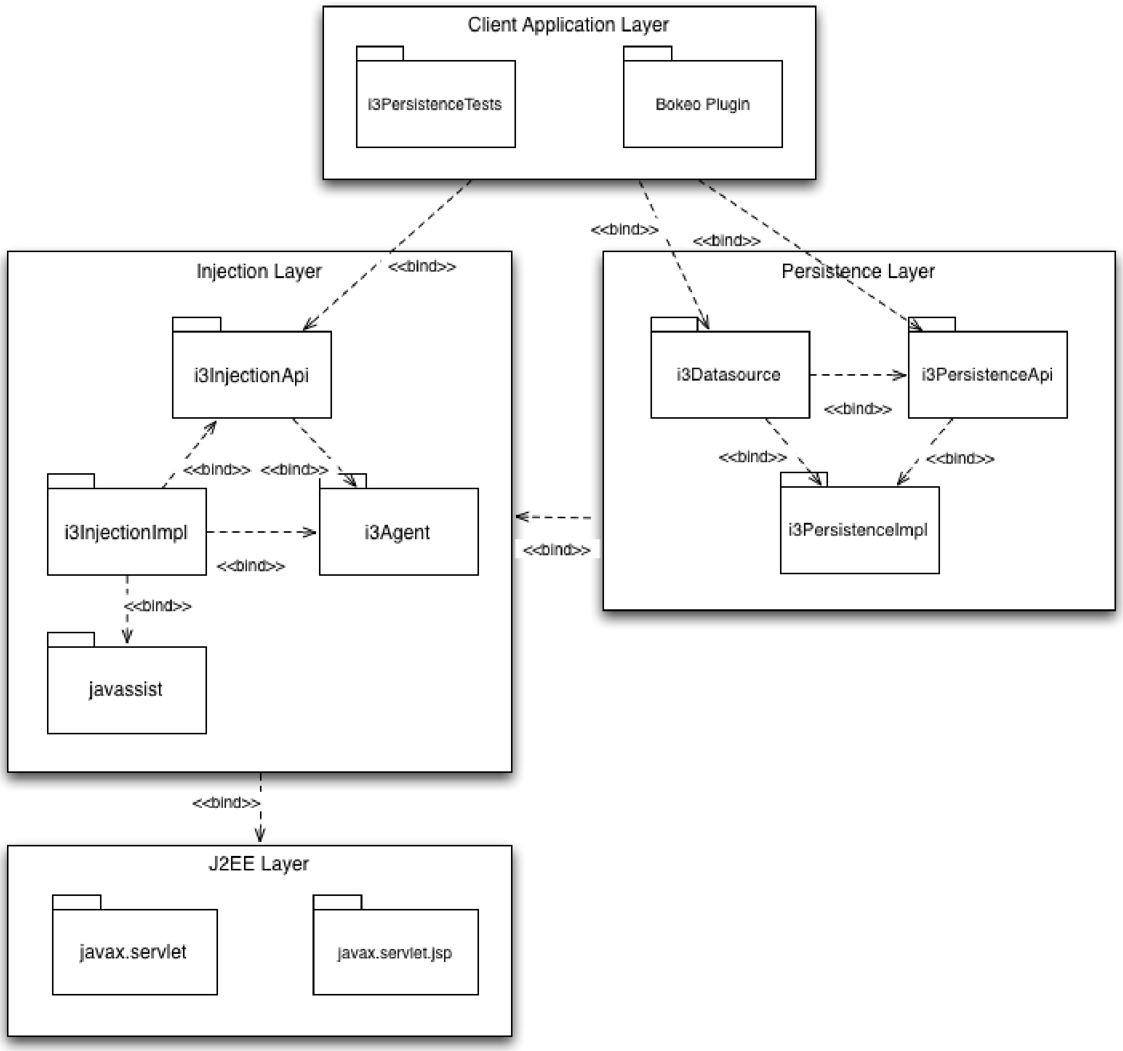


Figure 5.1: *i3Persistence Framework* Component-Layered Architecture

The *Injection Layer* has a hard binding to several J2EE modules to support deployment on Tomcat and JBoss.

The *Persistence Layer* is comprised of the following modules:

- `i3PersistenceApi` – The service abstraction for the *Persistence Layer* (see Section 4.2.1)
- `i3PersistenceImpl` – The implementation for the `i3PersistenceApi` services (see Section 4.2.1)
- `i3Datastore` – The database-specific modules

5.2 Java Object Persistence Scheme

The *i3Persistence Framework* persists Java objects in a Relational Database by utilizing Java *Serialization*. *Serialization* is the process of converting a set of object instances that contain references to each other into a linear stream of bytes as outlined in Figure 5.2.

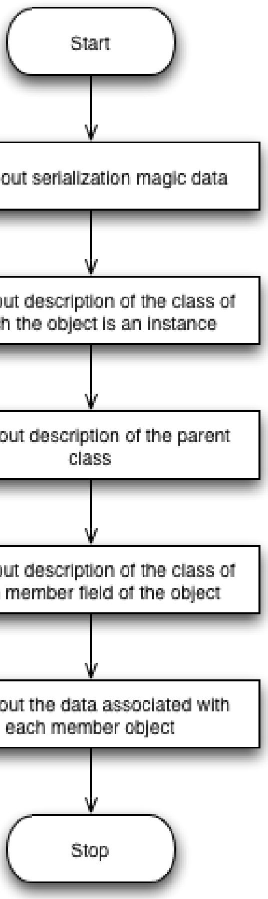

Start
Write out serialization magic data
Write out description of the class of which the object is an instance
Write out description of the parent class
Write out description of the class of each member field of the object
Write out the data associated with each member object
Stop

Figure 5.2: Java Object Serialization

The stream functions as a container for the object. Its contents include a partial representation of the object's internal structure, including variable types, names, and values as outlined in Section 6 of the Sun Microsystem *Java Object Serialization Specification rev. 1.4.4* [28].

The *Persistence Layer* services an object persistence request by generating a transient encoding of the object via the Java Serialization API. The framework then processes the serialized information modifying it for persistence and retrieval, then passes the modified information to the `i3Datastore` module. The `i3Datastore` module persists the object information in the schema depicted by Figure 5.3.

Java objects are broken down into their basic members and stored in the database tables listed in Table 5.1.

Each unique class is stored in `JAVA_CLASS`. All object instances are registered in the `JAVA_OBJECT` table along with their associated class name. For each field of an object, an entry is created in `JAVA_REFERENCE` to record the object hierarchy and in `JAVA_OBJECT_FIELD`

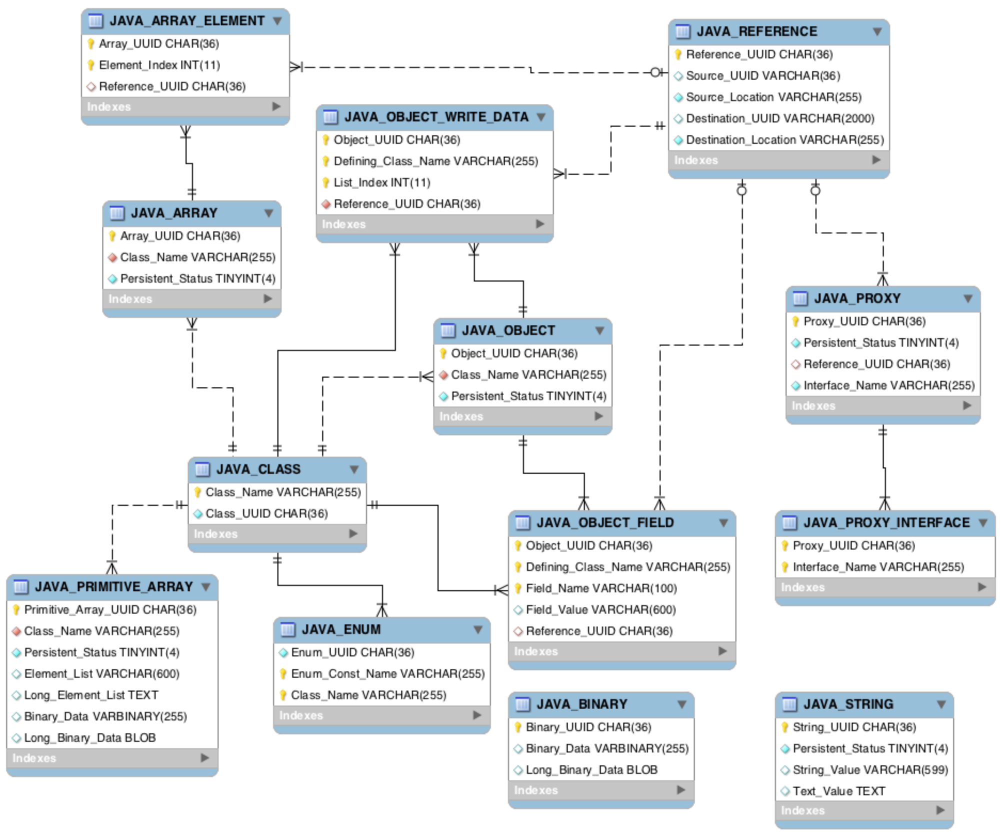


Figure 5.3: *i3Persistence Framework* Database ER Diagram

to record the data. The `Persistent_Status` field values of the `JAVA_OBJECT` table determine how long an object is retained by the `PersistenceManager` and determines if the object is visible to queries. Table 5.2 contains a list of the possible `PersistentStatus` values.

Object data is stored by type in the remaining tables. All `String` data are stored in the `JAVA_STRING` table to optimize searches.

The *i3Persistence Framework* abstracts the physical representation of the data store in the `i3Datastore` module with the intent to replace the current class *getter*-based query filtering with a more performant implementation and to eventually support multiple data sources in various formats and technologies.

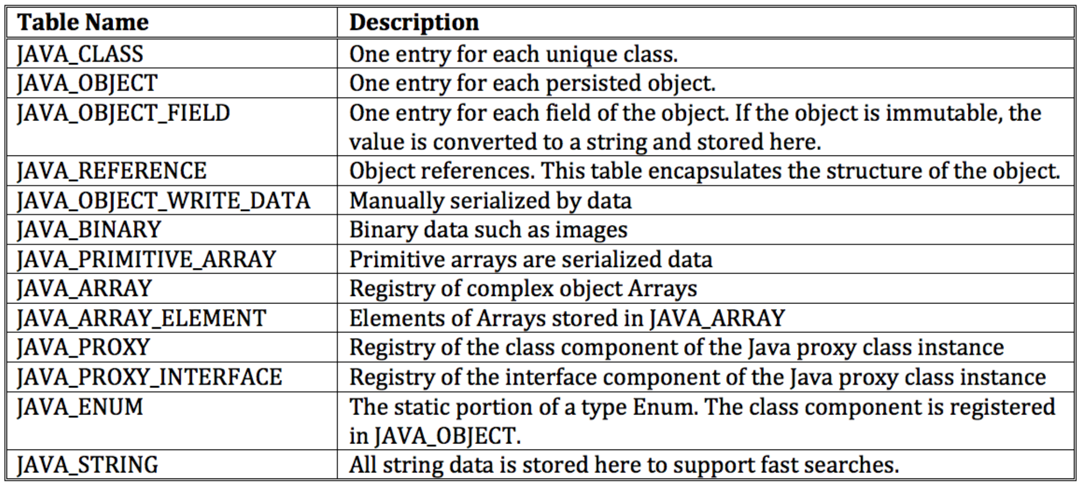
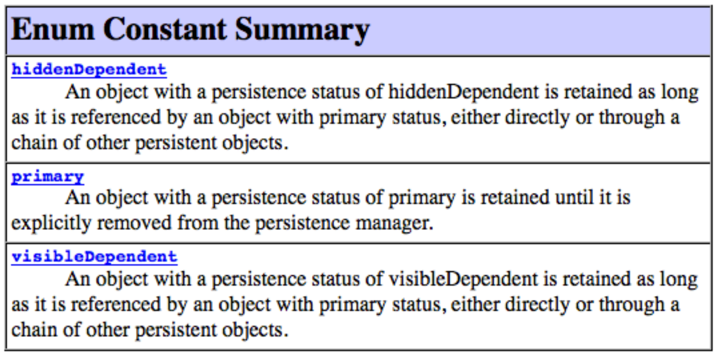


Table Name	Description
JAVA_CLASS	One entry for each unique class.
JAVA_OBJECT	One entry for each persisted object.
JAVA_OBJECT_FIELD	One entry for each field of the object. If the object is immutable, the value is converted to a string and stored here.
JAVA_REFERENCE	Object references. This table encapsulates the structure of the object.
JAVA_OBJECT_WRITE_DATA	Manually serialized by data
JAVA_BINARY	Binary data such as images
JAVA_PRIMITIVE_ARRAY	Primitive arrays are serialized data
JAVA_ARRAY	Registry of complex object Arrays
JAVA_ARRAY_ELEMENT	Elements of Arrays stored in JAVA_ARRAY
JAVA_PROXY	Registry of the class component of the Java proxy class instance
JAVA_PROXY_INTERFACE	Registry of the interface component of the Java proxy class instance
JAVA_ENUM	The static portion of a type Enum. The class component is registered in JAVA_OBJECT.
JAVA_STRING	All string data is stored here to support fast searches.

Table 5.1: *i3Persistence Framework* Database Table Definitions



Enum Constant Summary
`hiddenDependent` An object with a persistence status of hiddenDependent is retained as long as it is referenced by an object with primary status, either directly or through a chain of other persistent objects.
`primary` An object with a persistence status of primary is retained until it is explicitly removed from the persistence manager.
`visibleDependent` An object with a persistence status of visibleDependent is retained as long as it is referenced by an object with primary status, either directly or through a chain of other persistent objects.

Table 5.2: `PersistenceStatus` Values

5.2.1 Java Instrumentation and `i3Agent`

Java 5 introduced the Java Instrumentation mechanism, which allows developers to provide *Java Agents* that can inspect and modify the byte-code of the classes as they are loaded. A *Java Agent* is a pluggable library that runs embedded in a JVM and intercepts the class loading process.

The `i3Agent` module of the *i3Persistence Framework* provides a custom `Transformer` which is utilized by the *Java Agent* to support byte-code manipulation and object injection.

5.2.2 *Javassist* and Byte Code Manipulation

Javassist (Java Programming Assistant) is a class library for the runtime editing of byte-codes in Java [9]. It enables Java programs to define a new class at runtime and to modify a class file when the JVM loads it. The byte-code-level API allows users to directly edit a class declaration at runtime to add new methods.

Javassist also supports runtime reflection by enabling Java programs to use a metaobject that controls method calls on base-level objects.

The *Injection Layer* of the *i3Persistence Framework* uses *Javassist* for service injection.

5.3 `i3Injection`: Java Annotation

An annotation, in the Java programming language, is a special form of syntactic metadata that can be added to Java source code [25]. Classes, methods, variables, parameters and packages may be annotated. Unlike Javadoc tags, Java annotations can be reflective in that they can be embedded in class files generated by the compiler and may be retained by the Java VM to be made retrievable at run-time [20].

Annotations are used by the *i3Persistence Framework* to achieve the following:

1. Applying behaviors to user-defined classes and methods.
2. Used by the *Injection Layer* for service injection.
3. Used by the framework *Java Agent* hook to transform objects at runtime.

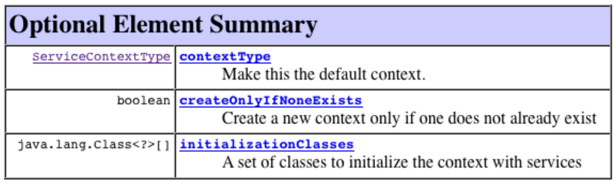
The `Transformer` object inserted into the VM at application startup by the `i3Agent` module, using the Java Automation API (see Section 5.2.1), intercepts the `Classloader` at runtime. It then scans the target class to load using Java reflection for supported annotations.

The following sections describe the custom annotations supported by the *i3Persistence Framework*.

5.3.1 `@ServiceContext`

`@ServiceContext` is a method-level annotation used to create a context within which registered objects and services are available for injection into method variables. When the `Transformer` detects the `@ServiceContext` annotation at class loading time, it manipulates the byte-code of the containing object and inserts additional code to the annotated method to access the service registry. This byte-code manipulation is achieved using the *Javassist* API (see Section 5.2.2).

Table 5.3 details the options for the `@ServiceContext` annotation.



Optional Element Summary	
`ServiceContextType`	**`contextType`** Make this the default context.
`boolean`	**`createOnlyIfNoneExists`** Create a new context only if one does not already exist
`java.lang.Class<?>[]`	**`initializationClasses`** A set of classes to initialize the context with services

Table 5.3: `ServiceContext` Annotation Optional Element Summary

5.3.1.1 Registering Services with `initializationClasses`

The `initializationClasses` option takes a list of comma-delimited runtime class objects to use to register injection implementations. These injection initialization classes (IIC), or *Initializer* classes, contain implementation details used by the `Transformer` to instantiate objects for injection. Listing 5.1 is an example of an injection initialization class.

Listing 5.1: `ServiceContext` ***Initializer*** **Class**

```
public class Initializer
{
  /**
   * 1) Register the TestObject interface so that it can be used
   *    with the @New annotation.
   */
  @RegisteredClass
  private final Class<TestObjectIntf> testObjectClass = TestObjectIntf.
      class;

  /**
   * 2) Register the TestService service so that it can be used
   *    with the @Service annotation.
```

```
13    */
14   @RegisteredService
15   private final TestService testServiceClass = new TestServiceImpl();
16
17   /**
18    * 3) Register a custom factory to use when the CustomTestObject
19    *    is auto-instantiated using the @New annotation.
20    */
21   @RegisteredService
22   Factory<CustomTestObject> customTestObjectClass = new
        CustomTestObjectFactoryImpl();
23 }
```

The *Initializer* class of Listing 5.1 registers three injection implementation references annotated with either `@RegisteredClass` or `@RegisteredService`. Sections 5.3.3 and 5.3.2 cover these annotations in detail. Each reference maps a left-hand side (LHS) type with a right-hand side (RHS) implementation. The variable name is used only to be syntactically correct. When the `Transformer` encounters an injection annotation (`@Service` or `@New`), it looks for the LHS type in the service registry of the current service context. If the type exists, it retrieves the RHS implementation details.

If the RHS is an `interface` (line 8), the default factory generates an in-memory implementation based on the `interface`'s *JavaBeans*-compliant *getter/setter* methods.

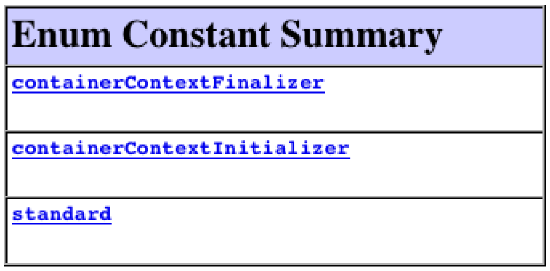
If the RHS is an object (line 15), the `Transformer` uses the object as the implementation to inject.

The use of the `Factory interface` in line 22 is detailed in Section 5.5.1.

A service context may have only one implementation mapped to each *Service Interface*. Two different injection sites can receive different implementations for the same *Service Interface* if the injection sites are bound to different service context initializations (see Section 5.3.5 for details).

5.3.1.2 Controlling the Scope of a `ServiceContext` with `contextType`

The lifespan or scope of a service context is controlled using the `contextType` option shown in Table 5.4.



Enum Constant Summary
containerContextFinalizer
containerContextInitializer
standard

Table 5.4: `ServiceContextType` Values

The default value, `standard`, limits the scope of the service context to the target method. When the method exits, the service context is destroyed. This setting is useful in Java SE, single-threaded environments where the scope of a context is tied to an execution thread. When the execution terminates, the service context is no longer needed and is destroyed.

The options `containerContextInitializer` and `containerContextFinalizer` allow developers to manually designate the beginning and ending of a service context. These settings are useful in J2EE, multi-threaded and asynchronous environments where program execution can be distributed across multiple independent processes.

Listing 5.2: `JUnit` Test for Manual Control of Service Context

```
public class Test
{
  /**
  * Create a service context
  */
  @ServiceContext(contextType=ServiceContextType.
      containerContextInitializer)
  @BeforeClass
  public static void setupBeforeClass() throws Exception {}

  /**
  * Delete a service context
  */
  @ServiceContext(contextType=ServiceContextType.
      containerContextFinalizer)
  @AfterClass
  public static void tearDownAfterClass() {}
}
```

Listing 5.2 shows how the `containerContextInitializer` and `containerContextFinalizer` options can be used to extend a service context scope in a `JUnit` test from the method to the class.

5.3.2 `@RegisterService`

`@RegisterService` is a field-level annotation used in *Initializer* classes to register a service, or a singleton, with the service context (Listing 5.1).

In an *Initializer* class, when a field marked with the `@RegisteredService` annotation is written to, the instance (RHS) assigned to the field is registered with the service context. The identifier for the registered service is defined by the LHS declared field type including the type parameters, if any.

When a field that is marked with the `@Service` annotation is discovered in any class, and the declared type of the field (including the type parameters, if any) exactly matches the declared type of the `@RegisteredService` field in the *Initializer* class, then the instance assigned to the `@RegisteredService` field will be injected into the `@Service` annotated field.

5.3.3 `@RegisteredClass`

`@RegisteredClass` is a field-level annotation used in *Initializer* classes to register `interfaces` and class implementations for injection. This annotation is a specialized version of `@RegisterService` designed to simplify the injection of auto-generated implementations.

In an *Initializer* class, when a field marked with the `@RegisteredClass` annotation is written to, a default *factory* is generated to synthesize the implementation of the RHS runtime class. If the RHS runtime class is an `interface`, the default *factory* will synthesize an in-memory implementation of all non-implemented *getters/setters* which comply with the *JavaBeans* naming convention.

An added feature of the `@RegisteredClass` annotation is that the RHS runtime class can be an `abstract class` with only the *getters/setters* of interest implemented. The default *factory* will auto-generate the remaining *getters/setters* based on their *JavaBeans*-compliant method names.

Listing 5.3: `LazyInterface` **example**

```java
public interface LazyInterface
{
  public List<String> getNames();
  public void setName(List<String> names);

  public int getCount();
  public void setCount(int count);
}
```

Listing 5.4: `LazyAbstractClass` **example**

```java
public abstract class LazyAbstractClass implements LazyInterface
{
  private List<String> names;

  @Override
  public List<String> getNames()
  {
    if (null == names)
    {
      names = new ArrayList<String>();
    }
    return names;
  }

  @Override
  public void setNames(List<String> names)
  {
    this.names = names;
  }
}
```

`LazyAbstractClass` in Listing 5.4 is an `abstract` class which implements two of the four methods required by `LazyInterface` of Listing 5.3.

Listing 5.5: `LazyInterface` ***Initializer*** **class**

```java
public class LazyAbstractClassInitializer
{
  @RegisterClass
  private Class<? extends LazyInterface> testObject = LazyAbstractClass
      .class;
}
```

In Listing 5.5, the *Initializer* class registers `LazyAbstractClass` as the implementation class for the `LazyInterface` type.

Listing 5.6: Instantiating an `abstract class` for Injection

```java
public class LazyClassInjectionTest
{
  /**
   * Main method for the Service Context
   */
  @ServiceContext(initializationClasses={LazyAbstractClassInitializer.
     class})
  public void lazyAbstractClassNewTest()
  {
    new Object()
    {
      // Inject the abstract class instance
      @New
      private LazyInterface lazy;

      public void run()
      {
        Assert.assertEquals(lazy.getNames().size(), 0);
      }
    }.run();
  }
}
```

According to the Java Programming Language Specification, `abstract classes` cannot be instantiated [20], but the *i3Persistence Framework* injection mechanism bypasses this restriction by automatically completing the implementation of `LazyInterface` using *Javassist* and byte-code manipulation. In Listing 5.6, the *i3Persistence Framework* transformation mechanism inserts into the `LazyAbstractClass` declaration at runtime a `count` field of type `int` and the `getCount()/setCount(int count)` *getter/setter*, effectively completing the implementation of `LazyInterface`.

The `@RegisterClass` annotation works in conjunction with the `@New` field-level annotation to inject implementations into fields (see Section 5.3.5). This feature greatly reduces the lines of code necessary when working with `abstract classes`.

5.3.4 `@Service`

`@Service` is a field-level annotation used to indicate that the marked field must be injected at runtime with a *service* that implements the functions defined by the declared type of the field. A *service* is a singleton implementation that is registered with a service context via the *Initializer* class using the `@RegisterService` annotation (see Listing 5.1).

Fields with the `@Service` annotations must be populated with an instance of a *service* before any of the non-static methods of the class (including constructors) are invoked. The *service* to be injected is identified by the declared type of the field, including the type parameters, if any. For example, when the field declaration in Listing 5.7 is discovered by the `Transformer`, it will search the service registry of the current service context for an implementation matching the LHS type signature, `Factory<MyServiceObject>`, to inject.

Listing 5.7: `@Service` declaration

```java
@Service
private MyService myService;

@Service
private Factory<MyServiceObject> myFactory;
```

If no implementation exists, then a `ServiceNotAvailableException` is thrown.

5.3.5 `@New`

`@New` is a field-level annotation used to mark a variable for injection. Its counterpart, `@RegisterClass`, is used to register the implementation details (see Section 5.3.3).

When the `Transformer` detects the `@New` annotation in Listing 5.8, it searches the service registry in the current service context for an implementation matching the LHS type signature of the marked field.

Listing 5.8: `@New` declaration

```java
@New
private LazyInterface lazyObject;
```

This implementation may have been previously registered with the service context using the `@RegisteredClass` annotation in an *Initializer* class in the `@ServiceContext` declaration. If no implementation was registered and if the LHS type is an `interface`, an in-memory implementation is auto-generated using the *Javassist* API. The `Transformer` then injects the generated object into the annotated field.

This feature reduces the boilerplate code necessary when working with DTOs by delegating the implementation of *JavaBeans*-compliant `interfaces` to the framework.

5.3.6 `@Transaction`

`@Transaction` is a method-level annotation which indicates that the work done by a method should be treated as a single unit of work (a single *transaction*). If an exception is thrown by the annotated method, then all changes done by the method to the database are undone. In other words, if a method tagged with this annotation throws an exception, then the work done by the method will have no persistent effect on the system. The annotation is defined as follows:

Listing 5.9: `@Transaction interface`

```java
@Retention(RetentionPolicy.RUNTIME)
@Target({ElementType.METHOD, ElementType.CONSTRUCTOR})
public @interface Transaction
{
  /**
   * Read only transaction will not commit any object changes to
     * persistent storage.
  */
  public boolean readOnly() default false;
}
```

The `readOnly` option ensures that no changes will be committed to the database.

5.4 Optimizing Object Injection

The Java Instrumentation mechanism does not discriminate which classes are analyzed for injection. This inefficiency can cause substantial degradation in performance for projects which depend heavily on third-party libraries. Consequently, the *i3Persistence Framework* provides mechanisms to declare which classes are candidates for transformation.

5.4.1 Fine Tuning The Injection with the `injection-conf.xml` File

Similar to the `connections.properties` file discussed in Section 6.1, the *i3Persistence Framework* searches for an `injection-config.xml` file at the root of the `META-INF` directory of every JAR loaded. This XML file contains 1) a list of regular expression filters used to validate the canonical class name of classes to transform and 2) a list of default *Initializer* classes to load when creating a service context. This configuration mechanism is used internally by the *i3Persistence Framework* to qualify framework classes for transformation and to register internal services. Listing 5.10 is the `injection-config.xml` file for the `i3InjectionImpl` module.

Listing 5.10: `i3InjectionImpl injection-config.xml` file

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE injection-config PUBLIC "-//Sequoia Lab//DTD Injection
   Configuration//EN" "/META-INF/dtd/injection-config.dtd">
<injection-config>
  <!-- Classes to transform -->
  <injection-class-list>
    <injection-class regex="edu\.byu\.cs\.sequoia\.bokeo\..*+"/>
    <injection-class regex="org\.apache\.jsp\..*_jsp"/>
  </injection-class-list>
</injection-config>
```

The two `classpaths` under the `injection-class-list` tag declared in Listing 5.10, `edu.byu.cs.sequoia.bokeo.*` and `org.apache.jsp.*`, comprise the system default class transformation filters. Each application with package structures outside those qualified by the system default filters, must contain a `connections.properties` file to extend the default filter list and qualify the application's classes for transformation.

Also, developers can simplify the declaration of the `@ServiceContext` annotation (Section 5.3.1) by registering default initialization classes in the `injection-config.xml` using the `initialization-class-list` tag. Listing 5.11 shows the `i3Datasource` module's `injection-config.xml` file with the default list of *Initializer* classes.

Listing 5.11: `i3Datasource injection-config.xml` **file**

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE injection-config PUBLIC "-//Sequoia Lab//DTD Injection
    Configuration//EN" "/META-INF/dtd/injection-config.dtd">
<injection-config>
  <initialization-class-list>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo.i3.
        datasource.connection.impl.Initializer"/>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo.i3.
        datasource.update.impl.Initializer"/>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo.i3.
        datasource.get.impl.Initializer"/>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo.i3.
        datasource.impl.Initializer"/>
  </initialization-class-list>
</injection-config>
```

The *Initializer* classes declared in the `injection-config.xml` file are evaluated upon service context creation. The *i3Persistence Framework* uses the `i3Datasource injection-config.xml` file to register default services with every service context.

5.4.2 `@DoNotTransform`

`@DoNotTransform` is a class-level annotation which developers can use to exempt classes that lie within the scope of the `injection-class` filters from transformation. Listing 5.12 shows how this annotation is used.

Listing 5.12: `@DoNotTransform` **annotation usage**

```java
@DoNotTransform
public class MyClass
{
...
}
```

The combination of the `injection-config.xml` file and the `@DoNotTransform` annotation enables developers to control the object injection process of the *i3Persistence Framework*.

5.5 Framework Services

The *i3Persistence Framework* provides default services to increase productivity, store objects to the database and query objects from the database. This section introduces these services.

5.5.1 The `Factory` *Service Interface*

The `Factory interface`, in conjunction with the `@Service` annotation, provides an easy-to-use mechanism to create an instance of the *Factory Method* design pattern. When the `Transformer` encounters a field declaration of LHS type `Factory` and marked with the `@Service` annotation, it searches the service registry of the current service context for an implementation matching the type `Factory` and its parameter type(s). If no implementation exists, the framework provides a *default implementation* which returns an instance of the parameter type.

Listing 5.13: Class Instance Factory

```
@ServiceContext
public void Test()
{
  @ServiceContext
  public List<Long> getList(int size)
  {
    /**
     * Inject a default factory which returns the auto-generated
     * implementation of the TestInterface
     */
    @Service
    private Factory<TestInterface> classFactory;

    /**
     * Inject a default factory which returns an instance
     * of the ArrayList<TestInterface> class
     */
    @Service
    Factory<ArrayList<TestInterface>> listFactory;

    List<TestInterface> list = listFactory.newInstance();
    for (int i = 0; i < size; i++)
    {
      list.add(classFactory.newInstance();
    }
    return list;
  }
}
```

In Listing 5.13, the `Transformer` first injects into the field `classFactory` a default factory to generate instances of the wrapper class `TestInterface`. It then injects into the field `listFactory` a default factory to generate instances of the `ArrayList<TestInterface>` class. In line 21 of the listing, an instance of `ArrayList<TestInterface>` is assigned to the variable `list`. In the `for` loop starting at line 22, instances of the wrapper class `TestInterface` are added to the variable *list*.

The developer can provide a custom RHS implementation which controls the instantiation of the object. This RHS implementation must implement the `interfaces` *Initializable* and the LHS `Factory` type with the corresponding parameters. Listing 5.14 shows an example of a custom implementation of the `Factory interface` which returns instances of the `ArrayList<Object>` class.

Listing 5.14: Custom Factory Implementation

```java
public class ListFactory implements Initializable, Factory<List<?>>
{
  @Override
  public List<?> newInstance()
  {
    return new ArrayList<Object>();
  }
}
```

Listing 5.15 is the *Initializer* class which registers the custom factory implementation for the `Factory<List<?>>` type with service context.

Listing 5.15: *Initializer* Class for Custom Factory Implementation

```java
public class Register
{
  @SuppressWarnings("unused")
  @RegisteredService
  private Factory<List<?>> listFactory = new ListFactory();
}
```

In Listing 5.16, the `@ServiceContext` annotation on line 3 creates a new service context within the scope of the `customFactoryImplTest()` method.

Listing 5.16: Custom Factory Implementation Injection

```
 1 public FactoryTest
 2 {
 3   @ServiceContext(initializationClasses={Register.class})
 4   public void customFactoryImplTest()
 5   {
 6     new Object()
 7     {
 8       /**
 9        * Inject the implementation registered in the
10        * Initializer class.
11        */
12       @Service
13       private Factory<List<?>> listFactory;
14 
15       public void run()
16       {
17         listFactory.newInstance();
18       }
19     }.run();
20   }
21 }
```

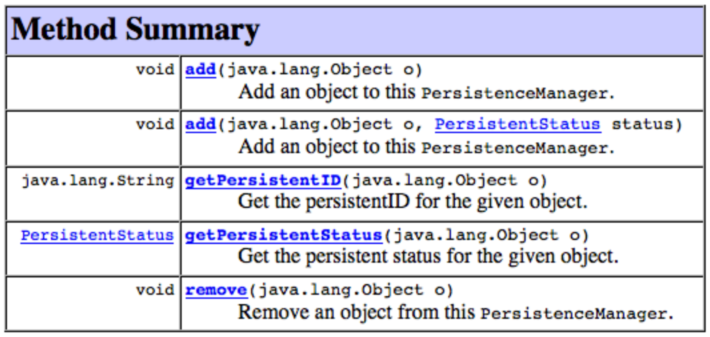
During the service context creation process, the framework uses the `initializationClasses` option to register the `ListFactory` instance for the type `Factory<List<?>> interface`. When the `Transformer` encounters the `@Service` annotation on line 12, it searches the service registry of the current service context for the implementation for the type with the signature `Factory<List<?>>` and injects it into the `listFactory` variable.

The *i3Persistence Framework* support of the *Factory Method Pattern* eliminates the need for the boilerplate code necessary when manually implementing the *Factory Method Pattern*.

5.5.2 The `PersistenceManager` Service

The `PersistenceManager` service is a framework service that is used to add objects to the database. Table 5.5 lists the methods supported by the `PersistenceManager`.

A `PersistentID` is a Universally Unique Identifier (UUID) guaranteed to be unique. This identifier allows database objects to be shared across instances of the *i3Persistence*



Method Summary	
void	add(java.lang.Object o) Add an object to this PersistenceManager.
void	add(java.lang.Object o, PersistentStatus status) Add an object to this PersistenceManager.
java.lang.String	getPersistentID(java.lang.Object o) Get the persistentID for the given object.
PersistentStatus	getPersistentStatus(java.lang.Object o) Get the persistent status for the given object.
void	remove(java.lang.Object o) Remove an object from this PersistenceManager.

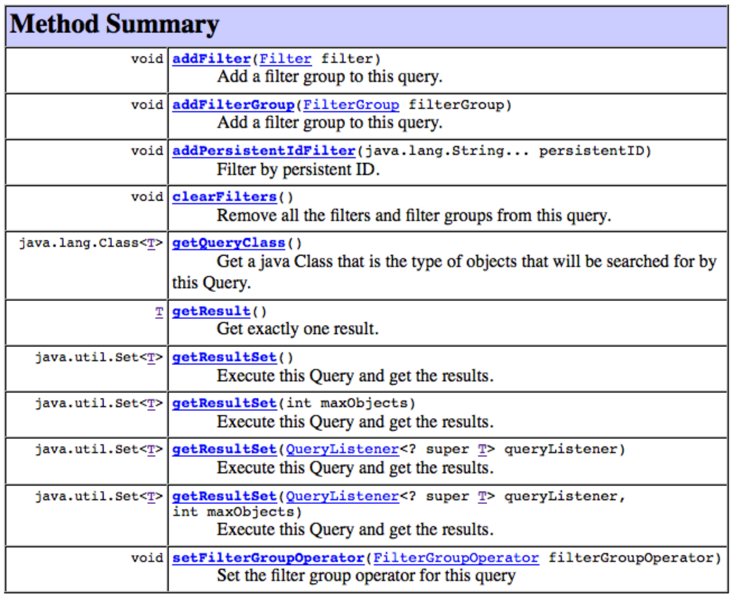
Table 5.5: `PresistenceManager` Method Summary

Framework. The `PersistenceManager` also manages the object's `PersistentStatus`. See Section 5.2 for details on `PersistentStatus`.

The source listing in Section 5.5.3 shows an example of how to use the `PersistenceManager, Query, Filters and FilterGroups`.

5.5.3 The `Query Interface`

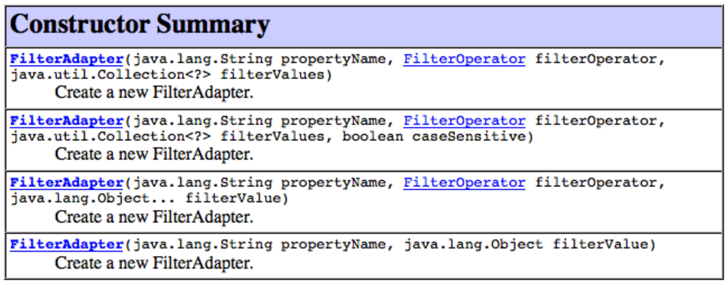
`Query` is a framework class (versus a *service*) that is used to retrieve objects from the database. A `Query` instance searches the database for instances of a specific class or its subclasses (polymorphic search). Table 5.6 summarizes the methods of the `Query` class.



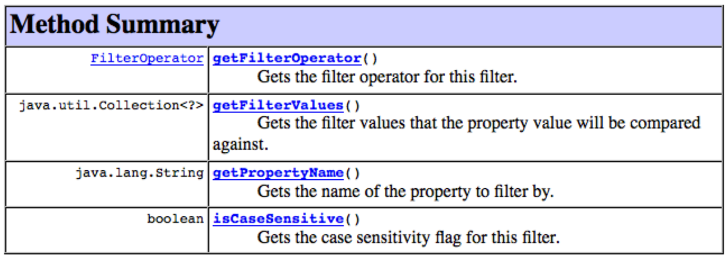
Method Summary	
void	addFilter(Filter filter) Add a filter group to this query.
void	addFilterGroup(FilterGroup filterGroup) Add a filter group to this query.
void	addPersistentIdFilter(java.lang.String... persistentID) Filter by persistent ID.
void	clearFilters() Remove all the filters and filter groups from this query.
java.lang.Class<T>	getQueryClass() Get a java Class that is the type of objects that will be searched for by this Query.
T	getResult() Get exactly one result.
java.util.Set<T>	getResultSet() Execute this Query and get the results.
java.util.Set<T>	getResultSet(int maxObjects) Execute this Query and get the results.
java.util.Set<T>	getResultSet(QueryListener<? super T> queryListener) Execute this Query and get the results.
java.util.Set<T>	getResultSet(QueryListener<? super T> queryListener, int maxObjects) Execute this Query and get the results.
void	setFilterGroupOperator(FilterGroupOperator filterGroupOperator) Set the filter group operator for this query

Table 5.6: `Query` Class Method Summary

The results of a `Query` can be restricted by adding a `Filter` or a `FilterGroup` that compares an object's properties to a set of values using a `FilterOperator` provided by the `Filters` and `FilterGroups`. `Filters` and `FilterGroups`, if used, must be added before the `execute()` method is invoked. `FilterAdapter` is a default implementation of the `Filter` `interface`. Table 5.7 summarizes the methods supported by `FilterAdapter`.



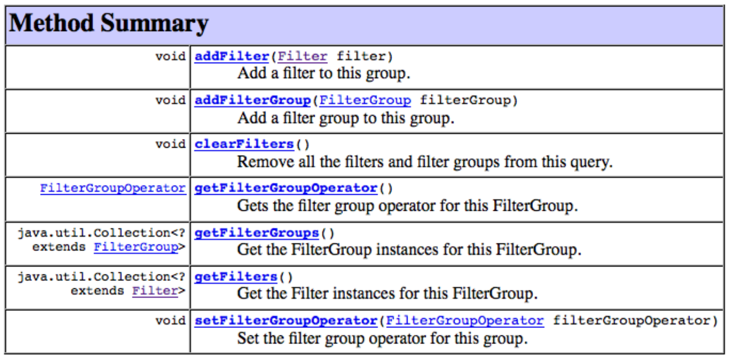
Constructor Summary
FilterAdapter(java.lang.String propertyName, FilterOperator filterOperator, java.util.Collection<?> filterValues) Create a new FilterAdapter.
FilterAdapter(java.lang.String propertyName, FilterOperator filterOperator, java.util.Collection<?> filterValues, boolean caseSensitive) Create a new FilterAdapter.
FilterAdapter(java.lang.String propertyName, FilterOperator filterOperator, java.lang.Object... filterValue) Create a new FilterAdapter.
FilterAdapter(java.lang.String propertyName, java.lang.Object filterValue) Create a new FilterAdapter.



Method Summary	
FilterOperator	**getFilterOperator**() Gets the filter operator for this filter.
java.util.Collection<?>	**getFilterValues**() Gets the filter values that the property value will be compared against.
java.lang.String	**getPropertyName**() Gets the name of the property to filter by.
boolean	**isCaseSensitive**() Gets the case sensitivity flag for this filter.

Table 5.7: `FilterAdapter` Class Method Summary

A `FilterGroup` allows multiple `Filters` to be combined into "AND" or "OR" groupings designated by `FilterGroupOperator` values (see Table 5.8).



Method Summary	
void	**addFilter**(Filter filter) Add a filter to this group.
void	**addFilterGroup**(FilterGroup filterGroup) Add a filter group to this group.
void	**clearFilters**() Remove all the filters and filter groups from this query.
FilterGroupOperator	**getFilterGroupOperator**() Gets the filter group operator for this FilterGroup.
java.util.Collection<? extends FilterGroup>	**getFilterGroups**() Get the FilterGroup instances for this FilterGroup.
java.util.Collection<? extends Filter>	**getFilters**() Get the Filter instances for this FilterGroup.
void	**setFilterGroupOperator**(FilterGroupOperator filterGroupOperator) Set the filter group operator for this group.

Table 5.8: `FilterGroupAdapter` Class Method Summary

The following is an example of how to use the `PersistenceManager`, `Query`, `Filters` and `FilterGroups`. Listing 5.17 shows the *JavaBeans*-compliant `interface` implemented by the class whose instance is to be persisted in the database.

Listing 5.17: `interface` **to Persist**

```java
public interface TestInterface
{
  public int getNumber();
  public void setNumber(int value);
  public String getText();
  public void setText();
}
```

Listing 5.18 shows the DAO class that will be responsible for saving and retrieving the objects.

Listing 5.18: ***Data Access Object*** **Class**

```java
public class DAOClass
{
  /**
   * Inject the framework PersistenceManager service
   */
  @Service
  private PersistenceManager pm;

  /**
   * Inject a default factory which returns the
   * auto-generated implementation of the TestInterface
   */
  @Service
  Factory<TestInterface> factory;

  /**
   * Method-scoped transactions to save/retrieve test
   * objects to/from the database.
   */
  @Transaction
  public void addObjects()
  {
    ...
  }

  @Transaction(readOnly = true)
  public List<TestInterface> getObjects()
  {
    ...
  }
}
```

In lines 6-7, the framework `PersistenceManager` *service* is injected into the `pm` field. In lines 13-14, a default factory which returns instances of `TestInterface` is injected into the `factory` field. The implementation of the `addObjects()` and `getObjects()` methods is listed below.

Listing 5.19: `DAOClass accessObjects()` **Method**

```java
@Transaction
public void addObjects()
{
  for (int i = 0; i < 20; i++)
  {
    TestInterface obj = factory.newInstance();
    obj.setNumber(i);
    obj.setText(Long.toString(i));
    pm.add(obj);
  }
}
```

Listing 5.19 begins by creating a transactional boundary scoped to the `addObjects()` method. The `addObjects()` method then saves 20 objects to the database.

Listing 5.20: `DAOClass getObjects()` **Method**

```java
@Transaction(readOnly = true)
public List<TestInterface> getObjects()
{
  /**
   * Framework Query service to retrieve TestInterface instances
   */
  @New
  Query<TestInterface> query;

  /**
   * Create two filters to retrieve objects
   */
  Filter filter1 = new FilterAdapter("number", 3);
  Filter filter2 = new FilterAdapter("number", FilterOperator.between
     , 5, 7);

  query.addFilter(filter1);
  TestInterface result = query.getResult();
  printSummary(new TestInterface[]{result});

  query.clearFilters();
  query.addFilter(filter2);
  Set<TestInterface> results = query.getResultSet();
  printSummary(results.asList());

  /**
   * Combine all the filters into one query.
27     */
28    FilterGroup filterGroup = new FilterGroupAdapter();
29    filterGroup.setFilterGroupOperator(FilterGroupOperator.and);
30    filterGroup.addFilters(new Filter[]{filter1, filter2});
31    query.clearFilters();
32    query.addFilterGroup(filterGroup);
33    results = query.getResultSet();
34    printSummary(results.asList());
35  }
```

Listing 5.20 begins by creating a read-only transaction scoped to the `getObjects()` method. In lines 7-8, a framework `Query` *service* is inserted into the variable `query`. On line 13, a `filter` to retrieve the object with the `number` field equal to 3 is instantiated. Line 14 is a `filter` to retrieve objects with the value of the `number` field between 5 and 7. The next two code blocks add the two `filters` in turn. They also invoke the `query` and print the results to standard output. On lines 28-34, the two `filters` are combined in a `FilterGroup` and added to the `query` object. The `query` is again executed and the results printed to standard output.

Listing 5.21: Test Main Harness

```
public class Test
{
  /**
   * This method will create a service context then
     * invoke the persistence operations.
     */
  @ServiceContext()
  public doPersistenceTest()
  {
    DAOClass daoObject = new DAOClass();
    daoObject.addObject();
    daoObject.getObjects();
  }

  /**
   * Application main
   */
  public static main()
  {
    try
    {
      Test test = new Test();
      test.doPersistenceTest();
    }
    catch(Exception e)
    {
      e.printStackTrace();
```

```
        }
    }
}
```

Listing 5.21 is the harness to launch the test application. In the `doPersistenceTest()` method, a service context is first created to make available the framework services. Then, an instance of the `DAOClass` is created to invoke the `addObject()` and `getObject()` methods. The test is invoked from the application `main()` method.

Chapter 6

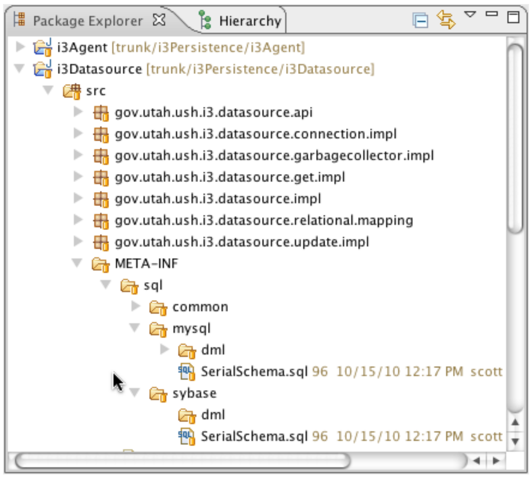
Setup and Deployment

One of the benefits of the *i3Persistence Framework* is the ease with which it can be integrated into an application. This section outlines the steps necessary to set up and deploy the *i3Persistence Framework* in Eclipse.

6.1 Database: Setup and Connection

Connecting the *i3Persistence Framework* to a database is a simple two-step process:

First, the necessary database tables are created using the supplied `SerialSchema.sql` script. Figure 6.1 shows the location of the scripts in the `i3Datastore` project.

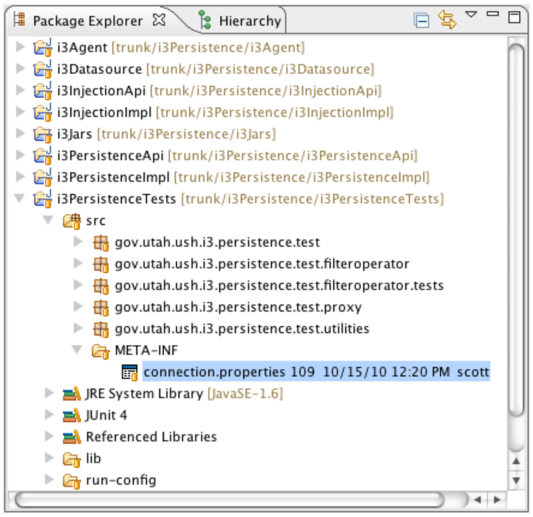


```
▶ i3Agent [trunk/i3Persistence/i3Agent]
▼ i3Datasource [trunk/i3Persistence/i3Datasource]
  ▼ src
    ▶ gov.utah.ush.i3.datasource.api
    ▶ gov.utah.ush.i3.datasource.connection.impl
    ▶ gov.utah.ush.i3.datasource.garbagecollector.impl
    ▶ gov.utah.ush.i3.datasource.get.impl
    ▶ gov.utah.ush.i3.datasource.impl
    ▶ gov.utah.ush.i3.datasource.relational.mapping
    ▶ gov.utah.ush.i3.datasource.update.impl
    ▼ META-INF
      ▼ sql
        ▶ common
        ▼ mysql
          ▶ dml
            SerialSchema.sql 96  10/15/10 12:17 PM  scott
        ▼ sybase
            dml
            SerialSchema.sql 96  10/15/10 12:17 PM  scott
```

Figure 6.1: `SerialSchema.sql` file location

Currently, the *i3Persistence Framework* supports Sybase and MySQL for its backend RDBMS. The `i3Datasource` module uses canned SQL scripts to save and retrieve objects. These files are located in the `/src/META-INF/sql` directory of the `i3Datasource` project. The `/src/META-INF/sql/common` directory contains SQL scripts that are common between Sybase and MySQL. The `/src/META-INF/sql/<database>/dml` directories contain SQL scripts which are specific to a database.

Second, the `connection.properties` file must be configured with the JDBC database connection settings. Figure 6.2 shows the location of the `META-INF` directory containing the `connection.properties` file.

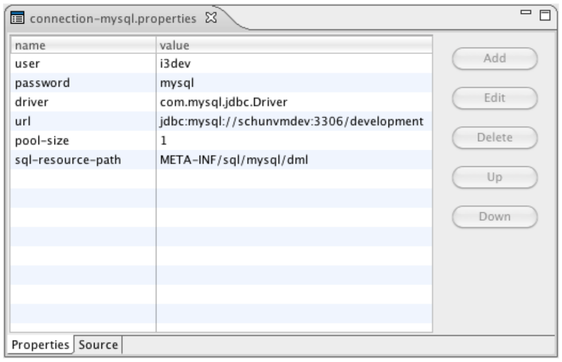


```
Package Explorer    Hierarchy
▶ i3Agent [trunk/i3Persistence/i3Agent]
▶ i3Datasource [trunk/i3Persistence/i3Datasource]
▶ i3InjectionApi [trunk/i3Persistence/i3InjectionApi]
▶ i3InjectionImpl [trunk/i3Persistence/i3InjectionImpl]
▶ i3Jars [trunk/i3Persistence/i3Jars]
▶ i3PersistenceApi [trunk/i3Persistence/i3PersistenceApi]
▶ i3PersistenceImpl [trunk/i3Persistence/i3PersistenceImpl]
▼ i3PersistenceTests [trunk/i3Persistence/i3PersistenceTests]
    ▼ src
        ▶ gov.utah.ush.i3.persistence.test
        ▶ gov.utah.ush.i3.persistence.test.filteroperator
        ▶ gov.utah.ush.i3.persistence.test.filteroperator.tests
        ▶ gov.utah.ush.i3.persistence.test.proxy
        ▶ gov.utah.ush.i3.persistence.test.utilities
        ▼ META-INF
            connection.properties 109  10/15/10 12:20 PM  scott
    ▶ JRE System Library [JavaSE-1.6]
    ▶ JUnit 4
    ▶ Referenced Libraries
    ▶ lib
    ▶ run-config
```

Figure 6.2: `connection.properties` file location

Each application using the *i3Persistence Framework* must have a `connection.properties` file in the `META-INF` directory at the root of where the compiled classes are stored. The `connection.properties` file contains name-value pair settings necessary for a JDBC driver to connect to a database. Figure 6.3 shows the contents of a `connection.properties` file configured to connect to a remote instance of a MySQL database.

The `pool-size` setting controls the number of connections in the connection-pool used to connect to the database. The `sql-resource-path` setting indicates the location of the SQL scripts specific to the target platform. The *i3Persistence Framework* ships with the jTDS (Sybase and MS SQL Server) and the MySQL native JDBC drivers and corresponding SQL scripts.



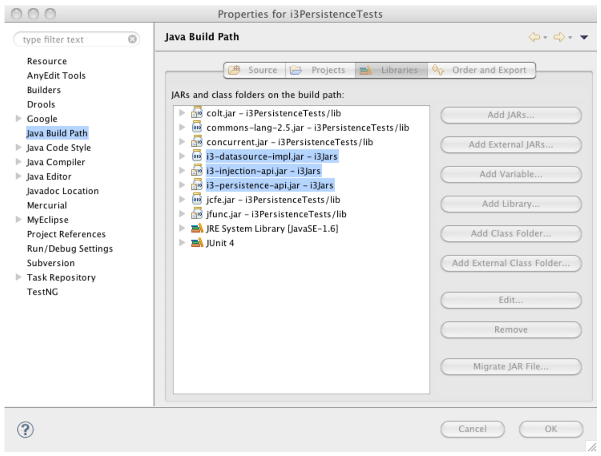
connection-mysql.properties

name	value
user	i3dev
password	mysql
driver	com.mysql.jdbc.Driver
url	jdbc:mysql://schunvmdev:3306/development
pool-size	1
sql-resource-path	META-INF/sql/mysql/dml

Figure 6.3: `connection.properties` file Settings

6.2 Preparing an Eclipse Project

Incorporating the *i3Persistence Framework* into an Eclipse project requires 1) the framework JAR files be added to the build and run environments and 2) the `i3Agent` be inserted into the VM via the Java Instrumentation mechanism.



Java Build Path

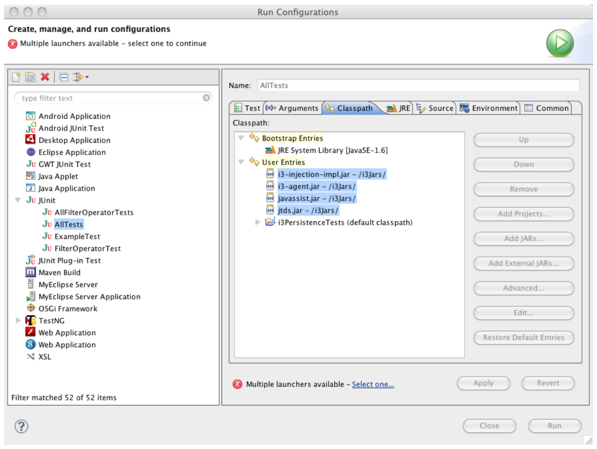
JARs and class folders on the build path:

- colt.jar – i3PersistenceTests/lib
- commons-lang-2.5.jar – i3PersistenceTests/lib
- concurrent.jar – i3PersistenceTests/lib
- i3-datasource-impl.jar – i3Jars
- i3-injection-api.jar – i3Jars
- i3-persistence-api.jar – i3Jars
- jcfe.jar – i3PersistenceTests/lib
- jfunc.jar – i3PersistenceTests/lib
- JRE System Library [JavaSE-1.6]
- JUnit 4

Figure 6.4: Eclipse Build Path

The project *Java Build Path* settings determine the *compile-time* `classpath` for building an application in Eclipse. Figure 6.4 shows the JAR files included in the *Java Build Path* setting. These *compile-time* dependent JAR files correspond directly to the *Service Interface* modules outlined in Section 5.1.1. The remaining JAR files are used specifically by the `i3PersistenceTests` project as part of the testing framework.

The `runtime-classpath` is configured for each runtime configuration associated with a project. The JAR files necessary to run the application must be added to the `Classpath` setting in either a debug configuration or a runtime configuration. These *runtime* dependent JAR files correspond to the implementation modules outlined in Section 5.1.1. Figure 6.5 shows how the `Classpath` setting can be modified in an Eclipse project runtime configuration.



Create, manage, and run configurations

Multiple launchers available – select one to continue

Name: AllTests

Classpath:

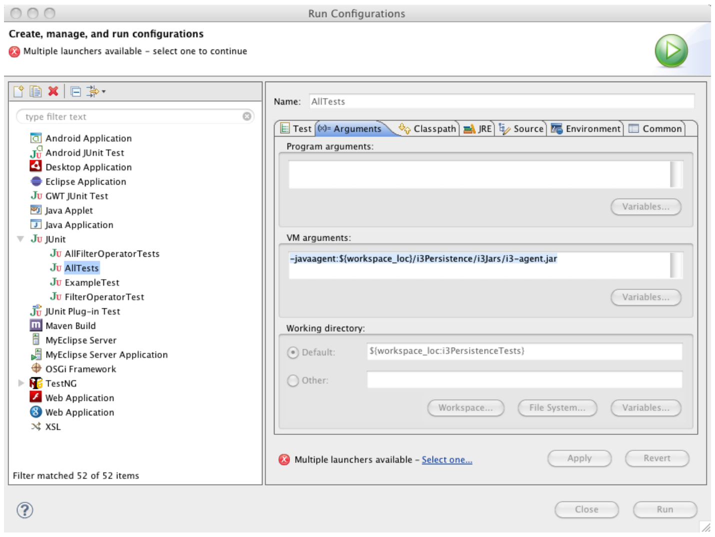
- Bootstrap Entries
  - JRE System Library [JavaSE-1.6]
- User Entries
  - i3-injection-impl.jar – /i3Jars/
  - i3-agent.jar – /i3Jars/
  - javassist.jar – /i3Jars/
  - jtds.jar – /i3Jars/
  - i3PersistenceTests (default classpath)

Multiple launchers available – Select one...

Filter matched 52 of 52 items

Figure 6.5: Eclipse Runtime Configuration `Classpath`

The final step is to enable the *i3Persistence Framework* Injection feature by hooking the `i3Agent` module into the Java VM at application bootup as shown in Figure 6.6.


Run Configurations

Create, manage, and run configurations

Multiple launchers available – select one to continue

Name: AllTests

Program arguments:

VM arguments:

```
-javaagent:${workspace_loc}/i3Persistence/i3Jars/i3-agent.jar
```

Working directory:

Default: ${workspace_loc:i3PersistenceTests}

Other:

Multiple launchers available – Select one...

Filter matched 52 of 52 items

Figure 6.6: Eclipse Runtime Agent Configuration `Classpath`

A custom agent can be inserted into the VM's bootup process by adding the `-javaagent` command-line option to the startup command. The syntax for the `-javaagent` option is:

```
java(w) -javaagent:jarpath[=options]
```

Chapter 7

Product Validation

7.1 Replicating the Modification Request Experiment

A project contributor usually modifies all the files necessary to accomplish a given task, then submits them together to the source repository in a single commit or *Modification Request* (MR) (see Figure 7.1, step 3). Knowing which files were modified at the same time allows researchers to analyze the logical coupling between files [15, 45].

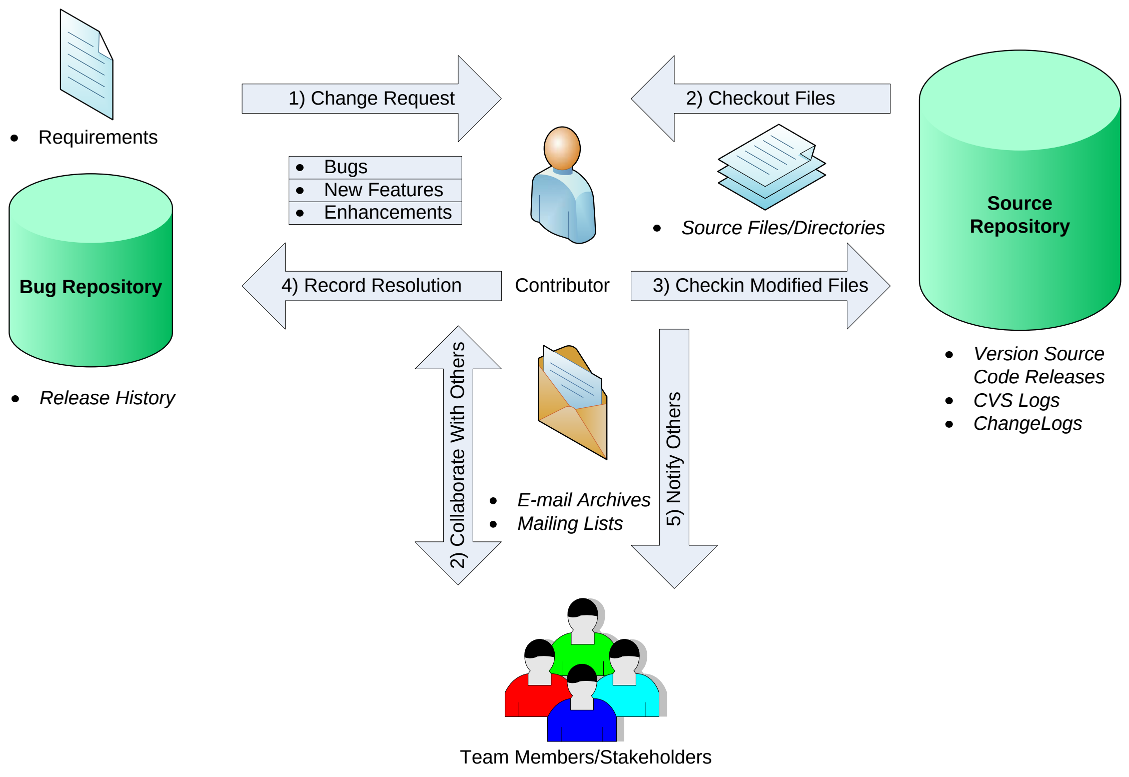


Figure 7.1: Software Trails

Over the past decade, CVS has emerged as the preferred choice for source code repositories in many open source projects. Consequently, CVS repositories have long evolution periods (5-10 years) and represent a ready resource for research on software evolution [43]. Unfortunately, CVS does not record the list of files committed together in an MR. Instead, each file is committed as a separate transaction. This makes it difficult to determine which files were committed together.

In 2004, Zimmermann et al. proposed the *fixed-time-window* algorithm for rebuilding MRs [46, 18]. The following year, Zimmermann et al. proposed the *sliding-time-window* algorithm asserting it to be superior to the previous *fixed-time-window* algorithm [47].

To validate the *sliding-time-window* algorithm, German rebuilt the MRs for the Mozilla, Evolution, PostgreSQL and GNU gcc projects [18]. To validate the effectiveness of the *i3Persistence Framework*, we replicated the GNU gcc portion of German's study first using the *i3Persistence Framework* and again using standard JDBC/SQL.

The following sections outline our replication process and compare the *i3Persistence Framework* and JDBC/SQL solutions.

7.1.1 The Sliding Time Window Algorithm

```
// front(List) removes the front of the list
// top(list) and last(list) query the corresponding elements of the list
// Initialize the set of all MRs to empty
$MRS = \emptyset$
for each A in Authors do
    List = Revisions by A ordered by date
    do
        MR.list = {front(List)}
        MR.sTime = time(MR.list_1)
        while $first(List).time - MR.sTime \leq \delta_{max} \wedge$
            $first(List).time - last(MR.list).time \leq \tau_{max} \wedge$
            $first(List).log = last(MR.list).log \wedge$
            $first(List).file \notin MR.list$ do
                $queue(MR.list, front(List))$
        do
        $MRS = MRS \cup \{MR\}$
    until $List \neq \emptyset$
do
```

Figure 7.2: The *sliding-time-window* algorithm

German utilized a heuristic based on the *sliding-time-window* algorithm to rebuild the MRs. This algorithm takes two parameters as input: the maximum length of time that an MR can last δ_{max}, and the maximum distance in time between two file revisions τ_{max} (see figure 7.2) [18].

In the *sliding-time-window* algorithm, a file revision is included in a given MR if:

1. All the file revisions in the MR and the candidate file revision were created by the same author and have the same log message (a comment added by the developer during the commit).
2. The candidate file revision is at most τ_{max} seconds apart from at least one file revision in the MR.
3. The addition of the candidate file revision to the MR keeps the MR at most δ_{max} seconds long.

7.1.2 Assumptions

CVS maintains the details of file revisions in log files which can be accessed using the `cvs log` command. The command supports many options to customize the information returned from the source repository. Consequently, the accuracy of the MR reconstruction is directly related to the parameters used when invoking the `cvs log` command [13]. The command parameters that may affect the composition of the file revision information returned from the CVS repository are:

- `-d dates`

  Print information about revisions with a checkin date/time in the range given by the semicolon-separated list of dates.

- `-rrevision`

  Prints information about revisions given in the comma-separated list revisions of revisions and ranges.

  `branch`

  An argument that is a branch means all revisions on that branch.

- `-s` <u>`states`</u>

  Print information about revisions whose state attributes match one of the states given in the comma-separated list states.

The only information available from the original experiment about which parameters were used to retrieve the `cvs log` is:

"A snapshot of their CVS repositories was made on Feb 17, 2004 [18]. "

Because the dataset and the `cvs log` command used in the original experiment were inaccessible, we proceeded with the replication experiment after making the following assumptions about the `cvs log` command used by German's team:

- Include `-d"<2004-02-18"` to retrieve all revisions made before midnight of Feb 17, 2004
- Exclude `-r` to retrieve revisions for every branch
- Exclude `-s` to retrieve revision for all states

An additional assumption we made was that file revision information with empty commit comments were considered valid and included in the analysis of the log information.

7.1.3 Unraveling the CVS Log Format with `cvs2cl`

Although CVS revision history log information can be retrieved using the `cvs log` command, the format of the information is not fully documented. In the original experiment, German utilized a "clean room" approach to reverse-engineer the log format [18]. Since the time of German's original experiment, many tools have emerged from the open source community that translate `cvs log` information into more human-readable formats.

Perl script `cvs2cl` is an industry standard tool that produces a GNU-style ChangeLog for CVS-controlled sources by running `cvs log` and parsing the output [13]. We modified `cvs2cl` to output the CVS file revision information. The `command-line` parameters we employed were as follows:

Listing 7.1: `cvs2cl` command-line options

```
cvs2cl -l "-d""<2004-02-18""" --utc -f ChangeLog_2004-02-17.xml
```

The actual `cvs log` command generated by `cvs2cl` is `cvs log -d<"2004-02-18"`, which complies with our assumptions of Section 7.1.2.

As part of our modification of `cvs2cl`, we wrapped user messages (comments) in `CDATA` tags to prevent any HTML markups contained in messages from confusing the *XML parser*. The `CDATA` tags also prevent parsing errors caused by invalid unsupported character encodings in messages.

7.1.4 The Application Design

The development plan for the replication experiment was to follow the phases outlined in *Bokeo*, namely extract, analyze, aggregate and present (see Section 1.2 for details). Because *Bokeo* is currently under development, we manually implemented each *Bokeo* phase.

7.1.4.1 *Extraction Phase*: The `ChangelogExtractor` Module

The `ChangelogExtractor` module encapsulates the *Extraction Phase* of *Bokeo*. Figure 7.3 is the UML class diagram and Table 7.1 is the detailed description of the classes that comprise the `ChangelogExtractor` module.

The `ChangelogExtractor` module is comprised of three class types: *XML Parsers*, DTOs, and *Service Interfaces*. The *XML Parsers* implement the *Service Interface* which is injected into classes in the *Analysis and Synthesis Phase* by the *i3Persistence Framework*. The DTOs are populated by the *XML Parsers* and passed to the clients via the `EventListener` *Service Interfaces*.

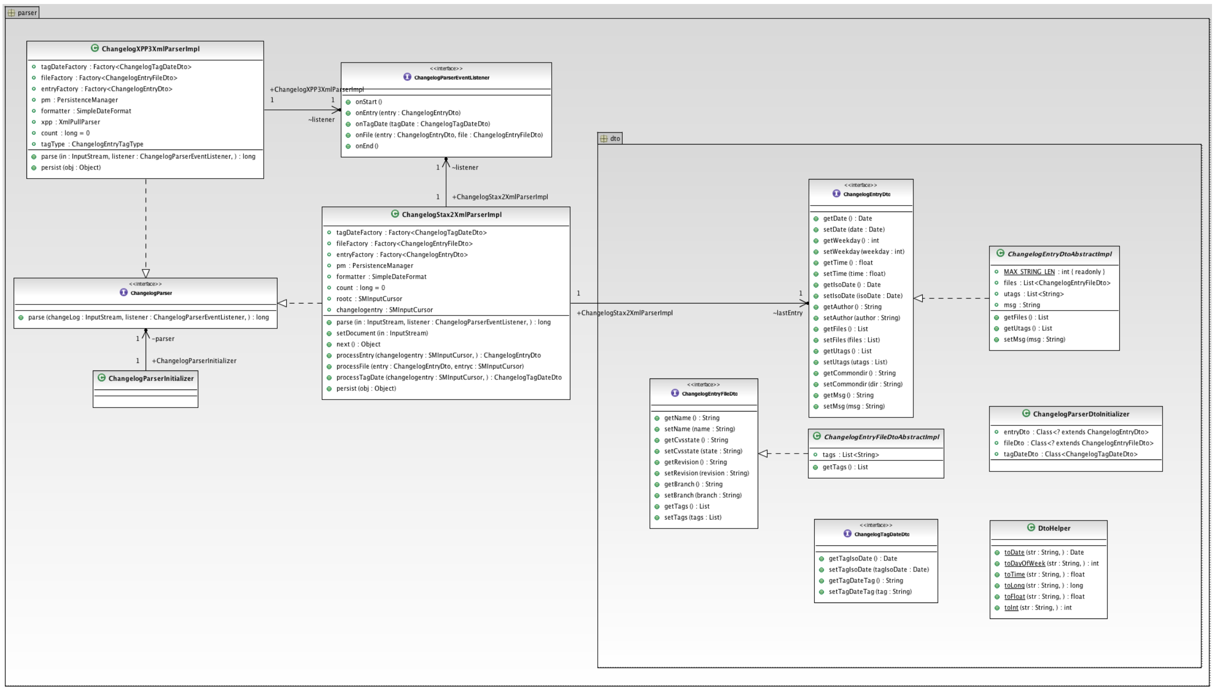

parser
ChangelogXPP3XmlParserImpl
tagDateFactory : Factory<ChangelogTagDateDto>
fileFactory : Factory<ChangelogEntryFileDto>
entryFactory : Factory<ChangelogEntryDto>
pm : PersistenceManager
formatter : SimpleDateFormat
xpp : XmlPullParser
count : long = 0
tagType : ChangelogEntryTagType
parse (in : InputStream, listener : ChangelogParserEventListener,) : long
persist (obj : Object)
+ChangelogXPP3XmlParserImpl
1
1
~listener
<<interface>>
ChangelogParserEventListener
onStart ()
onEntry (entry : ChangelogEntryDto)
onTagDate (tagDate : ChangelogTagDateDto)
onFile (entry : ChangelogEntryDto, file : ChangelogEntryFileDto)
onEnd ()
1
~listener
1
+ChangelogStax2XmlParserImpl
ChangelogStax2XmlParserImpl
tagDateFactory : Factory<ChangelogTagDateDto>
fileFactory : Factory<ChangelogEntryFileDto>
entryFactory : Factory<ChangelogEntryDto>
pm : PersistenceManager
formatter : SimpleDateFormat
count : long = 0
rootc : SMInputCursor
changelogentry : SMInputCursor
parse (in : InputStream, listener : ChangelogParserEventListener,) : long
setDocument (in : InputStream)
next () : Object
processEntry (changelogentry : SMInputCursor,) : ChangelogEntryDto
processFile (entry : ChangelogEntryDto, entryc : SMInputCursor)
processTagDate (changelogentry : SMInputCursor,) : ChangelogTagDateDto
persist (obj : Object)
<<interface>>
ChangelogParser
parse (changeLog : InputStream, listener : ChangelogParserEventListener,) : long
1
~parser
1
+ChangelogParserInitializer
ChangelogParserInitializer
1
+ChangelogStax2XmlParserImpl
1
~lastEntry
dto
<<interface>>
ChangelogEntryDto
getDate () : Date
setDate (date : Date)
getWeekday () : int
setWeekday (weekday : int)
getTime () : float
setTime (time : float)
getIsoDate () : Date
setIsoDate (isoDate : Date)
getAuthor () : String
setAuthor (author : String)
getFiles () : List
setFiles (files : List)
getUtags () : List
setUtags (utags : List)
getCommondir () : String
setCommondir (dir : String)
getMsg () : String
setMsg (msg : String)
ChangelogEntryDtoAbstractImpl
MAX_STRING_LEN : int { readonly }
files : List<ChangelogEntryFileDto>
utags : List<String>
msg : String
getFiles () : List
getUtags () : List
setMsg (msg : String)
<<interface>>
ChangelogEntryFileDto
getName () : String
setName (name : String)
getCvsstate () : String
setCvsstate (state : String)
getRevision () : String
setRevision (revision : String)
getBranch () : String
setBranch (branch : String)
getTags () : List
setTags (tags : List)
ChangelogEntryFileDtoAbstractImpl
tags : List<String>
getTags () : List
ChangelogParserDtoInitializer
entryDto : Class<? extends ChangelogEntryDto>
fileDto : Class<? extends ChangelogEntryFileDto>
tagDateDto : Class<ChangelogTagDateDto>
<<interface>>
ChangelogTagDateDto
getTagIsoDate () : Date
setTagIsoDate (tagIsoDate : Date)
getTagDateTag () : String
setTagDateTag (tag : String)
DtoHelper
toDate (str : String,) : Date
toDayOfWeek (str : String,) : int
toTime (str : String,) : float
toLong (str : String,) : long
toFloat (str : String,) : float
toInt (str : String,) : int

Figure 7.3: `ChangelogExtractor` module class diagram

Due to the large size of the cvs2cl output file, it was not possible to use a `DOM Parser` to extract the revision information. Our solution to this problem was to use an `XML Pull Parser` (XPP) which requires less memory and performs better than `DOM Parsers` [36, 31].

Our first selection of an XPP technology was StAX2 [38]. Since the StAX2 technology was new to our team, we used the *i3Persistence Framework Dependency Injection Pattern* to decouple the parser implementation from the rest of the module. `ChangelogStax2XmlParserImpl`, our implementation of the StAX2 parser, was mapped for injection into the `ChangelogParser` *Service Interface* by registering it in the `ServiceContext` *Initializer* class, `ChangelogParserInitializer`.

Next, we implemented the DTOs to carry the file revision information to and from the database. We created the `interfaces` and utilized the *i3Persistence* auto-synthesis *service* to generate the implementations. Since the implementation auto-generation process is limited to only synthesizing property variables, complex data types such as `List<>` must be initialized with an instance of a `List<>`. The purpose of the `ChangelogEntryDtoAbstractImpl` and `ChangelogEntryFileDtoAbstractImpl abstract classes` is to *lazy-load* the `List<>`

Class name	**Role**	**Description**
`ChangelogParser`	*Service Interface*	Exposes the module's functionality
`ChangelogStax2ParserImpl`	XPP	`XML Pull Parser` library based on the StAX2
`ChangelogXPP3ParserImpl`	XPP	`XML Pull Parser` library based on the XPP3
`ChangelogParserEventListener`	Event Listener *Service Interface*	Parser events listener `interface`
`ChangelogParserInitializer`	Injection *Initializer* Class	Registers service implementations for injection
`ChangelogEntryDto`	DTO Interface	Changelog Entry DTO `interface`
`ChangelogEntryDtoAbstractImpl`	Abstract DTO Class	`ChangelogEntryDto` partial implementation
`ChangelogEntryFileDto`	DTO Interface	Changelog Entry File DTO `interface`
`ChangelogEntryFileDtoAbstractImpl`	Abstract DTO Class	`ChangelogEntryFileDto` partial implementation
`ChangelogEntryTagDateDto`	DTO Interface	Changelog TagDate DTO `interface`
`DtoHelper`	Utility Class	Converts XML `Strings` to `Objects`
`ChangelogParserDtoInitializer`	Injection *Initializer* Class	Registers service implementations for injection

Table 7.1: `ChangelogExtractor` module class descriptions

type properties of the `ChangelogEntryDto` and `ChangelogEntryFileDto` `interfaces`. The remainder of the `interface` *getters/setter* are automatically synthesized by the *Injection Layer* as described in Section 4.2.5. This *i3Persistence Framework* feature allowed us to rapidly implement the object infrastructure necessary to persist the CVS file revision information to the database. It also significantly reduced the amount of boiler-plate code necessary to implement the DTO `interfaces`.

One point to note about Figure 7.3 is the lack of dependencies between the `Parser` and `Parser.Dto` packages. Although the *XML parsers* in the `Parser` package use the DTOs in the `Parser.Dto` package, there is no direct *association* between the classes of the two packages. This is due to *Dependency Injection* where service objects are instantiated and injected into the consumer classes by the *injection framework* and not directly created by the consumer classes (see Appendix C).

The next step was to register the *Initializer* classes to be loaded at application startup. This was done by adding the *Initializers* to the `injection-config.xml` file in the `META-INF` directory.

The final step was to setup the database and configure the connection information in the `connection.properties` file.

Of the eight hours spent on implementing the `ChangelogExtractor` module, approximately seven hours were spent on tasks related to parsing the XML file with the remaining hour allocated to implementing the persistence logic and the DTOs.

7.1.4.2 Adapting to a Crisis

The initial test of the `ChangelogStax2XmlParserImpl` *XML parser* uncovered a flaw in the StAX2 XPP library: the implementation was not able to process the encoding format used in several of the file revision messages. Although the messages were embedded in `CDATA` tags, the StAX2 XPP library attempted to parse the messages.

An investigation of other XPP technologies revealed that the XPP3 `Pull Parser` library was capable of processing the XML file in its entirety. We implemented an XPP3-based `XML Pull Parser` and replaced the faulty StAX2-based implementation registration in the `ChangelogParserInitializer` file in approximately 30 minutes. Aside from implementing the new parser and modifying the injection registration, no other changes were necessary.

7.1.4.3 *Analysis and Synthesis Phase*: The `ChangelogAnalyzer` Module

The `ChangelogAnalyzer` module encapsulates the Analysis and Synthesis Phase, *Aggregation Phase*, and *Presentation Phase* of *Bokeo*. Figure 7.4 is the UML class diagram of the `ChangelogAnalyzer` module.

Table 7.2 is the detailed description of the classes that comprise the `ChangelogAnalyzer` module.

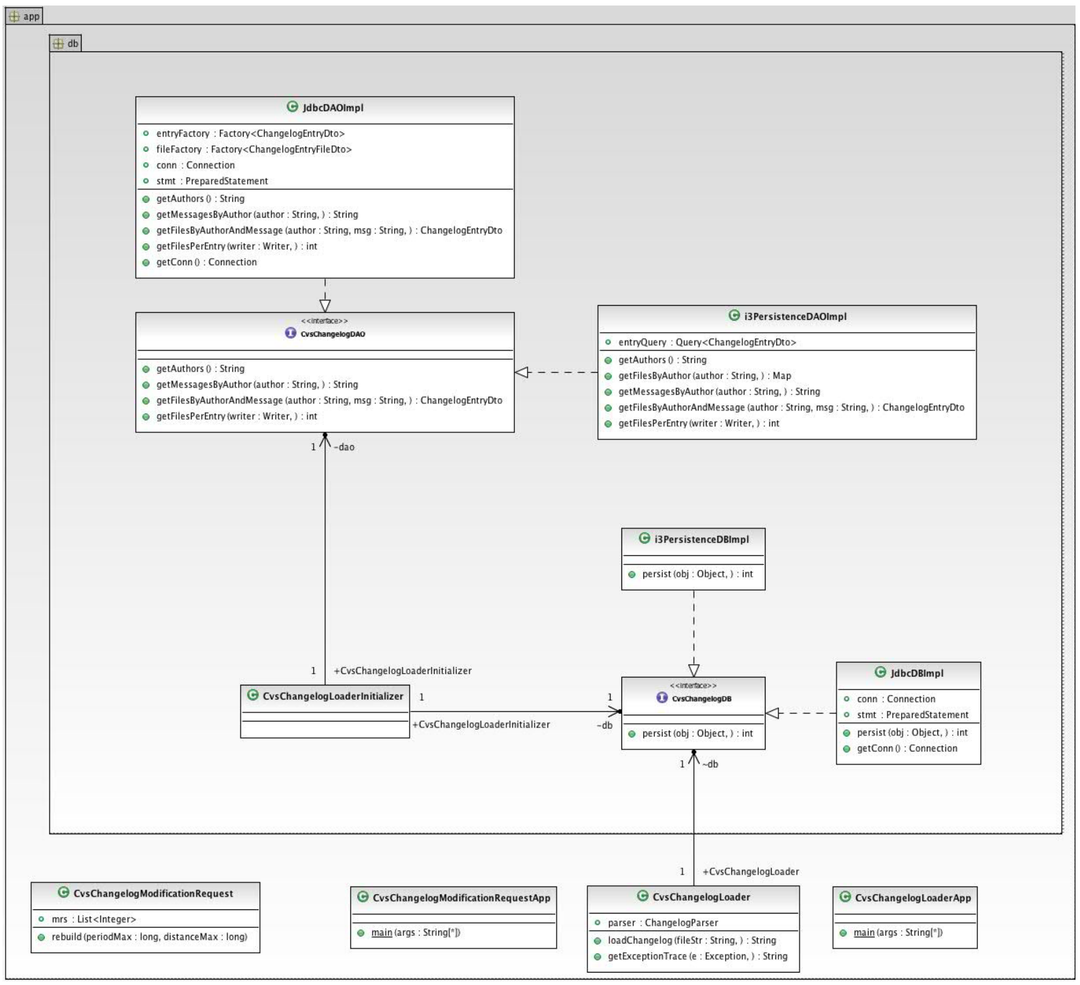

app
db
JdbcDAOImpl
entryFactory : Factory<ChangelogEntryDto>
fileFactory : Factory<ChangelogEntryFileDto>
conn : Connection
stmt : PreparedStatement
getAuthors () : String
getMessagesByAuthor (author : String,) : String
getFilesByAuthorAndMessage (author : String, msg : String,) : ChangelogEntryDto
getFilesPerEntry (writer : Writer,) : int
getConn () : Connection
<<interface>>
CvsChangelogDAO
getAuthors () : String
getMessagesByAuthor (author : String,) : String
getFilesByAuthorAndMessage (author : String, msg : String,) : ChangelogEntryDto
getFilesPerEntry (writer : Writer,) : int
i3PersistenceDAOImpl
entryQuery : Query<ChangelogEntryDto>
getAuthors () : String
getFilesByAuthor (author : String,) : Map
getMessagesByAuthor (author : String,) : String
getFilesByAuthorAndMessage (author : String, msg : String,) : ChangelogEntryDto
getFilesPerEntry (writer : Writer,) : int
1
-dao
i3PersistenceDBImpl
persist (obj : Object,) : int
1
+CvsChangelogLoaderInitializer
CvsChangelogLoaderInitializer
1
+CvsChangelogLoaderInitializer
1
-db
<<interface>>
CvsChangelogDB
persist (obj : Object,) : int
JdbcDBImpl
conn : Connection
stmt : PreparedStatement
persist (obj : Object,) : int
getConn () : Connection
1
~db
1
+CvsChangelogLoader
CvsChangelogModificationRequest
mrs : List<Integer>
rebuild (periodMax : long, distanceMax : long)
CvsChangelogModificationRequestApp
main (args : String[*])
CvsChangelogLoader
parser : ChangelogParser
loadChangelog (fileStr : String,) : String
getExceptionTrace (e : Exception,) : String
CvsChangelogLoaderApp
main (args : String[*])

Figure 7.4: `ChangelogAnalyzer` module class diagram

Rebuilding the CVS revision modification requests is a three-step process:

1. *Extraction Phase* and *Analysis and Synthesis Phase* – Invoke the `CvsChangelogLoaderApp` to parse the `cvs2cl` output XML file and store the file revision information in the database.

2. *Aggregation Phase* – Invoke `CvsChangelogModificationRequest` to generate the modification requests from the CVS file revision information.

3. *Presentation Phase* – Generate the report.

`CvsChangelogLoader` is the main worker class for the XML parsing process. To maximize portability, The *XML Parser* and database *Service Interface* implementations were

Class name	Role	Description
`CvsChangelogLoaderApp`	Application/Presentation	Main application to load the CVS logs
`CvsChangelogLoader`	Implementation	The implementation to load the CVS rlogs
`CvsChangelogModificationRequestApp`	Application/Presentation	Main application to rebuild the MRs
`CvsChangelogModificationRequest`	Implementation	The implementation to rebuild the MRs
`CvsChangelogDB`	*Service Interface*	The database *Service Interface*
`CvsChangelogDAO`	*Service Interface*	The data access object *Service Interface*
`i3PersistenceDBImpl`	Implementation Class	The i3Persistence database implementation
`JdbcDBImpl`	Implementation Class	The JDBC/SQL database implementation
`i3PersistenceDAOImpl`	Implementation Class	The i3Persistence DAO implementation
`JdbcDAOImpl`	Implementation Class	The JDBC/SQL DAO implementation
`CvsChangelogAnalyzerInitializer`	Injection *Initializer* Class	Registers service implementations for injection

Table 7.2: `ChangelogAnalyzer` module class descriptions

injected into the `CvsChangeLogLoader` by the framework. This allowed us to change the parser implementation between the StAX2 and XPP3 solutions by simply modifying the `ChangelogParserInitializer` *Initializer* class. We were also able to switch between the JDBC and *i3Persistence* based DB and DAO solutions by modifying the `CvsChangelogAnalyzerInitializer` class.

To compare the accuracy and productivity differences of using the *i3Persistence Framework* to technologies currently in use, we implemented a reference version of the `CvsChangelogDB` and `CvsChangelogDAO interfaces` using JDBC and SQL. The `ChangelogParser` injection implementation is defined in the `ChangelogExtractor` module `injection-config.properties` file (see Appendix D), and the `CvsChangelogDB` and `CvsChangelogDAO` injection implementations are defined in the `ChangelogAnalyzer` module injection-config.properties file (see Appendix E).

The MR statistics of Table 7.3 were collected by a custom `ChangelogEventListener` passed to the `ChangelogParser` by the `CvsChangelogModificationRequest` class. The data for Figures 7.5 and 7.6 were collected by `CvsChangelogDAO` during the MR rebuilding process.

7.2 Validating the Implementation

Because German's original study provides little information on implementation details against which to compare our application, we validated our implementation against the *sliding-time-window* algorithm [18, 47]. This algorithm defines four basic steps (see Figure 7.2):

1. Retrieve all distinct file revision authors.

2. Retrieve all distinct commit messages by each author.

3. Retrieve all files revisions having the same commit message by the same author.

4. Rebuild the MRs using the files retrieved in (3)

Steps (1) to (3) are implemented in the DAO classes. Step (4), the business module for the Modification Request Rebuilder, is implemented in the `CvsChangelogModificationRequest` class. We used the `JUnit` tests detailed in Appendix F to validate our implementation.

7.3 Replication Results

Table 7.3 shows the main statistics of the GNU gcc projects for the original and the replicated experiments.

Experiment	Authors	Files	Revisions
Original	214	24,463	60,311
Replicated	214	22,875	54,647
Error %	**0.0%**	**-6.49%**	**-9.06%**

Table 7.3: CVS statistics for the GNU gcc project

Figure 7.5 shows the distribution of the number of files in an MR (normalized to values from 0 to 1). Figure 7.6 shows the MRs per month during 2003.

Figure 7.6 shows that approximately 23 of 26 data points of the replicated experiment are within 1.0% of the original experimental results (see Appendix I.1). Figure 7.6 shows

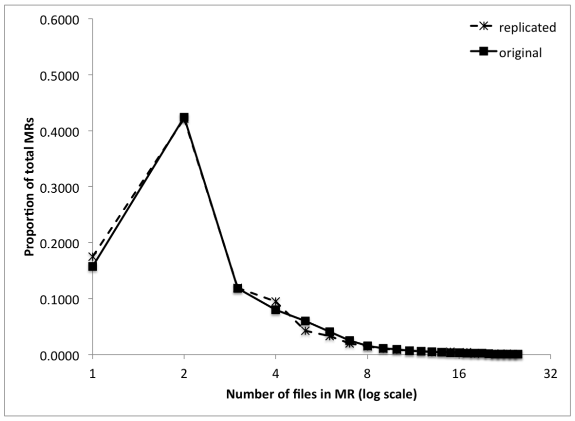


Figure 7.5: Number of files in MRs

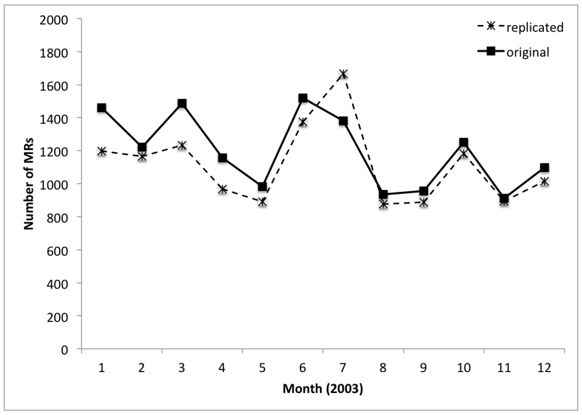


Figure 7.6: MRs per month, 2003

that the replicated data has basically the same progression as the original data except for July when the replicated data transitions from a negative to a positive offset (see Appendix J.1).

7.4 Conclusion

The differences between the original and replicated experiment results can be attributed to one or more, but not limited to, the following factors:

- Implementation technologies – We used Java while the original experiment used Perl.
- Database technologies - The *i3Persistence Framework* is a potential source of data variance.
- Datasets – The output of `cvs2pl` may not match the dataset used in the original experiment.
- Algorithms – We could have misinterpreted the *sliding-time-window* algorithm of the original experiment.

The following subsections discuss our analysis of each of the aforementioned factors.

7.4.1 Implementation Technologies

The differences between Java and Perl which may affect our experiment results are 1) the date/time functions 2) the math library and 3) text handling. In our replicated experiment application implementation, we used the industry-accepted `Jodatime` libraries to convert text representations of date/time to `DateTime` objects. We assume that the original experiment used the Perl `gmtime()` and `localtime()` libraries which are implemented in C. The Java and Perl functions are equivalent in functionality and should not cause any discrepancies in the data.

The math functions used are basic addition and subtraction of `Long Integers`. Java and Perl math function produce the same outputs.

Text handling is one area of difference between Java and Perl that may appreciably influence experiment results. This is due to the various text encoding formats used by project contributors. Text in certain native encodings can be construed by *XML Parsers* as invalid characters. To ensure that file revision messages are compared in its original form, we embedded message text in `CDATA` tags. When *XML parsers* encounter the `CDATA` tag, the enclosed text is passed directly to the invoking application without any processing, thus bypassing any potential encoding errors.

7.4.2 Database Technologies

Our `JUnit` tests proved that the *i3Persistence Framework*-based implementations functioned as designed (see Appendix F). Also, the comparison of the replicated experimental results using three independent database solutions (the *i3Persistence Framework*, JDBC/SQL and Berkeley DB technologies) was identical (see Appendix H). This consistency strengthens our argument that differences in database technologies are not a factor in the disparity between the original and replicated experimental results.

7.4.3 Datasets

Without the original dataset, we cannot quantitatively discuss the differences introduced by the dataset used in the replicated experiment. But because `cvs2cl` is an industry-accepted technology shipped with most Linux distributions, we feel confident that if any variances exist in the datasets, the `cvs2cl`-based output is more accurate than that obtained by German's reversed-engineered solution.

7.4.4 Algorithms

Without the original implementation details, we are not able to assess the differences in the approaches used in the original and the replicated solutions. Although we can estimate the potential margin of error between the original and replicated implementations based on the relative simplicity of the algorithm, a definitive comparison is not possible until such time when a more quantitative analysis is conducted.

7.5 Comparison of Technologies

Tables 7.4 and 7.5 compare the *i3Persistence Framework* and JDBC/SQL solutions based on three productivity factors: development time, lines of code, and McCabe Cyclomatic Complexity values [35].

DB Class	**Development Time**	**Lines of Code**	**McCabe Cyclomatic Complexity**
JDBC	$\approx$ 3 hours	84	5
i3Persistence	$\approx$ 15 min.	22	2
Ratio (JDBC:i3)	12:1	3.8:1	2.5:1

Table 7.4: JDBC vs. *i3Persistence*: Database class

Our experience showed that we were able to develop the DAO and DTO logic approximately 10 times faster using the *i3Persistence Framework* than using JDBC/SQL. Futhermore, the *i3Persistence Framework* based DB and DAO modules required fewer lines of code

DAO Class	Development Time	Lines of Code	McCabe Cyclomatic Complexity
JDBC	$\approx$ 5 hours	226	9
i3Persistence	$\approx$ 30 min	130	2
Ratio (JDBC:i3)	10:1	1.7:1	4.5:1

Table 7.5: JDBC vs. *i3Persistence*: DAO class

and had, in the case of the DAO classes, significantly lower McCabe's Cyclomatic Complexity values [29]. The majority of the time in implementing the JDBC/SQL versions of the DAO and DTO modules was spent:

1. Optimizing the schema.
2. Setting up the SQL query.
3. Mapping the JDBC table representations and data types to our object model.

In comparison, the *i3Persistence Framework*:

1. Has a fixed schema provided in the project that needs to be run once per database.
2. Requires no SQL.
3. Supports the persisting of objects, which allowed us to work in the object-oriented paradigm and with native Java data types.

The ease of maintenance of the *i3Persistence Framework* solutions, as reflected by the low McCabe's Cyclomatic Complexity values, was made evident in the relative ease with which we replaced the faulty StAX2 version of the XPP with the XPP3 version (see Section 7.1.4.2). The decoupling nature of *i3Persistence Framework* DI feature localized the system integration changes to a single configuration file. The injection feature also allowed us to easily switch between the JDBC/SQL and *i3Persistence Framework* versions of the DAO and DTO modules.

The research portion of the replication experiment, investigating the cause of the differences between the original and replicated results, consumed the majority of the four week replication project period. During this time, various permutations of the experimental variables were employed in an attempt to force a convergence of the original and replicated experiment results. Although we were unsuccessful in obtaining consistency in the data, modifying the JDBC/SQL solution required approximately five times more resources when compared to the resource demands of the *i3Persistence Framework* solution.

One noticeable overhead of using the *i3Persistence Framework* was the up-front time investment necessary for developers to learn to use the technology. This “learning curve” was evident in the differences in productivity between developers who were familiar with the framework and those who were working with it for the first time. In general, we observed that developers attained proficiency with the *i3Persistence Framework* relatively quickly when compared to developers working with JDBC/SQL. We attribute this to 1) the fact that the *i3Persistence Framework* is based on familiar standards and technologies [25, 26, 27] and 2) the relative simplicity of the *i3Persistence Framework* APIs when compared to the complex APIs and language syntax of JDBC/SQL.

Chapter 8

Conclusion

The Sequoia Lab at BYU is actively developing an extensible framework, *Bokeo*, to help researchers conduct artifact-based empirical experiments on software evolution. Researchers can use *Bokeo* to chain existing components and custom plug-ins into workflows to extract, analyze and visualize derived metrics and data from software repositories. The *i3Persistence Framework* was developed to allow researchers to 1) easily incorporate data-persistence features in their *Bokeo* plug-ins and 2) to promote developer productivity.

Although *Bokeo* is a general purpose framework for conducting artifact-based empirical experiments on software evolution, this industrial thesis focuses on how the *i3Persistence Framework* facilitates the replication of artifact-based empirical experiments on data from software repositories. The *i3Persistence Framework* promotes a Java-centric development model which allows researchers to employ rapid write-debug-modify cycles when implementing data-centric tools for their experimental replication efforts. DI, annotation-based feature invocation, auto-implementation synthesis, and simplified persistence APIs 1) reduce the need to write boilerplate code and 2) abstract technology and complexity behind easy to use interfaces. The result is that researchers are able to focus on the "business" aspects of their replication processes.

The initial release of the *i3Persistence Framework* focused primarily on features that would increase developer productivity. Our experience showed that the learning curve experienced by developers new to the framework was relatively small when compared to that of using JDBC/SQL. Once developers gained proficiency with our new technology, they were able to accomplish implementation tasks quickly and with relatively few lines of code. We attribute this increase in productivity to the fact that the *i3Persistence Framework* utilizes existing standards (annotations, object-oriented development, the Java programming language), de facto productivity design patterns (DI and Service Lookup), and a simple, terse API set.

Although our initial motivation to develop a new persistence framework was to compensate for the lack of existing tools which would facilitate the plug-in development requirements of *Bokeo*, the *i3Persistence Framework* was not designed for this purpose alone. We designed the *i3Persistence Framework* to address the general need in the software artifact-based empirical research community to increase developer productivity and decrease the cost of software maintenance.

We realize that there is yet much work to do to ready the *i3Persistence Framework* for general consumption. Security, scalability, performance, etc. are just a few of the areas yet to be addressed. Since the start of this industrial thesis, many tools have been developed that address these concerns, but we have yet to find any tool that combines the level of API simplicity and productivity features as does the *i3Persistence Framework.* It is our hope that our work will serve to further the development of tools not only in the area of experimental replication, but in other areas of data-centric research.

Chapter 9

Future Work

9.1 Point-in-Time Architecture

One of the fundamental requirements when replicating experiments on data from software repositories is the need for reference datasets along various points of the original experiment's computation process. These reference datasets can be used to validate the replication process. One way to gather reference data is to use a Point-in-Time Architecture (PTA) database.

A Point-in-Time Architecture system is able to present an image of the database as it existed at any previous point in time, without destroying the current image. In effect, a PTA maintains a searchable audit trail of all data that is persisted in the database over the life of that database.

9.2 Optimize Speed

A known trade-off when designing the database schema for the *i3Persistence Framework* is its performance limitations. The highly-normalized nature of the *i3Persistence* database tables requires multiple *joins* when storing and retrieving objects. Additionally, current RDBMSs distribute the computational load onto the database server while the*i3Persistence Framework* localizes it on the application server.

Performance issues were ignored in the initial release of the *i3Persistence Framework* with the justification that advancements in hardware performance will compensate for most of the performance issues and that the majority of the expense when developing database applications is in manpower costs versus hardware costs.

9.3 Support Large Datasets

Currently, the *i3Persistence Framework* retrieves the entire object hierarchy in memory for each query. This strategy is impractical for large datasets. Memory usage can greatly be reduced via hot loading and unloading of business objects.

9.4 Object Version Migration

Currently, the *i3Persistence Framework* does not track changes to class structure. This feature is critical in a prototyping environment such as when conducting one-off research experiments. One solution is to version `object` instances and use *Javassist* to generate version-specific class structures at runtime.

Bibliography

[1] MySQL gains 25% market share of database usage, latest Evans data survey shows. http://www.evansdata.com/press/viewRelease.php, March 2007.

[2] Troels Arvin. Comparison of different SQL implementations. http://troels.arvin.dk/db/rdbms/, August 2010.

[3] Victor R. Basili, Lionel C. Briand, and Walcélio L. Melo. How reuse influences productivity in object-oriented systems. *Communications of the ACM*, 39:104–116, October 1996.

[4] Victor R. Basili, Forrest Shull, and Filippo Lanubile. Building knowledge through families of experiments. *IEEE Transactions on Software Engineering*, 25:456–473, 1999.

[5] Mark Berler, Jeff Eastman, David Jordan, Craig Russell, Olaf Schadow, Torsten Stanienda, and Fernando Velez. *The object data standard: ODMG 3.0.* Morgan Kaufmann Publishers Inc., 2000.

[6] Hendrik Blockeel. Experiment databases: a novel methodology for experimental research. In *Knowledge Discovery in Inductive Databases, 4th International Workshop*, volume 3933 of *Lecture Notes in Computer Science*, pages 72–85. Springer, 2006.

[7] Hendrik Blockeel and Joaquin Vanschoren. Experiment databases: towards an improved experimental methodology in machine learning. In *Knowledge Discovery in Databases: PKDD 2007, 11th European Conference on Principles and Practice of Knowledge Discovery in Databases, Proceedings*, volume 4702 of *Lecture Notes in Computer Science*, pages 6–17. Springer, 2007.

[8] Andrew Brooks, John Daly, James Miller, Marc Roper, and Murray Wood. Replication of experimental results in software engineering. Technical report, International Software Engineering Research Network, Livingstone Tower, Richmond Street, Glasgow G1 1XH, UK, 1996.

[9] Shigeru Chiba. Javassist - a reflection-based programming wizard for Java. In *Proceedings of the ACM OOPSLA'98 Workshop on Reflective Programming in C++ and Java*, October 1998.

[10] Davor Cubranic, Gail C. Murphy, Ieee Computer Society, Janice Singer, and Kellogg S. Booth. Hipikat: a project memory for software development. *IEEE Transactions on Software Engineering*, 31:446–465, 2005.

[11] Prem Devanbu, Sakke Karstu, Walcélio Melo, and William Thomas. Analytical and empirical evaluation of software reuse metrics. In *Proceedings of the 18th International Conference on Software Engineering*, ICSE '96, pages 189–199, Washington, DC, USA, 1996. IEEE Computer Society.

[12] David Flanagan. *Javabeans convention.* O'Reilly Media, Inc., 5th edition, 2005.

[13] Karl Franz Fogel. *Open source development with CVS.* Coriolis Group Books, Scottsdale, AZ, USA, 1999.

[14] Martin Fowler. *Patterns of enterprise application architecture.* Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 2002.

[15] Harald Gall, Mehdi Jazayeri, and Jacek Krajewski. CVS release history data for detecting logical couplings. In *Proceedings of the 6th International Workshop on Principles of Software Evolution*, pages 13–23, Washington, DC, USA, 2003. IEEE Computer Society.

[16] Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. *Design patterns: elements of reusable object-oriented software.* Addison-Wesley Professional, January 1994.

[17] Daniel M. German. Using software trails to rebuild the evolution of software. In *Proceedings of the International Workshop on Evolution of Large-scale Industrial Software Applications (ELISA)*, Amsterdam, The Netherlands, 2003.

[18] Daniel M. German. Mining CVS repositories, the softChange experience. In *Proceedings of the First International Workshop on Mining Software Repositories*, pages 17–21, Edinburg, Scotland, UK, 2004.

[19] Arne G. Gleditsch and Per K. Gjemshus. LRX cross-referencing Linux. http://lxr.linux.no/, March 2008.

[20] James Gosling, Bill Joy, Guy Steele, and Gilad Bracha. *The Java(tm) language specification, the (3rd edition).* Addison-Wesley Professional, Upper Saddle River, NJ, 3rd edition, 06 2005.

[21] Tara Hernandez. The Bonsai project. http://www.mozilla.org/projects/bonsai/, March 2008.

[22] James Howison, Megan S. Conklin, and Kevin Crowston. FLOSSmole: a collaborative repository for FLOSS research data and analyses. *International Journal of Information Technology and Web Engineering*, 1(3):17–26, 2006.

[23] James Howison and Kevin Crowston. The perils and pitfalls of mining Sourceforge. In *Mining Software Repositories Workshop at the International Conference on Software Engineering (ICSE)*, Edinburgh, Scotland, 2004.

[24] Raymond Hubbard, Daniel E. Vetter, and Eldon L. Little. Replication in strategic management: scientific testing for validity, generalizability, and usefulness. *Strategic Management Journal*, 19:243–254, March 1998.

[25] Sun Microsystems Inc. JSR 175: a metadata facility for the Java programming language. http://www.jcp.org/en/jsr/detail?id=175.

[26] Sun Microsystems Inc. JSR 299: contexts and dependency injection for the Java EE platform. http://jcp.org/en/jsr/detail?id=299.

[27] Sun Microsystems Inc. JSR 330: dependency injection for Java. http://jcp.org/en/jsr/detail?id=330.

[28] Sun Microsystems Inc. Java object serialization specification, rev. 1.4.4. Technical report, Sun Microsystems Inc., 2001.

[29] Wei Li and Sallie Henry. Object-oriented metrics that predict maintainability. *Journal of Systems and Software*, 23(2):111–122, November 1993.

[30] Rob Lintern, Jeff Michaud, Margaret-Anne Storey, and Xiaomin Wu. Plugging-in visualization: experiences integrating a visualization tool with Eclipse. In *SoftVis '03: Proceedings of the 2003 ACM Symposium on Software Visualization*, SoftVis '03, New York, NY, USA, June 2003. ACM.

[31] Wei Lu, Kenneth Chiu, and Yinfei Pan. A parallel approach to XML parsing. pages 223–230, 2006.

[32] Stephen G. MacDonell. Rigor in software complexity measurement experimentation. *Journal of Systems and Software*, 16(2):141–149, 1991.

[33] Robert C. Martin. Object oriented design quality matrics: an analysis of dependencies. *ROAD*, Vol. 2, No.3(Sep-Oct), 1995.

[34] Bertrand Meyer. *Object-oriented software construction (2nd edition)*. Prentice Hall, 2nd edition, March 2000.

[35] John C. Munson and Taghi M. Khoshgoftaar. Measuring dynamic program complexity. *IEEE Software*, 9:48–55, 1992.

[36] Matthias Nicola and Jasmi John. XML parsing: a threat to database performance. In *Proceedings of the Twelfth International Conference on Information and Knowledge Management*, CIKM '03, pages 175–178, New York, NY, USA, 2003. ACM.

[37] Luc De Raedt. A perspective on inductive databases. *ACM SIGKDD Explorations Newsletter*, 4(2):69–77, 2002.

[38] Tatu Saloranta. StAX2. http://docs.codehaus.org/display/WSTX/StAX2, June 2009.

[39] Forrest Shull, Victor Basili, Jeffrey Carver, José C. Maldonado, Guilherme H. Travassos, Manoel MendonÃ§a, and Sandra Fabbri. Replicating software engineering experiments: addressing the tacit knowledge problem. In *Proceedings of the 2002 International Symposium on Empirical Software Engineering*, pages 7–16, 2002.

[40] Forrest Shull, Jeffrey Carver, and Guilherme H. Travassos. An empirical methodology for introducing software processes. In *Proceedings of the 8th European Software Engineering Conference Held Jointly with 9th ACM SIGSOFT International Symposium on Foundations of Software Engineering*, pages 288–296, Vienna, Austria, 2001. ACM.

[41] Margret-Anne Storey, Casey Best, and Jeff Michand. SHriMP views: an interactive environment for exploring Java programs. In *Proceedings of the 9th International Workshop on Program Comprehension*, pages 111–112, 2001.

[42] Giancarlo Succi, Luigi Benedicenti, and Tullio Vernazza. Analysis of the effects of software reuse on customer satisfaction in an RPG environment. *IEEE Transactions on Software Engineering*, 27:473–479, 2001.

[43] Lucian Voinea and Alexandru Telea. An open framework for CVS repository querying, analysis and visualization. In *Proceedings of the 2006 International Workshop on Mining Software Repositories*, pages 33–39, Shanghai, China, 2006. ACM.

[44] Xiaomin Wu, A. Murray, M.-A. Storey, and R. Lintern. A reverse engineering approach to support software maintenance: version control knowledge extraction. In *Proceedings of the 11th Working Conference on Reverse Engineering*, pages 90–99, 2004.

[45] Thomas Zimmermann, Stephan Diehl, and Andreas Zeller. How history justifies system architecture (or not). In *Proceedings of the Sixth International Workshop on Principles of Software Evolution*, pages 73–83, 2003.

[46] Thomas Zimmermann and Peter Weissgerber. Preprocessing CVS data for fine-grained analysis. *IEE Seminar Digests*, 2004:2–6, 2004.

[47] Thomas Zimmermann, Andreas Zeller, Peter Weissgerber, and Stephan Diehl. Mining version histories to guide software changes. *IEEE Transactions on Software Engineering*, 31:429–445, 2005.

Appendix A

Separating Responsibilities with a Component-Layered Architecture

Software architecture is commonly articulated in the form of the major components and services of the system and how they interact. A software component can be defined as a grouping of software that's intended to be used, without change, by an application that is outside the scope of control or knowledge of the writers of the component. When using the component, application source code is not changed, although the component's behavior may be altered by extending it in ways allowed by the component writers.

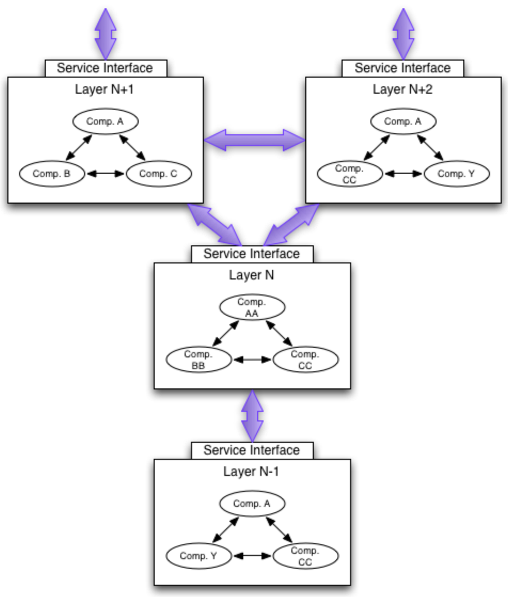


Figure A.1: Layered Architecture

The component-layered approach is one of the most common techniques used by software designers to organize a complicated software system. In this scheme, each layer is composed of one or more components that are tightly coupled. This complexity is abstracted from the outside world by the *Service Interface*. The layers are organized so that higher layers use various services defined by lower layers, but the lower layer is unaware of the higher layer. Furthermore, each lower layer usually hides its lower layers from the higher layers.

In the component-layered architecture depicted in Figure A.1, layer N relies on services from layer N-1 to provide a service to layer N+1 and N+2. In each layer, `interfaces` define the services offered.

Breaking down a system into layers has a number of important benefits:

- Complexity abstraction – The implementation details of a layer are hidden by the *Service Interface*, promoting simpler interactions between components and layers.

- Separation of Concerns – It is possible to understand a single layer as a coherent whole without knowing much about the other layers.
- Modularization – Since the service required from a lower layer is independent of its implementation, alternative implementations of the same basic services can be used without adversely affecting the system.
- Reduce Coupling – Dependency is isolated to adjacent layers which minimizes cross-layer coupling.
- Standardization – *Service Interface* present opportunities to standardize layer interaction.
- Code Reuse – As depicted in Figure A.1, a component can be reused in multiple layers and a single layer can service multiple clients, which promotes code reuse.

Appendix B

Decoupling Modules with the Dependency Inversion Principle

The *Service Interface*depicted in Figure 5.1 is an implementation of the *Dependency Inversion Principle*, which serves to resolve the shortcomings of the standard component-layered architecture where higher-level layers are coupled to lower-level layers. The primary disadvantages of the standard component-layered architecture are that designs tend to be:

- Rigid (hard to change due to dependencies, especially since dependencies are transitive);
- Fragile (changes cause unexpected bugs);
- Immobile (difficult to reuse across applications due to implicit dependence on current application code).

Robert Martin formulated the *Dependency Inversion Principle* (DIP) to address the disadvantages of the standard Component-Layered Architecture (see Appendix 4.2.1) [33]. The DIP states:

1. High-level modules should not depend upon low-level modules. Both should depend upon abstractions.
2. Abstractions should not depend upon details. Details should depend upon abstractions.

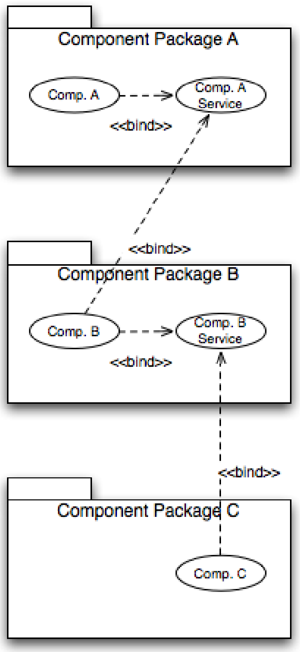


Figure B.1: Dependency Inversion Principle

The goal of the DIP is to decouple higher-level components from their dependency upon lower-level components. This may be achieved by creating `interfaces`, which define the component's external needs, as part of the higher-level component package. This allows the component to be isolated from any particular implementation of the provided `interface`, thus increasing the component's portability. In Java, this decoupling is achieved through the use of `interfaces`. Figure B.1 illustrates this relationship.

The *i3Persistence Framework* achieves reduction in coupling by using a *Dependency Inversion*-based Component-Layered Architecture (Section A) and *Dependency Injection* to "glue" the components and layers together into a cohesive software solution (Section C).

This decoupling facilitates the anonymous distributed development of the *i3Persistence Framework* components and layers.

Appendix C

Connecting Components and Layers with the Dependency Injection Pattern

A common issue facing developers of application frameworks is how to wire together the different elements of the framework. The complexity of this issue is magnified when portions of the software are built by different teams with little knowledge of each other. The *i3Persistence Framework* supports the *Dependency Injection Pattern* (DI) to loosely couple elements of the framework to the client application.

DI, a specific form of *Inversion of Control*, is an object-oriented design pattern whose purpose is to reduce coupling between software components by separating behavior from dependency resolution [14]. In most software applications, consumer components are tightly coupled to service components because of the need for the consumer component to explicitly state all the details of the creation of an instance of the service component. Figure C.1 depicts the hard coupling between consumer and service components.

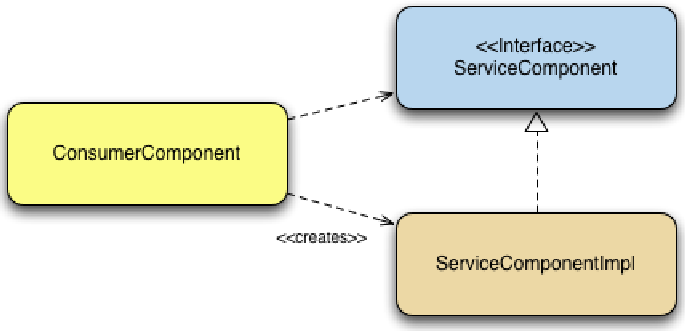


Figure C.1: Consumer-Service Dependency

DI eliminates the need for explicit service instantiation by externally injecting a reference to the service component inside the consumer component. In other words, objects are configured by an external entity. DI is an alternative to having the object configure itself.

In Figure C.2, the DI Container first resolves all of the server component's dependencies, meaning all the dependency injection requirements of the server component itself.

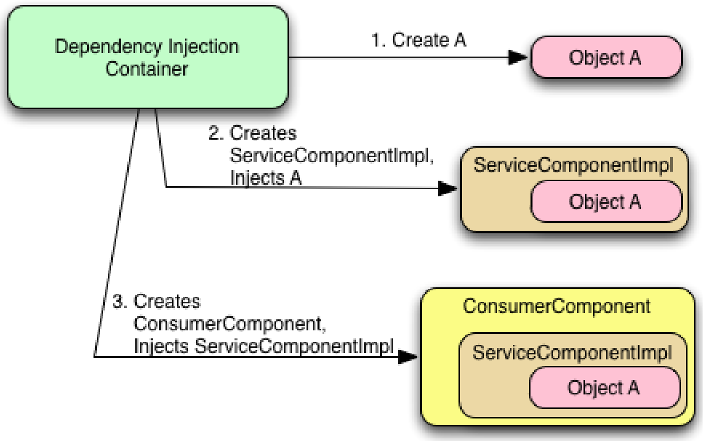

Dependency Injection Container
1. Create A
Object A
2. Creates ServiceComponentImpl, Injects A
ServiceComponentImpl
Object A
3. Creates ConsumerComponent, Injects ServiceComponentImpl
ConsumerComponent
ServiceComponentImpl
Object A

Figure C.2: The Dependency Injection Process

The DI Container then injects the fully resolved reference to the service component into the consumer component. For example, if `ServiceComponentImpl` is dependent on class A, the DI Container will execute the following tasks when the ConsumerComponent is instantiated:

1. Instantiate `ServiceComponentImpl`
2. Instantiate class A
3. Inject object A into the instance of `ServiceComponentImpl`
4. Inject `ServiceComponentImpl` into the instance of `ConsumerComponent`

Figure C.3 depicts the resulting dependencies.

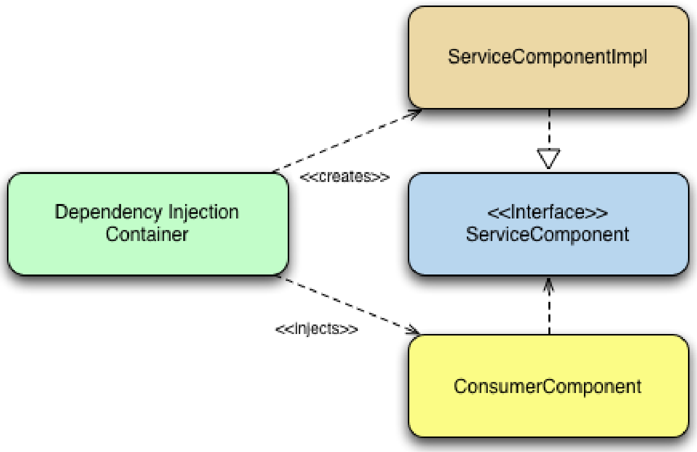

ServiceComponentImpl
<<creates>>
Dependency Injection Container
<<Interface>> ServiceComponent
<<injects>>
ConsumerComponent

Figure C.3: Dependency Injection Dependencies

The DI design pattern removes the hard dependency of the `ConsumerComponent` on the `ServiceComponentImpl` by introducing an external entity, the `DI Container`. The `DI container`, in turn, has dependencies to the `ServerComponentImpl` and the `ConsumerComponent`. The *i3Persistence Framework* eliminates the hard injection dependency of the `DI Container` to the `ConsumerComponent` by using *Javassist* and byte-code manipulation (see Section C.3 for details).

Appendix D

ChangelogExtractor Module injection-config.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE injection-config PUBLIC "-//Sequoia Lab//DTD Injection ⤸
Configuration//EN" "/META-INF/dtd/injection-config.dtd">

<injection-config>
  <injection-class-list>
      <injection-class regex="edu\.byu\.cs\.sequoia\.bokeo\..*+"/>
  </injection-class-list>
  <initialization-class-list>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo. ⤸
                                     changelogextractor.parser. ⤸
                                     ChangelogParserInitializer"/>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo. ⤸
                                     changelogextractor.parser.dto. ⤸
                                     ChangelogParserDtoInitializer"/>
  </initialization-class-list>
</injection-config>
```

Appendix E

`ChangelogAnalyzer` Module `injection-config.xml`

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE injection-config PUBLIC "-//Sequoia Lab//DTD Injection ⤸
Configuration//EN" "/META-INF/dtd/injection-config.dtd">

<injection-config>
  <injection-class-list>
      <injection-class regex="edu\.byu\.cs\.sequoia\.bokeo\..*+"/>
  </injection-class-list>
  <initialization-class-list>
    <initialization-class classname="edu.byu.cs.sequoia.bokeo. ⤸
                                      changeloganalyzer.app.db. ⤸
                                      CvsChangelogAnalyzerInitializer"/>
  </initialization-class-list>
</injection-config>
```

Appendix F

ChangelogDAOTest.java

```
package edu.byu.cs.sequoia.bokeo.changeloganalyzer.app.db;

import java.util.ArrayList;
import java.util.Comparator;
import java.util.Date;
import java.util.HashMap;
import java.util.HashSet;
import java.util.Iterator;
import java.util.List;
import java.util.Map;
import java.util.PriorityQueue;
import java.util.Set;

import junit.framework.Assert;

import org.junit.AfterClass;
import org.junit.BeforeClass;
import org.junit.Test;

import edu.byu.cs.sequoia.bokeo.changeloganalyzer.app. ⤸
ModificationRequestBuilder;
import edu.byu.cs.sequoia.bokeo.changeloganalyzer.app.db.ChangelogDAO;
import edu.byu.cs.sequoia.bokeo.changeloganalyzer.app.db.dto. ⤸
ModificationRequestDto;
import edu.byu.cs.sequoia.bokeo.changelogextractor.parser.dto.CvsFile;
import edu.byu.cs.sequoia.bokeo.changelogextractor.parser.dto. ⤸
CvsLogFileDto;
import gov.utah.ush.i3.annotations.Service;
```

```java
import gov.utah.ush.i3.annotations.ServiceContext;
import gov.utah.ush.i3.annotations.ServiceContextType;
import gov.utah.ush.i3.service.Factory;

public class ChangelogDAOTest
{
  @Service
  ChangelogDAO dao;

  @BeforeClass
  @ServiceContext(contextType = ServiceContextType. ↩
                  containerContextInitializer)
  public static void setup()
  {
    // Scope the service context to the class;
  }

  @AfterClass
  @ServiceContext(contextType = ServiceContextType. ↩
                  containerContextFinalizer)
  public static void teardown()
  {
    // Clean-up resources
    dao.close();
  }

  /**
   * Test the API to retrieve all the revision files.
   */
  @Test
  public void testGetFiles()
  {
    new Object()
    {
      Long fileCount = 0L;

      void run()
      {
        // Check each file
        Iterator<Object> itr = dao.getFiles();
        while (itr.hasNext())
        {
          fileCount++;
        }
        Assert.assertEquals(442075, fileCount.longValue());
      }
    }.run();
  }

  /**
   * Test the API which returns all the authors.
   */
  @Test
  public void testGetAuthors()
  {
    final Set<String> authors = new HashSet<String>();

    new Object()
    {
      void run()
      {
        Iterator<String> itr = dao.getAuthors();
        while (itr.hasNext())
        {
          authors.add(itr.next());
        }
      }
    }.run();
    Assert.assertEquals(214, authors.size());
  }

   /**
```

```
 * Test API to return messages by authors.
 */
@Test
public void testGetMessagesByAuthor()
{
  final Set<String> missingMsgs = new HashSet<String>();

  new Object()
  {
    void run()
    {
      // Check each author
      Iterator<String> itr = dao.getAuthors();
      while (itr.hasNext())
      {
        // Manually compile the messages per author
        Set<String> msgs = new HashSet<String>();
        String author = itr.next();
        Iterator<Object> filesByAuthor = dao.getFilesByAuthor(author);
        while (filesByAuthor.hasNext())
        {
          CvsFile file = (CvsFile) filesByAuthor.next();
          msgs.add(file.getMsg());
        }

        // Get the messages using the unique index
        Iterator<String> msgItr = dao.getMessagesByAuthor(author);
        while (msgItr.hasNext())
        {
          String msg = msgItr.next();
          if (!msgs.contains(msg))
          {
            missingMsgs.add(msg);
          }

          // Remove the message so that duplicates are considered as
```

```
⤸
            errors
            msgs.remove(msg);
          }
        }
      }
    }.run();
    Assert.assertEquals(0, missingMsgs.size());
  }

  /**
   * Test the API which returns the files with the same
   * message and author.
   */
  @Test
  public void testGetFilesByAuthorAndMessage()
  {
    new Object()
    {
      void run()
      {
        // Check each author
        Iterator<String> itr = dao.getAuthors();
        while (itr.hasNext())
        {
          // Manually compile the messages per author
          Map<String, List<CvsFile>> filesByMsg = new HashMap<String,
List< ⤸
                                                    CvsFile>>();
          String author = itr.next();
          Iterator<Object> filesByAuthor = dao.getFilesByAuthor(author);
          while (filesByAuthor.hasNext())
          {
            CvsFile file = (CvsFile) filesByAuthor.next();
            if (!filesByMsg.containsKey(file.getMsg()))
            {
```

```
            filesByMsg.put(file.getMsg(), new ArrayList<CvsFile>());
          }
          filesByMsg.get(file.getMsg()).add(file);
        }

        // Get the files for each generated message and author
        for (String msg : filesByMsg.keySet())
        {
          List<CvsFile> generatedFiles = filesByMsg.get(msg);

          // Get the indexed files
          Iterator<Object> fileItr = dao.getFilesByAuthorAndMessage( ⤸
                                           author, msg);

          // Compare the generated and indexed files
          while (fileItr.hasNext())
          {
            boolean found = false;
            CvsFile indexedFile = (CvsFile) fileItr.next();
            for (int i = 0; i < generatedFiles.size(); i++)
            {
              CvsFile generatedFile = generatedFiles.get(i);
              if (fileEquals(indexedFile, generatedFile))
              {
                generatedFiles.remove(i);
                found = true;
                break;
              }
            }

            if (!found)
            {
              Assert.fail("Indexed file not found in generated.");
            }
          }

          if (generatedFiles.size() > 0)
          {
            Assert.fail("Generated had more files then indexed.");
          }
        }
      }
    }
  }.run();
}

/**
 * Test the MR rebuilding logic.
 */
@Test
public void testGetMRs()
{
  new Object()
  {
    void run()
    {
      // Create the MRs
      List<ModificationRequestDto> mrs = new ArrayList<
                                   ModificationRequestDto>();
      generateMRs(mrs);
      Assert.assertEquals(4, mrs.size());
    }
  }.run();
}

/************************************************
 * Utility functions.
 ************************************************/
boolean fileEquals(CvsFile file1, CvsFile file2)
{
  Assert.assertEquals(file1.getId(), file2.getId());
  Assert.assertEquals(file1.getAuthor(), file2.getAuthor());
  Assert.assertEquals(file1.getCvsstate(), file2.getCvsstate());
  Assert.assertEquals(file1.getMsg(), file2.getMsg());
  Assert.assertEquals(file1.getTime(), file2.getTime());
  Assert.assertEquals(file1.getRevision(), file2.getRevision());

  return true;
}

/**
 * Generate test file revision data.
 */
void generateMRs(final List<ModificationRequestDto> mrs)
{
  new Object()
  {
    @Service
    Factory<CvsLogFileDto> fileFactory;

    public void run()
    {
      PriorityQueue<CvsFile> files = new  PriorityQueue<CvsFile>(1,
new ⤸
                                     CompareCvsFileByTime());
      Date now = new Date();
      long start = now.getTime();

      // First MR has 5 files
      files.add(makeFile(1L, "test", "Test message", start + 2));
      files.add(makeFile(2L, "test", "Test message", start + 4));
      files.add(makeFile(3L, "test", "Test message", start + 6));
      files.add(makeFile(4L, "test", "Test message", start + 8));
      files.add(makeFile(5L, "test", "Test message", start + 10));

      // Second MR has 3 files
      start += 650000;
      files.add(makeFile(6L, "test", "Test message", start + 2));
      files.add(makeFile(7L, "test", "Test message", start + 4));
      files.add(makeFile(8L, "test", "Test message", start + 6));

      // Third MR has 2 files
      start += 650000;
      files.add(makeFile(9L, "test", "Test message", start + 2));
      files.add(makeFile(10L, "test", "Test message", start + 4));

      // Fourth MR has 2 files
      start += 650000;
      files.add(makeFile(11L, "test4", "Test message", start));

      ModificationRequestBuilder builder = new ModificationRequestBuilder();
      mrs.addAll(builder.build(files, 45000L, 600000L));
      Assert.assertEquals(4, mrs.size());
    }

    CvsLogFileDto makeFile(Long id, String author, String msg, long time)
    {
      CvsLogFileDto f = fileFactory.newInstance();
      f.setId(id);;
      f.setAuthor(author);
      f.setMsg(msg);
      f.setTime(time);
      return f;
    }

    /**
     * Comparator to sort files by descending time.
     */
    class CompareCvsFileByTime implements Comparator<CvsFile>
    {
      @Override
      public int compare(CvsFile o1, CvsFile o2)
```

```
        {
          return o1.getTime().compareTo(o2.getTime());
        }
      }

    }.run();
  }
}
```

Appendix G

ModificationRequestBuilder.java

```
package edu.byu.cs.sequoia.bokeo.changeloganalyzer.app;

import java.util.ArrayList;
import java.util.List;
import java.util.PriorityQueue;

import edu.byu.cs.sequoia.bokeo.changeloganalyzer.app.db.bdb. ↩
ModificationRequestDto;
import edu.byu.cs.sequoia.bokeo.changelogextractor.parser.dto.CvsFile;

/**
 * Implementation of the sliding-time-window algorithm.
 *
 * @author scott
 *
 */
public class ModificationRequestBuilder
{
  /**
   * Build the modification requests.
   *
   * @param files
   * @param distanceMax
   * @param periodMax
   * @return
   */
  public     List<ModificationRequestDto> build(PriorityQueue<CvsFile>
files, ↩
```

```
                                          Long distanceMax, Long ↩
                                          periodMax)
{
  List<ModificationRequestDto> mrs = new ArrayList< ↩
                                     ModificationRequestDto>();

  // Bootstrap the process:
  // 1) Create a new MR
  // 2) Assign the first revision
  // 3) Set sTime (start time) and pTime (previous time)
  //    to the first revision time.
  ModificationRequestDto mr = new ModificationRequestDto();
  CvsFile currentFile = files.poll();
  mr.getFiles().add(currentFile.getId());
  mr.setTime(currentFile.getTime());
  Long startTime = currentFile.getTime();
  Long previousTime = startTime;

  // Check each file for distance and period
  while (files.size() > 0)
  {
    // Get the current file time
    currentFile = files.poll();
    Long currentTime = currentFile.getTime();

    // Check the distance and period
    if  ((currentTime - previousTime <= distanceMax) && (currentTime - ↩
        startTime <= periodMax))
    {
      // Add the revision to the MR
      mr.getFiles().add(currentFile.getId());
      previousTime = currentTime;
    }
    else
    {
        // Save the old MR and start a new MR
        mrs.add(mr);

        // Create the next MR
        mr = new ModificationRequestDto();

        // Bootstrap the process again.
        mr.getFiles().add(currentFile.getId());
        mr.setTime(currentFile.getTime());
        startTime = previousTime = currentFile.getTime();
      }
    }

    // Save the last one
    if (mr.getFiles().size() > 0)
    {
      mrs.add(mr);
    }

    return mrs;
  }
}
```

Appendix H

i3Persistence Framework , JDBC/SQL and Berkeley DB Test Results

Database	Authors	Files	Revisions
i3Persistence (MySQL)	214	22,875	54,647
JDBC/SQL (MySQL)	214	22,875	54,647
Berkeley DB	214	22,875	54,647

Table H.1: Comparison of `GNU gcc cvs log` Analysis

Appendix I

Gnu gcc: Distribution of the Number of Files in an MR

# Files	Replicated	Original	% Change
1	0.1744	0.1570	1.74%
2	0.4213	0.4240	-0.27%
3	0.1188	0.1180	0.08%
4	0.0946	0.0800	1.46%
5	0.0428	0.0600	-1.72%
6	0.0326	0.0410	-0.84%
7	0.0197	0.0250	-0.53%
8	0.0146	0.0150	-0.04%
9	0.0101	0.0110	-0.09%
10	0.0086	0.0090	-0.04%
11	0.0064	0.0070	-0.06%
12	0.0059	0.0060	-0.01%
13	0.0045	0.0050	-0.05%
14	0.0037	0.0040	-0.03%
15	0.0046	0.0035	0.11%
16	0.0033	0.0030	0.03%
17	0.0043	0.0025	0.18%
18	0.0017	0.0020	-0.03%
19	0.0019	0.0020	-0.01%
20	0.0014	0.0015	-0.01%
21	0.0012	0.0010	0.02%
22	0.0012	0.0010	0.02%
23	0.0012	0.0010	0.02%
24	0.0010	0.0010	0.00%
25	0.0010	0.0010	0.00%

Table I.1: Distribution of the Number of Files in an MR

Appendix J

Gnu gcc: Modification Requests per Month, 2003

Month	Replicated	Original	%
1	1198	1460	-21.87%
2	1164	1220	-4.81%
3	1233	1486	-20.52%
4	967	1157	-19.65%
5	890	984	-10.56%
6	1376	1520	-10.47%
7	1666	1380	17.17%
8	875	935	-6.86%
9	888	957	-7.77%
10	1184	1250	-5.57%
11	893	911	-2.02%
12	1016	1097	-7.97%

Table J.1: Modification Requests Per Month, 2003

Appendix K

UML Diagrams

K.1 `i3Datasource`: Module Statistics and Package Diagram

Metric	Total
Number of Packages	7
Number of Classes	62
Number of Interfaces	6
Total Lines of Code	4011

Table K.1: `i3Datasource` Module Metrics

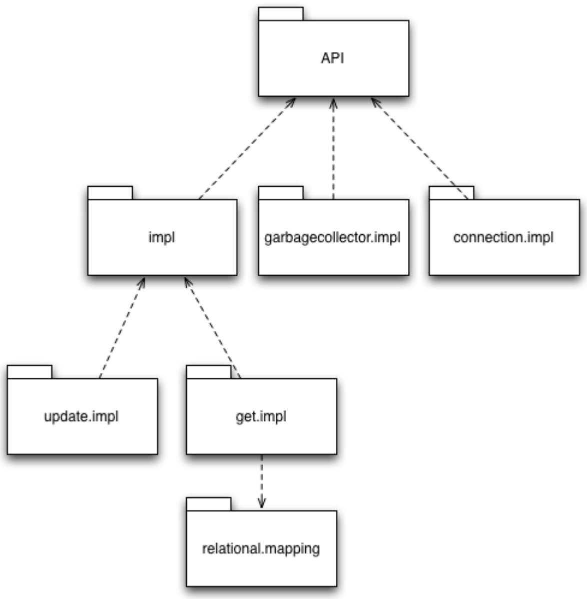


Figure K.1: `i3Datasource` Module Package Diagram

K.2 `i3InjectionApi`: Module Statistics and Class Diagram

Metric	Total
Number of Packages	5
Number of Classes	6
Number of Interfaces	20
Total Lines of Code	322

Table K.2: `i3InjectionApi` Module Metrics

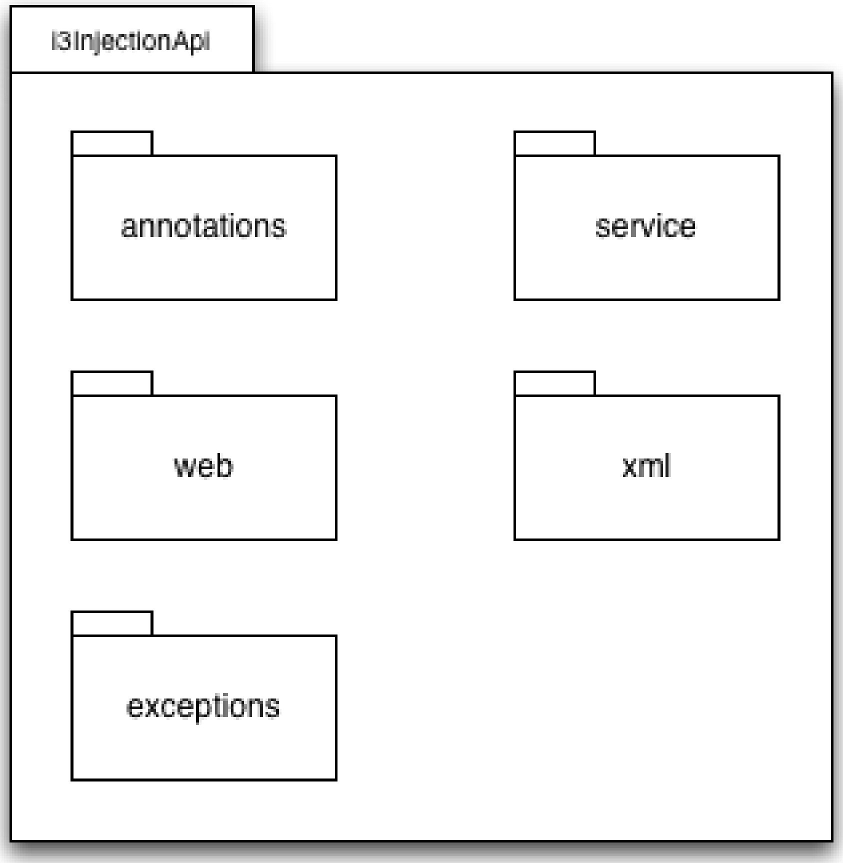


Figure K.2: `i3InjectionApi` Module Class Diagram

K.2.1 `i3InjectionApi: Service` Module Class Diagram

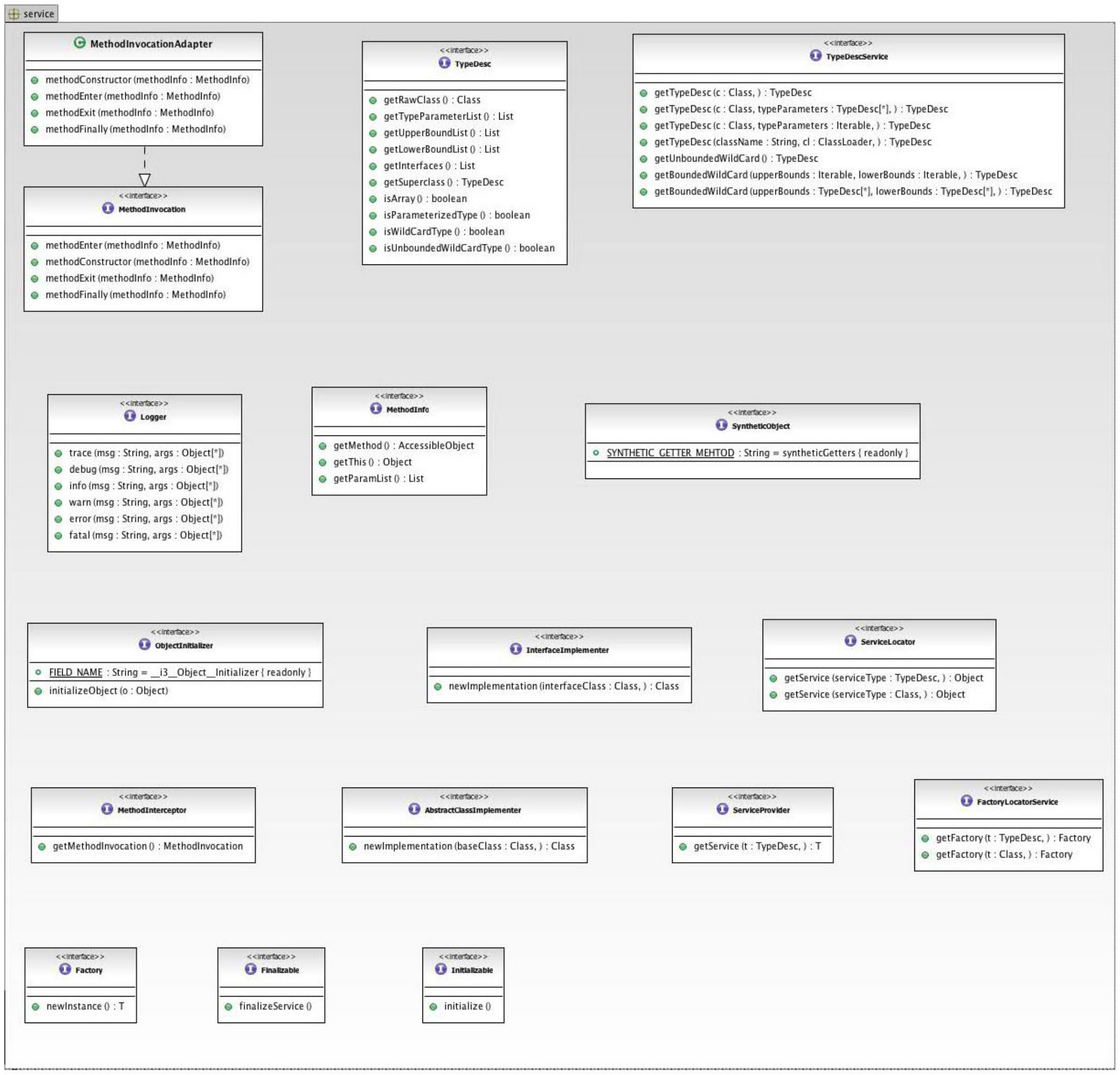

service
MethodInvocationAdapter
methodConstructor (methodInfo : MethodInfo)
methodEnter (methodInfo : MethodInfo)
methodExit (methodInfo : MethodInfo)
methodFinally (methodInfo : MethodInfo)
<<interface>> MethodInvocation
methodEnter (methodInfo : MethodInfo)
methodConstructor (methodInfo : MethodInfo)
methodExit (methodInfo : MethodInfo)
methodFinally (methodInfo : MethodInfo)
<<interface>> TypeDesc
getRawClass () : Class
getTypeParameterList () : List
getUpperBoundList () : List
getLowerBoundList () : List
getInterfaces () : List
getSuperclass () : TypeDesc
isArray () : boolean
isParameterizedType () : boolean
isWildCardType () : boolean
isUnboundedWildCardType () : boolean
<<interface>> TypeDescService
getTypeDesc (c : Class,) : TypeDesc
getTypeDesc (c : Class, typeParameters : TypeDesc[*],) : TypeDesc
getTypeDesc (c : Class, typeParameters : Iterable,) : TypeDesc
getTypeDesc (className : String, cl : ClassLoader,) : TypeDesc
getUnboundedWildCard () : TypeDesc
getBoundedWildCard (upperBounds : Iterable, lowerBounds : Iterable,) : TypeDesc
getBoundedWildCard (upperBounds : TypeDesc[*], lowerBounds : TypeDesc[*],) : TypeDesc
<<interface>> Logger
trace (msg : String, args : Object[*])
debug (msg : String, args : Object[*])
info (msg : String, args : Object[*])
warn (msg : String, args : Object[*])
error (msg : String, args : Object[*])
fatal (msg : String, args : Object[*])
<<interface>> MethodInfo
getMethod () : AccessibleObject
getThis () : Object
getParamList () : List
<<interface>> SyntheticObject
SYNTHETIC_GETTER_MEHTOD : String = syntheticGetters { readonly }
<<interface>> ObjectInitializer
FIELD_NAME : String = __i3__Object__Initializer { readonly }
initializeObject (o : Object)
<<interface>> InterfaceImplementer
newImplementation (interfaceClass : Class,) : Class
<<interface>> ServiceLocator
getService (serviceType : TypeDesc,) : Object
getService (serviceType : Class,) : Object
<<interface>> MethodInterceptor
getMethodInvocation () : MethodInvocation
<<interface>> AbstractClassImplementer
newImplementation (baseClass : Class,) : Class
<<interface>> ServiceProvider
getService (t : TypeDesc,) : T
<<interface>> FactoryLocatorService
getFactory (t : TypeDesc,) : Factory
getFactory (t : Class,) : Factory
<<interface>> Factory
newInstance () : T
<<interface>> Finalizable
finalizeService ()
<<interface>> Initializable
initialize ()

Figure K.3: `i3InjectionApi Service` Module Class Diagram

K.2.2 `i3InjectionApi`: Modules Class Diagram

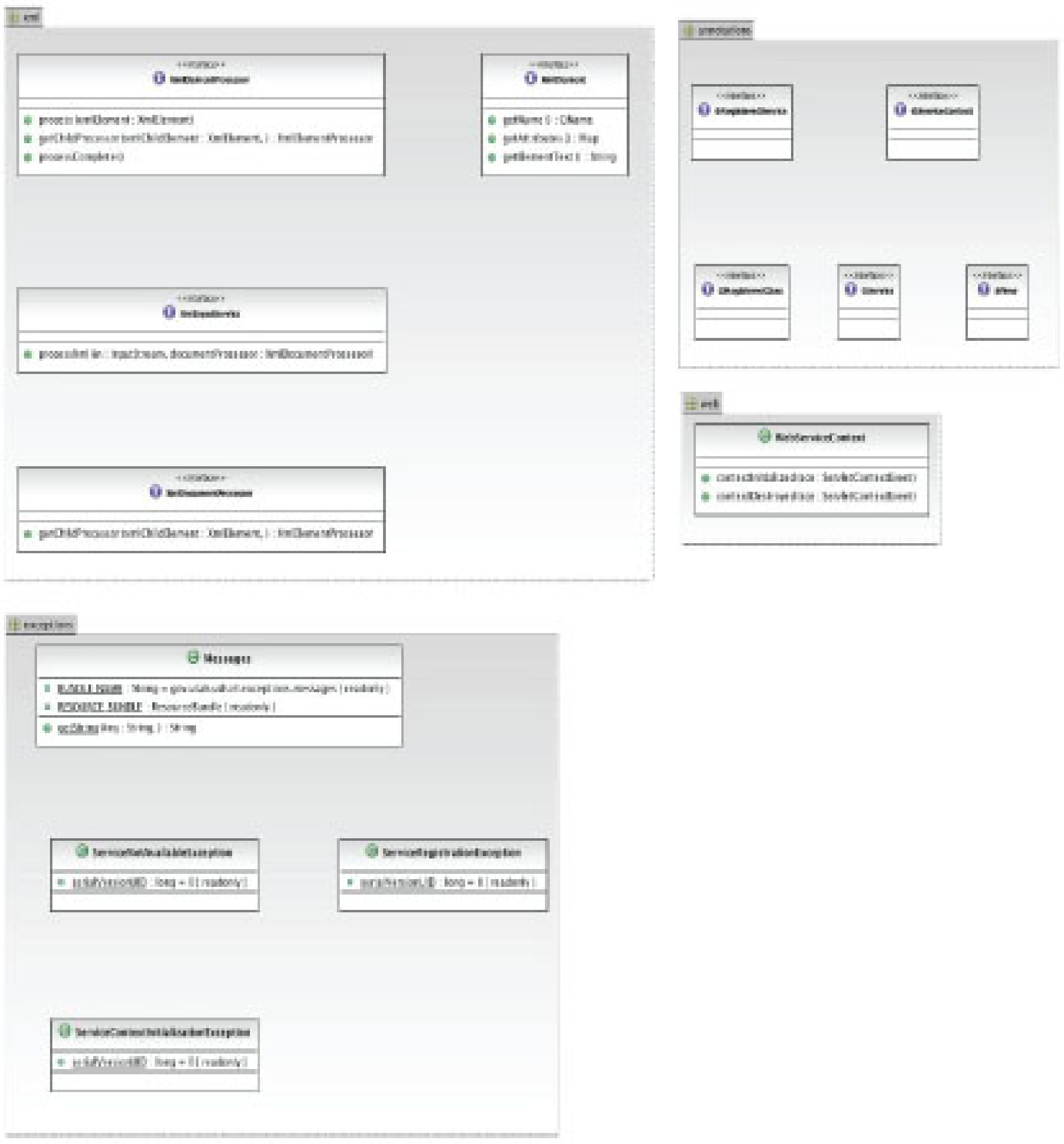

Messages
ServiceNotAvailableException
ServiceRegistrationException
ServiceContextInitialisationException
WebServiceContext

Figure K.4: `i3InjectionApi` Modules Class Diagram

K.3 `i3PersistenceApi`: Module Metrics and Package Diagram

Metric	Total
Number of Packages	5
Number of Classes	8
Number of Interfaces	11
Total Lines of Code	343

Table K.3: `i3PersistenceApi` Module Metrics

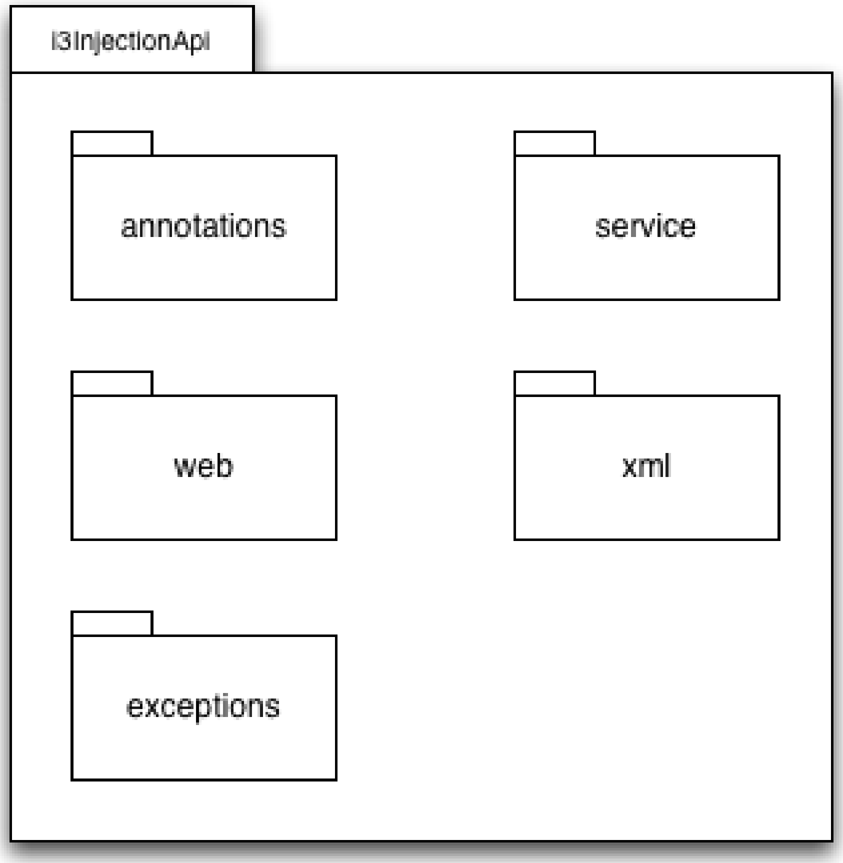


Figure K.5: `i3PersistenceApi` Module Package Diagram

K.3.1 `i3PersistenceApi`: `Query` Module Class Diagram

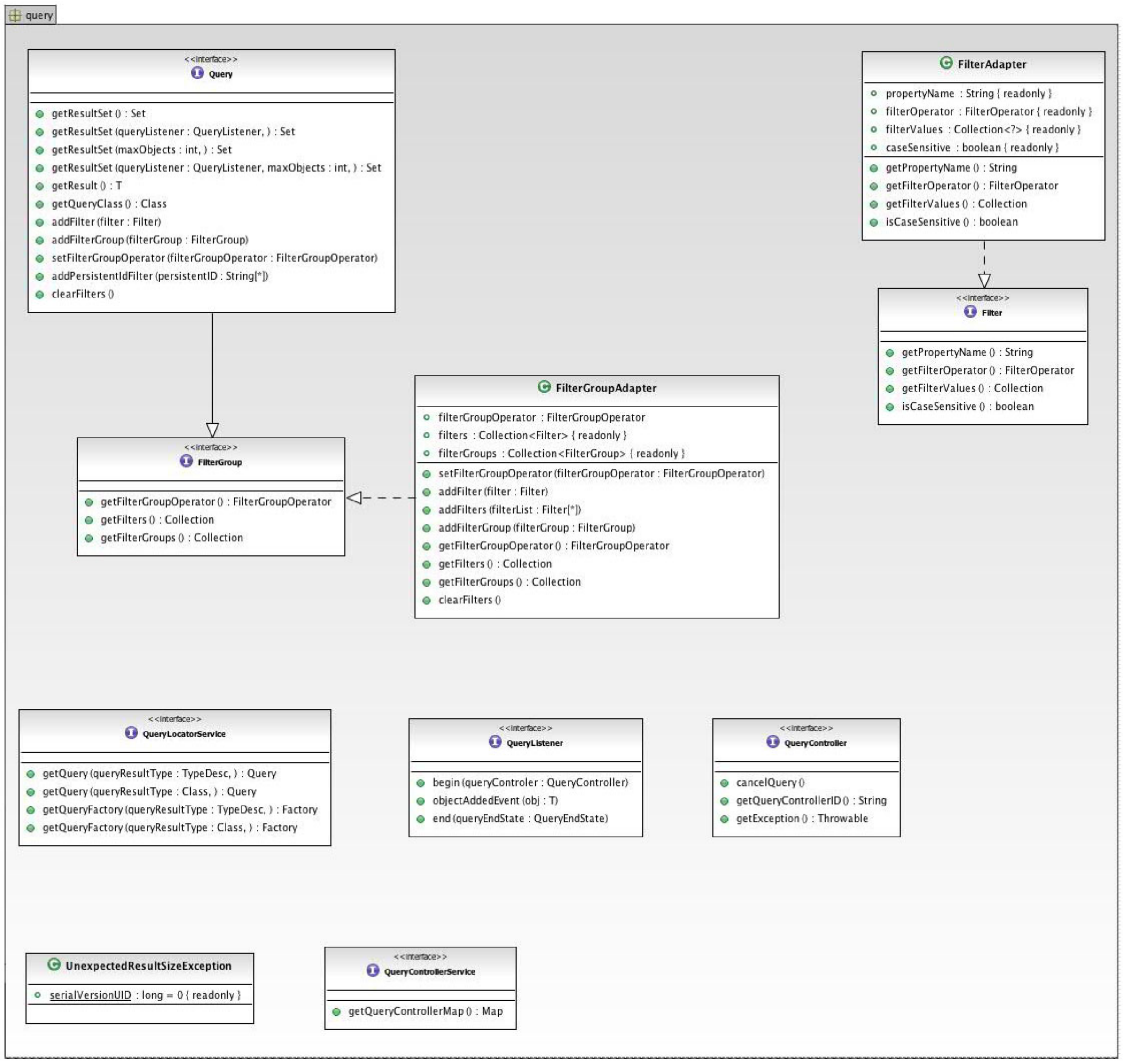

query
<<interface>>
Query
getResultSet () : Set
getResultSet (queryListener : QueryListener,) : Set
getResultSet (maxObjects : int,) : Set
getResultSet (queryListener : QueryListener, maxObjects : int,) : Set
getResult () : T
getQueryClass () : Class
addFilter (filter : Filter)
addFilterGroup (filterGroup : FilterGroup)
setFilterGroupOperator (filterGroupOperator : FilterGroupOperator)
addPersistentIdFilter (persistentID : String[*])
clearFilters ()
FilterAdapter
propertyName : String { readonly }
filterOperator : FilterOperator { readonly }
filterValues : Collection<?> { readonly }
caseSensitive : boolean { readonly }
getPropertyName () : String
getFilterOperator () : FilterOperator
getFilterValues () : Collection
isCaseSensitive () : boolean
<<interface>>
Filter
getPropertyName () : String
getFilterOperator () : FilterOperator
getFilterValues () : Collection
isCaseSensitive () : boolean
FilterGroupAdapter
filterGroupOperator : FilterGroupOperator
filters : Collection<Filter> { readonly }
filterGroups : Collection<FilterGroup> { readonly }
setFilterGroupOperator (filterGroupOperator : FilterGroupOperator)
addFilter (filter : Filter)
addFilters (filterList : Filter[*])
addFilterGroup (filterGroup : FilterGroup)
getFilterGroupOperator () : FilterGroupOperator
getFilters () : Collection
getFilterGroups () : Collection
clearFilters ()
<<interface>>
FilterGroup
getFilterGroupOperator () : FilterGroupOperator
getFilters () : Collection
getFilterGroups () : Collection
<<interface>>
QueryLocatorService
getQuery (queryResultType : TypeDesc,) : Query
getQuery (queryResultType : Class,) : Query
getQueryFactory (queryResultType : TypeDesc,) : Factory
getQueryFactory (queryResultType : Class,) : Factory
<<interface>>
QueryListener
begin (queryControler : QueryController)
objectAddedEvent (obj : T)
end (queryEndState : QueryEndState)
<<interface>>
QueryController
cancelQuery ()
getQueryControllerID () : String
getException () : Throwable
UnexpectedResultSizeException
serialVersionUID : long = 0 { readonly }
<<interface>>
QueryControllerService
getQueryControllerMap () : Map

Figure K.6: `i3PersistenceApi` `Query` Module Class Diagram

K.3.2 `i3PersistenceApi`: Modules Class Diagram

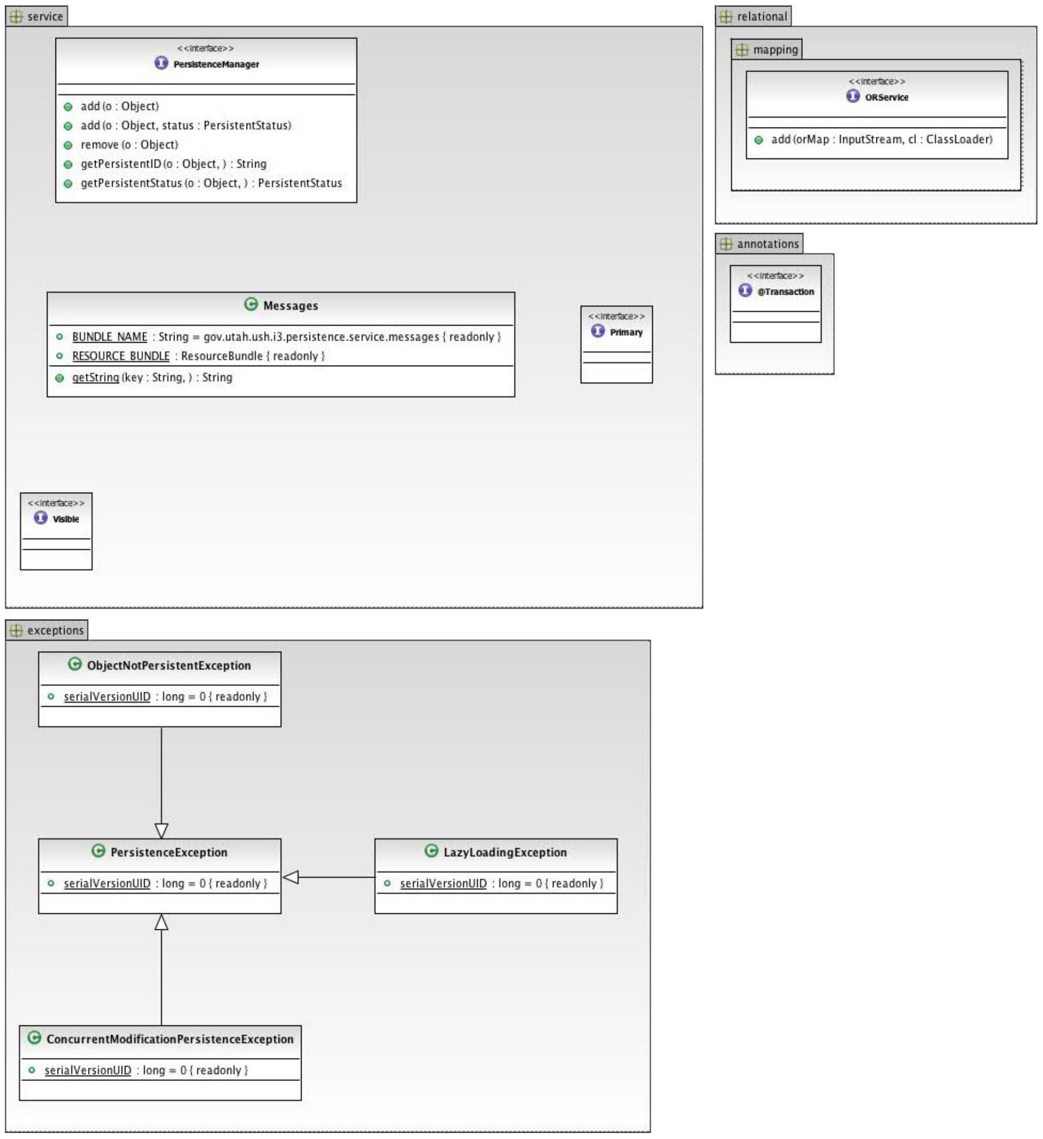

service
<<interface>>
PersistenceManager
add (o : Object)
add (o : Object, status : PersistentStatus)
remove (o : Object)
getPersistentID (o : Object,) : String
getPersistentStatus (o : Object,) : PersistentStatus
Messages
BUNDLE_NAME : String = gov.utah.ush.i3.persistence.service.messages { readonly }
RESOURCE_BUNDLE : ResourceBundle { readonly }
getString (key : String,) : String
<<interface>>
Primary
<<interface>>
Visible
relational
mapping
<<interface>>
ORService
add (orMap : InputStream, cl : ClassLoader)
annotations
<<interface>>
@Transaction
exceptions
ObjectNotPersistentException
serialVersionUID : long = 0 { readonly }
PersistenceException
serialVersionUID : long = 0 { readonly }
LazyLoadingException
serialVersionUID : long = 0 { readonly }
ConcurrentModificationPersistenceException
serialVersionUID : long = 0 { readonly }

Figure K.7: `i3PersistenceApi` Modules Class Diagram

K.4 `i3InjectionImpl`: Module Statistics and Package Diagram

Metric	Total
Number of Packages	11
Number of Classes	73
Number of Interfaces	4
Total Lines of Code	3981

Table K.4: `i3InjectionImpl` Module Metrics

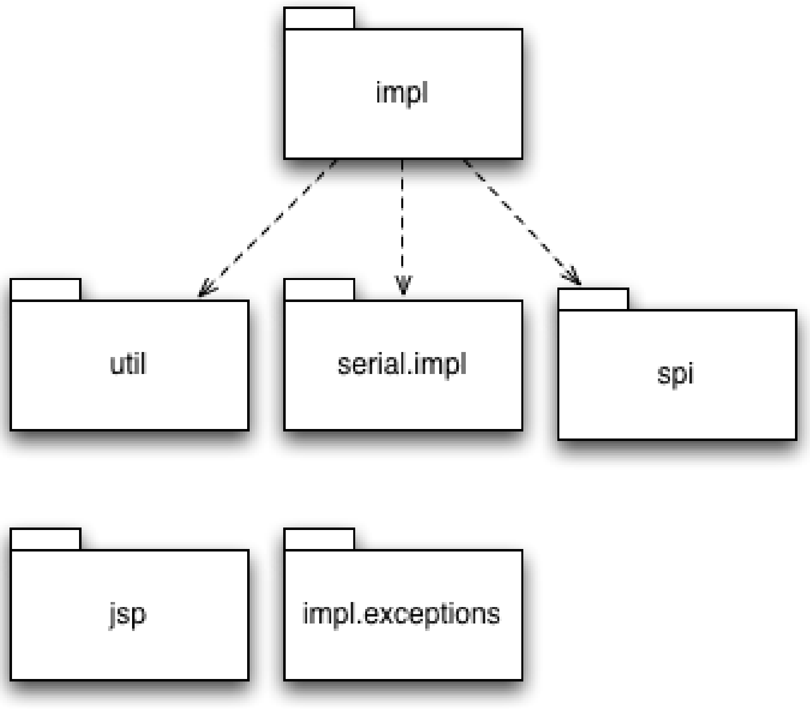


Figure K.8: `i3InjectionImpl` Module Package Diagram

K.5 `i3PersistenceImpl`: Module Statistics and Package Diagram

Metric	Total
Number of Packages	6
Number of Classes	61
Number of Interfaces	14
Total Lines of Code	4599

Table K.5: `i3PersistenceImpl` Module Metrics

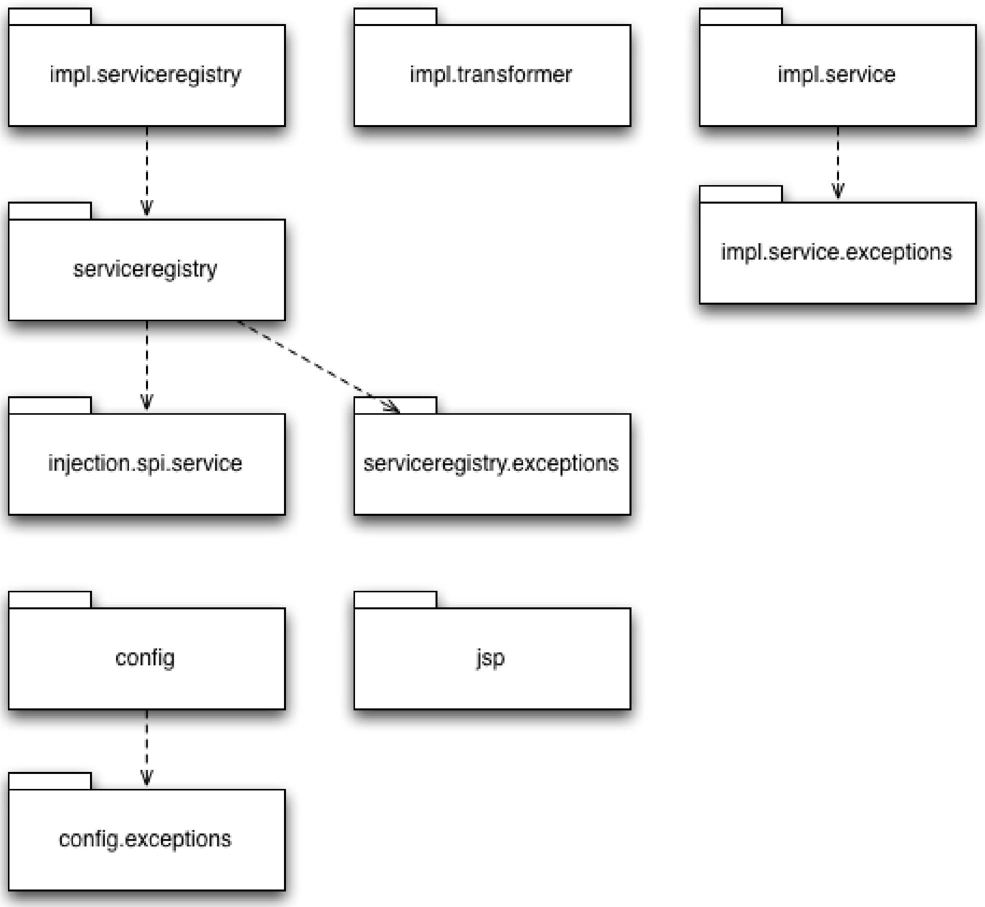


Figure K.9: `i3PersistenceImpl` Module Package Diagram