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Executive Summary

This deliverable reports on the (open-source) software output of **Task 2.4**.

Task 2.4: API Analysis This task will produce analyses to identify API and API usage information. The goal is to learn from existing projects about typical usage to be able to concretely advise software engineers about the use of open-source software components. The resulting analyses should be amenable to bespoke extensions.

The output of this task mainly consists of two software artifacts, together with their corresponding integration as components of the CROSSMINER platform, Knowledge Base, and IDE:

- FOCUS, a context-aware collaborative-filtering recommendation system that exploits cross-relationships between software projects to suggest API method calls and API usage patterns that assist developers in learning and using APIs; FOCUS is meant to be integrated with the CROSSMINER IDE to provide developers with recommendations tailored to the particular context they are faced with.
FOCUS is available at `https://github.com/crossminer/focus`

- MARACAS, a source code and bytecode analysis framework that automatically analyses changes in the APIs of software projects to assist developers in the migration of their code when the APIs they rely on evolve; MARACAS is meant to be integrated in both the CROSSMINER platform and dashboards (as a set of metrics allowing to understand how OSS projects evolve) and the CROSSMINER IDE (to provide recommendations regarding API migration directly while working on a software project).
MARACAS is available at `https://github.com/crossminer/maracas`

In this deliverable, we focus on the user documentation, developer documentation, and integration of FOCUS and MARACAS. We refer the reader to the companion deliverable **D2.7 – Framework and API Analysis – Final Report** for a detailed analysis of the research questions we address, our scientific contributions, the evaluation of the tools, and the project requirements they fulfill.

Concretely speaking, FOCUS and MARACAS are two complementary parts of the new **API Miner Component** of the CROSSMINER platform described in **D8.1 – Architecture Specification of the Integrated Platform** (cf. Section 3.3.2 and Figure 24).

This deliverable is organized as follows:

- In Part I, we present FOCUS and its integration in the CROSSMINER IDE;

- In Part II, we present MARACAS and its integration in the CROSSMINER platform, dashboards, and IDE.

*All the components presented here, along with the scientific contributions introduced in **D2.7** were created from scratch specifically for CROSSMINER and were not part of the previous OSSMETER project and platform.*

Part I

FOCUS: a Recommender System for Mining API Function Calls and Usage Patterns

1 Introduction

FOCUS is a context-aware collaborative-filtering recommendation system that exploits cross-relationships between software projects to suggest API method calls and usage patterns [3]. In this section, we show how FOCUS can be manipulated as a standalone project, and how it is integrated with other components of the CROSSMINER platform.

FOCUS has already been assessed by a committee of software experts as part of the Artifact Evaluation process of the *41st International Conference on Software Engineering* and received seals of approvals regarding its availability and reusability.[1]

2 Using FOCUS in standalone mode

The FOCUS tool is publicly available on our shared GitHub organization at the URL `https://github.com/crossminer/focus`. The precise version of FOCUS that we used for the evaluation in [3], along with the corresponding datasets, are also available with a dedicated DOI on the public archive Zenodo [2].

FOCUS relies on two main sub-components: FOCUS itself, which implements the context-aware recommendation system, and FocusRascal which implements the static Java source code analyzers that provide the necessary information about method declarations and method invocations to FOCUS.

2.1 FocusRascal

FocusRascal is a Rascal project used to mine Java projects (in source code or binary JAR form) to extract method invocations and declarations information used by the FOCUS recommender system. FocusRascal extracts M^3 models from source code and JARs, which are then turned into FOCUS-compatible models.

Installation FocusRascal can be implemented following these steps:

[1] `https://2019.icse-conferences.org/track/icse-2019-Artifact-Evaluation`

1. Install an appropriate version of Eclipse RCP and RAP according to your platform/distribution from this URL:
   https://www.eclipse.org/downloads/packages/release/2018-12/r/eclipse-ide-rcp-and-rap-developers

2. In Eclipse, navigate to `Help -> Install New Software...` and install Rascal using the following URL:
   https://update.rascal-mpl.org/unstable/

3. Restart Eclipse to complete the installation.

4. Clone locally the ‘rascal-java-build-manager‘ project which is a required dependency of FocusRascal and import it into Eclipse: https://github.com/cwi-swat/rascal-java-build-manager

5. In Eclipse, import the two projects ‘FocusRascal‘ and ‘rascal-java-build-manager‘ in the workspace

Configuration FocusRascal must be configured with a path to the local installation of Apache Maven and paths to the projects or datasets from which method declarations and invocations should be extracted. These parameters can be configured in the file `FocusRascal/src/focus/corpus/Configuration.rsc`:

```
// Pointer to mvn executable, used to build the classpath of Maven projects
loc mavenLocation = |file:///usr/bin/mvn|;

// Where the GitHub repositories are stored and/or cloned
loc datasetLocation = |file:///FOCUS_ROOT/tools/FocusRascal/dataset/|;

// Where the M3 and FOCUS models are stored
loc javaM3sLocation = |project://FocusRascal/data/m3/java-projects|;

// Where the FOCUS models built from JARs are stored
loc jarsM3sLocation = |project://FocusRascal/data/m3/jar-projects|;

// Where information about the GitHub projects to analyze is stored
loc githubConfigFile = |project://FocusRascal/config/github-repos.properties|;
```

Quick Start All manipulations must be done in a running Eclipse workbench:

1. First, open the Rascal perspective: `Window -> Perspective -> Open Perspective -> Rascal`

2. Right-click on the FocusRascal project and select `Rascal Console`, this opens a new Rascal console in the lower part of the IDE

3. In the console, import the `ExtractMetadata` module:

   ```
   > import focus::corpus::ExtractMetadata;
   ```

From here, the two main functions to invoke from the console are:

- `processGithubRepos()`, which reads the GitHub repositories stored in `FocusRascal/config/github-repos.properties`, clone all repositories, build their M^3 models, and write the output FOCUS files in `FocusRascal/data/m3/java-projects/`. By default, the `github-repos.properties` file points to the 17 libraries depicted in Table 1 of [3]. *This process takes a long time to complete.* To use it, simply type in the console:

```
> processGithubRepos();
```

- `processJARs(loc directory)` which takes as input the path to a directory containing a list of JARs, and writes as output the FOCUS models of those JARs in `FocusRascal/data/m3/jar-projects/`. For instance, to parse, analyse, and compute the M^3 and FOCUS models of the 3,600 JARs extracted from Maven Central (dataset MV_L in [3]), type the following in the Rascal console (replacing `/path/to/FOCUS` with the path to your clone of the FOCUS repository):

```
> processJARs(|file:///path/to/FOCUS/dataset/jars|);
```

2.2 FOCUS

The core FOCUS component exploits the meta-data extracted by FocusRascal to implement the recommender system.

Requirements FOCUS requires the following dependencies:

- Apache Maven >= 3.0
- Java >= 1.8

Running the tool To start the evaluation of FOCUS using the default `evaluation.properties` file (see below) which analyses the datasets used in [3], run the following command:

```
mvn clean compile exec:java -Dexec.mainClass=org.focus.Runner
```

To use a different `.properties` file, use the `-Dexec.args` argument:

```
mvn clean compile exec:java -Dexec.mainClass=org.focus.Runner -Dexec.args=confs/shs12.
    properties
```

Results (success rate, precision, recall) for different cut-off values are displayed in the console directly as follows:

Intermediate results for every fold (recommended invocations, groundtruth invocations, usage patterns, etc.) are stored in the `evaluation` folder of the corresponding dataset (e.g., `../../dataset/SH_S/evaluation/`).

Note that the evaluation might take a considerable amount of time and resources. The table below gives reference time for 10-fold cross-validation on a Linux 4.20.3 with Intel Core i7-6700HQ CPU @ 2.60GHz and 16GB of RAM.

```
FOCUS: A Context-Aware Recommender System!
Running ten-fold cross validation on ../../dataset/MV_L/ with configuration C1_1
Fold [9/10]: SimilarityCalculator took 454s
Fold [8/10]: SimilarityCalculator took 455s
Fold [2/10]: SimilarityCalculator took 466s
Fold [7/10]: SimilarityCalculator took 467s
Fold [9/10]: ContextAwareRecommendation took 17s
Fold [8/10]: ContextAwareRecommendation took 17s
Fold [0/10]: SimilarityCalculator took 476s
Fold [1/10]: SimilarityCalculator took 476s
Fold [6/10]: SimilarityCalculator took 477s
Fold [4/10]: SimilarityCalculator took 477s
Fold [7/10]: ContextAwareRecommendation took 13s
Fold [2/10]: ContextAwareRecommendation took 15s
Fold [1/10]: ContextAwareRecommendation took 7s
Fold [0/10]: ContextAwareRecommendation took 9s
Fold [6/10]: ContextAwareRecommendation took 9s
Fold [4/10]: ContextAwareRecommendation took 11s
Fold [3/10]: SimilarityCalculator took 231s
Fold [5/10]: SimilarityCalculator took 234s
Fold [3/10]: ContextAwareRecommendation took 6s
Fold [5/10]: ContextAwareRecommendation took 9s
### 10-FOLDS RESULTS ###
successRate@1 = 73.30556
precision@1   = 0.73305553
recall@1      = 0.06737014
successRate@5 = 82.66667
precision@5   = 0.6486667
recall@5      = 0.2956125
successRate@10 = 86.69446
precision@10   = 0.5511667
recall@10      = 0.49201664
successRate@15 = 88.22222
precision@15   = 0.4440371
recall@15      = 0.57449764
successRate@20 = 89.13888
precision@20   = 0.3645417
recall@20      = 0.6169203
10-fold took 716s
```

Dataset	Configuration	Time (seconds)
SH_S	C1.1	4
SH_S	C1.2	4
SH_S	C2.1	4
SH_S	C2.2	5
SH_L	C1.1	314
SH_L	C1.2	312
SH_L	C2.1	298
SH_L	C2.2	345
MV_S	C1.1	135
MV_S	C1.2	124
MV_S	C2.1	139
MV_S	C2.2	135
MV_L	C1.1	716
MV_L	C1.2	732
MV_L	C2.1	741
MV_L	C2.2	768

The `evaluation.properties` file The evaluation of FOCUS is configured with a `.properties` file that specifies (i) the dataset (ii) the configuration and (iii) the validation technique to be used. For instance, the default `evaluation.properties` runs 10-fold cross-validation on SH_S using the C1.1 configuration:

```
# Dataset directory (SH_L, SH_S, MV_L, MV_S)
sourceDirectory=../../dataset/SH_S/

# Configuration (C1.1, C1.2, C2.1, C2.2)
configuration=C1.1

# Validation type (ten-fold, leave-one-out)
validation=ten-fold
```

This file can be edited to point to a different dataset in the `../../dataset/` directory, to select a different configuration, or to switch between 10-fold and leave-one-out cross-validation. The repository also include `.properties` files for every dataset/configuration pair, which can be selected using the method described above.

3 Integration with the CROSSMINER platform

As described in **D2.7 – Framework and API Analysis – Final Report** and in Section 2.1, FOCUS employs static source code analysis techniques to extract the list of *method declarations* and *method invocations* from OSS projects, which are then encoded in 3D rating matrices, which are then analyzed to infer a ranked list of method invocations that match the current context in which a developer is working.

In the context of CROSSMINER, FOCUS extracts information about method declarations and invocations from two sources: the source code currently being developed in the CROSSMINER IDE (locally) and the source code already analyzed by the CROSSMINER Knowledge Base (remotely). The CROSSMINER IDE communicates with the CROSSMINER Knowledge Base to gather actionable information about projects currently being developed, to allow taking the current context of the developer into account. As FOCUS is intended to recommend additional method calls and usage patterns when the developer is using a particular API, we decided to integrate FOCUS as part of the Knowledge Base.

Instead of duplicating the information about the integration in two documents, we refer the interested reader to deliverable **D6.5 – The CROSSMINER Knowledge Base – Final Version** for more information about this integration. In particular, Sections 10.5.10 and 10.6.11 describe the two REST endpoints exposed by the Knowledge Base that support the recommendation of API function calls and usage patterns, which are:

/api/recommendation/focus/ "Given a project source code as input this resource returns a recommended list of API function calls".

/api/recommendation/recommended_API_call "Given a project code as input this resource returns a list of patterns that matches with the current code".

More information about the information that must be supplied to these endpoints, with concrete examples, is given in **D6.5**. An important part of the input is the list of method declarations, the list of method invocations, and the current declarations in the code currently being developed by the user of the the CROSSMINER IDE. To enable the IDE to compute this information and supply it to the Knowledge Base, we implemented a small tool that makes the extraction of M^3 models from the code currently being developed in the CROSSMINER IDE possible. The IDE thus first builds the M^3 models of the project being developed locally, uses it to extract the list of method declarations and invocations, and invokes the corresponding Knowledge Base endpoints to get accurate recommendations for new function calls and usage patterns. Naturally, the Knowledge Base uses the FOCUS tool described in this document to build such recommendations internally.

Part II

MARACAS: a Framework for API Evolution Analysis and Client Code Migration

4 Introduction

MARACAS is a framework for API evolution and migration developed at Centrum Wiskunde & Informatica and written in the Rascal programming language. Its primary purpose is to support the co-evolution of APIs and client code: how to help developers migrating the client code that uses an API that has evolved? The current version of MARACAS is hosted and actively developed under the CROSSMINER organization umbrella on GitHub (`https://github.com/crossminer/maracas`).

In this document, we introduce MARACAS from a user perspective: how to set it up, how to interact with it and manipulate it, etc. Details of the approach implemented by MARACAS, the underlying models it builds, and the algorithms we use are available in the companion deliverable **D2.7 – Framework and API Analysis – Final Report**.

5 User Scenarios

MARACAS considers two types of users: (i) API developers and (ii) developers of client projects that use the APIs. In this section, we give a high-level overview of the questions MARACAS can answer, providing insights to both kinds of users.

5.1 Using MARACAS as an API Developer

In the case of API developers, MARACAS can be used to get insightful information about the evolution of an API itself by computing the number and detailed list of changes between two arbitrary versions of an API. *Version* should be understood here in a broad sense. MARACAS is flexible enough to compute changes between any two states of the source code or bytecode of an API: between two major or minor versions, between two commits, etc. Moreover, MARACAS distinguishes between breaking and non-breaking changes. We consider that gathering information about both breaking and non-breaking changes is valuable for the API developers, although only breaking changes have an impact on the clients of their API. It enables API developers to get a complete overview of the changes introduced between two versions of the API and, most importantly, to analyze how these changes might affect their users. Some of the questions API developers are faced with that can be answered by MARACAS are as follows:

- Which changes have been introduced between two versions of an API?
- How many and which of them are breaking changes?
- Which declarations have been deprecated in the latest release?
- What are the new features introduced in the latest release of an API?

- Which parts of an API have been the most/the least affected by breaking changes in the recent past?

MARACAS can also analyze client projects to infer which parts of an API are used in practice (using *usage models*) and how the breaking changes introduced in an API affect the clients using this API (using *detection models*), cf. **D2.7 – Framework and API Analysis – Final Report**. Both of these analyses provide valuable feedback to API developers to better understand how their APIs are used and how the changes they introduce affect their users.

5.2 Using MARACAS as a Client Project Developer

Software project developers care the most about how the evolution of the APIs they are using might affect their code. In this case, we consider a client project that uses an old version of a given API and wants to migrate to a newer version. MARACAS is then meant to support client project developers during this migration process. The main goal is to reduce the amount of effort that developers need to invest in the migration activity, which, by itself, does not add any value to the client project in terms of new functionality. These questions are especially relevant in the context of CROSSMINER and are at the core of several use cases (Softeam, FrontEndArt), cf. **D1.1 – Project Requirements**. Currently, the tool computes and stores the API changes between two versions in a Δ-model. These changes are then considered to detect the locations in the client project that have been affected. MARACAS considers both breaking changes and deprecated elements, which must be analysed and managed by the client project developers. To this aim, the tool computes a *Detection* model that pinpoints the physical locations in the client project that use a modified API access point (i.e., type, method, or field). Thus, client project developers do not need to manually search for API changes. They can actually consider MARACAS mappings to replace their code with the suggested one. These suggestions are computed directly from the source code with complete accuracy, or by means of using similarity functions that map old and new API elements with a confidence score. In general, client project developers can answer questions such as:

- Which parts of the client project have been affected by the API migration?
- What are the API suggested changes?
- What are the newly introduced features in a given version of the API?

Furthermore, we can use MARACAS to compute Δ-models and *Detection* models in a codebase of client projects using a given API. With this information we can crosscheck our current suggestions against actual mappings obtained from migrated client projects. These suggestions can be refined with the previous information by means of using other techniques related to mining code repositories and recommender systems (cf. deliverable **D6.5 – The CROSSMINER knowledge base - Final Version**).

6 Getting Started

In this section, we present a quick guide to get started with the MARACAS framework. We consider both using it within Eclipse (cf. Section 6.2) and as a pure Java pipeline executed through Apache Maven (cf. Section 6.3).

6.1 Dependencies

MARACAS is implemented in Rascal, a functional programming language particularly suited for source code analysis and transformation [1]. It depends on a number of frameworks and libraries:

Rascal (version 0.12.0-SNAPSHOT and up) to parse and analyse source code and bytecode. The framework can be found at `https://update.rascal-mpl.org/unstable/`

java-string-similarity (version 1.1.0) for computing text distance and similarity through different methods and functions (e.g., Levenshtein, Jaro-Winkler). The library can be found at `https://github.com/tdebatty/java-string-similarity`

java-build-manager (version 0.0.1) for extracting the classpath of Maven and OSGi-based Java projects during M3 models creation The library is hosted at `https://github.com/cwi-swat/rascal-java-build-manager`

6.2 Using MARACAS in Eclipse

Using MARACAS in Eclipse enables users to manipulate the tool through a Read-Eval-Print Loop (REPL) which offers the best flexibility. Here, we present the main requirements to use MARACAS in the Eclipse IDE, and the main steps to benefit from the MARACAS API.

6.2.1 Requirements

Setting up MARACAS to be used in Eclipse is straightforward and involves the following steps:

1. Download and extract Eclipse RCP/RAP from the following URL:
   `https://www.eclipse.org/downloads/`
2. Install the current unstable version of the Rascal meta-programming environment using the following update site URL:
   `https://update.rascal-mpl.org/unstable`
3. Clone the Rascal project `java-build-manager` from the following URL and and import it into the Eclipse workspace:
   `https://github.com/cwi-swat/rascal-java-build-manager`

6.2.2 Step-by-step Guide

Once the Eclipse environment is ready, follow the steps below to import MARACAS, compute Δ-models and detection models, and render them in user-friendly HTML reports:

1. Clone the MARACAS project from the following URL and import it into the Eclipse workspace:
   `https://github.com/crossminer/maracas`
2. Run the Rascal REPL by right-clicking the `maracas` project and selecting `Rascal Console`.

3. In the REPL (> denotes the REPL prompt), import the `org::maracas::Maracas` module:

```
> import org::maracas::Maracas;
```

4. Define the following **loc** variables which point, respectively, to the initial version of the API to be analyzed, its updated version, and a client project. Don't forget to change the absolute paths to the projects:

```
> loc apiv1 = |file:///Users/your/path/myjar-0.1.0.jar|;
> loc apiv2 = |file:///Users/your/path/myjar-0.2.0.jar|;
> loc client = |file:///Users/your/path/client-of-myjar-0.1.0.jar|;
```

5. Build the Δ-model between the two versions of the API using the MARACAS API. The resulting Δ-model can be subsequently filtered to restrict the list of changes to, respectively, classes and interfaces, methods, or fields, as shown below:

```
> Delta delta = delta(apiv1, apiv2);
> cdelta = classDelta(delta);
> mdelta = methodDelta(delta);
> fdelta = fieldDelta(delta);
```

6. To compute the list of detections (i.e., parts of the client code that are impacted by changes in the Δ-model), use the `detections` function as depicted below:

```
> cdetection = detections(client, cdelta);
> mdetection = detections(client, mdelta);
> fdetection = detections(client, fdelta);
```

7. Optionally, Δ-models can be visualized in user-friendly HTML reports:

```
> import org::maracas::delta::vis::Visualizer;
> writeHtml(|file:///Users/your/path/ClassDelta.html|, cdelta);
> writeHtml(|file:///Users/your/path/MethodDelta.html|, mdelta);
> writeHtml(|file:///Users/your/path/FieldDelta.html|, fdelta);
```

6.3 Using MARACAS from Java

To ease the integration of MARACAS with the remainder of the CROSSMINER platform, we have implemented a Java API that can be employed to access MARACAS features from regular Java code, without having to rely on Eclipse and the REPL environment of Rascal. This API is specified in the Java class `org.maracas.Maracas`. This class also defines an entry point `main()` which can be directly invoked from Maven to ease the analysis of a whole dataset of APIs and projects. The arguments expected by the pipeline are as follows:

```
Usage: maracas <lib1Jar> <lib2Jar> <clientsPath> <reportPath>
```

Where `lib1Jar` is the path to the JAR file of the initial version of the considered API, `lib2Jar` is the JAR of the updated version of the API, `clientsPath` is a directory containing a list of JARs that use the API `lib1Jar`, and `reportPath` is a directory where the results of the MARACAS analysis will be serialized.

The full pipeline involves creating a Δ-model, filtering it to only consider breaking changes, and computing the *Detection* model of all the supplied clients. The models, as well as the HTML-based reports, are serialized for future analysis and are stored within a pre-selected folder. The pipeline can conveniently be invoked directly from Maven. For instance, using the pipeline to analyze API evolution and migration of clients between Guava 18.0 and Guava 19.0 is realized as follows:

```
mvn package exec:java -Dexec.mainClass="org.maracas.Maracas" -Dexec.args="/path/to/guava
    -18.0.jar /path/to/guava-19.0.jar /path/to/guava-clients /path/to/guava-report"
```

7 Additional Features

Besides the creation of Δ-models, *Detection* models, and *Migration* models, MARACAS exposes a number of convenient features, such as: filtering a Δ-model to only consider breaking changes, non-breaking changes, changes at the type, method, or field levels; generating user-friendly HTML reports; customizing MARACAS code matchers; and extending MARACAS with new matchers and similarity functions. We give an overview of these features in this section.

7.1 Built-in Δ-model Filters

As shown in Section 6.2, a Δ-model can be filtered to only get type-, method-, or field-level changes. This filtering is performed by means of creating the corresponding Δ-model and then passing it as an argument to filtering functions such as `classDelta(Delta)`, `methodDelta(Delta)`, and `fieldDelta(Delta)`. Additionally, the Δ-model can also be filtered to only consider the *breaking* changes, i.e., changes that break clients of the API:

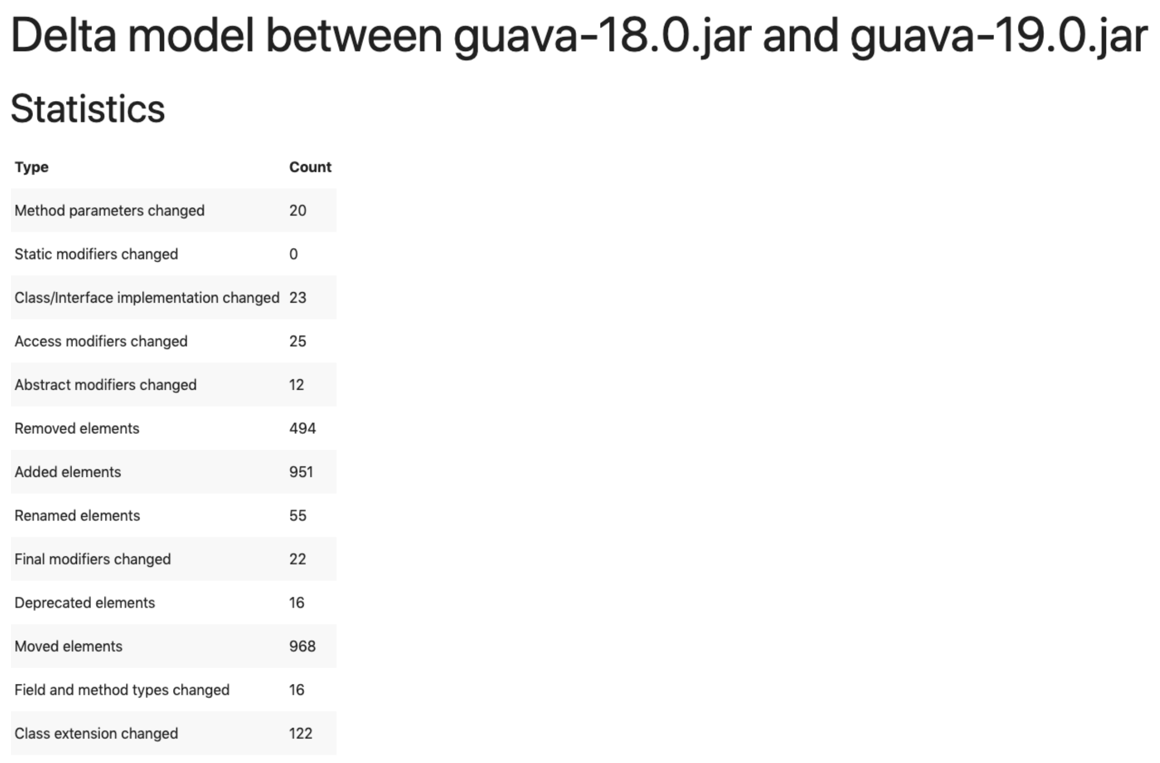
```
> Delta delta = delta(apiv1, apiv2);
> bc = breakingChanges(delta);
```

7.2 Generating Δ-model Reports

MARACAS is able to generate HTML reports that present Δ-model information in a user-friendly manner. As shown in the listing below, we invoke the `writeHTML(loc, Delta)` function from the `org::maracas::delta ::vis::Visualizer` module. The first parameter, of type `loc`, points to the physical location where the HTML report should be generated. The second parameter corresponds to the Δ-model itself.

```
> import org::maracas::delta::vis::Visualizer;
> writeHtml(|file:///Users/your/path/Delta.html|, cdelta);
```

The HTML report for an API such as Guava (versions 18.0 and 19.0) is showcased in Figures 1 and 2. Figure 1 presents some general statistics related to the content of the Δ-model, mainly the number of tuples per relation in the model. Then, the report describes the content of every single relation and attribute in the Δ-model. For instance, Figure 2 shows an excerpt of the HTML report related to the `abstractModifiers` relation. The table shows the location of the element that is impacted by a change in the Δ-model (column Old), and then the mapping that has been detected. In this case, the mapping is either from an `abstract` method to a non-`abstract` method, or the other way around. The report also displays the confidence score (*Score*) that indicates how confident a user should be in the accuracy of the mapping. This confidence score is of particular importance when checking the `renamed`, `moved`, and `deprecated` relations where similarity and distance functions are involved.

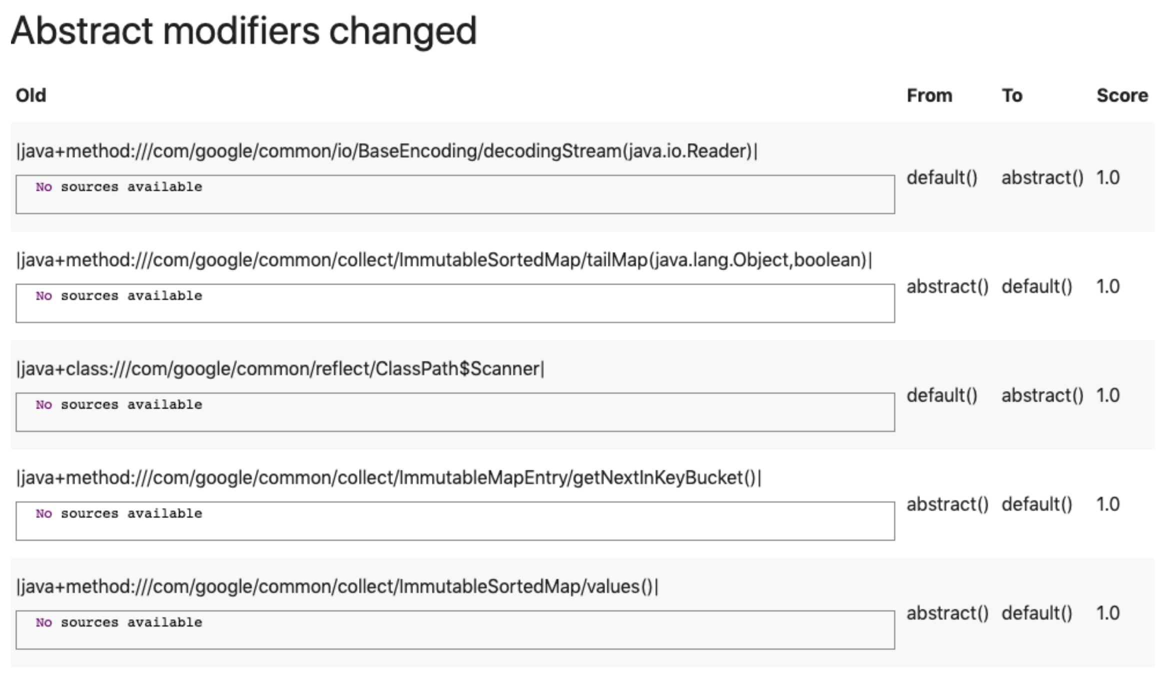


Delta model between guava-18.0.jar and guava-19.0.jar

Statistics

Type	Count
Method parameters changed	20
Static modifiers changed	0
Class/Interface implementation changed	23
Access modifiers changed	25
Abstract modifiers changed	12
Removed elements	494
Added elements	951
Renamed elements	55
Final modifiers changed	22
Deprecated elements	16
Moved elements	968
Field and method types changed	16
Class extension changed	122

Figure 1: General statistics about the Δ-model.



Abstract modifiers changed

Old	From	To	Score
|java+method:///com/google/common/io/BaseEncoding/decodingStream(java.io.Reader)| `No sources available`	default()	abstract()	1.0
|java+method:///com/google/common/collect/ImmutableSortedMap/tailMap(java.lang.Object,boolean)| `No sources available`	abstract()	default()	1.0
|java+class:///com/google/common/reflect/ClassPath$Scanner| `No sources available`	default()	abstract()	1.0
|java+method:///com/google/common/collect/ImmutableMapEntry/getNextInKeyBucket()| `No sources available`	abstract()	default()	1.0
|java+method:///com/google/common/collect/ImmutableSortedMap/values()| `No sources available`	abstract()	default()	1.0

Figure 2: Detailed description of changes in abstract modifiers reported in the Δ-model.

7.3 Tuning Matchers Configuration

MARACAS includes a configuration file that allows to tune the analysis process when matching old and new API elements. This is needed specially when mapping removed and added elements for the `renamed`, `moved`, and `deprecated` relations of the Δ-model. To specify your preferences, go to the `config.properties` file within the `config` folder in the MARACAS project. Identify the `matchers` key and assign the set of matchers that you would like to use to perform the API matching. Currently, MARACAS includes two built-in matchers: `levenshtein` and `jaccard`. However, customised matchers can be hooked to the tool (cf. Section 7.4). Besides, it is also possible to compute all possible matches between old and new API elements using both Levenshtein and Jaccard matchers by including the following line in the configuration file: `matchers = jaccard, levenshtein`. In this case, both matchers will be applied to all elements in the Δ-model, with their own confidence score. If no matcher is declared in the configuration file, the tool defaults to Jaccard.

7.4 Hooking New Matchers

MARACAS allows developers to hook new similarity functions and their corresponding data representations. All the modules to add or modify are contained in the `org::maracas::match` package. Hereafter, we present the main steps to follow in order to add a new method to map declarations between two versions of the same API.

1. Reuse or add (if needed) a data representation. The first thing to check is if the data representation that you need for your similarity or distance function is already defined within MARACAS. Data representations are declared in the `org::maracas::match::data::Data` module. Listing 1 depicts the `Data` datatype that represents the data structure used by a set of similarity and distance functions. In this case, we consider two representations: sets (`set`) and strings (`str`). Both of them include a `threshold` that might be used by similarity and distance functions, which defaults to `0.0`; and two `map` structures, namely `from` and `to`. Each of these maps includes a `loc elem` that references an API element, and a `repr` that represents the given element (either as a `set[loc]` or as a `str` in our two scenarios). The `from` map gathers all the removed declarations from the API with their corresponding representation, and the `to` map gathers all the added declarations to the new version of the API.

```
data Data
  = \set (
      real threshold = 0.0,
      map[loc elem, set[loc] repr] from = {},
      map[loc elem, set[loc] repr] to = {} )
  | string (
      real threshold = 0.0,
      map[loc elem, str repr] from = {},
      map[loc elem, str repr] to = {} )
  ;
```

Listing 1: The `Data` datatype.

Implementation a new representation, say a vector-based representation, would be possible by defining a new constructor in the `Data` datatype similar to the one depicted in Listing 2.

```
vector (
  real threshold = 0.0,
  map[loc elem, list[loc] repr] from = {},
  map[loc elem, list[loc] repr] to = {} )
```

Listing 2: An hypothetical `vector` constructor for the `Data` datatype.

2. Reuse or add (if needed) a similarity or distance function. Once your needed data representation is defined and customised for your needs, you can reuse or add a new similarity or distance function. Built-in functions are declared in the `org::maracas::match::fun` package. This package already contains the `SetSimilarity` and `StringSimilarity` modules. The former considers the `jaccardSimilarity (set[value], set[value])` function which, given two sets, computes a Jaccard score of type `real` (cf. Listing 3). The latter contains the `levenshteinSimilarity(str, str)` function which, given two strings, computes the normalized Levenshtein similarity score, also of type `real`. If you want to add a new similarity or distance function, make sure you create a new function (within one of the modules of the target package) that returns a value of type `real` and compares only **two** elements of your chosen type. This type should be the same you use for the `repr` attribute in the constructor of the `Data` data type. This type could be more generic as it is the case of the `jaccardSimilarity` function, which declares two parameters of type `set[value]`.

```
real jaccardSimilarity(set[value] x, set[value] y)
  = (size(x) > 0 && size(y) > 0) ? jaccard(x, y) : -1.0;
```

Listing 3: `jaccardSimilarity` function.

3. Create your own matcher. At this point, you have both the data representation you need as well as the similarity or distance function that operates with your data. Then, you can create your own matcher. Matchers are located in the `org::maracas::match::matcher` package and all of them rely on the `org::maracas::match::matcher::Matcher` module. We need two elements from this module, namely the `Matcher` data type depicted in Listing 4 and the `match(M3Diff, Data, real (&T, &T))` function. Every matcher should provide an implementation of the `match` function within the `Matcher` data type. In most cases, this implementation relies on the `match(M3Diff, Data, real (&T, &T))` function of the `Matcher` module.

```
data Matcher = matcher(
      set[Mapping[loc]] (M3Diff diff, real threshold) match);
```

Listing 4: `Matcher` data type.

```
set[Mapping[loc]] jaccardMatch(M3Diff diff, real threshold)
  = match(diff, createData(diff, threshold), jaccardSimilarity);
```

Listing 5: Jaccard matcher.

To illustrate the aforementioned statements, let us consider the implementation of the `match` function within the `org::maracas::match::matcher::JaccardMatcher`. Listing 5 shows this implementation. The `jaccardMatch` function declares the two expected parameters, namely a `M3Diff` computed in the `Delta` module, and a `real` that represents a threshold that might be used by the similarity or distance function. This declaration matches the expected function of the `Matcher` data type. The body of the declaration is an invocation of the `match(M3Diff, Data, real (&T, &T))` function provided by the `Matcher` module. In this case, we create our `Data` value with the `createData(M3Diff, real)` function, and we pass the `jaccardSimilarity(set[value], set[value])` as second argument. The `match` function computes the similarity of all the removed and added declarations contained in the `Data` value under the hood. In the end, we get a set of mappings pointing from an old API element to a new one. All these mappings are meant to have a higher score than the one defined with the threshold. This depends on the implementation of the chosen similarity or distance function.

4. Include your matcher as a new mapping option. Finally, to hook your matcher, add a new case to the switch statement within the `applyMatchers(M3Diff, map[str,str], str)` function in the `org::maracas::delta::DeltaBuilder` module. That is, select a string label for the matcher and hook the `match` function implementation to the matcher (cf. Listing 6). The selected label can then be used within the MARACAS configuration file (cf. Section 7.3).

```
Matcher currentMatcher;
switch (matcherLabel) {
  case "levenshtein" : currentMatcher = matcher(levenshteinMatch);
  case "jaccard" : currentMatcher = matcher(jaccardMatch);
  default : currentMatcher = matcher(jaccardMatch);
}
```

Listing 6: `applyMatchers` switch statement in the `DeltaBuilder` module.

8 Integration with the CROSSMINER platform

8.1 Platform and Dashboard Integration

MARACAS is incorporated as a component of the CROSSMINER platform under the name `org.eclipse.scava.maracas`, publicly available on our central repository `https://github.com/crossminer/scava`. This plug-in enables any metric provider of the platform to invoke the creation of *delta models*, *usage models*, and *detection models* which can then be analyzed to compute metrics of interest. More specifically, the plug-in exposes the MARACAS API described in Section 6.2 to metric providers of the platform. The CROSSMINER platform works by analyzing projects *every day*. Our integration of MARACAS complies with this requirement by allowing to analyze the changes introduced in a project and its API on a daily basis. Specifically, one of the main access points of the API is the function `computeDelta` which can be invoked to compute the daily *delta model* from the M^3 model of current date and the M^3 model of the previous date, as depicted in Listing 7. All arguments passed to this function are automatically provided by the platform infrastructure at run time: a metric's developer does not have to worry about them.

```
tuple[M3 old, M3 new, Delta delta] computeDelta(ProjectDelta projectDelta,
    rel[Language, loc, M3] m3s,
    map[loc, loc] scratchFolders) {
  M3 previousM3 = loadPreviousM3(scratchFolders, projectDelta.date);
  M3 newM3 = systemM3(m3s, delta = projectDelta);
  Delta d = deltaFromM3(previousM3, newM3);
  serializeNewM3(scratchFolders, newM3, projectDelta.date);

  return <previousM3, newM3, d>;
}
```

Listing 7: The `computeDelta` function computes the daily *delta model*

We used the features exposed through the MARACAS API to implement various metrics related to API analysis in the CROSSMINER platform. These metrics are implemented in a dedicated plug-in `org.eclipse.scava.metricprovider.trans.rascal.api`. Listing 8 depicts the implementation of three metrics that have been implemented atop the MARACAS infrastructure introduced above.

```
@metric{numberOfChanges}
@friendlyName{Number of changes}
@appliesTo{java()}
@resetOnEmptyDelta{}
@historic{}
int numberOfChanges(ProjectDelta projectDelta = ProjectDelta::\empty(),
    rel[Language, loc, M3] m3s = {},
    map[loc, loc] scratchFolders = ()) {
  tuple[M3 old, M3 new, Delta delta] t = computeDelta(projectDelta, m3s, scratchFolders);


  return countChanges(t.delta);
}

@metric{numberOfBreakingChanges}
@friendlyName{Number of breaking changes}
@appliesTo{java()}
@resetOnEmptyDelta{}
@historic{}
int numberOfBreakingChanges(ProjectDelta projectDelta = ProjectDelta::\empty(),
    rel[Language, loc, M3] m3s = {},
    map[loc, loc] scratchFolders = ()) {
  tuple[M3 old, M3 new, Delta delta] t = computeDelta(projectDelta, m3s, scratchFolders);


  return countChanges(breakingChanges(t.delta, t.old, t.new));
}

@metric{changedMethods}
@friendlyName{Changed methods}
@appliesTo{java()}
@resetOnEmptyDelta{}
@historic{}
set[loc] changedMethods(ProjectDelta projectDelta = ProjectDelta::\empty(),
    rel[Language, loc, M3] m3s = {},
    map[loc, loc] scratchFolders = ()) {
  tuple[M3 old, M3 new, Delta delta] t = computeDelta(projectDelta, m3s, scratchFolders);

  Delta methodDelta = getMethodDelta(t.delta);

  return
    domain(methodDelta.accessModifiers) +
    domain(methodDelta.finalModifiers) +
    domain(methodDelta.staticModifiers) +
    domain(methodDelta.abstractModifiers) +
    domain(methodDelta.paramLists) +
    domain(methodDelta.types) +
    domain(methodDelta.extends) +
    domain(methodDelta.implements) +
    domain(methodDelta.deprecated) +
    domain(methodDelta.renamed) +
    domain(methodDelta.moved) +
    domain(methodDelta.removed) +
    domain(methodDelta.added);
}
```

Listing 8: Examples of API-related metrics in CROSSMINER

All metrics follow a similar pattern: they first retrieve the current *delta model* from the platform and then analyze it to compute metric-specific information. The first metric, `numberOfChanges`, simply count the number of changes present in the *delta model*. The second metric, `numberOfBreakingChanges`, first filter the *delta model* to exclude non-breaking changes, and then counts the number of breaking changes. Finaly, the third metric, `changedMethods`, goes beyond simple quantitative analysis. It first filters the *delta model* to only retrieve changes related to Java methods using the `getMethoDelta` function. Then, it aggregates the names and locations of all methods that are impacted by any change in the *delta model*. This allows developers and users to analyse which parts of the API are the most impacted by changes over time.

All metrics are marked as historical by using the `@historic()` annotation, which instructs the platform to automatically keep an historical record of the successive values of the metric over time. These historical metric providers are then read by the CROSSMINER dashboard to display trends related to API changes in the CROSSMINER dashboard to assist developers and users of APIs in understanding how different APIs evolve.

The first couple metrics we have defined are considered helpful by our use case partners. In the remainder of the project, we will keep collaborating with them to tune existing metrics and define new ones that specifically address their requirements.

8.2 IDE Integration

Next to its use in the CROSSMINER dashboards, MARACAS is intended to be used directly within the CROSSMINER IDE to support developers as they are facing API evolution and migration scenarios.

In a similar fashion as for FOCUS (cf. Section 3), MARACAS is integrated as part of the CROSSMINER Knowledge Base, enabling the CROSSMINER IDE to query recommendations about API evolution and migration through a REST API. Thus, we refer the reader to **D6.5 – The CROSSMINER Knowledge Base – Final Version** for a complete presentation of how the Knowlege Base uses MARACAS to answer these queries.

The main endpoints that can be accessed are as follows:

/api/api-migration/documentation/ "This resource provides a list of StackOverflow posts related to API migration".

/api/api-migration/detection/ "This resource provides a list of client locations that are impacted by the evolution on the specific library".

/api/api-migration/recommend/ "This resource provides a list of code snippet that other clients use to support the breaking changes introduced by the adoption of a new version of a library".

References

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[2] Phuong T. Nguyen, Juri Di Rocco, Davide Di Ruscio, Lina Ochoa, Thomas Degueule, and Massimiliano Di Penta. crossminer/focus: Icse19-artifact-evaluation, January 2019.

[3] Phuong T. Nguyen, Juri Di Rocco, Davide Di Ruscio, Lina Ochoa, Thomas Degueule, and Massimiliano Di Penta. FOCUS: a recommender system for mining API function calls and usage patterns. In *Proceedings of the 41st International Conference on Software Engineering, ICSE 2019, Montreal, QC, Canada, May 25-31, 2019*, pages 1050–1060, 2019.