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Dependency Graph Creator Engine

Software Maintenance and Evolution

https://github.com/richardswesterhof/pyne

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Chapter 1

Introduction

Software maintenance has always been of great concern to software engineers. An application is almost never perfect on deployment and needs regular bug-fixes and enhancements to the system. To help with the software maintenance of an application, several different techniques have been developed.

One of these techniques is a dependency graph. A dependency graph is a directed graph that represents dependencies between objects of some application domain, where the nodes represent packages or classes of a software system and the edges the relation between them.

In this document we will compare an incomplete existing dependency graph creator called Pyne[1] with another widely used dependency graph creator engine called

The document is structured as follows: Chapter 2 will show how Pyne should be installed and used. Chapter 3 will discuss the design of Pyne itself. In Chapter 4 we will apply Pyne and Structure101 to a large java application called Apache Tajo[2]. In Chapter 5 we will discuss our dependency checker to evaluate the output of pyne. In chapter 6 we will discuss the problems of pyne and how we tried to fix them and finally in Chapter 7 and 8 we will discuss and conclude the project.

Chapter 2

User Guide

2.1 Running pyne

Installing
To install Pyne, Java JDK 11+ and Maven is required. The installation itself is rather straightforward: Clone or download our fork of the Pyne repository:

```
git clone https://github.com/richardswesterhof/pyne.git
```

Install Pyne's dependencies and build an executable jar by running the following command inside Pyne's root directory:

```
mvn install
```

Executing
After the application has been built, one can use this application via CLI. This can be done by running the following command from the root directory:

```
java -jar <path-to-jar>/pyne-cli-1.0-SNAPSHOT-jar-with-dependencies.jar
  ↪ <github-url>
```

Where the `<path-to-jar>` is the path to the built jar file (by default this is in `<pyne_root>/pyne-cli/target/`) and `<github-url>` is the url of the project you want to create a dependency graph for. For example, this would be the command to create a yearly dependency graph for the commits of Apache Tajo from 2015 to November 2020:

```
java -jar pyne-cli/target/pyne-cli-1.0-SNAPSHOT-jar-with-dependencies.jar
  ↪ https://github.com/apache/tajo -s "2015-01-01" -e "2020-11-21" -p
  ↪ "YEAR"
```

2.2 Running Structure101

To generate the output from Structure101, follow the steps below:

1. Make sure Structure101 is installed.
2. Create a new project, select "Maven" as the option for discovering bytecode, select the pom file of the project you want to analyse, and make sure to check the "Parse Tests" and "Parse Profiles" boxes to include as many sources as possible.
3. Now you should already be able to select the way you want everything to be organized, i.e. whether you want packages, leaf packages or classes. If you only want to analyse one of the two, you can select this now (note that for analysing on a package level, make sure to select "Leaf packages" instead of just "package"). However, if you want to analyse both, it is easier to select "Packages" here.
4. Select the "Detail" granularity, and check "Included injected dependencies" to again cover as many dependencies as possible.
5. Select "Show externals" so that external packages are shown as well as internal packages, and check "Parse archives contained in classpath archives".
6. Leave the list of exclusions empty, and select the project you want to analyse's folder as the sources.

Now the project is set up, and the results can be exported to CSV. If there are any issues during the setup of the project, there is a Structure101 project for Tajo available on our github repository[1].

7. To generate the expected matrix from Structure101, right-click anywhere outside the packages in the main graph view, hover over the "Flatten" option, and select "To leaf packages" (for comparing on package level) or "To classes" (for comparing on class level) from the sub-menu (skip this step if you already did this during the project setup).
8. Go to the "View" tab and select the composition view. You should now see the matrix that shows the amount of dependencies between each class/package.
9. A CSV file must be exported by clicking the export icon in the top right toolbar in the matrix panel. Make sure that you select "file" for the "Export to" option, then select "Matrix as CSV" in the "Export as" dropdown. Finally, select a file location to save the file to in the "Target file" field, and click "Ok" to export.
10. (optional) If you want to do an analysis on both class and package level, go back to the main view and use control+z to undo the flattening, then return to step 7.

Now you have the output file necessary from Structure101. This is the file you should use when using the dependency checker.

[1] `https://github.com/richardswesterhof/pyne/blob/master/structure101/tajo_structure101.java.hsp`

2.3 Running the dependency checker

To use the dependency checker, Java JDK 11+ and Maven is required. The installation itself is rather straightforward: Clone or download our fork of the Pyne repository. The dependency checker will be in there too.

```
git clone https://github.com/richardswesterhof/pyne.git
```

Install the dependency checker's dependencies and build an executable jar by running the following command inside the `dependency_checker/` folder:

```
mvn install
```

This will place a ready-to-execute jar file in the `target/` subfolder. Alternatively, a pre-built jar file is already located in the `dependency_checker/` folder.

Executing

After the application has been built, one can use this application via CLI. This can be done by running the following command from the directory where the jar file is located:

```
java -jar dependency_checker.jar -s [PATH/TO/STRUCTURE101_FILE.csv] -p
    ↪ [PATH/TO/PYNE_FILE.graphml] -d [CLASS|PACKAGE] [OPTIONS]
```

With `-d` you can specify whether you want to compare the dependencies between packages or classes, with `-p` you must specify the path to the .graphml output-file of pyne and with `-s` you must specify the path to the Structure101 .csv file. This file must either contain the relation of the classes or the packages depending on the specified option for `-d`. If the .csv file contains class relations, while `-d` is set to package, the dependency checker will not work. The other available options include:
The `-hr` option will create a human readable version of the output (with tabs and newlines, and more explicit definitions, so cross referencing IDs is not necessary). This is good for manually investigating the results.
The `-i` option will only indent the file (and place newlines), the `-hr` options implies this as well.
The `-c` option will generate a compact output, which aims to reduce duplicate data as much as possible. This is good for programmatically investigating the results.
Note that the options `-hr` and `-c` cannot be used together.

Given below is an example of how one could run the dependency checker:

```
java -jar dependency_checker.jar -s
    ↪ ../graph-files/tajo_dependencies_by_structure101.csv -p
    ↪ ../graph-files/tajo_dependencies_by_pyne.graphml -hr -d PACKAGE
```

Chapter 3

Design

Here we will go into more detail about the design of Pyne itself. The project has been analysed using the existing documentation [1], the source code and the structural and dependency graphs created by Structure101 (figure 3.2).

3.1 Requirements

According to the documentation [1] of the Pyne project, the project has the following requirements:

1. **The program should be able to create a graph from Java source files using git.**
2. The output graph should be the same as that of Arcan[1], a Java software analysis tool.
3. The program should parse Java source files in such a way so it can find the different Java classes and packages.
4. The program needs to be able to use Git.
5. The program should provide a command line interface.

When inspecting the functionality of the program, one can see that all these requirements have been met. When inspecting the source code of the program and the documentation, one can even see how they implemented the requirements.

From the documentation it was made clear that most of the requirements were met using external dependencies. For example: Requirement 2 was met using Apache Tinkerpop[2] for graph creation, which is the same technology Arcan uses.
Requirement 3 was met using Spoon[3], an extensive java source code parsing library. Lastly,

[1] `https://essere.disco.unimib.it/wiki/arcan/`
[2] `https://tinkerpop.apache.org/`
[3] `http://spoon.gforge.inria.fr/`

Requirement 4 was met using Jgit[4], a java git library.

In addition to that, using Structure101, we found that Requirement 5 is met using Apache Commons Cli[5] to provide a cli interface. Furthermore, Syncleus Ferma[6] was used as an extension to Tinkerpop. More information on this can be found in section 3.3.

3.2 Implementation

This application is divided into 3 different packages: pyne-demo, pyne-cli and pyne-api. The relations between these packages and their classes can be seen in figure 3.2. figure 3.1 represents the XS ("excess") diagram[3] of pyne. the XS diagram reflects the size of a method, package, class or other code item. It'll ensure that overly complex high level packages will have higher XS than a single method. This will reflect the likely negative impact on development. AS you can see from the diagram, there are two components used to measure the code items: fat and tangled. Fat measures the amount of basic complexity and tangled measures cyclic dependency. Tangled is mostly applied to higher level components like design and package.

Looking at figure 3.1, we can see that the fat of the methods in pyne is relatively small. This means that the methods in pyne are overall of a good size. However looking at the fat of the class and packages, we see that they are on the big side. To improve this, existing classes and packages could be split up into multiple classes/packages. looking at the design, we see that it is not really fat, but extremely tangled. This means that there are a lot of cyclic dependencies. Most of the time cyclic dependencies can have a negative impact on future development and maintenance of the application, so you would want to avoid them as much as possible.

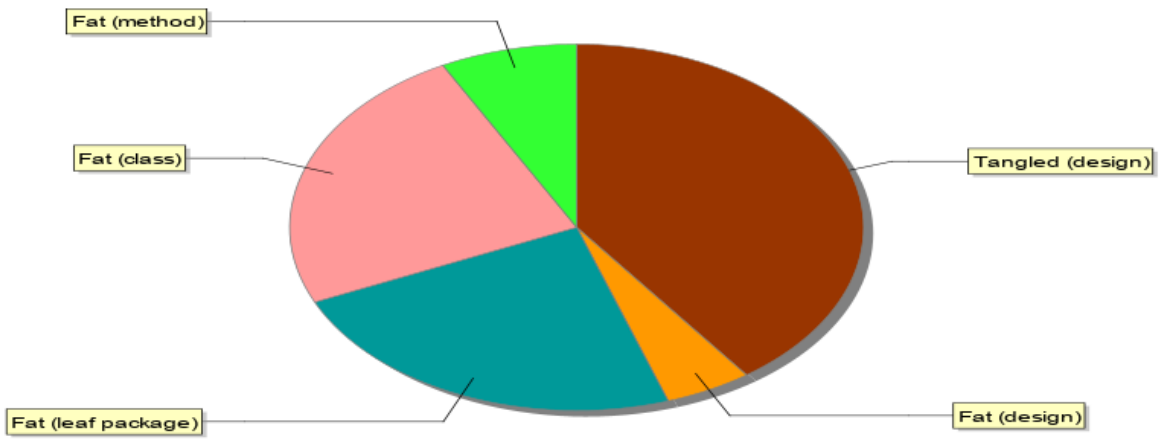

Figure 3.1: The XS diagram of the structure of Pyne, created by Structure101

[4] https://www.eclipse.org/jgit/
[5] https://commons.apache.org/proper/commons-cli/
[6] https://github.com/Syncleus/Ferma

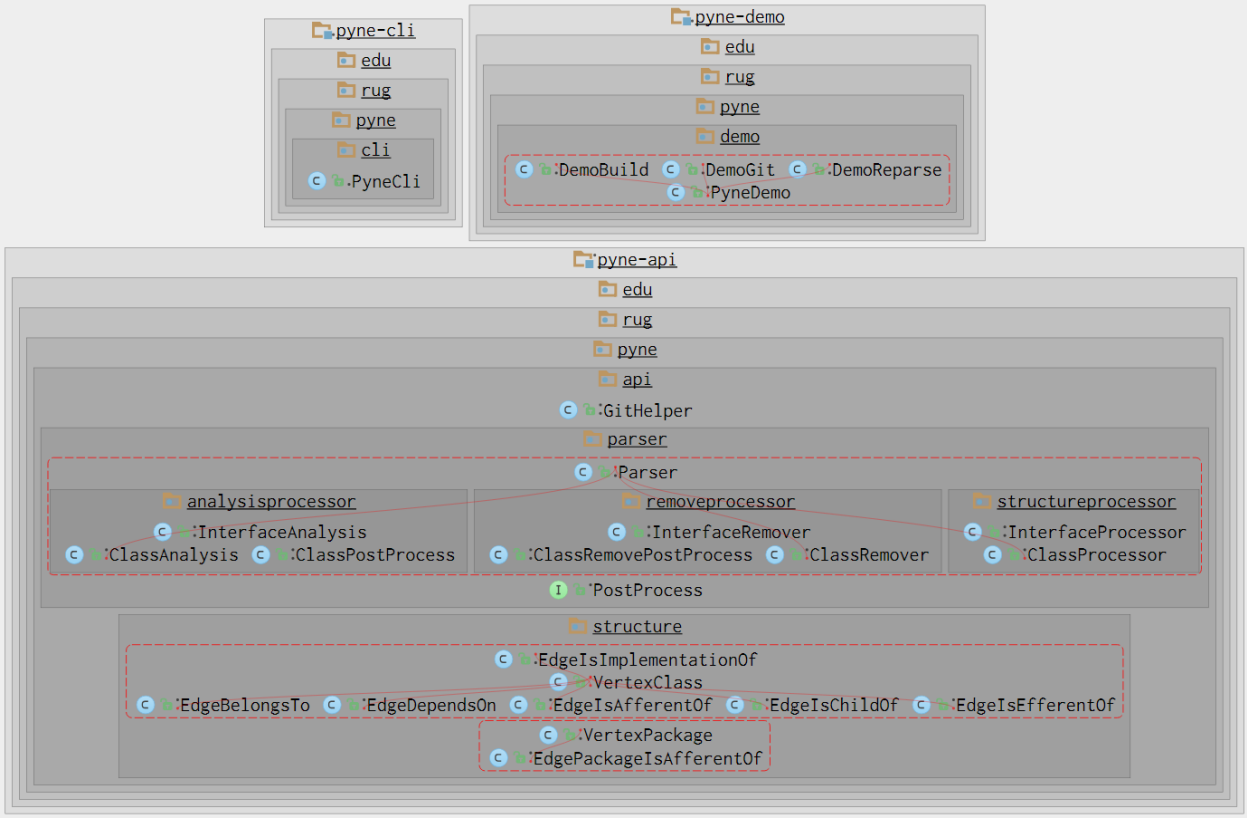

Figure 3.2: The full graph of the relations between the classes of Pyne, created by Structure101

Now that we have looked at the overal fat and tangles of pyne, we will briefly explain the 3 main packages within pyne. The pyne-api package will be explained in more detail, since this is the main component of the system.

3.2.1 Pyne-demo

This package acts as a testing ground for pyne. Most of the data in this package has been hard-coded to work only with a specific repository that was probably present on the creators local machine. Since we do not know which repository they used for testing and it is not present within the project, This package will not be able to work and we will consider this package deprecated.

3.2.2 Pyne-cli

This package acts as a layer of communication between the user and the Pyne-api via a CLI (Command Line Interface). Given a git repository as a program argument, it will automatically start communicating with the pyne-api and create a dependency graph in `.graphml` format for each commit. A number of options can be given to the pyne-cli program. The first required argument is of course the repository itself, but one can also specify the

starting and end date to parse from, the interval between each commit and an input and output directory.

3.2.3 Pyne-api

This package is the heart of the program and is the one that is actually responsible for the dependency graph creation. This package is again subdivided into 2 packages: parser and structure, and contains one class: GitHelper, as can be seen in figure 3.3.

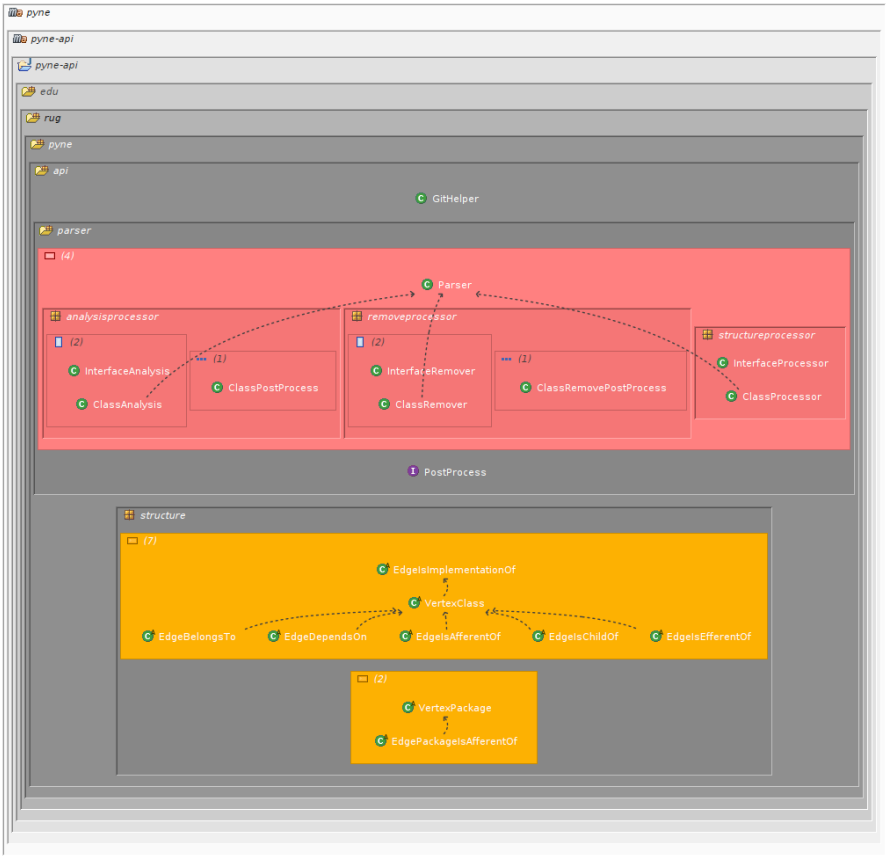

Figure 3.3: The graph of the relations between the classes of the pyne-api package created by Structure101

The GitHelper is a part of the API responsible for git related functionality like cloning a repository in a temporary location, parsing a commit or processing a commit. Most of the functionality of the GitHelper depends on the parser class to create the dependency graph.

The structure package does not contain any functionality, instead it provides abstract classes to build a dependency graph from. Special edges have been created for different kinds of relations: BelongsTo, DependsOn, AfferentOf, ChildOf, EfferentOf, ImplementationOf and

PackageisAfferentOF. Special vertexes have also been created to represent either a package or a class.

The parser package again consist of three sub-packages: analysisProcessor, removeProcessor, and structureProcessor. It also contains the Parser class and the PostProcess interface.

All communication with this package goes through the Parser class. This class is used to keep track of the files that have changed in the selected commit, and it holds lists of all types of processor classes, each of which are responsible for analysing the code in a different way.

The parser class will then in turn communicate with the analysis processor package, remove processor package and structure processor package to create a dependency graph. These packages provide the following functionality: The remove processor package will take care of removing nodes or edges from the graph if classes or relations have been removed or changed. The structure processor package takes care of adding nodes to the dependency graph and the analysis processor package analyses the different classes and packages and their relations to each other.

3.3 External dependencies

The main external dependencies used by the project are:

- **Apache Tinkerpop**
  A flexible graphic framework. This library was chosen since Arcan, the software this project is suppose to mimic, also uses this framework.
- **Spoon**
  A java source code parsing library. This library was chosen so that a java parser did not need to be build from scratch[1].
- **Jgit**
  A java library that provides git functionality. This library was chosen so that the program is able to collect the source files using git.
- **Apache Commons CLI**
  A java library that provides CLI parsing and some basic CLI functionality. This library was used to not have to write a CLI parser from scratch.
- **log4j**
  A logging library. Used to log actions in the program.
- **Ferma**
  An extension to Apache Tinkerpop. Used to help building the graph.

Most of these dependencies were noted in the report [1], like Apacke Tinkerpop, Spoon and Jgit. Others, like Apache Commons Cli, log4j and Ferma, were found using Structure101.

In figure 3.5 and figure 3.4 you will find the graphs depicting the relation between the packages of Pyne and the dependencies. Note that the used external dependencies have not been shown for pyne-demo. This is because pyne-demo does not provide any graph creation functionality, only a "demo" and it uses approximately 20 extra external dependencies that are not used in the rest of the project. It would therefore be unreadable and not really relevant to the workings of Pyne itself.

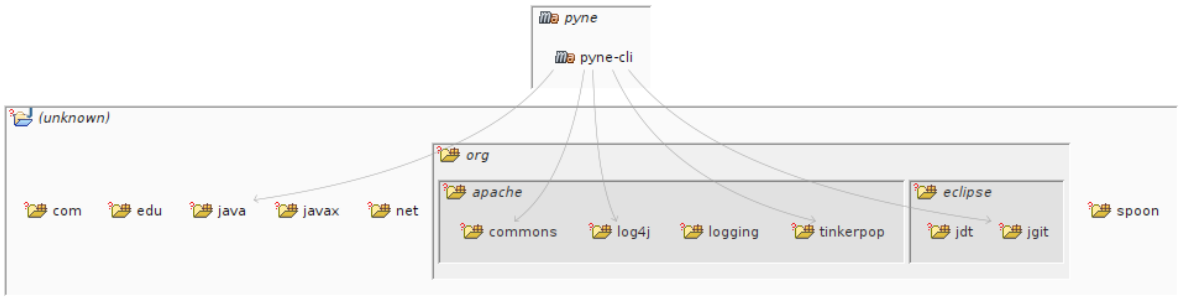

Figure 3.4: The graph of the external dependencies of pyne-cli, created by Structure101

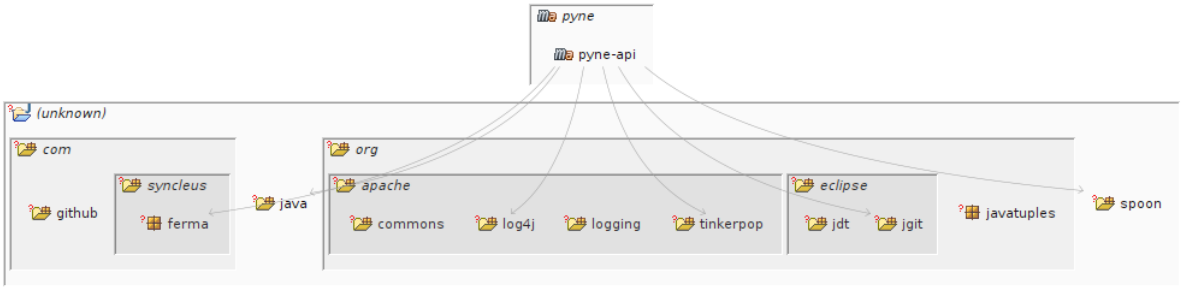

Figure 3.5: The graph of the external dependencies of pyne-api, created by Structure101

Chapter 4

Pyne vs Structure101

To compare Pyne to Structure101, we will test them both on a large existing system. For this we have selected Apache Tajo (`www.tajo.apache.org`). The first section will describe the resulting graph for Tajo using Structure101. The following section will go into more detail about the design of Tajo using the graph generated by Structure101, then lastly we will run Pyne on Tajo and analyse the difference between Pyne and Structure101. Note that in the commands we show, we renamed the generated pyne-cli jar to simply `pyne-cli.jar` for brevity.

4.1 Running Structure101 on Tajo

Next we will run Structure101 on Apache Tajo. Since Structure101 uses a GUI instead of a CLI, we followed the steps in the GUI to create a Structure101 project. For ease of use, we have provided this Structure101 project in our GitHub repository under `structure101/tajo_structure101.java.hsp`. As mentioned before, the downside of Structure101 is the need to compile the target system before it will allow you to import it. This was difficult since we had first switched to java 11 to compile and run Pyne, but Tajo requires java 8. This was however not indicated clearly, so it took some time to figure out.

However, by being able to use a maven pom file, Structure101 does have the advantage of being able to find dependencies to external packages instead of only internal packages, like Pyne does.

Structure101 has more options for exporting as well, allowing users to export to `.png`, `.jpeg`, and "Graph as XML", which sounds a lot like `.graphml`, but they are not the same, and in fact the program we used to open the `.graphml` files did not display this file correctly.

Figure 4.1 shows what an exported image from Structure101 looks like.

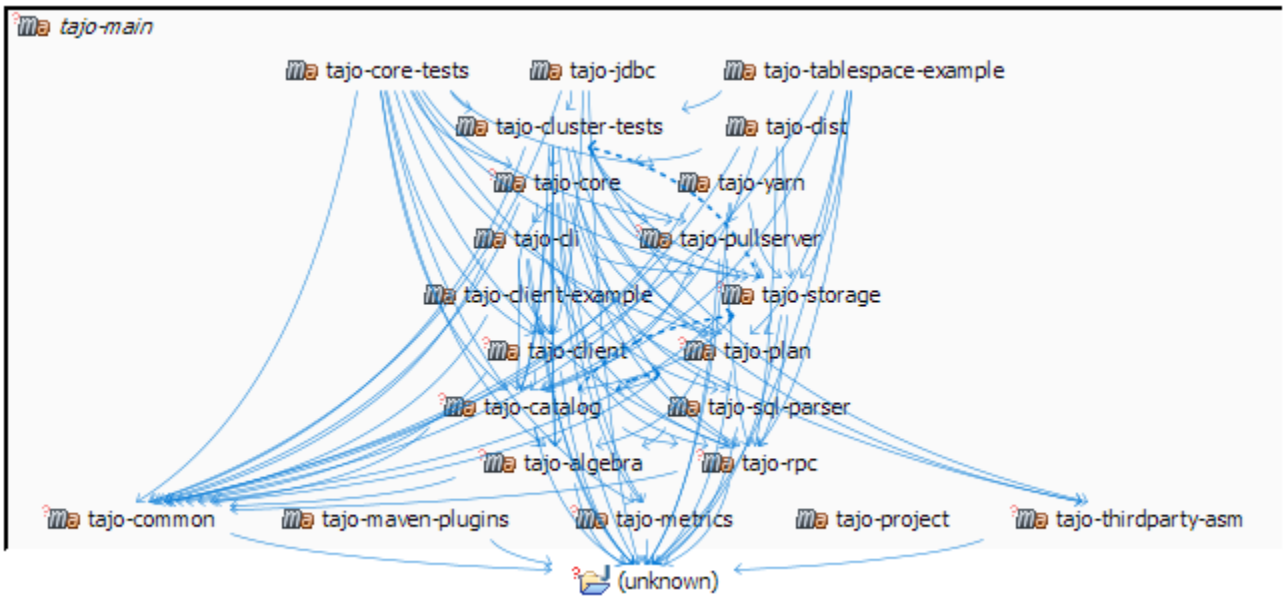

Figure 4.1: The graph of Tajo, created by Structure101

4.2 Design of Tajo

As you can see form figure 4.1, Tajo consists of several different packages working together. Firstly, We will briefly explain these components. Lastly we will go into more detail about the external dependencies tajo relies on.

4.2.1 components

Here we will list the components of Apache Tajo, describe what they do and how they interact with each other. Below you will find a list of all the main components according to a maven build file in the source directory and Structure101. The responsibilities of each component has been approximated using the build file and the source code.

- `tajo-core` is responsible for the main functionality of Tajo. This component uses a master worker pattern to perform its work. The master is responsible for query planning and coordinating the workers. It divides a query into sub-tasks and assigns these sub-tasks to individual workers. The workers are then responsible for executing these sub-tasks. The core structure can be seen in figure 4.2.
- `tajo-core-tests` and `tajo-cluster-tests` are responsible for testing the core and cluster respectively, where the focus is mainly on the correctness of query execution. Because they are testing libraries, they have only outgoing dependencies and are not really part of the core functionality. One exception is however the dependency of tajo-storage (more specifically the internal tajo-storage-kafka and tajo-storage-pgsql packages) on tajo-cluster-tests. This dependency was however caused by the fact that tajo-cluster-tests was added in as a dependency in the pom.xml file, while non of the

classes actually needed it. In other words, this dependency could've been removed from the pom.xml file.

- `tajo-plan` is responsible for the planning or scheduling within tajo. This package seems to be heavily used by the other components of the system. Tajo-core for example has around 4500 references to tajo-plan.
- In the dependency graph of 4.1 You can see the `tajo-project` component and that it has no dependencies. That is because it is not a java package. It is a parent POM for all Tajo Maven modules. All plugins and dependencies versions are defined here.
- `tajo-algebra` contains Algebraic expressions for database interaction. An example of a couple of expressions here are Join, DropTable, Sort and CreateDatabase. It only depends on the tajo-common package within the project and has several other components, among which the tajo-core component, depend on it.
- `tajo-catalog` contains a catalog of plugins for a server, client, drivers and common. According to Structure101, this package seems to be used by a lot of components, and seems to be depending on a few too. One could therefore say that it is an important component.
- `tajo-common` contains some common modules. This consists of some google protobuf[4] definitions and some helper functions. Since this is basically a util package, it does not depend on other components. Not surprisingly, all the other major components do seem to depend on it.
- `tajo-client` is responsible for the Client API and its implementation. The tajo-cli will communicate with the tajo-client, which will then in turn communicate with the server. Tajo-client has a few minor incoming and outgoing dependencies, but the most notable one is that of tajo-core with 460 references. It goes without saying that Tajo-client is an indispensable part of the system.
- `tajo-client-example` provides a Client API example and `tajo-tablespace-example` provides a table example. No components seem to depend on these parts. This proves that the do not provide any core functionality, they just act as examples.
- `tajo-cli` provides the command line interface for the user to communicate with tajo. It depends on a number of components in the system and even tajo-core seems to depend on it.
- `tajo-dist` This component is responsible for assembling the Tajo distribution. It depends on a few components, among which tajo-core, but no other component depends on it. Since this component should just assemble the Tajo distribution, no component should indeed depend on tajo-dist.
- `tajo-jdbc` represents the Tajo Java Database Connectivity driver. It is responsible for handeling the communication with the database. Tajo-jdbc depends on tajo-common and tajo-client, but no other class seems to depend on it. It could be that this package is no longer used by the system.

- `tajo-maven-plugins` contains the maven plugins. From the dependency graph it can be seen that no component depends on tajo-maven-plugins. Therefore it is reasonable to assume that tajo-maven-plugins does not provide any functionality for tajo. It only contains some plugins
- `tajo-metrics` provides Metrics for quantitative assessment of tajo. just like tajo-algebra it just provides a few functions for tajo-core and the two test classes to apply a metric. Therefore only those classes depend on it and itself does not depend on anything else.
- `tajo-pullserver` is mainly responsible for fetching data from the server. The main components that use this service are tajo-core and tajo-yarn.
- `tajo-rpc` is responsible for the Remote procedure calls. This components seems to be used by most of the components in the system. It is therefore also a key component in the system.
- `tajo-sql-parser` is, as the name implies, responsible for the parsing of SQL commands. This component is only used by the cli and tajo-core, but still very important.
- `tajo-storage` is responsible for storage and the relevant plugins. This component seems to have a lot of dependencies both incoming and outgoing. Tajo-core even references it 530 times. It can therefore also be considered an important part of the system.
- `tajo-yarn` is presumable an extension of tajo in order to use it with yarn[5]. No main component seems to depend on yarn, so we can assume it is not an significantly important component.
- `thirdpart-asm` is a java code parser that provides functionality to parse compiled java code. It seems to be only used by tajo-core and the test components.

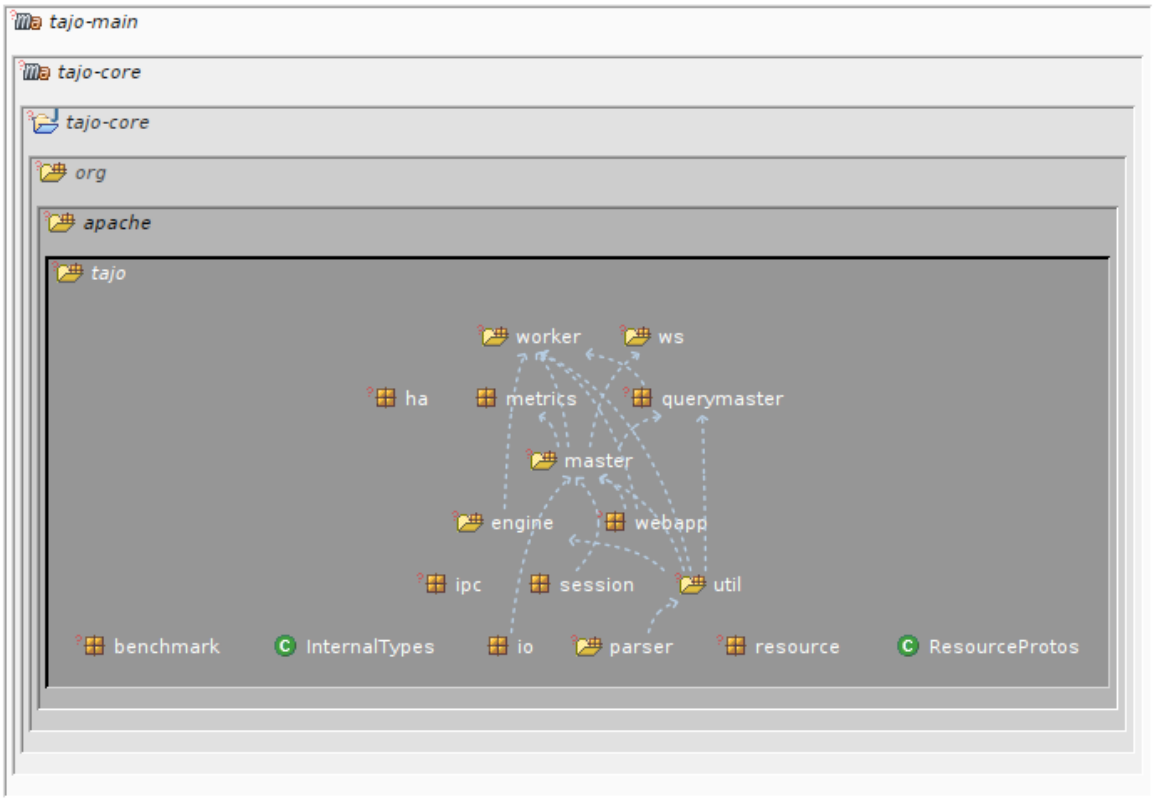

Figure 4.2: The graph of Tajo-core, created by Structure101

4.2.2 External dependencies

Here we will list a few of the main dependencies of tajo. This list will mainly include the external dependencies tajo-core uses, since that means those libraries are part of the core functionality of tajo. In addition to that, a few dependencies used by other components which can be considered important, will be listed as well.

One of the important external dependencies of Tajo is that to google protocol buffers[4]. These are Google's language-neutral, platform-neutral, extensible mechanism for serializing structured data, much like JSON or XML, but smaller, faster and simpler. Tajo uses this to communicate with other services.

Another notable external dependency is that of amazonaws[6]. The features of this library are used by the tajo-storage component to enable authorisation or the enabling of retrieving credentials via the AWS service.

An important dependency used by tajo-core is codahale[7] and gmetric4j[8]. These two library provide metrics to give insight into what the code does in production and measure the behavior of critical components in the production environment.

Another dependency of tajo-core is minidev.json[9], which provides functionality of reading and parsing json-documents. The dependency jayway.jsonpath[10] is used in combination with minidev.json in a few minor cases to read the json documents.

Another remarkable dependecy is the maxmind.geoip library[11]. This library is mainly used for identifying the location and other characteristics of an internet user. Looking at the source-code, it seems that tajo is only after the country-code and then only uses that information to find out the correct timezone you're in. It looks like tajo is not after your personalised location data for ad revenue.

two important dependencies for tajo-cli are the JLine library[12] and jansi[13], which provides functionality to handle and format console input.

antlr[14] is also used by both tajo-core and tajo-sql-parser to generate a parser for reading, processing, executing or translating structured text or binary files. Looking at the source code of tajo-core, it seems to be only used for SQL parsing.

A very important dependency of tajo-core is hadoop[15]. Not to mention that it is even required to have hadoop installed in order to use apache tajo. Hadoop provides a software framework for distributed storage and processing of big data.

Another important dependency used by tajo-core and tajo-rpc is glassfish.jersey[16]: An open source framework for developing RESTful Web Services in Java.

Snappy[17] is a dependency used by tajo-common for decompression/compression with the aim of highspeed and reasonable compression. This library is based of the original C++ version from google, but now written in Java. According to the git repository, it produces a byte-for-byte exact copy of the output created by the original C++ code.

Tajo-core uses mortbay jetty[18] as a java web server. More particularly Tajo-core uses this framework for their machine to machine communications.

Tajo-core also uses reflections[19]. Reflections scans your classpath, indexes the metadata, allows you to query it on runtime and may save and collect that information for many modules within your project.

another neat dependency is the SLF4j[20] or the simple logging facade for java. It allows the the end user to plug in the desired logging framework at deployment time.

4.3 Running Pyne on Tajo

We will start by running Pyne on Apache Tajo. The command we used to get a graph for the latest commit of Tajo is as follows:

```
1 java -jar pyne-cli.jar https://github.com/apache/tajo -s "2020-05-10" -e
  ↪ "2020-05-12" -p "DAY"
```

This creates a `.graphml` file[1], but unfortunately this does have some issues. See Appendix A.

[1] available on our github repository, under `graphs/tajo_dependencies_pyne.grahpml`

This is the only format Pyne can currently export, and opening a `.graphml` does require users to install a specialized program. We decided to use yEd Graph Editor[2] for this purpose. This has the advantage of being able to automatically rearrange the graph. Using this feature, we obtained figure 4.3.

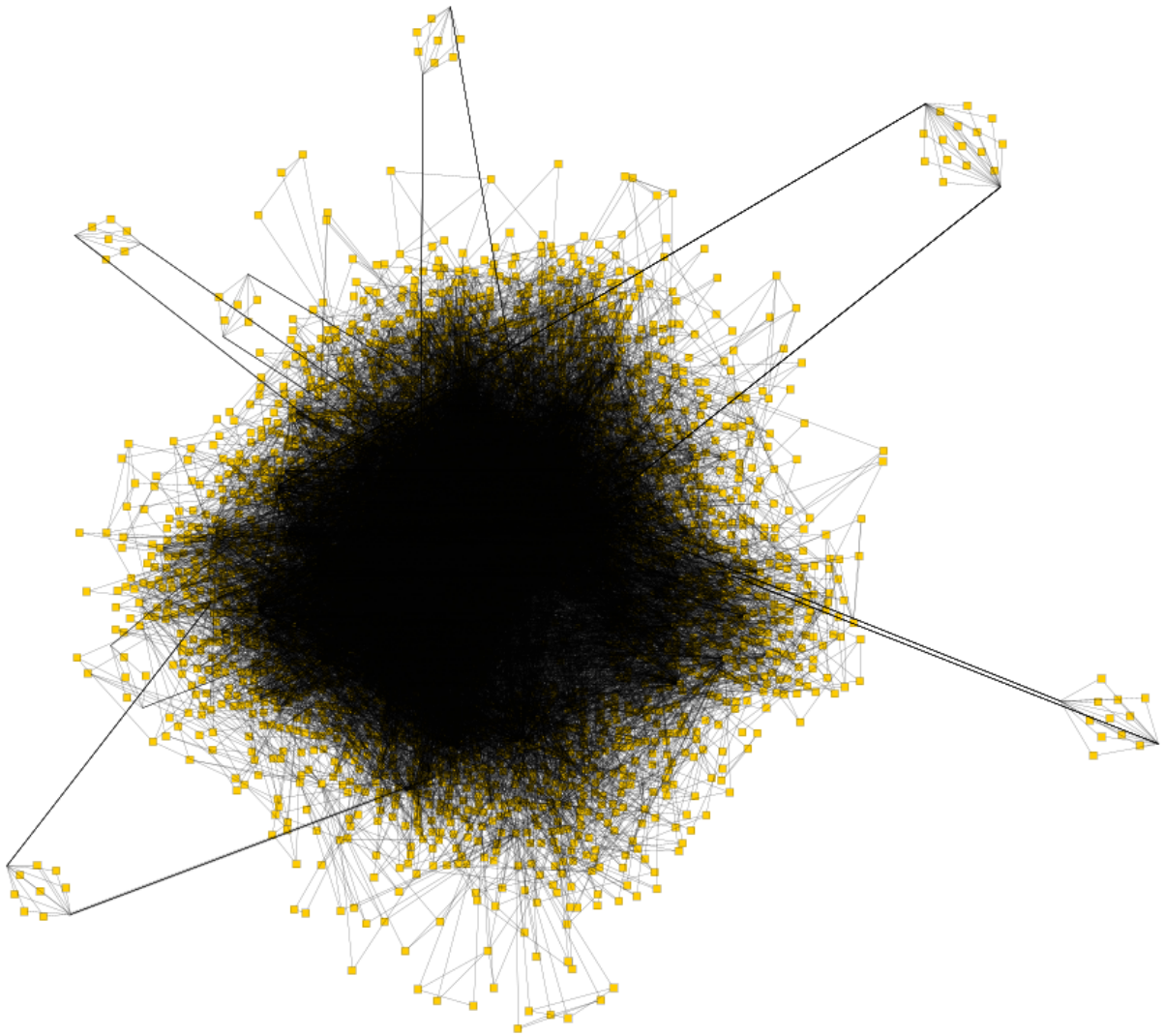

Figure 4.3: The automatically rearranged graph of Tajo, created by Pyne and rearranged by yEd

The nice thing about Pyne though, is that it can generate this graph without the need to compile the target system first, which in the case of Tajo, proved to be a difficult task on its own as we will see in the next section.

[2] `https://www.yworks.com/products/yed`

4.4 Comparing the feature sets

Feature	Pyne	Structure101
GUI	NO	YES
IDE plugin support	NO	YES[3]
Needs compiled sources	NO	YES
Shows external dependencies	YES	YES
Shows fully qualified class names	YES	NO[4]
Open-source	YES	NO
Freely available	YES	NO
Multiple OS support	YES	YES
Allows direct analysis of remote repositories	YES	NO
`.graphml` export	YES	NO
`.png` export	NO	YES
`.jpeg` export	NO	YES
`.csv` export	NO	YES

Table 4.1: Comparing the features of Pyne and Structure101

4.5 Comparing the Results of Pyne to Structure101

To compare the results of Pyne with Structure101, we needed to obtain a machine parsable format as the output of both tools. Pyne already does this, by exporting a `.graphml` file, however for Structure101 this was a little more difficult to find, since Structure101 is mainly focused on exporting images. However, Structure101 does have the option to export to `.csv`. After exploring the exported `.csv` from Structure101, we came to the conclusion that we could use this as our machine parsable format that we needed, though it is not an ideal file to work with.

Note that even though both of these programs are dependency graph creator engines, Pyne uses the source code to create the dependency graph, while Structure101 uses the .jar files to create the dependency graph. This will cause unavoidable differences in output for both programs, which are not necessarily wrong.

[3] though this is quite a bit more limited than using the full program
[4] for some reason, it only show the fully qualified names for packages

Chapter 5

Comparing results programmatically

5.1 Creating a dependency checker program

Once we found a machine parsable format we could export from both tools, we wrote a Java program[1] which extracts the found dependencies from both of the generated files. It then checks if there any dependencies that were found by one tool, but not by the other, and provides some statistics on the results as well. A general flow diagram of this program can be found in Figure 5.1.

5.1.1 Design of the dependency checker

The dependency checker was made with the technologies from Pyne kept in mind. This means we used the same java version as Pyne does (version 11), and we export the results as an XML file. This way, not only does this mean that we don't have to awkwardly switch java version each time we want to run one or the other, but it also means we can easily migrate the code from being an external tool to being a feature in Pyne, if we ever want to do so. In the same spirit, the structure of the program was very much designed to be modular. This was achieved by creating what is known as a black box around the internal functionalities, and exposing a set of intuitive methods that execute all steps of the program.

A flow diagram of the dependency checker can be found in Figure 5.1.

[1] Available in our GitHub repository, under `dependency_checker/`

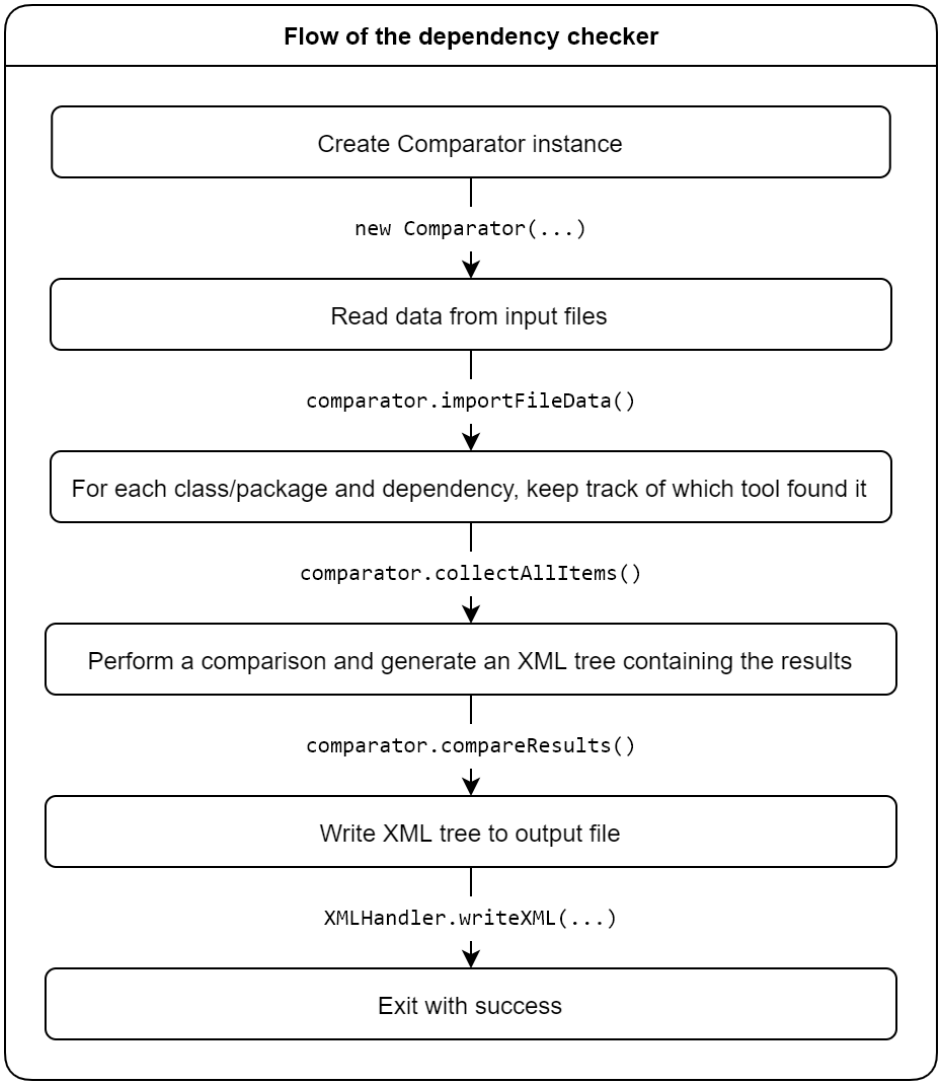

Figure 5.1: The flow diagram of the dependency checker program

The structure of the XML output of our dependency checker can be seen in Listing D.1, in appendix D.

The root element is called "results", which has 3 children: "allPackages"/"allClasses", "allDependencies" and "tools". The first contains the combined list of the packages or classes found by each individual tool. The second contains the combined list of the dependencies found by each individual tool. The last contains a list of all tools that we are comparing, where each tool contains:

- a list of packages or classes this tool did find
- a list of packages or classes this tool missed (by comparing the found packages or classes against all, mentioned earlier)
- a list of the dependencies this tool did find

- a list of dependencies this tool missed (by comparing the found dependencies against all dependencies, mentioned earlier)

Many elements also contain fields that provide some insights to the data without having to actually go through all items in the lists (which can get quite long for a big project, such as Apache Tajo). These fields include:

- ”count”, ”countInternal”, ”countExternal”, ”countUnknown” tell the amount of items in a list, where ”count” stands for the total amount of items, and the others tell the amount of items which are internal, external, or unknown, respectively.
- ”internal” specifies whether a package is internal or not (i.e. external).
- ”name” gives the name of the tool that the ”tool” element represents.
- ”percentageTotal”, ”percentageInternal”, ”percentageExternal”, ”percentageUnknown” specify the percentage that the amount of items in the list, which this field is on, is of all items of that category.

5.2 Running our dependency checker program

Using the fields on the XML elements of the output specified in subsection 5.1.1, we can obtain the statistics from comparing the unmodified version of Pyne to Structure101, using Apache Tajo as a benchmark again. These can be found in Listing 5.1 and Listing 5.2.

```
<results>
    <allPackages count="430" countExternal="242" countInternal="188" countUnknown="0"></allPackages>
    <allDependencies count="3558"></allDependencies>
    <tools count="2">
        <tool name="STRUCTURE101">
            <foundPackages count="429" countExternal="241" countInternal="188" countUnknown="0" percentageExternal="99.58678" percentageInternal="100.0" percentageTotal="99.76744" percentageUnknown="0"></foundPackages>
            <missedPackages count="1" countExternal="1" countInternal="0" countUnknown="0" percentageExternal="0.41322312" percentageInternal="0" percentageTotal="0.23255813" percentageUnknown="0"></missedPackages>
            <foundDependencies count="3327" percentageTotal="93.50759"></foundDependencies>
            <missedDependencies count="231" percentageTotal="6.492411"></missedDependencies>
        </tool>
        <tool name="PYNE">
            <foundPackages count="193" countExternal="47" countInternal="146" countUnknown="0" percentageExternal="19.421488" percentageInternal="77.65958" percentageTotal="44.88372" percentageUnknown="0"></foundPackages>
            <missedPackages count="237" countExternal="195" countInternal="42" countUnknown="0" percentageExternal="80.578514"
```

```
    ↪ percentageInternal="22.340425" percentageTotal="55.11628"
    ↪ percentageUnknown="0"></missedPackages>
14              <foundDependencies count="1020"
    ↪ percentageTotal="28.66779"></foundDependencies>
15              <missedDependencies count="2538"
    ↪ percentageTotal="71.33221"></missedDependencies>
16          </tool>
17      </tools>
18  </results>
```

Listing 5.1: A comparison of results on a package level before modifying Pyne

```
1   <results>
2       <allClasses count="3970" countExternal="237" countInternal="2184"
    ↪ countUnknown="1549"></allClasses>
3       <allDependencies count="41266"></allDependencies>
4       <tools count="2">
5           <tool name="STRUCTURE101">
6               <foundClasses count="3259" countExternal="223"
    ↪ countInternal="1487" countUnknown="1549"
    ↪ percentageExternal="94.09283" percentageInternal="68.08608"
    ↪ percentageTotal="82.09068" percentageUnknown="100.0"></foundClasses>
7               <missedClasses count="711" countExternal="14"
    ↪ countInternal="697" countUnknown="0" percentageExternal="5.907173"
    ↪ percentageInternal="31.913918" percentageTotal="17.909319"
    ↪ percentageUnknown="0"></missedClasses>
8               <foundDependencies count="36319"
    ↪ percentageTotal="88.01192"></foundDependencies>
9               <missedDependencies count="4947"
    ↪ percentageTotal="11.988077"></missedDependencies>
10          </tool>
11          <tool name="PYNE">
12              <foundClasses count="2348" countExternal="164"
    ↪ countInternal="2184" countUnknown="0" percentageExternal="69.19831"
    ↪ percentageInternal="100.0" percentageTotal="59.143578"
    ↪ percentageUnknown="0"></foundClasses>
13              <missedClasses count="1622" countExternal="73"
    ↪ countInternal="0" countUnknown="1549" percentageExternal="30.801687"
    ↪ percentageInternal="0" percentageTotal="40.856422"
    ↪ percentageUnknown="100.0"></missedClasses>
14              <foundDependencies count="7809"
    ↪ percentageTotal="18.923569"></foundDependencies>
15              <missedDependencies count="33457"
    ↪ percentageTotal="81.07643"></missedDependencies>
16          </tool>
17      </tools>
18  </results>
```

Listing 5.2: A comparison of results on a class level before modifying Pyne

Here we can see that Pyne initially performed much worse than Structure101, only finding less than half of the package Structure101 did, and less than two thirds of the classes. We also see that Pyne found one package that Structure101 didn't find though. After investigating,

it turns out that the dependency that Structure101 missed was `PrimitiveType`. Our first instinct was that Pyne could use this to label primitive types like `int` or `bool`, but this turned out not to be true. When we investigated further, we found that this package contains one class according to Pyne, namely `PrimitiveTypeNameConverter`. Searching for this term online returns a javadoc page from Apache Parquet[2]. The reason why it didn't get labelled by its full name (`org.apache.parquet.schema.PrimitiveType.PrimitiveTypeNameConverter`) is unknown.

Furthermore, Pyne missed 100% of the unknown classes. This makes sense, since Structure101 very often doesn't mention for classes whether they are internal or external (it only does this consistently for packages). Pyne on the other hand can always tell, so it makes sense it would not have any classes marked as unknown.

[2] `https://www.javadoc.io/static/org.apache.parquet/parquet-column/1.8.2/org/apache/parquet/schema/PrimitiveType.html`

Chapter 6

Improving Pyne

In this chapter we will go over the changes we made to Pyne in order for it to include all dependencies. We will be using the results from the dependency checker, which we discussed in chapter 5, and the source code of Pyne to find out what Pyne is missing and fix it.

6.1 Faults in Pyne

Here we will enumerate some of the "mistakes" in Pyne which makes its output different from Structure101. Note that the word mistake is a bit harsh here, some choices made in the implementation in Pyne are not necessarily wrong, but still give a different output. For example, Pyne does not include any folders with "test" or "example" in it, which is not necessarily wrong since those folders are not part of the main functionality of the program anyway. The first few points will discuss differences between Pyne and Structure101, which are not faults per se. The latter points will discuss the actual missing dependencies in Pyne and how it misses them. Most of these mistakes were made in the `ClassAnalysis` class, with most of them originating from the `getClassReferences()` function.

1. **Files that are not in the source code are not parsed**
   Maybe an obvious fault of Pyne, if you can even call it a fault, but it should be mentioned anyway. Since Pyne uses the source files to create the dependency graph and Structure101 uses the .jar files, there are going to be unavoidable differences is the resulting dependency diagram. A lot of classes, mostly classes generated by Google Protobuf during compile time, are not in the source code yet and are only created when the program is compiled. It also goes the other way around. Some packages, like tajo-docs and tajo-project are not included in the jar file, while they are in the source code.

2. **Packages with no dependencies are skipped**
   This is a feature of Pyne explicitly implemented by the creator. Pyne has a whole post-process analysis where it traverses the graph and removes any nodes without edges. Structure101 does include packages without dependencies, so this feature will show a

difference in output.

3. **Pyne does not parse any folder with "test" or "example" in its name or packages that do not have the folder "src" or "main" in it.**
   Pyne explicitly filters out any folders without a folder named "src" or "main" in it. It also removes any folders that contain the word "test" and "example". It is not wrong to consider example and test files to not be part of the project and use the "src" or "main" keyword to find project folders, but it does result in a different output that Structure101.

4. **Pyne does not check the constructor**
   Moving on to the actual faults in Pyne, or the missing dependencies, the first one we found was the missing check for the constructor in `getClassReferences()`. This function is responsible for returning the names (more specifically `CtTypeReferences`) of all classes this class depends on. It did go over each method in the class, but forgot about the constructor.

5. **Pyne uses the return type of an invocation for its dependency, not the declaration for the method itself.**
   This was a mistake in the inner class `ExecutatbleConsumer`. The function `getClassReferences()` gave each invocation in the class, aka a method call like `dependencyClass.function()`, to the executable consumer which in turn should retrieve the name of the dependency. Instead of retrieving the class where the method was defined, it got the return type of the method. As can be seen in this code snippet:

```
1  public void accept(CtElement element) {
2      if (!(element instanceof CtExecutableReference<?>)) {
3          return;
4      }
5      CtExecutableReference executable = (CtExecutableReference)
   ↪ element;
6      try {
7          CtTypeReference executableType = executable.getType();
8          if (executableType != null &&
   ↪ executableType.getDeclaration() != null) {
9              dependences.add(executableType.getTypeDeclaration());
10         }
11     }catch (NullPointerException e){
12         // Ignore Spoon errors
13     }
14 }
```

   If we ignore the empty catch statement made by the creator of Pyne (which is still painful to see) and focus our eyes on line 5 and 7, we can see where it goes wrong. On line 5, the element is cast to an executable, which is the invocation that is being checked. Then on line 7, the type from this invocation is retrieved with `getType()`. This will however not return the declaring type, but the return type of the invocation. The function that should've been used is `getDeclaringType()`.

6. **Pyne had to retrieve the type declaration (so the entire class + body) in**

order to make the dependency, but then later needed only the referenced-type (aka the full name).
This caused Spoon a lot of trouble when looking up external libraries. Getting the declaration was not necessary, only the name would suffice. So Spoon had to go back and forth for finding the reference name. For an example, see the code snippet below:

```
1  private void processClassReferences(CtType clazz, VertexClass
   ↪ vertexClass) {
2      for (CtType referencedClass : getClassReferences(clazz)) {
3          if (referencedClass == null ||
   ↪ referencedClass.getReference() == null) {
4              continue;
5          }
6          VertexClass referencedClassVertex
7                      =
   ↪ getOrCreateVertexClass(referencedClass.getReference());
8              vertexClass.addDependOnClass(referencedClassVertex);
9      }
10 }
```

```
1  private List<CtType> getClassReferences(CtType clazz) {...}
```

The `processClassReferences()` function takes a list of types (which is a definition for a clazz or interface). This list will then contain the class definition, methods and fields for each class this specific class depends on. But when creating the vertex on line 8, it only needs the reference, which is essentially just the package+name of the class. Since the type is retrieved from the reference in `getClassReferences()`, this step is totally unnecessary. getClassReference should return a CtTypeReference, not a CtType.

7. **Pyne did not look at the type of the parameters and return value of each method in the class.**
   As you can see in section C.1 in the Appendix, there is no retrieval of parameters or return value for each method in `getClassReferences()`. Class a does depend on Class B if one of it's methods uses Class B as a parameter or return value, so it should be considered.

8. **Pyne did not look at the type of fields in each class.**
   As you can see in section C.1 in the Appendix, Pyne does check the annotations of the fields, but not the type of the field.

9. **Spoon has some issues getting declarations of nested executable references.**
   This is actually not an issue with Pyne, but an issue with Spoon. To elaborate more on what we mean with "nested executable references", it is something like this: "dependencyClass.function().anotherFuction()". Spoon has trouble finding out what the Class is that defines anotherFuction(). This is especially a problem for external packages, where Spoon does not have the source code for either the class that defines function() or the class that defines anotherFuction(). Since this is a Spoon issue and

not an issue with Pyne, we would need to replace the entire parser and rewrite Pyne almost entirely from scratch.

6.2 Changes to Pyne

Here we will go over each fault in Pyne and describe how we chose to fix it. Almost all of these fixes were performed in the ClassAnalysis class, of which the new source code can be found in section C.2 in the Appendix.

1. **Files that are not in the source code are not parsed**
   For obvious reasons, this issue could not be fixed. However to filter out all of the files that Structure101 finds but Pyne does not, we manually inspect all the missing internal dependencies of Pyne. From the resulting output we see that the only missing packages are not there because they are either not in the source code or do not have dependencies at all.

2. **Packages with no dependencies are skipped**
   Since this is also a core feature of Pyne, this issue could not be fixed. However we applied the same technique as before to inspect the missing internal dependencies of Pyne. As mentioned, From the resulting output we see that the only missing packages are not there because they are either not in the source code or do not have dependencies at all.

3. **Pyne does not parse any folder with "test" or "example" in its name or packages that do not have the folder "src" or "main" in it.**
   We choose to include test and example folders in our project as well, since Structure101 does this too. This fix was as easy as removing the filters from the parser class. We did choose to keep the filter that specified that the folder must contain an "main" or "src" folder since Spoon would return errors if we removed this. The obvious problem is that Spoon cannot parse a directory that is not a source code directory.

4. **Pyne does not check the constructor**
   As you can see in section C.1 in the Appendix, Pyne previously used this line of code to retrieve all of its methods.

```
for (CtMethod<?> ctMethod : (Set<CtMethod<?>>) clazz.getMethods())
```

   We added the constructor to this for loop with the following code, as can be seen in C.2 in the Appendix.

```
ArrayList<CtExecutable<?>> executables = new ArrayList<>();
executables.addAll((Set<CtExecutable<?>>) clazz.getMethods());
if (clazz instanceof CtClass) {
    executables.addAll((Set<CtExecutable<?>>) ((CtClass)
    ↪ clazz).getConstructors());
}
for (CtExecutable<?> ctExecutable : executables)
```

Essentially what we do is we add the list of methods and the list of constructors together and then loop over that instead. No real changed needed to be made to the body of the for loop, since most of the functions used there came from CtExecutable anyway, not from the child class CtMethod.

5. **Pyne uses the return type of an invocation for its dependency, not the declaration for the method itself.**
On first sight, this looked like an easy fix. Just replace `getType()` with `getDeclaringType()`. However the executableConsumer also handled constructor calls (like `new dependencyClass()`) for which `getType()` was the correct method to use. That is why we decided to remove the executableConsumer class and let `getClassReferences()` handle finding the references for constructor calls and invocations separately. The resulting code can be seen in section C.2 in the Appendix.

6. **Pyne had to retrieve the type declaration (so the entire class + body) in order to make the dependency, but then later needed only the referenced-type (aka the full name).**
This was a simple fix. The only thing that needed to be done was rewrite statements like `c.getType().getTypeDeclaration()` to `c.getType()` and change the return value of `getClassReferences()`.

7. **Pyne did not look at the type of the parameters and return value of each method in the class.**
To fix this a few extra checks needed to be added. This can be seen in section C.2 in the Appendix but also in the code below. This code snippet added the type of each method to the list of references.

```
references.add(ctExecutable.getType());
```

And this code snippet added all the annotations of the methods parameters and parameters types to the list of references.

```
for (CtParameter<?> parameter : ctExecutable.getParameters()) {
    parameter.getAnnotations().forEach(annotationConsumer);
    references.add(parameter.getType());
    tempCheck(parameter.getType(), clazz, parameter.toString());
}
```

8. **Pyne did not look at the type of fields in each class.**
To fix this a few extra checks needed to be added. This can be seen in section C.2 in the Appendix but also in the code below. This code snippet added all the annotations of the fields and field types to the list of references.

```
for (CtField<?> field : (List<CtField<?>>) clazz.getFields()) {
    field.getAnnotations().forEach(annotationConsumer);
    references.add(field.getType());
    tempCheck(field.getType(), clazz, field.toString());
}
```

9. **Spoon has some issues getting declarations of nested executable references.** This unfortunately could not be fixed. This is an issue that does not lie in Pyne, but in Spoon instead. The only way to fix this is use an entirely new parser and rewrite Pyne entirely. Even then it would not ensure that this problem will be fixed.

6.3 Result

Here we will compare the result of our dependency checker on the original version of Pyne to our improved version. The result of the original version can be found in 5.2. In order to accurately compare the results, we created table 6.1 containing the number of found and missing dependencies and packages. The output of the dependency checker on the improved version is as follows. The blocks have been collapsed to not show all the individual missing and found dependencies or classes. Otherwise this document would consist of a few hundred extra pages.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<results>
    <allPackages count="706" countExternal="514" countInternal="192"
    ↪ countUnknown="0">
    <allDependencies count="4307">
    <tools count="2">
        <tool name="STRUCTURE101">
            <foundPackages count="429" countExternal="237"
    ↪ countInternal="192" countUnknown="0" percentageExternal="46.108948"
    ↪ percentageInternal="100.0" percentageTotal="60.764874"
    ↪ percentageUnknown="0">
            <missedPackages count="277" countExternal="277"
    ↪ countInternal="0" countUnknown="0" percentageExternal="53.891052"
    ↪ percentageInternal="0" percentageTotal="39.235126"
    ↪ percentageUnknown="0">
            <foundDependencies count="3327" percentageTotal="77.246346">
            <missedDependencies count="980" percentageTotal="22.753658">
        </tool>
        <tool name="PYNE">
            <foundPackages count="626" countExternal="469"
    ↪ countInternal="157" countUnknown="0" percentageExternal="91.24514"
    ↪ percentageInternal="81.77083" percentageTotal="88.66856"
    ↪ percentageUnknown="0">
            <missedPackages count="80" countExternal="45"
    ↪ countInternal="35" countUnknown="0" percentageExternal="8.754864"
    ↪ percentageInternal="18.229168" percentageTotal="11.331445"
    ↪ percentageUnknown="0">
            <foundDependencies count="2814" percentageTotal="65.3355">
            <missedDependencies count="1493" percentageTotal="34.6645">
        </tool>
    </tools>
</results>
```

Listing 6.1: A comparison of results on a package level after modifying Pyne

```
<results>
    <allClasses count="5393" countExternal="2298" countInternal="2269"
    ↪ countUnknown="826"></allClasses>
    <allDependencies count="59914"></allDependencies>
    <tools count="2">
        <tool name="STRUCTURE101">
            <foundClasses count="3259" countExternal="942"
    ↪ countInternal="1491" countUnknown="826"
    ↪ percentageExternal="40.99217" percentageInternal="65.71177"
    ↪ percentageTotal="60.430187" percentageUnknown="100.0"></foundClasses>
            <missedClasses count="2134" countExternal="1356"
    ↪ countInternal="778" countUnknown="0" percentageExternal="59.007835"
    ↪ percentageInternal="34.288235" percentageTotal="39.569813"
    ↪ percentageUnknown="0"></missedClasses>
            <foundDependencies count="36319"
    ↪ percentageTotal="60.618557"></foundDependencies>
            <missedDependencies count="23595"
    ↪ percentageTotal="39.381447"></missedDependencies>
    </tool>
        <tool name="PYNE">
            <foundClasses count="4517" countExternal="2248"
    ↪ countInternal="2269" countUnknown="0" percentageExternal="97.82419"
    ↪ percentageInternal="100.0" percentageTotal="83.75672"
    ↪ percentageUnknown="0"></foundClasses>
            <missedClasses count="876" countExternal="50"
    ↪ countInternal="0" countUnknown="826" percentageExternal="2.175805"
    ↪ percentageInternal="0" percentageTotal="16.243279"
    ↪ percentageUnknown="100.0"></missedClasses>
            <foundDependencies count="30090"
    ↪ percentageTotal="50.221985"></foundDependencies>
            <missedDependencies count="29824"
    ↪ percentageTotal="49.778015"></missedDependencies>
    </tool>
  </tools>
</results>
```

Listing 6.2: A comparison of results on a class level after modifying Pyne

The first thing you might be able to notice is the increase in total packages and dependencies compared to the original version. This is because Spoon sometimes has trouble retrieving the complete package name of (mostly external) dependencies. It'll then return either the class name or a part of the package name. This is also why Structure101 has an increase in missed package and dependencies, since Structure101 is able to find the total package name. We decided to leave these in there, since the dependencies belonging to that are correct, even though the dependency checker will label them as incorrect.

The most important thing to notice from the table is the decrease in missed dependencies for Pyne. The missing dependencies decreased from 2538 dependencies to 1493. So the missing dependencies are almost halved. This alone proves that our changes improved Pyne drastically. In addition to that, the actual missed dependencies may be even lower. As mentioned before, Spoon might not be able to find the full package name of some external

	original	improved
Total packages	430	706
Total package dependencies	3558	4307
Total classes	3970	5393
Total class dependencies	41226	59914
Structure101		
Found packages	429	429
Missed packages	1	277
Found package dependencies	3327	3327
Missed package dependencies	231	980
Found classes	3259	3259
Missed classes	711	2134
Found class dependencies	36319	36319
Missed class dependencies	4947	23595
Pyne		
Found packages	193	626
Missed packages	237	80
Found package dependencies	1020	2814
Missed package dependencies	2538	1493
Found classes	2348	4517
Missed classes	1622	876
Found class dependencies	7809	30090
Missed class dependencies	33457	29824

Table 6.1: Results of the dependency checker for the original and improved version of Pyne

dependencies, but is able to find the dependency. Even though the dependency checker will mark these dependencies unequal to Structure101 even though they are in a sense equal. The package name is just not complete, which makes programmatically comparing them very hard. The remaining missed dependencies, after manual inspection of around 30 of them, can be explained as follows. All of the inspected internal missing dependencies and a large portion of the external ones are caused by the fact that the classes are not in the source-code, but are present in the jar file. A lot of these classes are Google Protobuf[4] classes, which are presumably created on compile time. One last issue explaining the rest of the inspected missing dependencies, is the fact that Spoon has trouble finding the declaration of nested dependencies, as mentioned before. Since this is a Spoon specific issue, nothing can be changed to Pyne to fix it. Using another parser might be an option, but a full rewrite of Pyne will be needed and using a different parser might introduce new and different problems.

References

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Appendix A

Troubleshooting

Here we present several problems encountered and how we tried to solve them.

1. **Bug in graph creator**:
   When I open a graph in a graph editor like draw.io or yEd graph editor, only one square appears. But the file is 2.25mb. Turns out that all the squares are stacked upon each-other, but the relation between the squares is still there (which is visible from the neighbours tab in yEd graph editor).
   It seems that the squares itself do not contain any data on the classes they represent. They do not have any value assigned to them. Furthermore, opening any graph will give a warning about the 'linesOfCode' property being of type long, which apparently isn't supported. I sincerely hope that an integer would be enough to count the amount of lines of code anyway, so we'll change that.

2. **Default cli values**:
   The default options for cli are not the best choice. Namely the period option is set to days by default, which will create a separate graph for each day. The start date is set to 5 periods (so 5 days on default) from the end date (which is the current date by default). It is relatively rare for a git repository to have commits from the past 5 days. We shall therefore change the default values.

3. **Error handling**:
   In a few cases, where something goes wrong or no graph is created, no error is thrown and the user does not know why no graph has been made. For that reason more error logging statements need to be added.

4. **Java Version**:
   Pyne requires java version 11, however to compile Tajo version 1.8 is needed. This leads to confusing errors if you try to compile Tajo for yourself after upgrading to java 11 to compile Pyne.

5. **First manual inspection**:
   On the first manual inspection of the dependencies pyne is not able to see using

the source code and our created dependency checker, the following mistakes were recognized:
Pyne is not able to inspect the constructor. (adding this fixed two packages)
Pyne is not able to inspect arguments of methods and constructors.
Pyne is not able to inspect return values of methods.

6. **scanned directories**:
   After manually analysing the directories from the git repository added to pyne by the githelper, we already found some inconsistencies. tajo-core-test, Tajo-tablespace-example, tajo-cluster-tests, tajo-client-example, tajo-project are all missing from the list of added directories. In addition to that tajo-docs is present in pyne, while not present in structure101. The latter is probably due to the fact that tajo-docs is not present in the jar-file, but only in the git repository. Looking ruther into the source code of pyne, it seems that in the finsSourceDirectories() method, pyne specifically filters out any directories with "test" or "example" in it and any directory that does not contain a src/java or src/main in their directory. Since there is no real reason why tests should not be tested on dependencies, this filter should be removed.
7. **missing packages in graph**:
   The missing packages in the graph are probably mainly due to the fact that pyne filters out packages without incoming or outgoing dependencies.
8. **inconsistencies structure101 and source code**:
   Since structure101 analyses the .jar files and pyne the source files, there are going to be some obvious inconsistencies. When comparing the source code structure with the structure101 diagram, you might notice that a few minor packages within the components are missing from the source code or missing from the diagram. We will have to keep this in mind.
9. **Compiling Tajo**:
   To let Structure101 analyse Tajo, we had to compile it first. While the requirements for compiling Tajo[1] say that java 8 or above can be used, we weren't able to compile it with java 11, so we used java 8 instead. On top of that, it seems like there is one failing test case during the build stage, which prevents the build from finishing. To get around this, we compiled with the `-DskipTests` flag in Maven.

[1] `https://github.com/apache/tajo#requirements`

Appendix B

Change Log

ID	Author	Student Number	Email Address
JH	Job Heersink	s3364321	j.g.heersink@student.rug.nl
RW	Richard Westerhof	s3479692	r.s.westerhof.2@student.rug.nl

Table B.1: The authors that contributed to this document

Ver.	ID	Date	Revision
0.1	JH	21-11-2020	Create User guide.
	JH	21-11-2020	Create Design section.
	JH	21-11-2020	Create problem (troubleshooting) section.
	RW	22-11-2020	Added classes and dependency graph to design
	RW	22-11-2020	Revised User guide
	RW	22-11-2020	Revised problem section

Ver.	ID	Date	Revision
0.2	JH	01-12-2020	Reformatted the document.
	JH	01-12-2020	Added frontpage.
	JH	01-12-2020	Added introduction.
	JH	01-12-2020	Rewrote design section.
	JH	01-12-2020	Moved and renamed troubleshooting section to appendix.
	RW	01-12-2020	Create chapter 4.
	RW	01-12-2020	Add "java version" item to Troubleshooting appendix.

Ver.	ID	Date	Revision
0.3	RW	03-12-2020	Incorporate TA feedback in document.
	JH	04-12-2020	Added external dependencies section.
	JH	05-12-2020	Added requirements section.
	RW	07-12-2020	Improve internal structure of document and improve consistency.
	RW	08-12-2020	Add XS diagram and graphs of Tajo created by both Structure101 and Pyne.

Ver.	ID	Date	Revision
0.4	JH	12-12-2020	Incorporate TA feedback in document.
	JH	12-12-2020	Add design of Tajo.
	JH	13-12-2020	Add external dependencies of Tajo.
	JH	14-12-2020	Added all software to reference list.
	RW	14-12-2020	Write code for automatic comparison, perform analysis using results from this comparison.
	RW	14-12-2020	Write section 4.5 (reporting on code and analysis).

Ver.	ID	Date	Revision
0.5	RW	21-12-20	Expanding section Creating a dependency checker program.
	RW	24-12-20	Write more details in Creating a dependency checker program.
	JH	29-12-20	Created chapter 6 and added faults of pyne.
	JH	30-12-20	Added improvements made to Pyne in chapter 6
	RW	02-01-21	Moved dependency checker sections to new chapter
	RW	02-01-21	Added flow diagram of dependency checker
	JH	02-01-21	Added comparison between original and improved Pyne in chapter 6
	JH	03-01-21	Added explanation to figure 3.1
	JH	03-01-21	Added section on running the dependency checker.
	RW	04-01-21	Added Tajo compilation to issues section.
	RW	04-01-21	Wrote user guide section for Structure101.
	RW	04-01-21	Expanded user guide section for dependency checker.
	JH	05-01-21	Updated introduction section.
	RW	05-01-21	Fixed spelling in the document.
	RW	05-01-21	Added results for class level analyses.

Appendix C

Code Snippets

C.1 Original ClassAnalysis class

```java
/**
 * This a analysis processor. It takes the source code class and analyzes the
 * dependencies it has.
 *
 * @author Patrick Beuks (s2288842) <code@beuks.net>
 */
public class ClassAnalysis extends AbstractProcessor<CtClass<?>> {

    // The graph with the vertex classes
    private final FramedGraph framedGraph;

    // The parser containing additional information
    private final Parser parser;

    /**
     * A consumer for annotations, used to get the type and add the declaration
     * of it
     */
    private class AnnotationConsumer
            implements Consumer<CtAnnotation<? extends Annotation>> {

        private final List<CtType> dependences;

        /**
         * A consumer for annotations, used to get the type and add the
         * declaration of it
         *
         * @param dependences The list to add the found type to
         */
        public AnnotationConsumer(List<CtType> dependences) {
            this.dependences = dependences;
```

```
32          }
33
34          @Override
35          public void accept(CtAnnotation<? extends Annotation> annotation)
    ↪ {
36
    ↪ dependences.add(annotation.getAnnotationType().getDeclaration());
37          }
38
39      }
40
41      /**
42       * A consumer for elements, used to get the type and add the
    ↪ declaration of
43       * it
44       */
45      private class ExecutatbleConsumer implements Consumer<CtElement> {
46
47          private final List<CtType> dependences;
48
49          /**
50           * A consumer for elements, used to get the type and add the
    ↪ declaration
51           * of it
52           *
53           * @param dependences The list to add the found type to
54           */
55          public ExecutatbleConsumer(List<CtType> dependences) {
56              this.dependences = dependences;
57          }
58
59          @Override
60          public void accept(CtElement element) {
61              if (!(element instanceof CtExecutableReference<?>)) {
62                  return;
63              }
64              CtExecutableReference executable = (CtExecutableReference)
    ↪ element;
65              try {
66                  CtTypeReference executableType = executable.getType();
67                  if (executableType != null &&
    ↪ executableType.getDeclaration() != null) {
68                      dependences.add(executableType.getTypeDeclaration());
69                  }
70              }catch (NullPointerException e){
71                  // Ignore spoon errors
72              }
73          }
74      }
75
76      /**
77       * This class processor implements a spoon processor to analyze
    ↪ source code
78       * classes
```

```
79          *
80          * @param parser The parser to use
81          * @param framedGraph The graph with the vertex classes
82          */
83         public ClassAnalysis(Parser parser, FramedGraph framedGraph) {
84             this.framedGraph = framedGraph;
85             this.parser = parser;
86         }
87
88         /**
89          * Processes a single source code class
90          *
91          * @param clazz The class to process
92          */
93         @Override
94         public void process(CtClass<?> clazz) {
95             this.processClass(clazz);
96         }
97
98         /**
99          * Processes a single source code class or interface
100         *
101         * @param clazz The class or interface to process
102         */
103        public void processClass(CtType<?> clazz) {
104
105            VertexClass vertex = VertexClass
106                    .getVertexClassByName(framedGraph,
    ↪ clazz.getQualifiedName());
107
108            if (vertex == null) {
109                return;
110            }
111
112            // Check if added files is set, and if so only analyze those
    ↪ classes
113            if (parser.getAddedFiles() != null) {
114                File file = clazz.getPosition().getFile();
115                if (!parser.getAddedFiles().contains(file)) {
116                    return;
117                }
118            }
119
120            processClassDependencies(clazz, vertex);
121            processClassReferences(clazz, vertex);
122
123        }
124
125        /**
126         * Checks if the given class has a superclass or implements
    ↪ interfaces and
127         * if so adds the corresponding edges to the vertex.
128         *
129         * @param clazz The class being processed
```

```
130      * @param vertexClass The corresponding vertex
131      */
132     private void processClassDependencies(
133             CtType clazz, VertexClass vertexClass
134     ) {
135
136         if (clazz.getSuperclass() != null) {
137             VertexClass superClass
138                     = getOrCreateVertexClass(clazz.getSuperclass());
139             vertexClass.addChildOfClass(superClass);
140         }
141
142         for (CtTypeReference<?> superInterface :
    ↪ clazz.getSuperInterfaces()) {
143             if (superInterface == null)
144                 continue;
145             VertexClass superInterfaceClass
146                     = getOrCreateVertexClass(superInterface);
147             vertexClass.addImplematationOfClass(superInterfaceClass);
148         }
149
150     }
151
152     /**
153      * Goes over all class references for the given class and adds the
154      * corresponding edges.
155      *
156      * @param clazz The class being processed
157      * @param vertexClass The corresponding vertex
158      */
159     private void processClassReferences(CtType clazz, VertexClass
    ↪ vertexClass) {
160
161         for (CtType referencedClass : getClassReferences(clazz)) {
162             if (referencedClass == null || referencedClass.getReference()
    ↪ == null) {
163                 continue;
164             }
165             VertexClass referencedClassVertex
166                     =
    ↪ getOrCreateVertexClass(referencedClass.getReference());
167             vertexClass.addDependOnClass(referencedClassVertex);
168         }
169
170     }
171
172     /**
173      * Finds all dependencies the given class has.
174      *
175      * @param clazz The class being processed
176      */
177     private List<CtType> getClassReferences(CtType clazz) {
178         List<CtType> references = new ArrayList<>();
179
```

```
180         // Sets up the consumers that will add the references.
181         AnnotationConsumer annotationConsumer
182                 = new AnnotationConsumer(references);
183         ExecutatbleConsumer executatbleConsumer
184                 = new ExecutatbleConsumer(references);
185
186         // Get all methods and loop over them
187         for (CtMethod<?> ctMethod : (Set<CtMethod<?>>)
    ↪ clazz.getMethods()) {
188
189             // Get binaryOperators used in the method, so we can check if
    ↪ they
190             // are instanceof elements and add the dependency if so.
191             List<CtBinaryOperator<?>> BinaryElements = ctMethod
192                     .getElements(new
    ↪ TypeFilter<>(CtBinaryOperator.class));
193
194             for (CtBinaryOperator<?> element : BinaryElements) {
195                 if
    ↪ (element.getKind().equals(BinaryOperatorKind.INSTANCEOF)) {
196                     references.add(element.getRightHandOperand().getType()
197                             .getTypeDeclaration());
198                 }
199             }
200
201             // Add all references for annotations this method uses
202             ctMethod.getAnnotations().forEach(annotationConsumer);
203             for (CtParameter<?> parameter : ctMethod.getParameters()) {
204                 parameter.getAnnotations().forEach(annotationConsumer);
205             }
206
207             // Get the body if the method has one
208             CtBlock<?> body = ctMethod.getBody();
209             if (body == null) {
210                 continue;
211             }
212
213             // Get all constructors in the method
214             List<CtConstructorCall<?>> constructorElements = body
215                     .getElements(new
    ↪ TypeFilter<>(CtConstructorCall.class));
216
217             // Get all invocations in the method
218             List<CtInvocation<?>> invocationElements = body
219                     .getElements(new TypeFilter<>(CtInvocation.class));
220
221             // Add all references from the constructors
222             constructorElements.forEach((constructorCall) -> {
223                 constructorCall.getDirectChildren()
224                         .forEach(executatbleConsumer);
225             });
226
227             // Add all references from the invocations.
228             invocationElements.forEach((statement) -> {
```

```
229
    ↪ statement.getDirectChildren().forEach(executatbleConsumer);
230             });
231
232         }
233
234         // Get all annotations the class uses and add them
235         clazz.getAnnotations().forEach(annotationConsumer);
236         for (CtField<?> field : (List<CtField<?>>) clazz.getFields()) {
237             field.getAnnotations().forEach(annotationConsumer);
238         }
239
240         return references;
241     }
242
243     /**
244      * Gets the vertex class by the reference. If it does not exists a new
245      * vertex class, with SystemType set to RetrievedClass, is created and
246      * returned.
247      *
248      * @param clazz The class to find in the graph
249      * @return The found vertex, or a newly created one if it does not
    ↪ exists
250      */
251     private VertexClass getOrCreateVertexClass(CtTypeReference clazz) {
252         // Find the vertex class by name
253         VertexClass vertexClass = VertexClass
254                 .getVertexClassByName(framedGraph,
    ↪ clazz.getQualifiedName());
255
256         // If found we are done and it can be returned
257         if (vertexClass != null) {
258             return vertexClass;
259         }
260
261         // A new vertex class is created.
262         vertexClass = VertexClass
263                 .createRetrievedClass(framedGraph,
    ↪ clazz.getQualifiedName());
264
265         // An inner class does not have a package. So we need to go
    ↪ outside
266         // until we find the parent class that does have a package.
267         CtTypeReference cur = clazz;
268         while (!cur.isPrimitive() && cur.getPackage() == null) {
269             var tmp = cur.getDeclaringType();
270             if (tmp == null || tmp.getPackage() == null)
271                 break;
272             cur = tmp;
273         }
274
275         VertexPackage packageVertex = null;
276         // If the type is a primative (like int or byte) it does not have
    ↪ a
```

```
277             // package, So we set it to java.lang
278             if (cur.isPrimitive()) {
279                 packageVertex = VertexPackage
280                         .getVertexPackageByName(framedGraph, "java.lang");
281                 if (packageVertex == null) {
282                     packageVertex = VertexPackage.createRetrievedPackage(
283                             framedGraph, "java.lang"
284                     );
285                 }
286             } else {
287                 // Get or create the package by name.
288                 CtPackageReference ctPackage = cur.getPackage();
289                 if (ctPackage != null) {
290                     packageVertex = VertexPackage.getVertexPackageByName(
291                             framedGraph, ctPackage.getQualifiedName()
292                     );
293                     if (packageVertex == null) {
294                         packageVertex = VertexPackage.createVertexPackage(
295                                 framedGraph, ctPackage
296                         );
297                     }
298                 }
299             }
300
301             // Set the belongsTo edge.
302             if (packageVertex != null) {
303                 vertexClass.setBelongsTo(packageVertex);
304             }
305
306             return vertexClass;
307         }
308
309 }
```

C.2 Fixed ClassAnalysis class

```
1  /**
2   * This a analysis processor. It takes the source code class and analyzes
      ↪ the
3   * dependencies it has.
4   *
5   * @author Patrick Beuks (s2288842) <code@beuks.net>
6   */
7  public class ClassAnalysis extends AbstractProcessor<CtClass<?>> {
8
9      // The graph with the vertex classes
10     private final FramedGraph framedGraph;
11
12     // The parser containing additional information
13     private final Parser parser;
14
15     // Create a logger
```

```
16      private static final Logger LOGGER
17              = LogManager.getLogger(ClassAnalysis.class);
18
19      /**
20       * A consumer for annotations, used to get the type and add the
    ↪ declaration
21       * of it
22       */
23      private class AnnotationConsumer
24              implements Consumer<CtAnnotation<? extends Annotation>> {
25
26          private final List<CtTypeReference> dependences;
27
28          /**
29           * A consumer for annotations, used to get the type and add the
30           * declaration of it
31           *
32           * @param dependences The list to add the found type to
33           */
34          public AnnotationConsumer(List<CtTypeReference> dependences) {
35              this.dependences = dependences;
36          }
37
38          @Override
39          public void accept(CtAnnotation<? extends Annotation> annotation)
    ↪ {
40              dependences.add(annotation.getAnnotationType());
41          }
42
43      }
44
45      /**
46       * This class processor implements a spoon processor to analyze
    ↪ source code
47       * classes
48       *
49       * @param parser The parser to use
50       * @param framedGraph The graph with the vertex classes
51       */
52      public ClassAnalysis(Parser parser, FramedGraph framedGraph) {
53          this.framedGraph = framedGraph;
54          this.parser = parser;
55      }
56
57      /**
58       * Processes a single source code class
59       *
60       * @param clazz The class to process
61       */
62      @Override
63      public void process(CtClass<?> clazz) {
64          this.processClass(clazz);
65      }
66
```

```
67      /**
68       * Processes a single source code class or interface
69       *
70       * @param clazz The class or interface to process
71       */
72      public void processClass(CtType<?> clazz) {
73
74          VertexClass vertex = VertexClass
75                  .getVertexClassByName(framedGraph,
    ↪ clazz.getQualifiedName());
76
77          if (vertex == null) {
78              return;
79          }
80
81          // Check if added files is set, and if so only analyze those
    ↪ classes
82          if (parser.getAddedFiles() != null) {
83              File file = clazz.getPosition().getFile();
84              if (!parser.getAddedFiles().contains(file)) {
85                  return;
86              }
87          }
88
89          processClassDependencies(clazz, vertex);
90          processClassReferences(clazz, vertex);
91
92      }
93
94      /**
95       * Checks if the given class has a superclass or implements
    ↪ interfaces and
96       * if so adds the corresponding edges to the vertex.
97       *
98       * @param clazz The class being processed
99       * @param vertexClass The corresponding vertex
100      */
101     private void processClassDependencies(
102             CtType clazz, VertexClass vertexClass
103     ) {
104
105         if (clazz.getSuperclass() != null) {
106             VertexClass superClass
107                     = getOrCreateVertexClass(clazz.getSuperclass());
108             vertexClass.addChildOfClass(superClass);
109         }
110
111         for (CtTypeReference<?> superInterface :
    ↪ clazz.getSuperInterfaces()) {
112             if (superInterface == null)
113                 continue;
114             VertexClass superInterfaceClass
115                     = getOrCreateVertexClass(superInterface);
116             vertexClass.addImplematationOfClass(superInterfaceClass);
```

```
117         }
118
119     }
120
121     /**
122      * Goes over all class references for the given class and adds the
123      * corresponding edges.
124      *
125      * @param clazz The class being processed
126      * @param vertexClass The corresponding vertex
127      */
128     private void processClassReferences(CtType clazz, VertexClass
    ↪ vertexClass) {
129
130         for (CtTypeReference referencedClass : getClassReferences(clazz))
    ↪ {
131
132             if (referencedClass == null) {
133                 continue;
134             }
135
136             VertexClass referencedClassVertex =
    ↪ getOrCreateVertexClass(referencedClass);
137             vertexClass.addDependOnClass(referencedClassVertex);
138         }
139     }
140
141     /**
142      * Finds all dependencies the given class has.
143      *
144      * @param clazz The class being processed
145      */
146     private List<CtTypeReference> getClassReferences(CtType clazz) {
147         List<CtTypeReference> references = new ArrayList<>();
148
149         // Sets up the consumers that will add the references.
150         AnnotationConsumer annotationConsumer
151                 = new AnnotationConsumer(references);
152
153         //Creates a list of methods and constructors
154         ArrayList<CtExecutable<?>> executables = new ArrayList<>();
155         executables.addAll((Set<CtExecutable<?>>) clazz.getMethods());
156         if (clazz instanceof CtClass) {
157             executables.addAll((Set<CtExecutable<?>>) ((CtClass)
    ↪ clazz).getConstructors());
158         }
159
160         //retrieve the dependencies out of all the methods and
    ↪ constructors
161         for (CtExecutable<?> ctExecutable : executables) {
162
163             //add return value of method
164             references.add(ctExecutable.getType());
165
```

```
166             // Get binaryOperators used in the method, so we can check if
    ↪ they
167             // are instanceof elements and add the dependency if so.
168             List<CtBinaryOperator<?>> BinaryElements = ctExecutable
169                     .getElements(new
    ↪ TypeFilter<>(CtBinaryOperator.class));
170
171             for (CtBinaryOperator<?> element : BinaryElements) {
172                 if
    ↪ (element.getKind().equals(BinaryOperatorKind.INSTANCEOF)) {
173
    ↪ references.add(element.getRightHandOperand().getType());
174                 }
175             }
176
177             // Add all paramater references and annotations
178             ctExecutable.getAnnotations().forEach(annotationConsumer);
179             for (CtParameter<?> parameter : ctExecutable.getParameters())
    ↪ {
180                 parameter.getAnnotations().forEach(annotationConsumer);
181                 references.add(parameter.getType());
182             }
183
184             // Get the body if the method has one
185             CtBlock<?> body = ctExecutable.getBody();
186             if (body == null) {
187                 continue;
188             }
189
190             // Get all constructors in the method
191             List<CtConstructorCall<?>> constructorElements = body
192                     .getElements(new
    ↪ TypeFilter<>(CtConstructorCall.class));
193
194             //add all references for the constructor calls in the method
195             for(CtConstructorCall<?> c : constructorElements){
196                 references.add(c.getType());
197             }
198
199             // Get all invocations in the method
200             List<CtInvocation<?>> invocationElements = body
201                     .getElements(new TypeFilter<>(CtInvocation.class));
202
203             // Retrieve the dependencies of all invocations
204             for(CtInvocation<?> c : invocationElements){
205                 if(c.getExecutable().getDeclaringType() == null){
206                     LOGGER.warn("Spoon cannot find the declaration of " +
    ↪ c);
207                 }else {
208                     references.add(c.getExecutable().getDeclaringType());
209                 }
210             }
211         }
212
```

```
213         // Get all annotations the class uses and add them
214         clazz.getAnnotations().forEach(annotationConsumer);
215
216         // add all the fields types and annotations
217         for (CtField<?> field : (List<CtField<?>>) clazz.getFields()) {
218             field.getAnnotations().forEach(annotationConsumer);
219             references.add(field.getType());
220         }
221
222         return references;
223     }
224
225
226     /**
227      * Gets the vertex class by the reference. If it does not exists a new
228      * vertex class, with SystemType set to RetrievedClass, is created and
229      * returned.
230      *
231      * @param clazz The class to find in the graph
232      * @return The found vertex, or a newly created one if it does not
    ↪ exists
233      */
234     private VertexClass getOrCreateVertexClass(CtTypeReference clazz) {
235
236         // Find the vertex class by name
237         VertexClass vertexClass = VertexClass
238                 .getVertexClassByName(framedGraph,
    ↪ clazz.getQualifiedName());
239
240         // If found we are done and it can be returned
241         if (vertexClass != null) {
242             return vertexClass;
243         }
244
245         // A new vertex class is created.
246         vertexClass = VertexClass
247                 .createRetrievedClass(framedGraph,
    ↪ clazz.getQualifiedName());
248
249         // An inner class does not have a package. So we need to go
    ↪ outside
250         // until we find the parent class that does have a package.
251         CtTypeReference cur = clazz;
252         while (!cur.isPrimitive() && cur.getPackage() == null) {
253             var tmp = cur.getDeclaringType();
254             if (tmp == null || tmp.getPackage() == null)
255                 break;
256             cur = tmp;
257         }
258
259         VertexPackage packageVertex = null;
260         // If the type is a primative (like int or byte) it does not have
    ↪ a
261         // package, So we set it to java.lang
```

```
262             if (cur.isPrimitive()) {
263                 packageVertex = VertexPackage
264                         .getVertexPackageByName(framedGraph, "java.lang");
265                 if (packageVertex == null) {
266                     packageVertex = VertexPackage.createRetrievedPackage(
267                             framedGraph, "java.lang"
268                     );
269                 }
270             } else {
271                 // Get or create the package by name.
272                 CtPackageReference ctPackage = cur.getPackage();
273                 if (ctPackage != null) {
274                     packageVertex = VertexPackage.getVertexPackageByName(
275                             framedGraph, ctPackage.getQualifiedName()
276                     );
277                     if (packageVertex == null) {
278                         packageVertex = VertexPackage.createVertexPackage(
279                                 framedGraph, ctPackage
280                         );
281                     }
282                 }
283             }
284 
285             // Set the belongsTo edge.
286             if (packageVertex != null) {
287                 vertexClass.setBelongsTo(packageVertex);
288             }
289 
290             return vertexClass;
291         }
292 
293 }
```

Appendix D

Sample Output

D.1 Output Template

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<results>
  <allPackages count="Integer" countExternal="Integer"
  ↪ countInternal="Integer" countUnknown="Integer">
    <pkg id="Integer" internal="Boolean">name.of.package</dependency>
    etc.
  </alPackages>
  <allDependencies count="Integer">
    <dep fromID="Integer" toID="Integer">
      <!-- the following elements are only present when the
  ↪ "human-readable" option is used -->
      <fromIsInternal>Boolean</fromIsInternal>
      <fromName>name.of.package</fromName>
      <toIsInternal>Boolean</toIsInternal>
      <toName>name.of.other.package</toName>
    </dep>
    etc.
  </allDependencies>
  <tools count="Integer">
    <tool name="String">
      <foundPackages count="Integer" countExternal="Integer"
  ↪ countInternal="Integer" countUnknown="Integer"
  ↪ percentageExternal="Float" percentageInternal="Float"
  ↪ percentageTotal="Float" percentageUnknown="Float">
        <!-- the "internal" attribute and the package name are not
  ↪ present when the "compact" option is used -->
        <pkg id="Integer" internal="Boolean">name.of.package</pkg>
        etc.
      </foundPackages>
      <missedPackages count="Integer" countExternal="Integer"
  ↪ countInternal="Integer" countUnknown="Integer"
  ↪ percentageExternal="Float" percentageInternal="Float"
  ↪ percentageTotal="Float" percentageUnknown="Float">
```

```
25          <!-- the "internal" attribute and the package name are not
    ↪ present when the "compact" option is used -->
26          <pkg id="Integer" internal="Boolean">name.of.package</pkg>
27          etc.
28        </missedPackages>
29        <foundDependencies count="Integer" percentageTotal="Float">
30          <dep fromID="Integer" toID="Integer">
31            <!-- the following elements are only present when the
    ↪ "human-readable" option is used -->
32            <fromIsInternal>Boolean</fromIsInternal>
33            <fromName>name.of.package</fromName>
34            <toIsInternal>Boolean</toIsInternal>
35            <toName>name.of.other.package</toName>
36          </dep>
37          etc.
38        </foundDependencies>
39        <missedDependencies count="Integer" percentageTotal="Float">
40          <dep fromID="Integer" toID="Integer">
41            <!-- the following elements are only present when the
    ↪ "human-readable" option is used -->
42            <fromIsInternal>Boolean</fromIsInternal>
43            <fromName>name.of.package</fromName>
44            <toIsInternal>Boolean</toIsInternal>
45            <toName>name.of.other.package</toName>
46          </dep>
47          etc.
48        </missedDependencies>
49      </tool>
50      etc.
51    </tools>
52  </results>
```

Listing D.1: The structure of the output of our dependency checker