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Towards a Software Metric for OSGi

Graduation Thesis

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*“If I have seen farther than others,
it is because I stood on the shoulders of giants.”*

— SIR ISAAC NEWTON

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CONTENTS

ABSTRACT	7
RESUMO	8
LIST OF FIGURES	9
LIST OF TABLES	10
LIST OF ABBREVIATIONS AND ACRONYMS	11
1 INTRODUCTION	12
1.1 Context	12
1.2 Objectives	13
1.3 Organization	13
2 STATE OF ART	14
2.1 Software Quality	14
2.1.1 Quality Measurement	15
2.1.2 Software Metrics	16
2.1.3 Program Analysis	17
2.1.4 Quality Analysis Tools	18
2.2 Java and OSGi	19
2.2.1 The Java language	20
2.2.2 The OSGi service platform	21
2.2.3 Vanilla Java vs OSGi	24
2.3 JBoss Forge	26
2.3.1 Introduction	26
2.3.2 Forge Plugin	26
2.3.3 Facets	26
2.3.4 Project Locator	27
2.3.5 Applications	28
3 INTRABUNDLE - AN OSGI BUNDLE INTROSPECTION TOOL	29
3.1 Introduction	29
3.2 Design Decisions	29
3.3 Implementation Overview	31
3.4 Identifying OSGi Projects and Bundles	32

3.5	Collecting Bundle Data	32
3.6	Metrics Calculation	32
3.7	Intrabundle Quality	32
3.7.1	Internal quality	32
3.7.2	External quality	33
4	BUNDLE INTROSPECTION RESULTS	35
5	CONCLUSION	36
	REFERENCES	37

ABSTRACT

Today's software applications are becoming more complex, bigger, dynamic and harder to maintain. One way to overcome modern systems complexities is to build modular applications so we can divide it into small blocks which collaborate to solve bigger problems, the so called *divide to conquer*. Another important aspect in the software industry that helps building large applications is the concept of software quality because it's well known that higher quality softwares are easier to maintain and evolve at long term.

The Open Services Gateway Initiative(OSGi) is the *de facto* standard for building Java modular applications but there is no automated way to measure the quality of OSGi systems. In the context of Java applications there are many well known quality metrics and tools to measure application's quality but when we move to Java modular applications where standard quality metrics does not fit or even exist, for example module dependency metrics, we run out of options.

In this work will be presented a tool called *Intrabundle* that analyses OSGi projects and measure their quality. It also proposed 6 metrics based on good practices inside OSGi world which are applied to 10 real OSGi projects that vary in size, teams and domain.

Keywords: OSGi. java. quality. metrics. modularity. intrabundle.

RESUMO

As aplicações de software hoje em dia estão cada vez mais complexas, maiores, dinâmicas e mais difíceis de manter. Uma maneira de superar as complexidades dos sistemas modernos é através de aplicações modulares as quais são divididas em partes menores que colaboram entre si para resolver problemas maiores, o famoso *dividir para conquistar*. Outro aspecto importante na indústria de software que ajuda à construir aplicações grandes é o conceito de qualidade de software já que é sabido que quanto maior a qualidade do software mais fácil de mantê-lo e evolui-lo a longo prazo será.

The Open Services Gateway Initiative(OSGi) é o *padrão de fato* para se criar aplicações modulares em Java porém não existe forma automatizada de se medir a qualidade de sistemas OSGi. No âmbito de aplicações java existem diversas métricas de qualidade e ferramentas para medir a qualidade de software mas quando entramos no contexto de aplicações modulares, onde as métricas conhecidas não se encaixam ou não existem, por exemplo dependência entre módulos, ficamos sem opções.

Neste trabalho será apresentada uma ferramenta chamada *Intrabundle* que analisa projetos OSGi a mede sua qualidade. Ainda serão propostas métricas de qualidade baseadas em boas práticas conhecidas do mundo OSGi que serão aplicadas em 10 projetos reais que variam em tamanho, equipes e domínio.

Palavras-chave: OSGi. java. quality. metrics. modularity. intrabundle.

LIST OF FIGURES

2.1	Internal and external quality audience	15
2.2	Intrabundle PMD rule violation	19
2.3	Intrabunde PMD ruleset	19
2.4	JVM architecture	20
2.5	OSGi architecture	21
2.6	Module Layer	23
2.7	OSGi bundle Lifecycle	23
2.8	Lifecycle Layer	24
2.9	Service Layer	24
2.10	Java jar hell	25
2.11	Bundle classpath	25
3.1	Intrabundle Architecture	32
3.2	Intrabundle code coverage	33
3.3	Intrabundle integration tests	34

LIST OF TABLES

2.1	Quality characteristics to be considered	16
2.2	Common Software metrics	17
2.3	Quality analysis tools	18

LIST OF ABBREVIATIONS AND ACRONYMS

CISQ Consortium for IT Software Quality

JVM Java Virtual Machine

IEC International Electrotechnical Commission

ISO International Organization for Standardization

API Application Programming Interface

IDE Integrated Development Environment

GUI Graphic User Interface

LOC Lines of Code

KLOC Kilo Lines of Code

1 INTRODUCTION

This chapter will drive the reader through the context and motivation of this work followed by the objectives and later the organization of this text is presented.

1.1 Context

One of the pillars of sustainable software development is its quality which can basically be defined as internal and external where the first focuses on how software meets its specification and works accordingly to its requirements and the second is aimed on how well the software is structured and designed. To measure external quality there is the need to execute the software¹ either by an end user accessing the system or an automated process like for example functional testing or performance testing. Internal quality however can be verified by either *static analysis* that is mainly the inspection of the source code itself or by dynamic analysis which means executing the software like for example automated *whitebox testing*, the detailed investigation of internal logic and structure of the code (KHAN et al., 2012).

With good software quality in mind we take applications to another level where maintainability is increased, correctness is enhanced, defects are identified in early development stages, which can lead up to 100 times reduced costs (BEOHM et al., 2001), and also other characteristics like reusability, reliability and portability are benefited by higher software quality.

A well known and successful way to structure software architecture is to modularize its components allowing easier evolution of the system because smaller modules are typically easier to maintain than monolith applications. In the Java ecosystem there is a moving to modularize the JDK and Java applications with the project Jigsaw (KRILL, P.) and also a recent interest in *microservices* (KNORR, E.) arise. Although all this interest in modular application today the only practical working and well known solution for modular Java applications is OSGi, a very popular component-based and service-oriented framework for building Java modular applications. OSGi is the *de facto* standard solution for this kind of software since early 2000's and have being used as basis of most JavaEE² application servers³, the open source IDE Eclipse, Atlassian Jira and Confluence to cite a few big players using OSGi.

In the context of Java modular applications using OSGi and software quality there is no known standard way neither tools to measure OSGi projects *internal quality* (Hamza et al., 2013) although for *external quality* the classical approaches like automated testing are sufficient and widely used.

¹Also known as dynamic analysis

²A Java platform dedicated for enterprise applications which are usually secure and robust systems that display, manipulate and store large amounts of complex data maintained by an organization

³Java application servers are like an extended virtual machine for running applications, transparently handling connections to the database, connections to the Web client, managing components like Enterprise Java Beans(EJB) and so on

1.2 Objectives

The main objective of this work is to create software metrics to measure internal quality of OSGi based projects where this metrics must reflect good practices in the OSGi world. The main difference the proposed metrics have compared to classical software metrics is that the first will be based on modularity attributes that only exists in modular applications.

Another aim of this work is to create a tool to apply and validate the metrics on real OSGi projects and finally analyze the resulting qualities produced by the tool.

1.3 Organization

This text is organized in the following way. First chapter defines the context, motivation and objectives of this work. The second chapter will introduce the main concepts and technologies used in this work and will be divided into two main sections where the first will be focused in the area of software quality like quality measurement, quality metrics, program analysis and quality analysis tools and the second section of chapter two will present Java and OSGi, how standard Java and OSGi are different in respect to quality metrics and why we need different metrics for OSGi. The third chapter presents **Intrabundle**, an OSGi code introspection tool to measure internal quality, we will see how Intrabundle works, what kind of information it extracts and what metrics it is applying. The fourth chapter will analyze the results Intrabundle produces and validate them to decide if this work has a valid contribution or not. The last chapter will present the conclusions and future work on this subject.

2 STATE OF ART

This chapter presents an overview of the concepts and technologies that were studied and used on the development of this work. In section 2.1 - *Software Quality*, will be presented general aspects of software quality such as *quality measurement*, *software metrics*, *program analysis* and some tools that are used in this area.

Section 2.2 - *Java and OSGi* will introduce OSGi a framework for build service oriented Java modular applications. Finally section 2.3 will introduce JBoss Forge, a Java framework used as runtime¹ for Intrabundle².

2.1 Software Quality

There has been many definitions of software quality (KAN, 2002, p. 23) and there is even an ISO norm for it, the ISO/IEC 25010 (ISO25010, 2011). All this definitions agree that the main motivation to perform continuous software quality management is to avoid **software failures** and increase **maintainability** in the sense that the more quality a program has the easier will be to maintain, the less bugs or abnormal behavior it will have and the more it will conform with its functional and non functional requirements³.

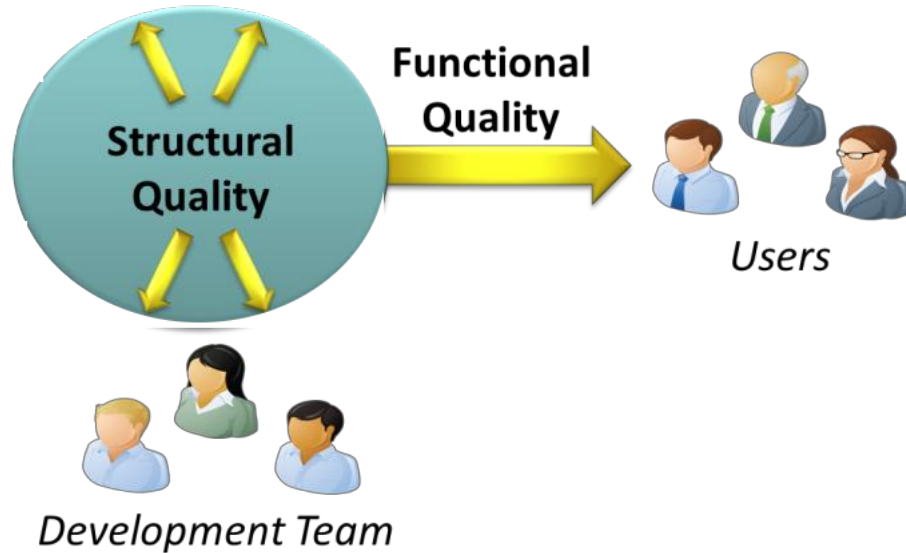
Another important aspect of software quality is that it can be divided in two groups, the **external** and **internal** quality. When we talk about *external quality* we are aiming to the user view which is the one that sees the software working and use it, this kind of quality is usually enforced through software testing. External quality can also be mapped to functional requirements so the greater external quality is the more usable and less defects it will have for example. The opposite is internal or structural quality that aims to how the software is architect-ed internally which is the perspective of the programmer and non functional requirements so the higher internal quality the better the code is structured, efficient, robust and maintainable it should be. Image 2.1 illustrates internal and external quality and its target audience.

¹Is software designed to support the execution of computer programs written in some computer language

²A Java based project that will be presented later on this work

³Functional and non functional requirements can be simply defined as *what* the software does and *how* the software will do respectively

Figure 2.1: Internal and external quality audience



2.1.1 Quality Measurement

Quality measurement focuses on quantifying software desirable characteristics and each characteristic can have a set of measurable attributes, for example *high cohesion* is a desirable characteristic and *LOC - lines of code* is a measurable attribute related to cohesion. Quality measurement is close related to internal quality and in most cases is performed via static code analysis where program code is inspected to search for quality attributes to be measured but in some cases a dynamic analysis, where the program analysis is done during software execution, can be performed to measure characteristics that can be perceived only when software is running, for example performance or code coverage⁴.

In the extent of this work the characteristics of software to be considered and measured later are listed and described in table 2.1:

⁴A technique that measures the code lines that are executed for a given set of software tests, its also considered a software metric.

Table 2.1: Quality characteristics to be considered

Characteristic	Description	OSGi example
Reliability	the degree to which a system or component performs its required functions under stated conditions for a specified period of time.	Bundles should not have stale service references.
Performance Efficiency	Performance relative to the amount of resources used under stated conditions for a specified period of time.	Bundle startup time, also bundle dependency can decrease performance.
Security	the degree of protection of information and data so that unauthorized persons or systems cannot read, access or modify them.	Bundles should declare permissions
Maintainability	The degree to which the product can be modified.	Modules should be loosely coupled, bundles should publish only interfaces etc.

Source: CISQ (2013)

2.1.2 Software Metrics

A software metric is the measurement of a software attribute which in turn is a quantitative calculation of a characteristic. Software metrics can be classified into three categories: product metrics⁵, process metrics⁶, and project metrics⁷. Software quality metrics are a subset of software metrics that focus on the quality aspects of the product, process, and project (KAN, 2002).

2.1.2.1 Good Software Metrics

Good metrics may have the following aspects:

- *Linear*: metric values should follow an intuitive way to compare its values like for example higher values should correspond to better quality whereas lower values to worse quality and vice versa.
- *Independent*: two metric values should not interfere on each other.
- *Repeatable*: this is a very important aspect in continuous quality management where software is changing all the time and we want to measure quality on every change.
- *Accurate*: the metric should be meaningful and should help answer how good a software

⁵Product metrics describe the characteristics of the product such as size, complexity, design features, performance

⁶Process metrics can be used to improve software development and maintenance. Examples include the effectiveness of defect removal during development and response time of bug fixing

⁷Project metrics describe the project characteristics and execution. Examples include the number of software developers, cost, schedule, and productivity

attribute is, for example using latency⁸ to calculate response time⁹ in a web application isn't accurate.

2.1.2.2 Common Software Metrics

The table 2.2 below shows some well known software metrics and its description:

Table 2.2: Common Software metrics

Metric	Description
Cyclomatic complexity	It is a quantitative measure of the complexity of programming instructions.
Cohesion	measure the dependency between units of code like for example classes in object oriented programming or modules in modular programming like OSGi.
Coupling	measures how well two software components are data related or how dependent they are.
Lines of code (LOC)	used to measure the size of a computer program by counting the number of lines in the text of the program's source code.
Code coverage	measures the code lines that are executed for a given set of software tests
Function point analysis (FPA)	used to measure the size (functions) of software.

Source: SQA (2012)

2.1.3 Program Analysis

Program analysis is the process of automatically analyzing the behavior of computer programs. Two main approaches in program analysis are **static program analysis** and **dynamic program analysis**. Main applications of program analysis are program correctness, program optimization and quality measurement.

2.1.3.1 Static Program Analysis

Is the analysis of computer software that is performed without actually executing programs (Wichmann et al., 1995). In this kind of analysis source code is inspected and valuable information is collected based on its internal structure and components.

⁸The delay incurred in communicating a message, the time the message spends "on the wire"

⁹The total time it takes from when a user makes a request until they receive a response

2.1.3.2 Dynamic Program Analysis

Is a technique that analyze the system's behavior on the fly, while it is executing. The main objectives of this kind of analyze is to catch *memory leaks*¹⁰, identify arithmetic errors and extract code coverage.

2.1.4 Quality Analysis Tools

The table 2.3 lists some code quality analysis tools in the Java ecosystem:

Table 2.3: Quality analysis tools

Name	Description	Type
SonarQube	An open source platform for continuous inspection of code quality.	static
FindBugs	An open-source static bytecode analyzer for Java.	static
Checkstyle	A static code analysis tool used in software development for checking if Java source code complies with coding rules.	static
PMD	A static ruleset based Java source code analyzer that identifies potential problems.	static
ThreadSafe	A static analysis tool for Java focused on finding concurrency bugs.	static
InFusion	Full control of architecture and design quality.	static
JProfiler	helps you resolve performance bottlenecks, pin down memory leaks and understand threading issues	dynamic
JaCoCo	A free code coverage library for Java.	dynamic
Javamelody	Java or Java EE application Monitoring in QA and production environments.	dynamic
Introscope	An application management solution that helps enterprises keep their mission-critical applications high-performing and available 24x7.	dynamic

Figure 2.2 shows the execution of static analysis on *Intrabundle* using *PMD*, note that it is based on rules and *Intrabundle* break some of them(intentionally) like *Unused variables*, *EmptyCatchBlock* so *PMD* consider them compile failure and the project cannot be compiled until the rules are fixed in code:

¹⁰Resources that are hold on system's memory and aren't released

Figure 2.2: Intrabundle PMD rule violation

```
[INFO] >>> maven-pmd-plugin:3.2:check (default) @ intrabundle >>>
[INFO]
[INFO] --- maven-pmd-plugin:3.2:pmd (pmd) @ intrabundle ---
[INFO]
[INFO] <<< maven-pmd-plugin:3.2:check (default) @ intrabundle <<<
[INFO]
[INFO] --- maven-pmd-plugin:3.2:check (default) @ intrabundle ---
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.metric.DefaultMetricsCalculator:119 Rule:EmptyCatchBlock Priority:2 Must handle exceptions.
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:143 Rule:StringInstantiation Priority:2 Avoid instantiating String objects; this is usually unnecessary..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:160 Rule:UseIndexOfChar Priority:3 String.indexOf(char) is faster than String.indexOf(String)..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:162 Rule:UseIndexOfChar Priority:3 String.indexOf(char) is faster than String.indexOf(String)..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:201 Rule:UseIndexOfChar Priority:3 String.indexOf(char) is faster than String.indexOf(String)..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:255 Rule:UseIndexOfChar Priority:3 String.indexOf(char) is faster than String.indexOf(String)..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.ManifestMetadata:309 Rule:UseIndexOfChar Priority:3 String.indexOf(char) is faster than String.indexOf(String)..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.OSGiModuleImpl:186 Rule:EmptyCatchBlock Priority:2 Must handle exceptions.
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.OSGiProjectImpl:37 Rule:UnusedPrivateField Priority:3 Avoid unused private fields such as 'projectMetric'..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.model.OSGiProjectImpl:38 Rule:UnusedPrivateField Priority:3 Avoid unused private fields such as 'metrics'..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.plugin.BundlePlugin:22 Rule:UnusedPrivateField Priority:3 Avoid unused private fields such as 'prompt'..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.plugin.LocalePlugin:34 Rule:UnusedPrivateField Priority:3 Avoid unused private fields such as 'event'..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.plugin.OSGiScanPlugin:39 Rule:UnusedPrivateField Priority:3 Avoid unused private fields such as 'moduleLevel's'..
[INFO] PMD Failure: br.ufprgs.rmpestano.intrabundle.util.ProjectUtils:328 Rule:UnusedLocalVariable Priority:3 Avoid unused local variables such as 'line'..
[INFO] -----
[INFO] BUILD FAILURE
```

The rules are totally customizable via xml configuration, Intrabundle PMD rules are shown in Figure 2.3:

Figure 2.3: Intrabundle PMD ruleset

```
1  <?xml version="1.0"?>
2  <ruleset name="Custom ruleset" xmlns="http://pmd.sourceforge.net/ruleset/2.0.0"
3      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
4      xsi:schemaLocation="http://pmd.sourceforge.net/ruleset/2.0.0">
5      <description>
6          This ruleset checks my code for bad stuff
7      </description>
8
9      <exclude-pattern>.*src/test/*.*</exclude-pattern>
10
11      <!-- Here's some rules we'll specify one at a time -->
12      <rule ref="rulesets/java/unusedcode.xml/UnusedLocalVariable" />
13      <rule ref="rulesets/java/unusedcode.xml/UnusedPrivateField" />
14      <rule ref="rulesets/java/imports.xml/DuplicateImports" />
15      <rule ref="rulesets/java/basic.xml/UnnecessaryConversionTemporary" />
16
17      <rule ref="rulesets/java/strings.xml">
18          <exclude name="AvoidDuplicateLiterals" />
19          <exclude name="AppendCharacterWithChar" />
20          <exclude name="ConsecutiveLiteralAppends" />
21          <exclude name="InefficientStringBuffering" />
22      </rule>
23
24      <!-- We want to customize this rule a bit, change the message and raise
25           the priority -->
26      <rule ref="rulesets/java/basic.xml/EmptyCatchBlock" message="Must handle exceptions">
27          <priority>2</priority>
28      </rule>
29
30      <!-- Now we'll customize a rule's property value -->
31      <rule ref="rulesets/java/codesize.xml/CyclomaticComplexity">
```

Source: intrabundle ruleset (2014)

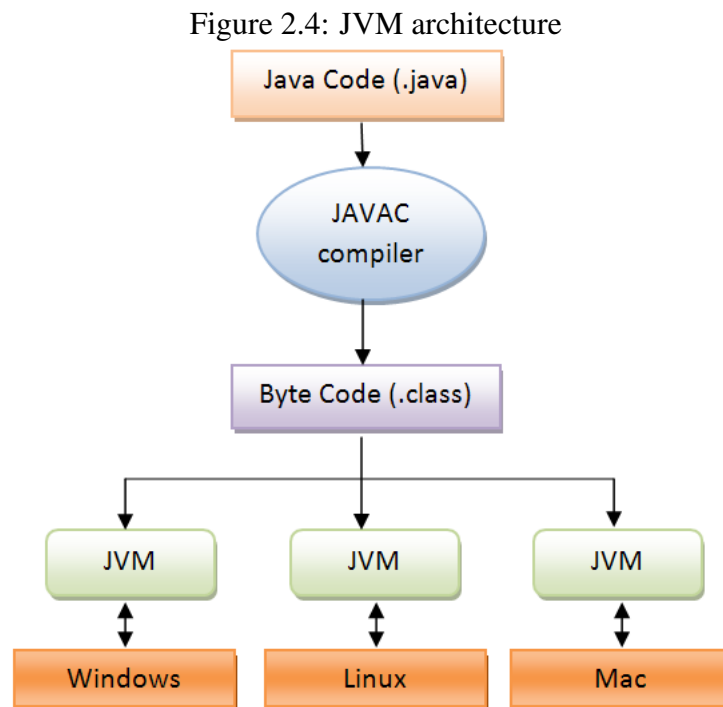
2.2 Java and OSGi

In the context of JavaTM programming language (Arnold et al., 2005), which accordingly to IEEE spectrum of this year is the most popular programming language (IEEE Spectrum, 2014),

and modular applications¹¹ this section will introduce the Java language and OSGi framework.

2.2.1 The Java language

Java is a general purpose object oriented¹² programming language created by Sun Microsystems in 1995 which aims on simplicity, readability and universality. Java runs on top of the so called JVM, the acronym for Java Virtual Machine, which is an abstract computing machine¹³ and platform-independent execution environment that execute Java byte code¹⁴. The JVM converts java byte code into host machine language(e.g. linux, windows etc...) allowing Java programs to "run everywhere" independently of operating system or platform. JVM implementations are different for each platform but the generated bytecode is the same, Figure 2.4 illustrates how JVM works:



Other aspects of Java are listed below:

- Type safe¹⁵
- Dynamic: during the execution of a program, Java can dynamically load classes
- Strong memory management(no explicit pointer)

¹¹A software design technique that emphasizes separating the functionality of a program into independent, interchangeable modules which represent a separation of concerns and improves maintainability

¹²Object-oriented programming(OOP) integrates code and data using the concept of an "object" which is a piece of software that holds state and behavior

¹³Also known as *Virtual Machine* which is an emulation of a particular computer system

¹⁴The intermediate output of the compilation of a program written in Java that can be read by the JVM

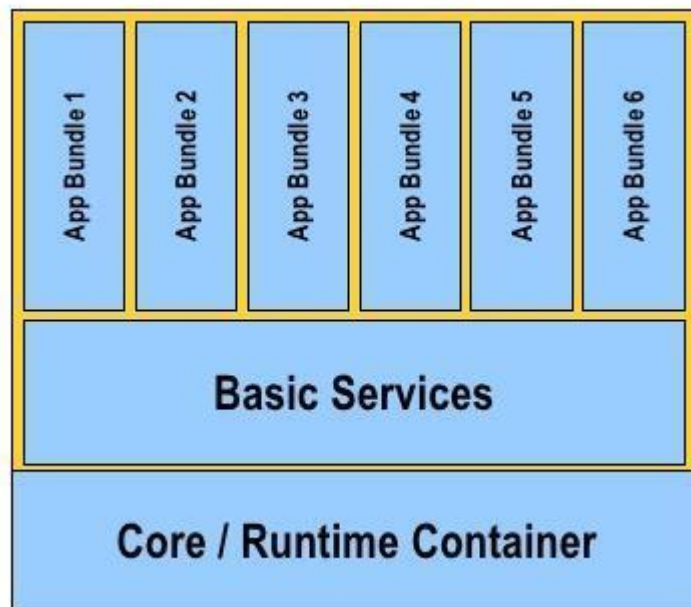
¹⁵Type safety is the extent to which a programming language discourages or prevents type errors

- Automatic garbage collection to release unused objects from memory
- Robust: extensive compile-time checking so bugs can be found early
- Multithreaded¹⁶
- Distributed: networking capability is inherently integrated into Java

2.2.2 The OSGi service platform

OSGi is a component based service oriented platform specification maintained by *OSGi Alliance*¹⁷ that runs on top of Java. As of November 2014 the specification is at version 6 and currently has four implementations¹⁸. It is composed by *OSGi framework* and *OSGi standard services*. The framework is the runtime that provides the basis of all OSGi module system functionalities like modules management for example. Standard services define some reusable apis and extension points to easy development of OSGi based applications. Figure 2.5 illustrates OSGi platform architecture:

Figure 2.5: OSGi architecture



2.2.2.1 Bundles

Bundles are the building blocks of OSGi applications. A bundle¹⁹ is a group of Java classes and resources packed as .jar extension with additional metadata in manifest MANIFEST.MF file

¹⁶Multithreading is a program's capability to perform several tasks simultaneously

¹⁷A non profit worldwide consortium of technology innovators

¹⁸[Apache Felix](#), [Eclipse Equinox](#), [Knopflerfish](#) and [ProSyst](#)

¹⁹Also known as module

describing its module boundaries like for example the packages it imports and exports. Below is an OSGi manifest file example:

```
Bundle-Name: Hello World
Bundle-SymbolicName: org.wikipedia.helloworld
Bundle-Description: A Hello World bundle
Bundle-ManifestVersion: 2
Bundle-Version: 1.0.0
Bundle-Activator: org.wikipedia.Activator
Export-Package: org.wikipedia.helloworld;version="1.0.0"
Import-Package: org.acme.api;version="1.1.0"
```

Looking at manifest OSGi can ensure its most important aspect, *modularity*, so for example our **Hello World** bundle will only be started (later we will explore bundle lifecycle) if and only if there is a bundle (in resolved or installed state) that exports *org.acme.api* package, this is called **explicit boundaries**.

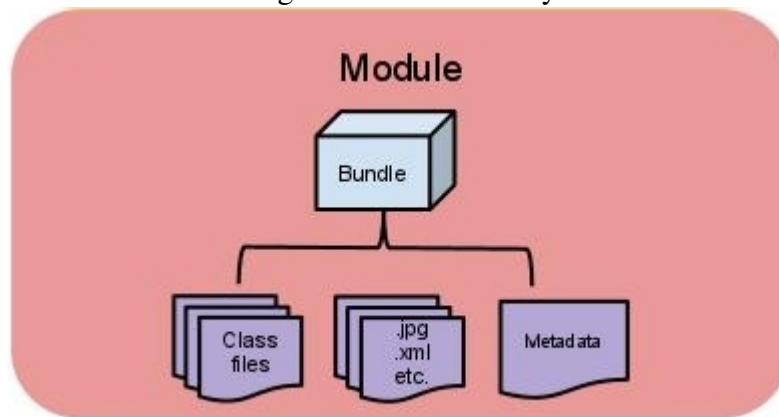
With OSGi, you modularize applications into bundles. Each bundle is a tightly coupled, dynamically loadable collection of classes packed in JARs²⁰, and configuration files that explicitly declare any external dependencies. All these characteristics are provided in OSGi by three conceptual layers that will be briefly presented here, *Module*, *Lifecycle* and *Service*.

2.2.2.2 *Module layer*

This layer is the basis for others as modularization is the key concept of OSGi. The module layer defines OSGi module concept - bundle, which is a JAR file with extra metadata. It also handles the packaging and sharing of Java packages between bundles and the hiding of packages from other bundles. The OSGi framework dynamically resolves dependencies among bundles and performs bundle resolution to match imported and exported packages. This layer ensures that class loading happens in a consistent and predictable way.

²⁰acronym for Java Archive, a file that used to aggregate many Java class files and associated metadata and resources (text, images, etc.) into one file to distribute

Figure 2.6: Module Layer

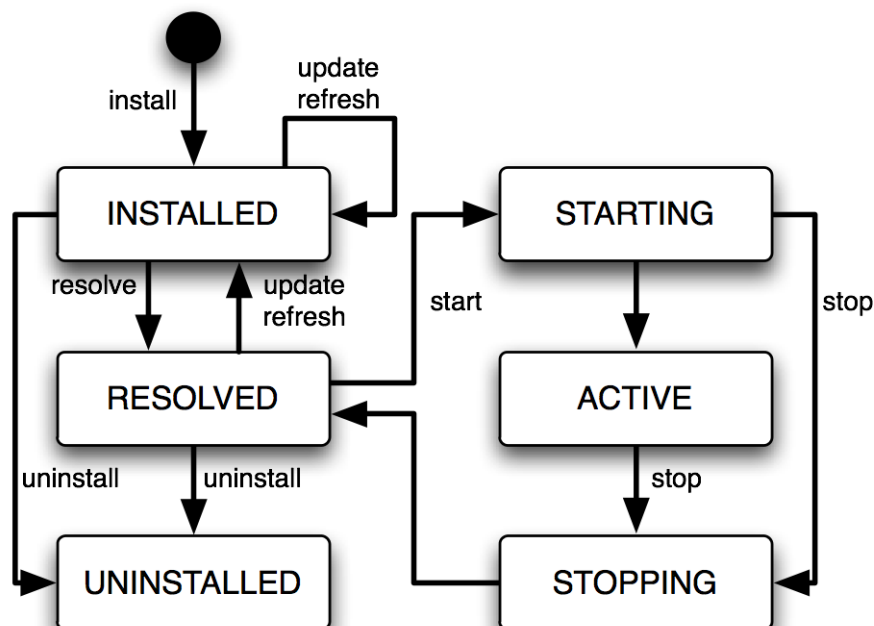


Source: OSGi conceptual layers (2011)

2.2.2.3 Lifecycle layer

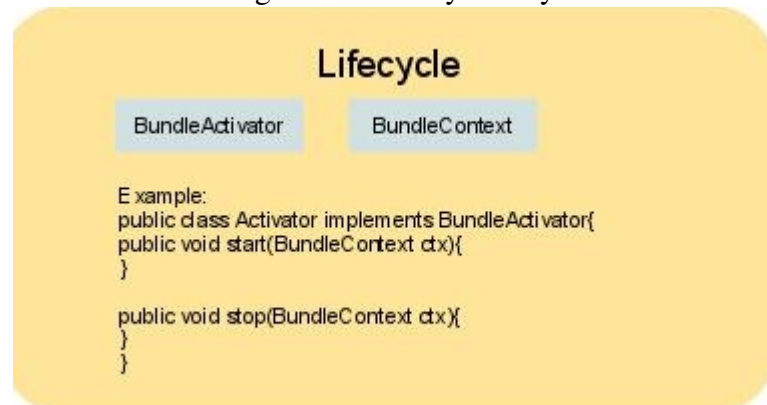
Provides access to the underlying OSGi framework through the *Bundle Context* object. This layer handles the lifecycle of individual bundles so you can manage your application dynamically, including starting and stopping bundles to manage and evolve them over time. Bundles can be dynamically installed, started, updated, stopped and uninstalled. Figure 2.7 shows bundle lifecycle and its possible states where transitions are performed by OSGi commands like *start* or *stop* for example and states are represented in squares:

Figure 2.7: OSGi bundle Lifecycle



If OSGi were a car, module layer would provide modules such as tire, seat, etc, and the lifecycle layer would provide electrical wiring which makes the car run.

Figure 2.8: Lifecycle Layer



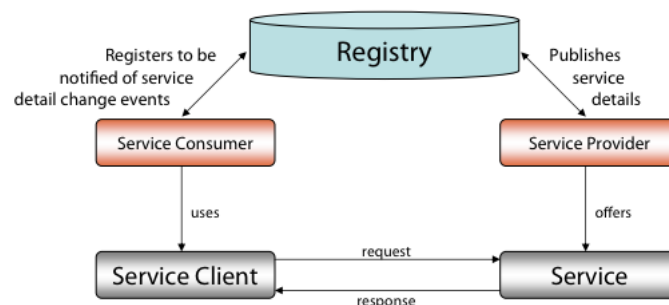
Source: OSGi conceptual layers (2011)

2.2.2.4 Service layer

This layer provides communication among modules and their contained components. Service providers publish services²¹ to *service registry*, while service clients search the registry to find available services to use. The registry is accessible to all bundles so they can *publish* its services as well *consume* services from other bundles.

This is like a service-oriented architecture (SOA) which has been largely used in web services. Here OSGi services are local to a single VM, so it is sometimes called SOA in a VM.

Figure 2.9: Service Layer



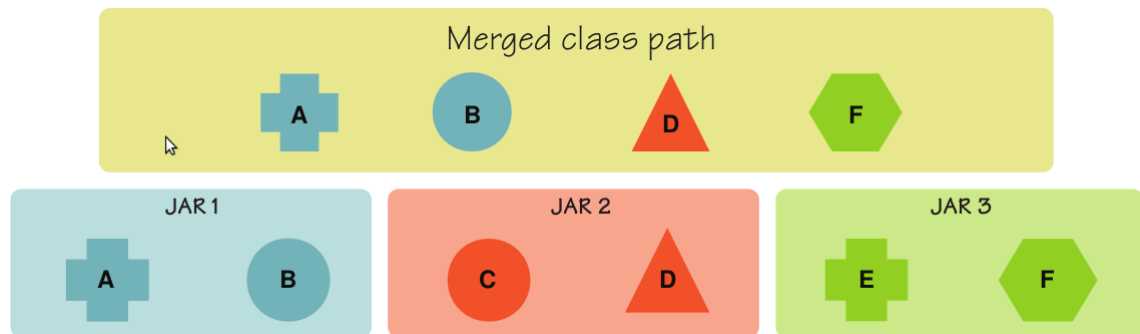
2.2.3 Vanilla Java vs OSGi

The main motivation behind OSGi and advantage over standard Java application, as illustrated before, is the modularity. The main issue with Java default runtime is the way Java classes are loaded, it is the root cause that inhibits modularity in classical Java applications. In standard

²¹A Service is an operation offered as an interface that stands alone in the model, without encapsulating state (Evans and Fowler, 2003)

Java, user classes²² are loaded by a classloader²³ from the same classpath²⁴ which is commonly referred as a *flat classpath*. A flat classpath is the main cause of a well known problem in Java applications, the *Jar Hell*²⁵. Figure 2.10 is an example of Jar hell where multiple JARs containing overlapping classes(consider each shape as being a Java class) and/or packages are merged based on their order of appearance in the class path.

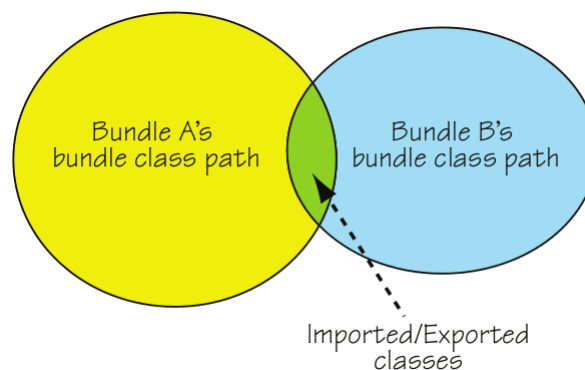
Figure 2.10: Java jar hell



Source: (HALL et al., 2011, p. 7)

In the OSGi environment instead of a *flat classpath* each bundle has its classloader and its classpath. See Figure 2.11 where Bundle A's classpath is defined as the union of its bundle classpath with its imported packages, which are provided by bundle B's exports.

Figure 2.11: Bundle classpath



Source: (HALL et al., 2011, p. 59)

In OSGi runtime we can say we have a graph of classpaths that allows powerful versioning mechanisms so for example we can have multiple versions of the same class or resource loaded at the same time(used by different bundles). This enables independent evolution of dependent artifacts which, in the Java world, is unique to OSGi environments (semantic versioning, 2010).

²²Classes that are defined by developers and third parties and that do not take advantage of the extension mechanism

²³A class loader is an object that is responsible for loading classes

²⁴classpath tells Java virtual machine where to look in the filesystem for files defining these classes

²⁵A term used to describe all the various ways in which the classloading process can end up not working

2.3 JBoss Forge

2.3.1 Introduction

[JBoss Forge](#) is a modular²⁶ plugin based general purpose command line development tool.

2.3.2 Forge Plugin

A Forge plugin can be as simple as a tool to print files to the console, or as complex as deploying an application to a server, tweeting²⁷ the status of your latest source-code commit, or even sending commands to a home-automation system. The sky is the limit!.

Every plugin offers a set o commands that may be restricted by a facet.

2.3.2.1 Example

Below is a simple Forge plugin named *hello-world* with a command named *sayHello* that prints "Hello World" when executed:

```
@Alias("hello-world")
public class HelloWorldPlugin implements Plugin {

    @Command(value = "sayHello")
    public void countBundles(PipeOut out) {
        out.println("Hello_World" );
    }

}
```

Plugin is just a marker interface so Forge can identify plugins. To fire the *sayHello* command one have to start forge, install the *HelloPlugin* and then can use the command by typing *hello-world sayHello* in Forge console and so "Hello World" should be printed in console.

2.3.3 Facets

A Facet in the Forge environment is responsible for restricting the usage of a plugin. It is in fact an interface²⁸ with a method with return type boolean that must decide if the facet is installed.

²⁶Forge runtime is based on [JBoss modules](#) which is a technology, like OSGi but not so popular, for building modular applications

²⁷Term used to refer as publishing messages to the twitter social media.

²⁸In object oriented programming is a contract that defines which methods the implementors of the interface must provide

2.3.3.1 Example

Below is an example of facet that restricts the usage of hello-world plugin, in the example the command should be only available when user is in a directory named *hello* otherwise Forge will claim that the command does not exist in current context.

```
public class HelloFacet implements Facet {

    @Inject
    Project project;

    @Override
    public boolean isInstalled() {
        return project.getProjectRoot().getName().equals("hello");
    }
}
```

So the idea of a facet is that it is active when isInstalled method return true. In HelloFacet only when user current directory is named "hello". To get user current directory we ask forge, through dependency injection, for the current project. Project is a Java object that holds information of the current user project like its directory.

To activate the facet we must annotate HelloWorld plugin with RequiresFacet:

```
@Alias("hello-world")
@RequiresFacet(HelloFacet.class)
public class HelloWorldPlugin implements Plugin {

    @Command(value = "sayHello")
    public void countBundles(PipeOut out) {
        out.println("Hello_World");
    }
}
```

2.3.4 Project Locator

A project locator is a component responsible for creating Java objects that represent useful information in the forge runtime, they are called *project* in forge. Forge calls all locators available when user change directory in command line and the first locator that is matched will create a Java object representing the current Project. Its the same idea of facets but instead of restricting plugin commands it creates object and made them available for Forge runtime. That

was how we could inject current user project in HelloFacet before.

2.3.5 Applications

Forge can be used as a command line tool or integrated in main IDEs like Eclipse, Netbeans or IntelliJ. To be used as command line tool one must download a zip distribution containing a forge executable that runs on main operating systems²⁹.

Forge has an important role on this work as it was the ground for creating Intrabundle, a tool based on forge runtime that will be introduced later on this work.

²⁹As forge runs on top of Java, Forge inherits its *universality*

3 INTRABUNDLE - AN OSGI BUNDLE INTROSPECTION TOOL

3.1 Introduction

It was clear in previous chapters that modular and non modular applications have many differences and specific features hence the need for dedicated approach for quality analysis. This chapter presents a tool called *Intrabundle* (intrabundle github, 2014), an open source Java based application created in the context of this work. Intrabundle introspects OSGi projects collecting useful information and calculates OSGi bundle and project **internal quality**.

3.2 Design Decisions

To analyze and extract data from large code bases of OSGi projects, which can vary from KLOCs to thousands of KLOCs, there was the need of a lightweight approach. Some *functional requirements* were:

- Analyze different formats of OSGi projects like Maven¹, Eclipse projects and BND²;
- It should be able to dive deep into projects source code like counting methods calls, differentiate classes and interfaces and so on;
- Get general informations like project version, revision or latest commit in source repository;
- Should be easy analyze lots of projects;
- Should output a detailed Human readable quality report so the extracted information can be analyzed.

and the following *non functional requirements*:

- Only open sourced projects³ because we focus on internal quality where the code is important;
- The tool should be lightweight to analyze real, complex and huge OSGi projects;
- Find and Introspect manifest files where valuable OSGi information rely;
- Should be testable;
- Fast;
- Use Java to leverage the author's experience in the language;
- Use a good file system API⁴ because file manipulation is one of the most frequent tasks the tool should perform.

¹Maven is a build tool for Java

²BND is a tool to easy OSGi projects development

³Projects that have its source code made available with a license in which the copyright holder provides the rights to study, change and distribute the software to anyone and for any purpose

⁴An API expresses a software component in terms of its operations, inputs, outputs, and underlying types.

The following alternatives were evaluated:

1. Build a standalone Java client application using javaFX⁵;
2. Create an eclipse plugin⁶;
3. Create a Maven plugin⁷;
4. Build the tool on top of JBoss Forge;
5. Extend an existing static/internal analysis tool like PMD.

The chosen among the above options was JBoss Forge, due to the following facts:

- Works inside and outside eclipse;
- Works regardless of build tool;
- As its a command line tool its very lightweight and can analyze multiple OSGi projects at the same time;
- The programing model is based on top of the so called CDI⁸ so managing Objects lifecyle and event is handled by CDI automatically;
- Forge has a very well established and documented file system manipulation api based on java.io;
- Forge is very flexible so generating quality reports is a matter of using a report API inside it;
- The author already had experience with JBoss Forge and CDI.

Creating an eclipse plugin for analyzing OSGi projects could be not as lightweight as forge plugin. We would need eclipse started and OSGi projects imported inside IDE so the eclipse plugin could identify the project resources.

JavaFX would require use standard Java file system manipulation api(java.io) which has many caveats and pitfalls so for example its easy to create a memory leak or too many files opens error. Also with JavaFX there the need to implement the interface/GUI which is already well done in Eclipse or Forge.

Maven plugins are limited to maven projects.

PMD⁹ has a very limited API so it could be hard to generate reports or analyze multiple projects using it.

⁵JavaFX is a set of graphics and media packages that enables developers to design, create, test, debug, and deploy rich client applications

⁶Eclipse plug-ins are software components with the objective to extend Eclipse IDE

⁷Maven is a build tool that consists of a core engine which provides basic project-processing capabilities and build-process management, and a host of *plugins* which are used to execute the actual build tasks.

⁸Context and Dependency Injection for the Java platform. CDI is a dependency injection framework where instead of dependencies construct themselves they are injected by some external means, in cae CDI

⁹A very nice tool for static code analysis. It is based on rules that can be created via xml or xpath expression. When a rule is violated it can output warns or errors to the console

3.3 Implementation Overview

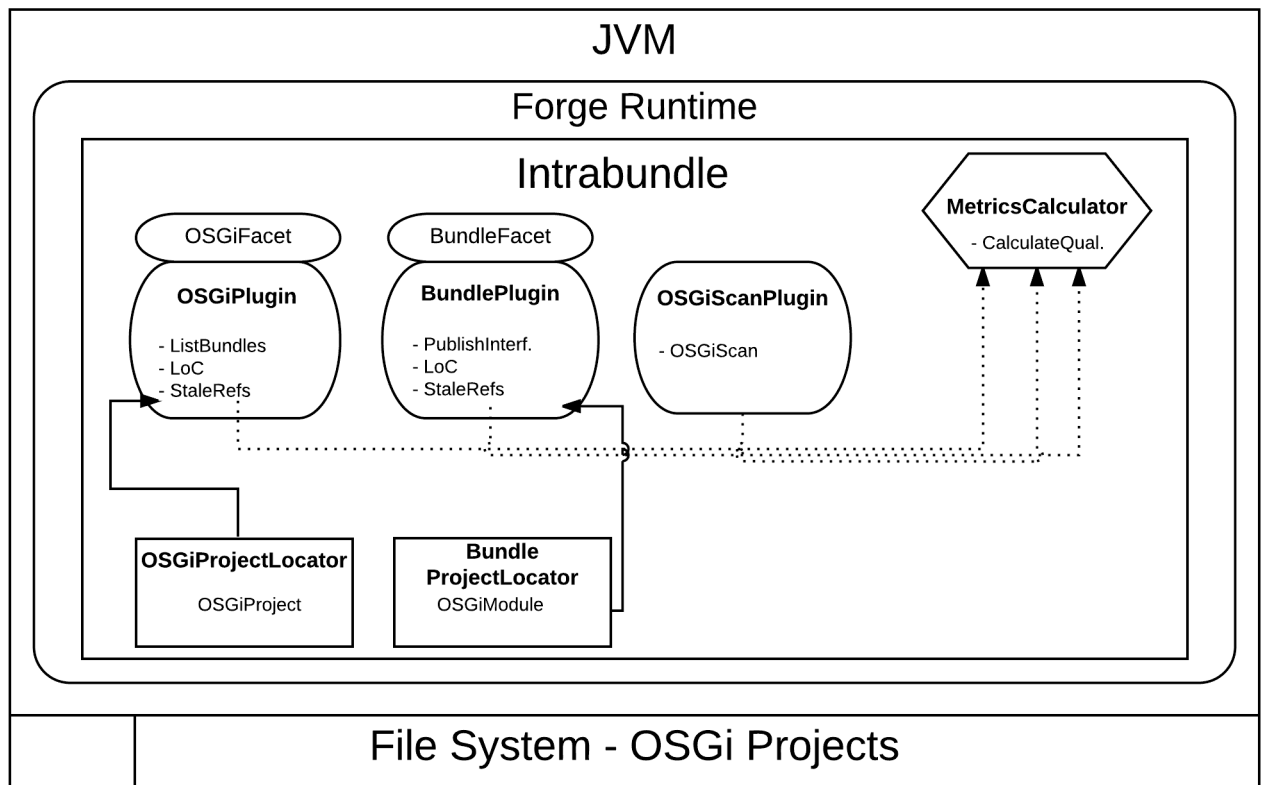
Intrabundle is composed by 3 Forge plugins, see section 2.3.2 for details about Forge plugins. The first is *BundlePlugin* which extracts OSGi bundle information, second is *OSGiPlugin* that has a vision of all bundles composed by the project. Third is *OSGiScan* a plugin responsible for scanning OSGi bundles recursively in file system. Another component in the architecture is *MetricsCalculator* that calculates bundle and OSGi project quality based on metrics produced by *OSGiPlugin* and *BundlePlugin*.

Intrabundle also provides 2 facets, see section 2.3.3 for details about Forge facets. *BundleFacet* and *OSGiFacet*, both restricts commands provided by *BundlePlugin* and *OSGiPlugin* in the context of OSGi bundle and project respectively. *OSGiFacet* is active when user enter on a directory containing an *OSGiBundle* and *OSGiFacet* is active when user in on a directory that contains at least one *OSGiBundle*. When *BundleFacet* is active then *OSGiFacet* is disabled meaning that only *BundlePlugin* commands will be active.

Another important component in Intrabundle architecture is the Project Locator, see section 2.3.4 for details about forge locators. Intrabundle provides 2 locators. The first is *BundleLocator* that creates a Forge project object named *OSGiModule* representing and gathering data related to OSGi bundle. *BundleLocator* is activated when user is at an OSGi bundle directory. The second is *OSGiProjectLocator* which creates a Forge project object named *OSGiProject* representing an OSGi project which is a collection of bundles. *OSGiProject* locator is activated when user is in a directory that has at least one child directory that is an *OSGiBundle*.

Image 3.1 illustrates Intrabundle architecture:

Figure 3.1: Intrabundle Architecture



3.4 Identifying OSGi Projects and Bundles

3.5 Collecting Bundle Data

3.6 Metrics Calculation

The data collected earlier will be materialized into six metrics that will be used to calculate OSGi projects quality

3.7 Intrabundle Quality

In this section we will see how Intrabundle's quality is managed and how some concepts of *section 2.1* were applied to the project. As the project is not OSGi based we can't apply Intrabundle's metrics on itself so we used classical approaches to assure the quality of the project.

3.7.1 Internal quality































Intrabundle internal is managed by PMD and JaCoCo. PMD is an static analysis tool and JaCoCo a dynamic analysis one. Both were presented at Chapter two in *section Quality Analysis Tools* with the objective to guarantee non functional requirements.

3.7.1.1 Example

PMD was already illustrated at Chapter 2 as an example of static analysis tool. JaCoCo is used to calculate code coverage to track files and methods that automated tests are covering. Figure 3.1 shows JaCoCo code coverage report for Intrabundle:

Figure 3.2: Intrabundle code coverage

intrabundle

Element	Missed Instructions	Cov.	Missed Branches	Cov.	Missed	Cxty	Missed	Lines	Missed	Methods	Missed	Classes
 br.ufersg.rmpestano.intrabundle.factory		100%		83%	1	6	0	6	0	3	0	1
 br.ufersg.rmpestano.intrabundle.event		100%		n/a	0	3	0	5	0	3	0	2
 br.ufersg.rmpestano.intrabundle.locator		97%		70%	3	11	2	34	0	6	0	2
 br.ufersg.rmpestano.intrabundle.jdt		95%		88%	2	11	1	18	1	7	0	2
 br.ufersg.rmpestano.intrabundle.plugin		89%		80%	27	114	20	251	4	54	0	4
 br.ufersg.rmpestano.intrabundle.facet		89%		73%	15	38	7	40	3	16	0	4
 br.ufersg.rmpestano.intrabundle.model		81%		61%	138	289	101	497	11	89	0	7
 br.ufersg.rmpestano.intrabundle.metric		78%		64%	15	40	21	100	0	13	0	2
 br.ufersg.rmpestano.intrabundle.util		76%		64%	67	140	52	197	4	34	0	7
 br.ufersg.rmpestano.intrabundle.i18n		67%		100%	0	6	3	12	0	5	0	1
Total	1,040 of 6,080	83%	293 of 852	66%	268	658	207	1,160	23	230	0	32

Created with JaCoCo 0.7.1

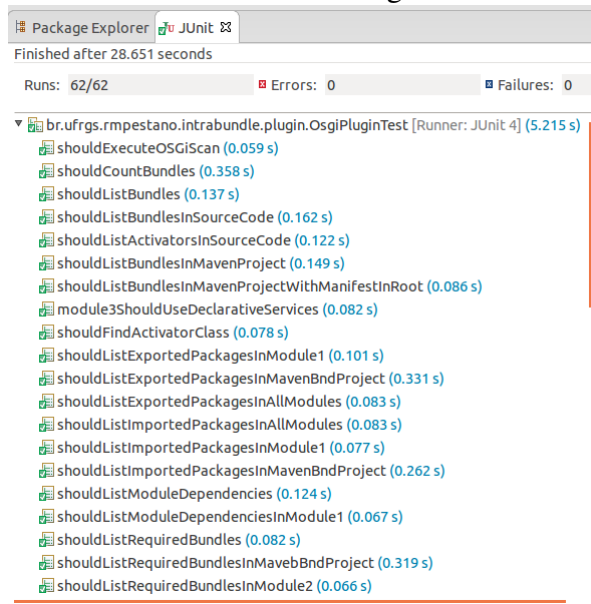
3.7.2 External quality

Intrabundle external quality is assured by automated whitebox tests so we can verify if Intrabundle is working as expected, if it meets its functional requirements.

3.7.2.1 Example

As of November 2014 Intrabundle performs 62 **integration tests** which can be defined as automated tests aimed to detect any inconsistencies between the software units that are integrated together. In this kind of automated tests the system must be running and in case of Intrabundle we also need the Forge runtime up and running during tests and that is done by Arquillian (dan, 2011), an integration test platform. Figure 3.2 shows the result of integration tests execution:

Figure 3.3: Intrabundle integration tests



4 BUNDLE INTROSPECTION RESULTS

This chapter will make a deep analysis of results and prove that my contribution is valid(or not)

5 CONCLUSION

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