UNIVERSITY OF WESTERN ONTARIO

DEPARTMENT OF COMPUTER SCIENCE

CS4470Y: SOFTWARE MAINTENANCE AND CONFIGURATION

FINAL PROJECT REPORT

Faulty: Fault Localization as a Service

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Abstract

Lorem ipsum sodales, accumsan neque eu, placerat purus. Interdum et malesuada fames ac ante ipsum primis in faucibus. Nulla id varius metus, id vestibulum purus. Nullam malesuada urna purus, quis euismod velit tristique et. Fusce auctor laoreet arcu ac maximus. Duis ultricies malesuada dui id pharetra. Donec tempus semper enim, in interdum ante pharetra sed. Vivamus vel accumsan metus. Vivamus eu enim est. Duis ac dolor a quam lacinia interdum in ut sem. Ut ipsum orci, dignissim vel ante eget, blandit sollicitudin dolor. Sed eu orci dolor sit amet, consectetur adipiscing elit. Duis dapibus nisl vitae tempor placerat. Duis feugiat odio vitae quam pellentesque, ac semper ex sagittis. Nunc id egestas tortor. Morbi nibh tortor, suscipit vel libero quis, placerat molestie nulla. Nullam pellentesque ex ac viverra lobortis. Donec hendrerit nibh nisi, a bibendum urna efficitur ut. Cras venenatis sem magna, vel dignissim augue convallis a. Proin sapien justo, viverra ac enim sit amet, cursus aliquet tellus. Nulla at lacus magna. Nullam sit amet dui convallis, interdum felis eu, viverra ligula. Pellentesque sed mollis nibh, at ultricies nisi.Quisque id velit suscipit ipsum auctor egestas egestas sit amet dui. Curabitur at sem nunc. Nunc non ultrices ex, et egestas odio.

Introduction *(1.5 pages max)*

Concepts, Terms, Definitions, Equations

RSF

An RSF is a map of relationships betweens tokens within a codebase, where a token is a keyword in the codebase such as a method. It is generated using preprocessing scripts, and the result allows us to verify tokens inside of bug reports.

Bug Report

A database entry for each bug report used for the analysis. Each bug report contains a String field containing what a user wrote inside their bug report.

Token Expansion

Tokens extracted from the bug report are expanded to find other similar tokens. Token expansion includes tokens that are referenced by the original token set.

Clique

A collection of tokens that are referenced the most within the expanded set of tokens

Cluster

A group of relationships that are closely related to each other

Background and Related Work

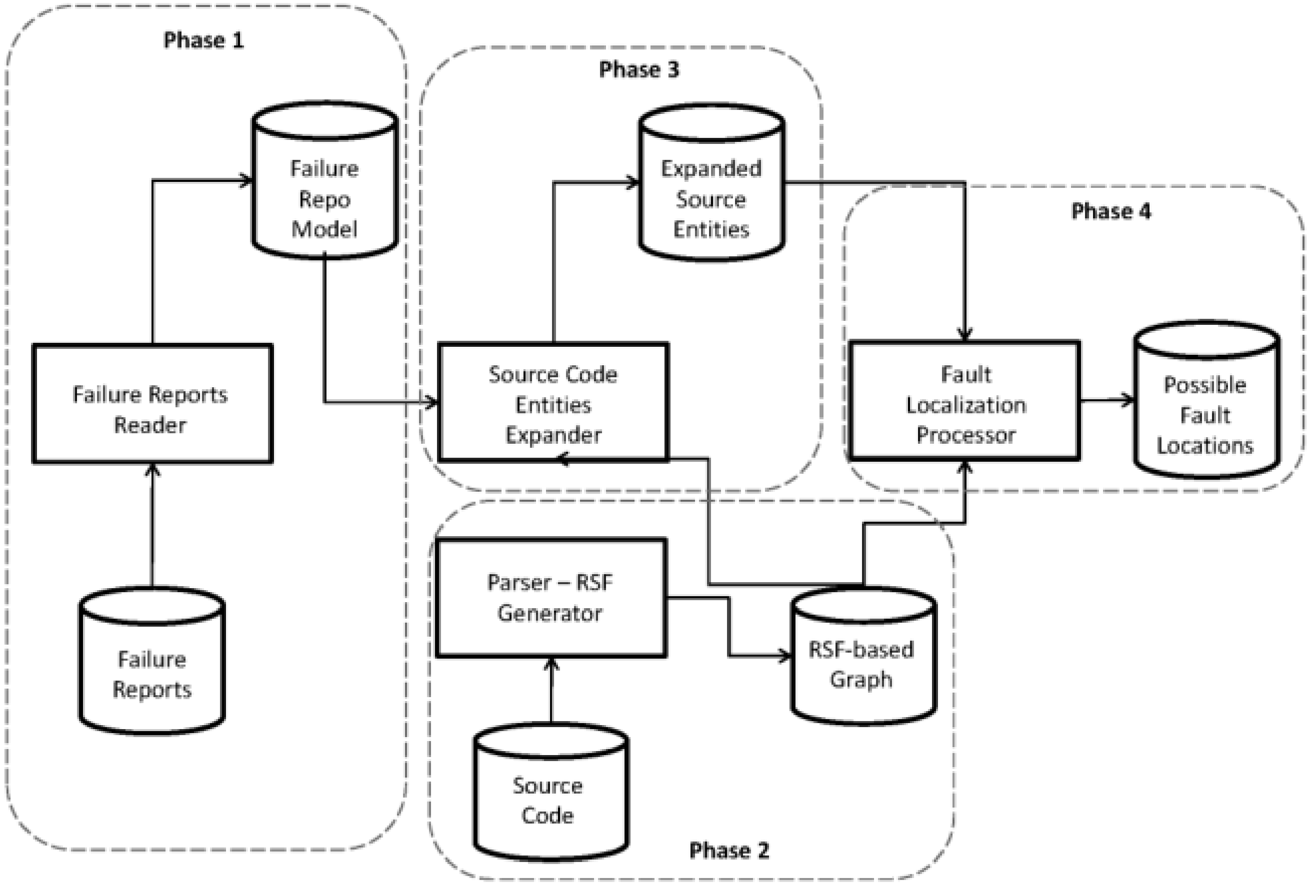
The main purpose of this project is to assist in locating faults so developers can isolate errors quicker. There are three main categories of fault localization: static-analysis/test-case based approach, machine learning based approach, and a type based approach. The method that we are expanding upon falls into the first category with an approach that heavily relies on preforming static analysis on the code and bug texts.

This project was conceived from research that Professor Kontogainnis had completed with past students regarding the task of determining faults in a large codebase using only past bug reports. Past students had experimented with multiple algorithms for processing large amounts of bug reports in order to come up with an index of files that are most likely to have a new bug within them.

The project operated in many phases. Each one containing one very specific task. The first phase involved extracting bug reports from a repository and parsing them through a reader into an object model that allowed easier processing. The second phase handled pulling the source code of the project and generating tokens. Tokens can be entities in the codebase but for our specific use they are method names that are later lifted up to filenames. A map of these tokens is created and then using the results from phase 1 and 2, the next piece of software is ready to make a connection between these two datasets. In phase 3 each of the tokens extracted from the bug report are verified and expanded to generate a set of tokens that include all relatives to each token. A token's relative is defined as a token that makes a call to or from the original token.

The first three phases mostly involved preprocessing different datasets into a form that would be ideal for making a conclusion. At this point we have a large set of entities that we suspect are vaguely related to the bug report we want to process. Phase 4 is where we begin making conclusions on the data. The software chooses between two algorithms for determining the score that will indicate the faulty files. If the amount of files associated with the bug are less than 15% of the total system files, we choose the simpler algorithm and find the score by determining which files have the most outward connections to the codebase. If the bug effects more than 15% of total files, we generate clusters of related entities using our relationship map produced in phase 2 and then for each cluster we check how connected it is to the most important files related to our bug. The cluster that is most connected has the highest chance of containing the bug.

The original system consisted of a collection of scripts written in Java, Python and Shell. The scripts were fairly distributed and had very little documentation. Most of the work was done in intermediate steps and did not fit well together as a system because too much user intervention was required between steps.



Development Objectives

The focus will be to design and develop a system that is capable of processing bug reports and extracting useful information about them, and then using that information to provide the developers useful insight into where the bug may be within a large code base. The goal is to reduce the amount of time a developer will need to reach the correct bug after initially reviewing the bug report.

The system will be developed in such a way that it is easily integrated into a continuous delivery pipeline. The project can be divided into three distinct components.

Data Processing (O1)

In order for the entire system to work correctly the core essential data processing and analysis has to be effective in detecting the errors. Therefore, the first step is developing a system that can use NLP to process all the bug reports associated with a project to come up with a list of keywords and process the code base to determine a map of relationships between function calls. This code has now been written and is mostly within our project.

User Interface (O2)

The next step in delivering the system to a real user, is developing a front end where a user can input a repository for the system to begin processing. Ideal operation of this tool would occur like other DevOps pipeline tools such as travis-ci.org where a user can link a repository they own and the tool can push it's results back into the bug report for developers to see. There will not be too many interactions available on the front end other than viewing the results of the system and picking new repositories. This portion of the project is not yet completed. Refer to deviations section to understand the reasoning for putting the interface as the last priority.

Runtime Processing (O3)

Since the front end will be making REST API calls to Github repositories, and we need a way to persist processing while providing consistent feedback to users, there needs to be a backend API service allowing those operations to occur. Another task this portion will be responsible for is handling the flow of information when a new bug report appears. The backend will be responsible for detecting this, starting a new processing task, and posting a "Fault Report" back into the bug discussion. A substantial amount of work has been done on this portion of the project. The backend is able to communicate with Github and catch issues posted by users.

System Requirements

Section A : Data Processing

- **Feature 1:** Able to generate entity relationship rsf from codebase
  - FR 1: Pass code through cdif2rsf to generate rsf
  - FR 2: Clean up incorrect entity and relationships
  - FR 3: Store in accessible data storage for next step to use
- **Feature 2:** Able to generate set of keywords from bug description
  - FR 1: Compare each token to codebase to find valid functions
  - FR 2: Expand initial token set by a factor of 3
  - FR 3: Use NLP to determine question context
- **Feature 3:** Able to combine keywords and rsf into ranked outcomes
  - FR 1: Run LSI on each token and generate search space for each
  - FR 2: Expand the search space for each result in FR 1
  - FR 3: Find similarities between the initial token expansion and the final set of tokens
  - FR 4: Apply ranking equation from research paper to come up with final outcome

Section B : Front-End User Interface

- **Feature 4:** User is able to scan and mark a new repository for processing
  - FR 1: Scan user's Github repos using Github's API

  - FR 2: Allow the user to select ones they wish to run processing on
  - FR 3: Remember which ones the user selected by storing on backend

- **Feature 5:** User is able to view the results of a new bug report's processing
  - FR 1: Monitor output from backend endpoints showing new results for user's repos
  - FR 2: When a new bug report is created, and the processing finishes, show the output of that processing on a separate page
  - FR 3: Allow the user to rerun processing on a specific bug report by sending a request to backend

- **Feature 6:** User is able to login using their Github credentials
  - FR 1: On first usage redirect user to Github's App authentication page
  - FR 2: Ask backend to associate bug reports and repositories with this user
  - FR 3: Redirect user to main UI

Section C : Back-End Runtime Processing

- **Feature 7:** Support front-end operations
  - FR 1: Allow registration using Github Auth
  - FR 2: Allow retrieval of processing results for each bug report
  - FR 3: Support re-running processing on a specific bug report
  - FR 4: Create a API where the UI can fetch everything from

- **Feature 8:** Manage the automation of Data Processing (F1, F2, and F3)
  - FR 1: Automate RSF generation when a new repository is linked
  - FR 2: Automate keyword generation when a new repository is linked
  - FR 3: Continuously improve and modify RSF and keywords as code/bugs change

- **Feature 9:** Handle processing and evaluation when a new bug report comes in
  - FR 1: Monitor marked repositories for each registered user and trigger when new issue is filed
  - FR 2: Run through automated ranking algorithm
  - FR 3: Store result for later retrieval
  - FR 4: Be able to connect to a repository and fetch an issue when it is posted

- **Feature 10:** Combine each element of data processing into the backend runtime
  - FR 1: Combine entity generation into token generation
  - FR 2: Combine FR1 with RSF processing all into one unit
  - FR 3: Move all functionality to an exposed part of the API
  - FR 4: Create all endpoints for data processing functionality

Development Strategy

Since this project had many parts of it already implemented, just in poor condition, we did not have many choices over what development tools and languages to use. The majority of the project was written in Java, with some separate Python scripts used for data manipulation at some of the stages in the system.

Since we started the API from scratch, we had more choices on technologies and tools in that section. The API was written in Kotlin because it allowed us to have easy access to the Java code since it is still a JVM language but also provide higher level functionality and cleaner syntax to speed up development. The API is supported by MongoDB for storing data from Github issues and the future UI.

Git and Github were used for collaboration between the two developers and ngrok was used to host the services. Another tool that really helped our development strategy was Robo3t as it allowed us to monitor the MongoDB for incoming objects and see them in realtime.

All the datasets we used for our processing came from BugZilla as that was the only platform supported by the preexisting preprocessing scripts. The project repositories we accessed were amarok, konjueror, k3b, and kopete.

Technologies

- Kotlin
- Python
- Java
- Javalin
- MongoDB
- Github Webhooks

Tools

- Intellij Idea
- NeoVim
- Robo3T
- ngrok
- Git
- Github

Datasets

- BugZilla bug reports
  - amarok repository
  - Konqueror repository
  - k3b repository
  - kopete repository

Results

BugLocalization Project

- Restructured and cleaned up codebase
- Reduced very large codebase to 10 files
- Documented and made more readable for easier integration
- Cleaned up data flow to allow easier integration with API

The BugLocalization project has been completely revamped to work better with the API design. A large amount of redundant code has been removed and only the essential functionality exists. Everything has been commented and documented for easier maintainability and modularity.

This project produces two types of output depending on the input and which algorithm is chosen for processing the token scoring. Figures 4 and 5 show you examples of each type of output figure 4 shows the results received when you run BugLocalization with a small bug and a simple algorithm is chosen. Figure 5 shows the results when you run BugLocalization with a large bug and make use of the complex ranking algorithm.

API

- Able to monitor a GitHub repo for events
- Detect new issues and add into a Mongo database
- Able to start and end deployments on Pull Requests

The API was started from scratch and has progressed into something that can be relied on to fetch and process incoming bug reports and support a future UI. Currently the API is able to catch incoming Github webhooks and take repository information from the HTTP request. Using this information and the object model of the repository it can create an entry in the database to represent it. When new issues come in they are added to the object model inside the database and when processing begins it can read that model from the database.

The results produced by the API are visible inside the object model of the database. This model populated with some dummy issues can be seen in the Robo3t screenshot in figure 6

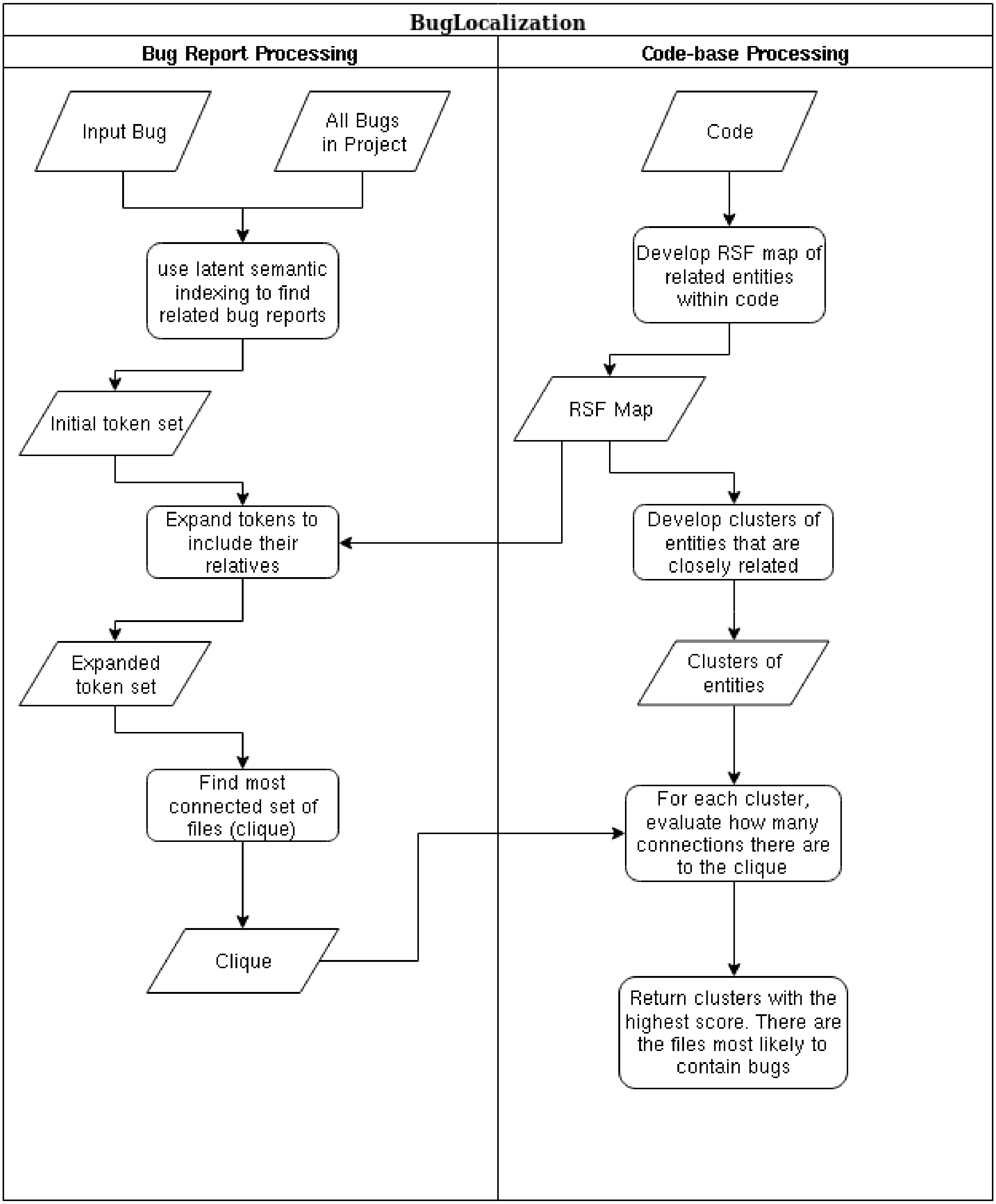

BugLocalization
Bug Report Processing
Code-base Processing
Input Bug
All Bugs in Project
use latent semantic indexing to find related bug reports
Initial token set
Expand tokens to include their relatives
Expanded token set
Find most connected set of files (clique)
Clique
Code
Develop RSF map of related entities within code
RSF Map
Develop clusters of entities that are closely related
Clusters of entities
For each cluster, evaluate how many connections there are to the clique
Return clusters with the highest score. There are the files most likely to contain bugs

Figure 2

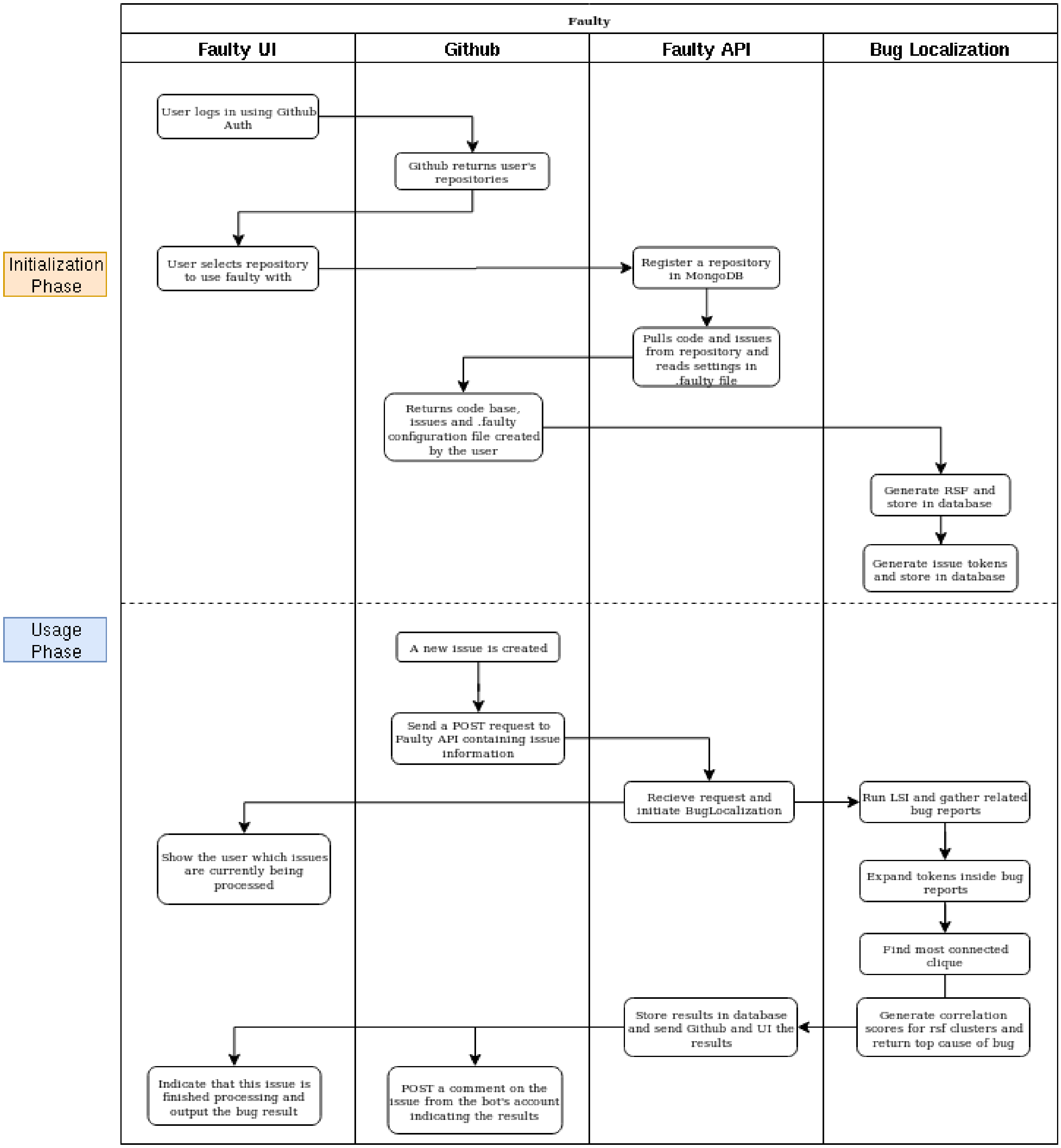

Faulty
Faulty UI
Github
Faulty API
Bug Localization
Initialization Phase
Usage Phase
User logs in using Github Auth
Github returns user's repositories
User selects repository to use faulty with
Register a repository in MongoDB
Pulls code and issues from repository and reads settings in .faulty file
Returns code base, issues and .faulty configuration file created by the user
Generate RSF and store in database
Generate issue tokens and store in database
A new issue is created
Send a POST request to Faulty API containing issue information
Recieve request and initiate BugLocalization
Run LSI and gather related bug reports
Show the user which issues are currently being processed
Expand tokens inside bug reports
Find most connected clique
Store results in database and send Github and UI the results
Generate correlation scores for rsf clusters and return top cause of bug
Indicate that this issue is finished processing and output the bug result
POST a comment on the issue from the bot's account indicating the results

Figure 3

```
productName :
168660_LSA.txt
Total expansion Steps = 0
Total System Files = 816
Total non .h Files = 448.0
Total non .h Files from Expansion= 0.0
Starting with 0 files, after removing .h I am left with 0 files
clique size = 0
168660
-------------------------------------
315463_LSA.txt
Total expansion Steps = 1
Total System Files = 816
Total non .h Files = 448.0
Total non .h Files from Expansion= 4.0
Starting with 4 files, after removing .h I am left with 4 files
clique size = 1
315463
        src/projects/k3bdataprojectmodel.cpp                                                        3.000000
        src/main.cpp                                                                                3.000000
        src/k3bjobprogressdialog.cpp                                                                8.000000 <-------------
        libk3b/projects/videodvd/k3bvideodvddoc.cpp                                                 2.000000
-------------------------------------
```

Figure 4

```
productName :
322474_LSA.txt
Total expansion Steps = 1
Total System Files = 2088
Total non .h Files = 1104.0
Total non .h Files from Expansion= 307.0
LsaFileTokens at start = 74
LsaFileTokens after expansion 416
Recall (Pre reduction)= 1.0
Starting with 416 files, after removing .h I am left with 307 files
**********************PERFORMING CLUSTERING***********************
21
meanExpectation = 3.3848820261458132
ClusterName                                                      Score   expectation  Connect
src/services/magnatune/magnatuneredownloadhandler.cpp           4.000000   0.026230     4.00
tests/core-impl/collections/support/testmemoryquerymaker.cpp    4.000000   0.026230     4.00
tests/services/amazon/testamazonparser.cpp                      4.000000   0.026230     4.00
src/mediadevicemonitor.cpp                                      4.000000   0.026230     4.00
src/dialogs/tagguesserdialog.cpp                                5.000000   0.049180    10.00
src/core-impl/collections/db/sql/sqlcollection.cpp              5.000000   0.049180    10.00
src/services/opmldirectory/opmldirectoryview.h                  5.000000   0.032787     5.00
src/services/mp3tunes/mp3tuneslocker.cpp                        5.000000   0.032787     5.00
src/context/popupdropper/libpud/popupdropper.cpp                5.400000   0.053115    36.00
src/aboutdialog/extendedaboutdialog.cpp                         5.400000   0.053115     9.00
src/core-impl/collections/db/sql/sqlregistry.cpp                5.909091   0.096870    13.00
src/services/jamendo/jamendoxmlparser.cpp                       6.000000   0.039344     3.00
src/services/scriptable/scriptableservice.cpp                   7.333333   0.096175    11.00
src/scriptmanager.cpp                                           7.500000   0.073770    15.00
src/svghandler.cpp                                              8.000000   0.078689     8.00
src/covermanager/covermanager.cpp                               8.322581   0.163723    43.00
src/context/applets/albums/albums.cpp                           8.461538   0.138714    22.00
src/services/lastfm/lastfmservice.cpp                           9.230769   0.181589    40.00
src/services/amazon/amazonstore.cpp                            11.666667   0.191257    14.00
src/context/engines/wikipedia/wikipediaengine.cpp              12.077922   0.395997    93.00
src/browsers/browserbreadcrumbwidget.cpp                       15.000000   0.295082    50.00
src/amarokurls/amarokurlhandler.cpp                            15.396825   0.504814    97.00
src/mainwindow.cpp                                             19.500000   0.895082    78.00
src/core-impl/collections/nepomukcollection/nepomukquerymaker.cpp  Infinity   Infinity     1.00
```

Figure 5

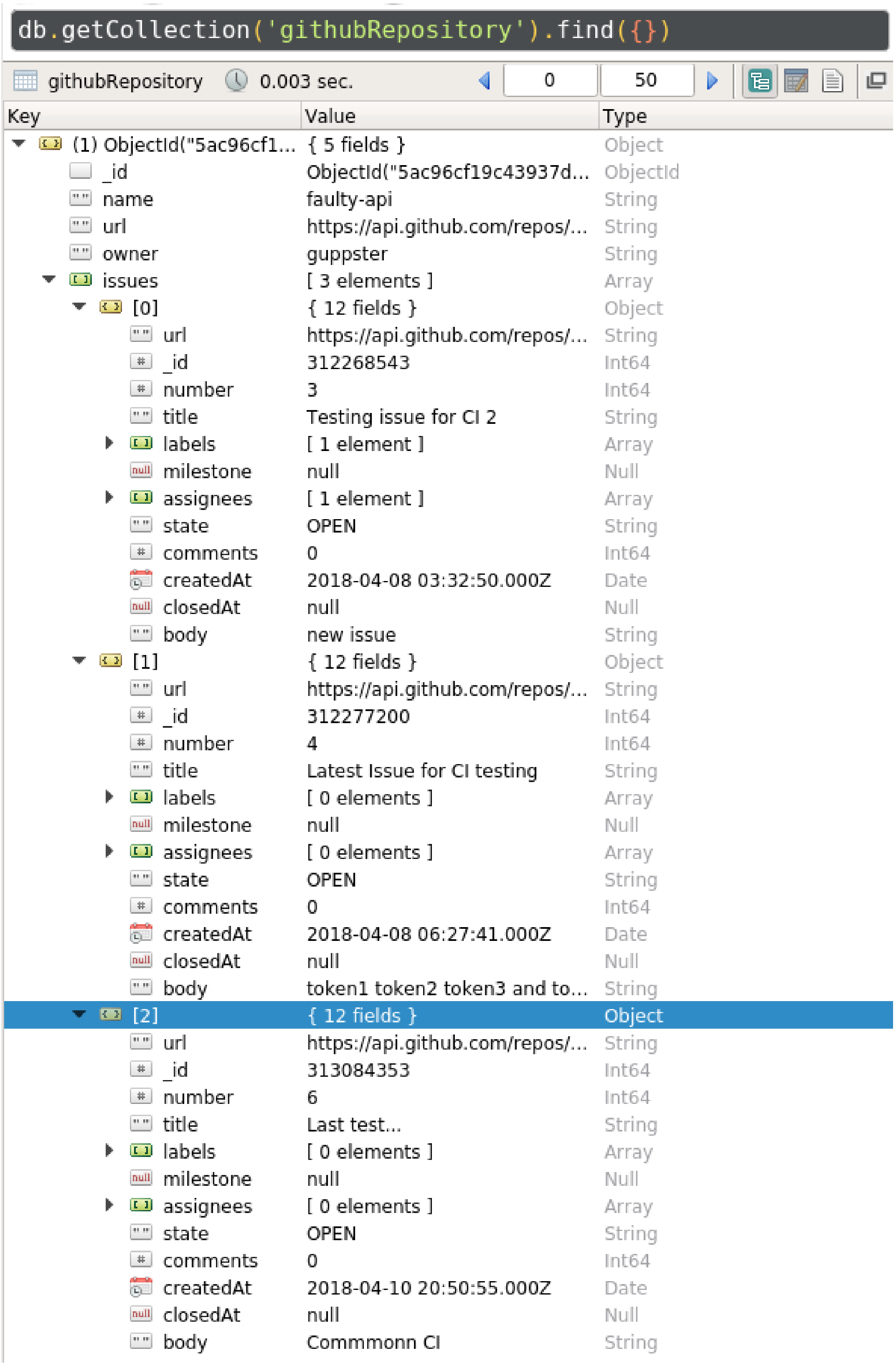

db.getCollection('githubRepository').find({})
githubRepository
0.003 sec.
0
50
Key
Value
Type
(1) ObjectId("5ac96cf1... { 5 fields } Object
_id ObjectId("5ac96cf19c43937d... ObjectId
name faulty-api String
url https://api.github.com/repos/... String
owner guppster String
issues [3 elements] Array
[0] { 12 fields } Object
url https://api.github.com/repos/... String
_id 312268543 Int64
number 3 Int64
title Testing issue for CI 2 String
labels [1 element] Array
milestone null Null
assignees [1 element] Array
state OPEN String
comments 0 Int64
createdAt 2018-04-08 03:32:50.000Z Date
closedAt null Null
body new issue String
[1] { 12 fields } Object
url https://api.github.com/repos/... String
_id 312277200 Int64
number 4 Int64
title Latest Issue for CI testing String
labels [0 elements] Array
milestone null Null
assignees [0 elements] Array
state OPEN String
comments 0 Int64
createdAt 2018-04-08 06:27:41.000Z Date
closedAt null Null
body token1 token2 token3 and to... String
[2] { 12 fields } Object
url https://api.github.com/repos/... String
_id 313084353 Int64
number 6 Int64
title Last test... String
labels [0 elements] Array
milestone null Null
assignees [0 elements] Array
state OPEN String
comments 0 Int64
createdAt 2018-04-10 20:50:55.000Z Date
closedAt null Null
body Commmonn CI String

Figure 6

Discussion

Threats to the validity of the results

Due to the large amount of bug reports and the possibility of having reports without enough details, the results are not guaranteed to find where the fault occurs. The ranking used in the system is useful in mitigating incorrect results, but does not ensure that any of the results will be useful in determining the cause of fault in the software. A lot of other methods used to minimize the threats to validity were already implemented in the project, but it was mentioned that using different algorithms would allow us to compare the accuracy of different methods.

Implications of the results

One of the original goals of this project was to implement another algorithm for determining the cause of fault to then use to compare the validity of the results for both algorithms. The validity of the results is important for a system like this because of how flexible it is for testing on software projects. The system would be language agnostic and allow the user to be able to accurately detect specific points of faults in software projects that use multiple languages. This is much more useful than traditional tools used for detecting issues in software and would be applicable to any project, where those that have large projects and/or use multiple languages would benefit the most. This system would save software engineers lots of time and effort wasted on debugging issues with software systems that don't provide enough information about where a fault in the program occurs.

Limitations of the results

The main limitation to this project is the complexity of being able to detect a fault based on reports alone. When developing, users have many methods of getting feedback through logs and error detection that are not available to our system. The best way to remove this limitation would be to get more details from failure reports, but unfortunately there are not many alternatives that offer nearly as many reports as BugZilla.

Conclusions

Unfortunately, for our project we had some communication problems for a large portion of the year. We ended up getting a late start to the project and had to re-purpose the project after the second milestone. Due to our late start and a couple missing scripts, we did not have access to all parts of the system needed to create a complete system and did not have enough time to create a standalone service with a UI. The implications of creating a complete system would mean that the computer running the system would have to be powerful enough to process all parts of the analysis within a reasonable amount of time in order to be of use to the programmer. Based on our testing with the components we had, we believe that this would be achievable if given access to the remaining parts of the program. We were able to refactor the code and greatly improve the structure and readability. The main method contained too much of the logic of the system, so modularizing the code and adding comments made it much easier to understand for others who will look at the code.

Completing O2 added the ability to connect to GitHub using their API and get issues from their tracker. Since the biggest change to the existing system is the report data used, the main structure of the system remains the same while allowing it to be used in another useful domain. Using this system in GitHub allows developers to easily discover faults in their applications. The system is set to be run whenever an issue was added by a user and would notify the repo owner.

Future Work and Lessons Learnt

Future work

For further development, we would want to develop software to process issues incrementally into the BugLocalization. We would then integrate the BugLocalization project as part of the API and utilize its full power. Since we did not manage to complete O3, we would also want to make a web UI similar to Travis to display results.

Lessons learnt

We have learned from this project how important it is to develop consistent communication plan with stakeholders. At many times during this project, we went long periods of time without meeting to discuss how our progress is going. This created some problems because we were unsure of how to run the program initially and had to email a grad student to get some of the missing files. Getting email responses took longer than in person, so having more consistency to meet and discuss problems in person would have been beneficial.