Maintaining differently refactored views in Java

by

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Abstract

When developers collaborate on a project there are times when the code diverges. This could be due to refactoring, or the code being reused in another project. It could even be due to throw away code or code used for debugging. This could at times also involve how the structure of the program is presented or the variable and method names that are being used. In these cases you may need to refactor the code to best suit your changes before you apply them. The ability to have a separate view which although functionally equivalent to other views can present the code in a different form in these situations would be valuable. It enables the programmer to refactor or change the code with minimal impact on others. Changes in the order of of methods and the addition of comments currently impact other developers even if there is no change in how the code works. A tool has been written to detect where source code has been moved within a file or comments has been added removed or edited. This gives us an indication that it would be useful for version control systems to differentiate between changes to a program that also change the behaviour and changes to a program that do not change any behaviour.

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Chapter 1

Introduction

According to Bertino [3] *Version control systems* provide a way of allowing multiple developer to collaborate. When multiple developers work on the same source code there is a risk that they have conflicting changes for the same portion of the source code. One way of managing these conflicting changes is by ensuring only one person can edit a file at a time. This locking mechanism was recommended by Tichy [16] for the RCS version control system. The problem with this is that one person can stop anyone else from being able to edit the file.

An alternative approach is to allow multiple changes to a file and to automatically resolve most of them in a process called a *merge*. The merge process compares the changes made for one version with the changes made on the other revision. If the merge process determines that changes can coexist it creates a merged file that contains all the changes. The changes that cannot be automatically merged are known as *merge conflicts*. The merge conflicts need to be manually checked and edited to form a merged file with the correct changes.

Internally the merge process needs to determine what changes have happened to both of the revisions being compared. In figure 1.1 there are two revision that are derived from a common ancestor. It is possible to determine what has been deleted, inserted or changed by comparing each

Figure 1.1: A file that has two different revisions

of the revisions against the common ancestor. This is often done as a linear comparison. This works very well provided there has been no change in the order or structure of the file.

However, if there has been a change where a block of source code has been moved from one place to another a linear comparison instead determines that two changes have occurred. This is equivalent to deleting a block of source code from the common ancestor and inserting that source code elsewhere. This change becomes pointless when a program behaves in the same manner even when source code is in a different order. An example of this is if a Java programmer changes the order of methods within a program. The program will behave in the same way as changing the order of methods does not change any functionality, however the source code is now different. The swapping of the order of the method is still counted as being two different changes even though the program behaves in the same manner as it did before the change took place.

Without any further analysis this unnecessary change is recorded in the merged file. Although there has been no functional change the version control systems will treat the relocation of blocks of source code exactly like a change in functionality. Whenever a programmer attempts to update

their code to incorporate any change in functionality, the change to the order of methods is also made to their code. If a programmer is already familiar with the old structure of code, swapping methods unnecessarily could be disconcerting.

If there are two separate revisions that both have changes in the order of methods then it is possible to get a merge conflict. In both of the revisions the behaviour of the program has not changed. Conflicting but pointless changes to the structure of the source code require manual intervention. This issue has highlighted the need to develop smarter ways to merge.

It is becoming more important to have accurate merges because of the scale of many software projects and the number of developers working on them. Large online repositories, like GitHub, contain many open source projects can make source code available to many developers at a time. It is possible for two developers to work on the same project while having little personal contact. Care needs to be taken when their individual work is combined. Preferably most of the problems with merging their work should be automatically resolved, however there still could be instances where either or both developers will have to figure out how the code should interact. Having better automatic merges reduces the risk that time will be spent manually figuring out how different changes should be combined.

This thesis explores a way of allowing a version source control system to detect when there is a change in the source code but not in the behaviour of a program. Examples of this is if items have been reordered, if comments have been inserted or there have been changes to the formating. It also introduces the concept of maintaining multiple separate views of differently ordered but equivalent source code for the purpose of reducing the number of changes introduced during a merge.

In order to do this the source code needs to be divided into understandable sections. When each of these sections for each revising are compared

it is possible to determine if a section has been moved. This enhances what can be detected when examining the differences between two files.

Chapter 2

Background

As this thesis is about maintaining differently refactored branches within a version control system refactoring what follows is some background concerning version control systems and how they determine if a change has occurred in source code. We will also cover refactoring before looking more closely at JDime and other tools that attempt to reduce merge conflicts caused by refactoring.

2.1 Version Control Systems

Version control systems are a way of managing different revisions (or versions). Version control systems can be used to keep revisions of files that are in any format. Most commonly they are used for maintaining source code written for a plain text programming language (e.g. Java, C, etc.). There are a number of reasons why we might want to use a version control system. It can be used to refer to previous revisions, to maintain a revision that has an experimental feature, to associate additional documentation about a feature or to collaborate with multiple developers who are on the same programming project.

Revisit revisions using tagging. A version control system can be used by

a single person to manage different revisions of their program. A previous revision can always be revisited at a later date and changed. If there is something significant about a particular revision it can be labelled with a *tag*. A tag assigns a name to all the files in the revision you are interested in so that you can more easily revisit the code at a certain point. This is helpful if a software package has a number of released versions. If you need to go back and revisit a particular release it becomes a lot easier if you have tagged the code at that point with the release name or identification.

Use branching for experimental features. It is also possible to maintain multiple revisions of all the files for a software project. This is useful if there is an experimental feature which you want to explore but want to maintain the original as a separate project. As shown in figure 2.1 a version control system can keep these multiple interests separate by putting them on different *branches*. It is still possible to easily switch between the different branches depending on which project you want to make changes to. A good use of this feature is if you have a software project that you have written on behalf two different companies but each of them would like their own unique customisations on top of the base product. By making two copies of the base product and having a record of when it was divided the branches can later be recombined to include some or all of the features that have been introduced. According to Willaims [**?**] branching and merging still is complex and it is hard to get good results from a text-based merge.

Attach documentation to a feature. Another useful feature of version control is the ability to record meta information beside changes to a set of files. The reason this is useful is that you can specify what the change was for. It is possible to associate a change that has occurred over multiple files as being for the same reason. Once the change

has been made is possible in most version control systems to write a message when the documents are checked in. In some version control systems this message is required to check-in any set of documents. The reason this is useful is at a later date if queries are made about what a certain change to a document was for. Since there is a message beside all the documents about the reason for a particular change it becomes easier to figure out the reason for the individual change we are interested in. If following the example above we were to examine a document and wonder why the address changed we could examine the check in with that change and see the message that the person changing it wrote.

When used on source code in tandem with an issue tracking system the message can contain the identification number for the bug being fixed or feature being added. This means that anybody who is examining the revision to see the reasoning for the change has access to a lot more information via the issue tracking system. An example of this is the issue tracking ability that is built in to GitHub, an online version control system. In GitHub an issue can be created as shown in figure 2.2. The issue tracker has also been linked with the messages that you need to write when you check in some files. If you include a hash sign followed by a number in the message you check in then GitHub updates the issue with that number as shown in figure 2.3.

Collaborate with multiple developers. Version control systems make it possible to have individual revisions that contain each persons changes. The version control system then manages the way these changes are merged into a composite product. Bertino [3] describes the ability to merge the work of multiple people as being a powerful collaborative tool. A version control system allows multiple people to work on the same document. In some circumstances it allows them to work

on the document at the same time. A version control system allows people with different ideas to collaborate on a single document.

In order to manage the different version or revisions version control systems work better on plain text documents. One of the main uses for a version control system is to maintain source code written in a plain text programming language, such as Java or C.

2.1.1   Dealing with conflicts

When people work on the same software project there is a need to interact with each other. If they require the same source code then there is competition to access that file for each of them to successfully do their work. There is the risk that they will attempt to change the same block of source code at the same time. If different changes are made to the same block of source code then they have a *merge conflict* and need to figure out how to combine the changes manually. There are a few ways of dealing with these conflicts.

Locking

One approach is to require that the file is only able to be used by one person at a time and that anyone else has to wait. This method avoids the need to resolve any conflict. The advantage of locking a file like this is that the file is always in a consistent state. This is how one of the original version control systems, RCS ensured that the document stayed consistent. Tichy has explained why he considers locking in a version control system to be a good idea in the design for RCS[16] The disadvantage is if one person retains the document for extended periods of time, it cannot be changed by anybody else. If a lot of work has been done on the document before it is unlocked for others to edit it. Furthermore the resulting document may be barely recognisable as the original if extensive work is done on it. If the two parties change distinctly different parts of the file,

or both independently make exactly the same changes this restriction is unnecessary.

Smaller structured units

Another way to reduce conflicts is to split the programming code into smaller units. The advantage of this is that if you are using locking you minimise the risk that similar. If we go back to the illustration of two people working on the same set of documents. If instead of one person having sole possession of a document at a time that person only has possession of the page or pages they are changing. As those pages are smaller than the whole document they are likely to retain them for shorter periods.

Merging documents

Finally we could allow both parties to change the document and try to figure out what the problems are afterwards. This resolution of anything that remains a problem is known as a *merge conflict*. This occurs whenever the computer cannot automatically process a merge. The merge then needs to be sorted out manually.

If not regularly merged is possible for the source code to diverge greatly and it becomes harder and harder to reconcile. According to Bertino it is possible to keep a smaller more easily deployed repository by evaluating what is necessary and what is unnecessary [3]. Although Bertino refers to unnecessary files this premise may also be applicable for the smaller blocks of code we are interested in. This suggests that maintaining a record about what is relevant and what is irrelevant may have some benefit. Version control still can have problems with merge conflicts. These issues have a far greater chance of occurring if there is a dramatic change such as refactoring.

Manual Merging

If you have two files you want to merge but no common starting point
for them both you will need to manually merge any differences. The com-
puter has no record about what the original file looked like so it can not
determine which changes were intended. Features that they have in com-
mon will not need to be affected however a decision needs to be made
about any differences by the developers responsible for those changes.

Automatic Merging

If there is a three way merge it is possible for the computer to calculate
the merge independently provided that there are no merge conflicts. To
do three way merging requires three different revisions are required, the
original revision, the revision containing changes we have made and the
revision containing changes made by other developers. By comparing the
differences between our revision and the original one it is possible to de-
termine which changes we have made. If we compare the changes made
by other developers to the original the changes that they have made can be
determined. If we attempt to update our code by merging other peoples
changes and a change only occurs in our code then that change is retained.
If we attempt to update our code by merging other peoples changes and
a change only occur in the other persons code the the change is inserted
into our code. Only if a different change is made in both your revision and
others revision to the same area in the code from the original that a merge
conflict can occur.

2.1.2   Architecture

Centralised version control In a centralised version system all the changes
    are made to one location. This is called a centralised repository.
    Having a centralised repository means that only one place needs to
    be checked in order to access the most up-to-date and agreed upon

source code. The need to be connected to a central system solved a lot of issues but often had a large overhead. In some centralised system it required a specialist to be involved just to look after the server and ensure that merges were done correctly. However according to Chacon [5] this single point of management has some advantages as it is possible to manage what developers had access to. According to ChaconA [5] and Bertino [3] the main flaw with centralised version control systems is that they have a single point of failure. If anything goes wrong with the server you could lose all your work.

Distributed version control According to Chacon [5] and Bertino [3] this is like having a complete copy of a repository present on every computer that has access to that project

An advantage to having a complete copy of a project from the repository is that it is possible to make changes to the program remotely. You are also able to select which changes others have made you want to incorporate into your personal copy.

Online version control systems Whilst is is possible for a measure of collaboration just by using git on it own it requires that you have some method of obtaining the separate branches on one machine before they can be merged. One way of doing this within a company is to set up a git server. This might suitable for projects that are closed source and have a select group of people who work on the source code. For larger projects that have has programmers in different parts of the world a publicly accessible git server that is on the web may be a better solution. Loeliger [12] how it is possible to access and use a web based git server to achieve this. A good example of a web based git server is GitHub. GitHub provide a way for many developers in different parts of the world to change source code for an open source project. It is possible that the developers for a particular project have not even met in real life or even know about each other.

Figure 2.4 shows the amount of activity that there has been on the
JGit project. It shows that there are 74 contributors to the source code
and 3245 individual changes over 20 branches. With such a large de-
velopment team the potential to have conflicting changes must be
high. Having many separate branches may indicate that merges of-
ten need to happen. This one example could indicate the need for
good merge tools that can reconcile conflicts even if the developers
have little contact with each other.

2.2   Longest Common Subsequence

According to Balcan [**?**]The longest common subsequence problem is at-
tempting to find the maximum number of common items in two strings
when the strings are examined from left to right. A subsequence does not
need to be in a single contiguous block however. Algorithms that solve
the longest common subsequence can determine the differences between
two lists by working out what is the same.

2.2.1   Example

An example of finding the longest common subsequence is:

Imagine we have have two similar sets of Java source code that we
want to compare with each other. We would like to know what is the
same and what is different. A longest common subsequence for the source
would contain a list of all the lines that are the same and in the same order.

The first listing is as follows:

```java
public class SampleLCS {

  public static double area(double radius){
    return Math.PI * square(radius);
  }
```

```
public static void main(String[] args){
   System.out.println(area(3));
 }

 public static double square(double num){
   return num * num;
 }
}
```

In the second listing the order of a number of methods has changed but the way the code works has not been changed.

```
public class SampleLCS {

 public static void main(String[] args){
   System.out.println(area(3));
 }

 public static double square(double num){
   return num * num;
 }

 public static double area(double radius){
   return Math.PI * square(radius);
 }
}
```

A listing containing only the common lines in the same order between both listings follows. If this is the longest listing possible it is known as the longest common subsequence.

```
public class SampleLCS {
```

```java
  public static double area(double radius){
    return Math.PI * square(radius);
  }

}
```

It is possible to have more than one longest common subsequence if there are multiple listings of common lines that have the same number of lines in common and have the maximum number of lines that match. For instance the following listing is also a longest common subsequence of the above example.

```java
public class SampleLCS {

 public static void main(String[] args){
    System.out.println(area(3));
 }

}
```

As there are possibly multiple longest common subsequences identifying the longest common subsequence that is going to be most useful becomes difficult.

2.2.2   Methods of calculating LCS

According to Arslan [2] there are many algorithms that solve longest common subsequence problem. As is it possible for there to be multiple correct solutions to a LCS problem a reason for having a different algorithm may be to find the LCS that make the most intuitive sense. The algorithms used in JGit for example are the the Myers, Patience and Histogram algorithms.

2.2.3 Myers

The Myers algorithm was discovered by Eugene Myers who claimed that finding the minimal differences between any two documents was the equivalent to finding the shortest or longest path in a graph [15].

2.2.4 Patience

The patience algorithm instead of figuring out the longest common subsequence directly uses the longest increasing subsequence. When this is used with line numbers from the source code the longest common subsequence can be established. By examining only unique lines present in both copies of source code it is comparing it ignores items that are repeated multiple times. as they produce longest common subsequence could give a sub-optimal result. As Bram Cohen has pointed out in his blog there are instances where a LCS algorithm can return results that are not as helpful to a developer as they could be. Instead of noticing that a method has been inserted it is possible for a LCS algorithm to return that the closing brace of one method followed by another method without the closing brace has changed instead.

2.2.5 Histogram

According to comments in the source code a histogram algorithm claims to be equivalent to a patience sort in some circumstances but provides a better result for when there are multiple copies of some items being merged.

2.2.6 The problem with LCS

There is still a problem with longest common subsequence. It does not notice changes of order in a document. For the example we have been looking at two methods have swapped positions. The program still behaves in the same manner when it is run. It is unnecessary to make any changes to

this code in order to get them to behave the same way. *Diff tools* that solely use the longest common subsequence do not take different ordered items into account even if they can be considered equivalent.

2.2.7   How LCS is used in differencing tools

Differencing tools (often shortened to "diff tools") are a range of standalone prorams that compare the contents of two files and show the similarities and differences. In many diff toola hash code is assigned to each line of the files to speed up the differencing process. This means that the differencing tool can work much faster as it does not need to compare each character in the line but can compare hash codes instead. However the granularity of what is compared is more course as it shows complete line differeces rather than word or character differences. In the source code for many programming languages the white space is not relevant so many diff tools have the option of ignoring the white-space and only comparing the code. This has an impact on the hash codes for each line as the hash code needs to be generated just from the text rather than the white spaces in the code.

Additionally with some diff tools it is possible to use regular expressions to ignore program features such as comments when doing a diff. The reason this is important is if it it is possible exclude changes that have no affect on behaviour from a diff then it is possible to also exclude them from a merge. If we exclude them from a merge we could have less conflicts.

2.3   Refactoring

A common concern with coding is the need to periodically refactor the code. Refactoring does not involve changing any of features the source code or change how the compiled program functions. Refactoring simply reorganises the source code so that it is easier to read and add changes.

According to Fowler et al. the main time for refactoring is when new functionality is added [9]. Similarly according to Kerievsky some of the motivations for refactoring include adding more code and understanding existing code [11]. As adding more functionality is one of the motivations for refactoring let us consider what happens in a multi-developer environment. Two developers could have different views on what is considered an appropriate refactoring. This is especially true if they need to add different functionality from each other.

A simple example is illustrated as follows:

```java
public TempConv() {
  Scanner keyboard = new Scanner(System.in);
  System.out.println("Enter the temperature in Celsius");
  int celsius = keyboard.nextInt();
  System.out.println("Degrees Fahrenheit is approx "
    + (celsius * 2 + 30) );
  keyboard.close();
}
```

Refactoring this code depends on what functionality you need to add. One developer may recognize that conversion from Celsius may be used several times throughout the code and so extract the calculations as a separate method as follows:

```java
public TempConv() {
  Scanner keyboard = new Scanner(System.in);
  System.out.println("Enter the temperature in Celsius");
  int celsius = keyboard.nextInt();
  System.out.println("Degrees Fahrenheit is approx "
    + celsiusToFahrenheit(celsius));
  keyboard.close();
}
```

```
public int celsiusToFahrenheit(int celsius){
  return celsius * 2 + 30;
}
```

This change, in spite of producing the same output as the first, provides a number of advantages. Firstly if other programs need to convert from Celsius to Fahrenheit the new method can easily be reused. Secondly since the calculation is a crude estimation it becomes a lot clearer where the code needs to be changed to improve the formula. The ability to add a method that clearly indicates that the calculation is from Celsius to Fahrenheit helps with the readability of the code. There are also disadvantages to doing this refactoring however. If we do not care about conversion between Celsius and Fahrenheit the refactoring simply adds to the amount of code we need to wade through before understanding what the code does. An alternate way of refactoring is as follows:

```
public TempConv(){
  Scanner keyboard = new Scanner(System.in);
  System.out.println("Enter the temperature in Celsius");
  int celsius = keyboard.nextInt();
  int celsiusToFahrenheit = celsius *2 + 30;
  System.out.println("Degrees Fahrenheit is approx "
    + celsiusToFahrenheit);
  keyboard.close();
}
```

While this again expresses the same functionality as the code above it has not created a new method to do so. This has some of the same advantages. It separates and identifies the formula to convert between Celsius and Fahrenheit. It also uses less code to express this separation than forming a new method. It does not expose the conversion formula outside this method to be used by other calculations however.

As the value of a particular refactoring appears to depend on what is

trying to be achieved it is very hard to claim that one refactoring is better than another. It depends entirely on the wider context of the intention for the refactoring, in this case the level of access required for the approximation to convert Celsius to Fahrenheit.

Although this was a simple example it is easy to imagine a case where a much larger refactoring process is undertaken. In such circumstances a merge becomes difficult.

2.4 JDime

Part of the inspiration for this tool come from JDime. If there is a conflict in a text based merge JDime provides a way for some refactored content to be merged.

2.4.1 What Jdime can be used for

JDime can be used to compare two different versions of Java source codes which have been refactored and to produce a copy common to them both.

2.4.2 How Jdime works

JDime instead of testing against a source code repository test against files in the system under the base, left and right directories. While this may be useful in quickly being able to show what JDime is able to achieve it requires that the inputs need to be previously extracted from a repository into the file system.

Before doing any calculations, JDime runs a regular text merge over the source code. If the regular text merge has conflicts then JDime parses the file into an abstract syntax tree (AST). JDime uses the AST to determine if sections of the source code need to be in a particular order or could be in any order. What then happens depends on if order is required in the section of code JDime is examining.

2.4.3   Testing JDimes suitability

Jdime has been written mostly in Java by Apel and Lesßnich [1] . There are a few exceptions including the linear programming libraries that need to be created. As we are attempting to combine some of their work with Git it was decided to use JGit rather than the C implementation of Git. As the Java implementation may run a bit slower then in order to get a good timing test running we need to run redo the tests of JDime using JGit instead.

Also the tests that Leßnich did on JDime were from files rather than from a repository. It is necessary to set the files back up in the original repository structure to get a adequate baseline.

As JDime performs a type of automatic merge it requires 3 different revisions. JDime requires a revision that has changes that we want included. This is commonly called the right revision however I will call this the merger revision as the changes in it are meant to be merged. JDime also requires a revision that we want to merge into. This is commonly called the left revision, however I will refer to this as being the mergee. Finally JDime requires an original revision that both the merger and the mergee are based on. This is commonly called the base revision.

At the moment it cannot access a version control system so each of the revisions need to be set up as directories. Each directory needs a full copy of the source code for that revision This means that the necessary Java source code to be used by JDime in base, left and right directories.

In order to show how JDime performs extra refactoring based merging we need to attempt to try something that would incorrectly cause a conflict in a text based merge. The reason that this is necessary is that if there are no conflicts in a text based merge the refactoring aware portion of JDime will not be run. This saves the overhead of loading the program into an AST in the event that the initial text merge has no conflicts. One way to get a lot of text conflicts between two pieces of code that are equivalent when they run is to change the order of the methods. Although the methods are

in different order the programs are still functionally equivalent. In order to examine how JDime works and test its suitability a test handler was written. The test handler creates all of the directories and files for JDime to process. The methods inside the files are reordered differently for both the left and the right directories.

Once the test was set up using the test handler the JDime run to process the directories. What we expected to happen was that JDime would reorder the methods to match the order in the mergee. When we compared the methods using a graphical merge tool however we found that the order of the methods in the files did not match.

It is about this point in analysis that you begin to second guess yourself. For this reason the output of JDime was compared also with the merger and the base. The order of the methods in the output did not match the order of any of the equivalent input files.

If it detects an unordered section it does not preserve the order of the output.

2.4.4 Reasons why Jdime cannot currently be used to create separate views

The aim of this thesis is to be able to maintain two views of Java that although having a different format function in the same manner. Although this tool sounds like it would be able to help achieve those aims there are a few reasons why it cannot be used without changes.

The first issue is that as explained above that the resulting code could be in a totally different order to any of the versions combined to create it.

The second issue is that when JDime parses the code into an AST it strips out any comments or white-space placed in the code. Although the comments do not have any functional impact on how the program runs they do have an impact on how the source code is understood. To limit the impact a merge makes on one view comments need to be evaluated as

well. In some ways retaining comments or even white-space in the code aids in determining if a section of the code has been copied verbatim from one place to another.

The only time an AST based merge is performed is if there are conflicts. There could be advantage to determining if items that haven't conflicted in the text based merge but have moved from one position in the code to another. If a method has both been moved and changed in both branches it could have a conflict. This conflict would appear to the text-merge as a deletion agreed upon by both branches followed by two insertions at different points. It would not be picked up by the text-merge as containing a conflict even if one was potentially present. Since the conflict is not detected by a text-merge it is not set aside for testing by examining the AST tree. In this case comparing AST trees could detect that there was a conflict. Although JDime is an improvement over a text-based merge this is a potential conflict that neither detect. There is a performance reason for this design decision. JDime can take a long time to determine if two files contain equivalent source code.

The final concern is that after JDime does the initial comparison of text and finds conflicts it discards those results. It parses the entire file into an AST and begins analysing it again without knowing which parts differ.

## 2.5   Other refactoring aware versioning tools

JDime is not the only tool that can be used to address refactor aware version control. Ekman and Asklund [8] introduced a plug-in for eclipse that recorded information about refactoring in to version control so that it was easier to recognise where refactoring took place. They did this in a very similar manner as Apel and Leßnich when they developed JDime. Both make use of ASTs to record information about any refactoring that took place. Freese [10] also developed a tool that was very similar written in Object-Z. Despite this interest in refactoring aware merges however the

idea of keeping separate branches as consistent as possible has not been discussed.
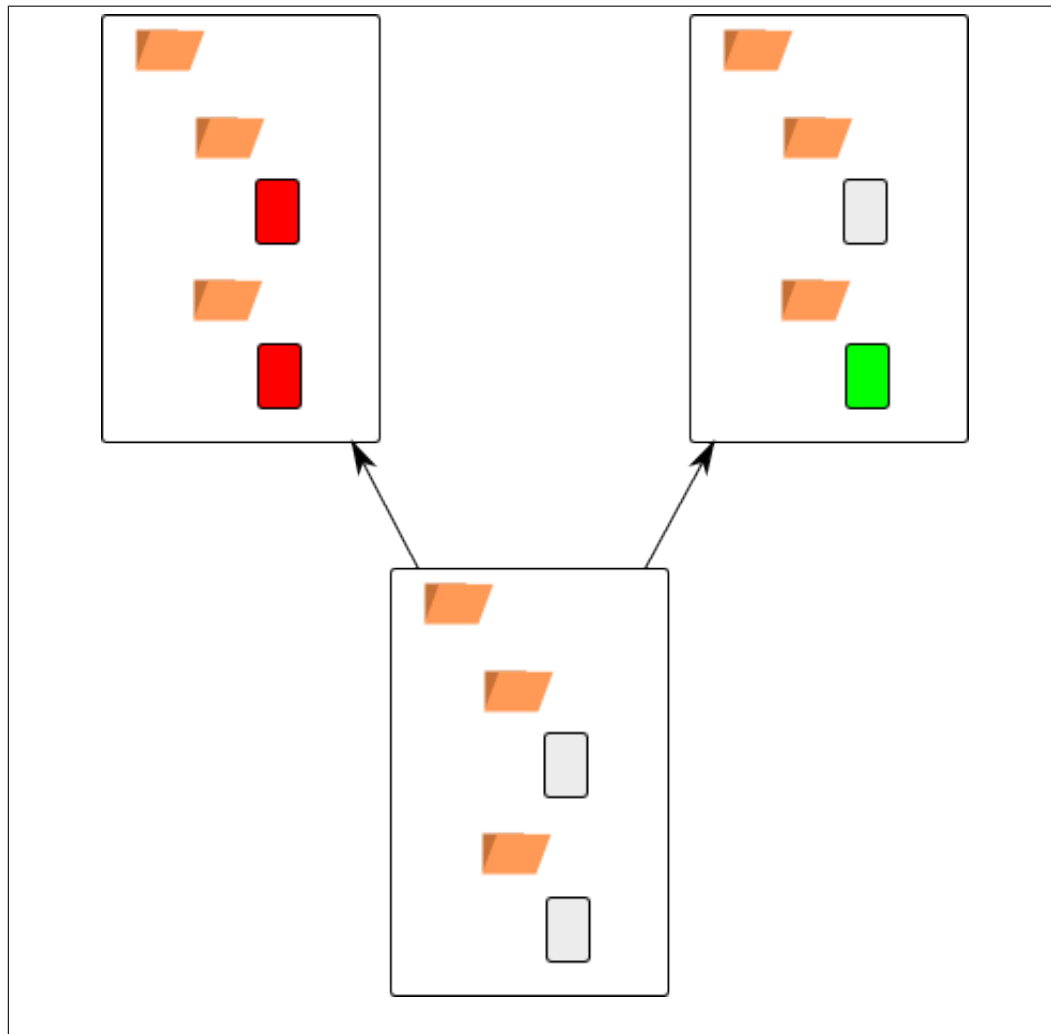
Figure 2.1: A project that has been split into two branches
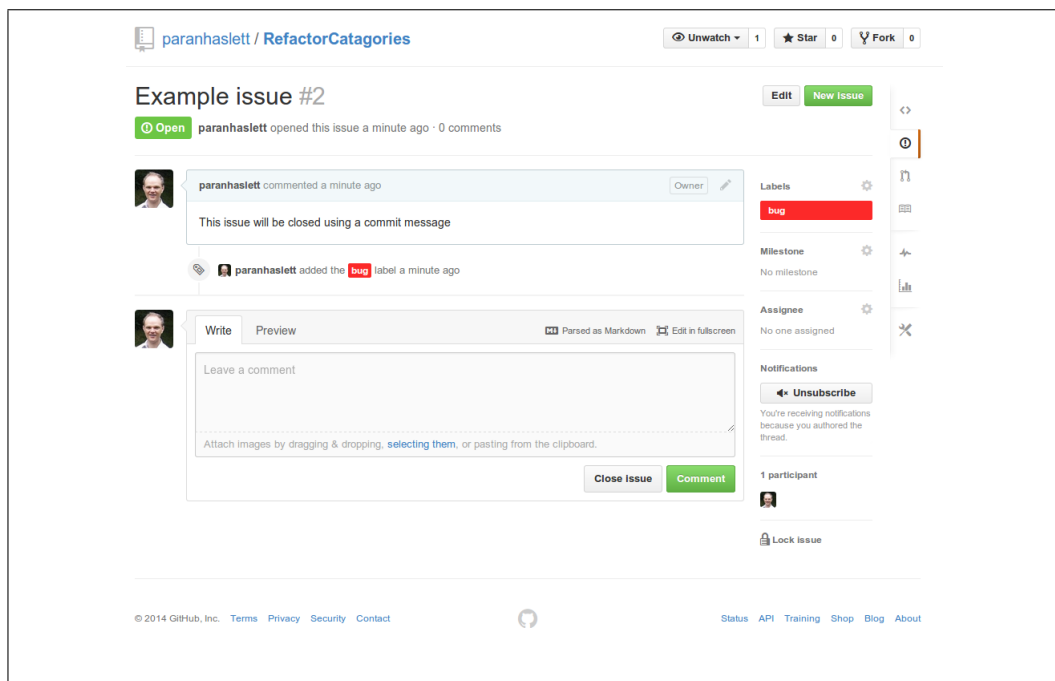
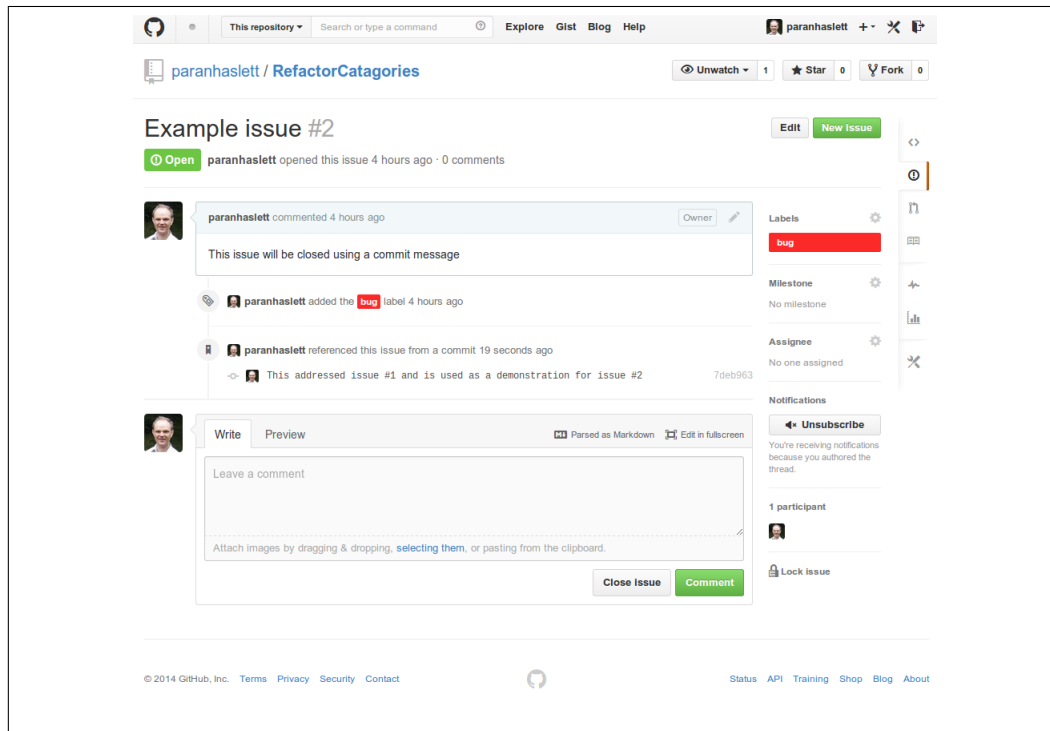**Figure 2.2:** A issue that has been created in GitHub

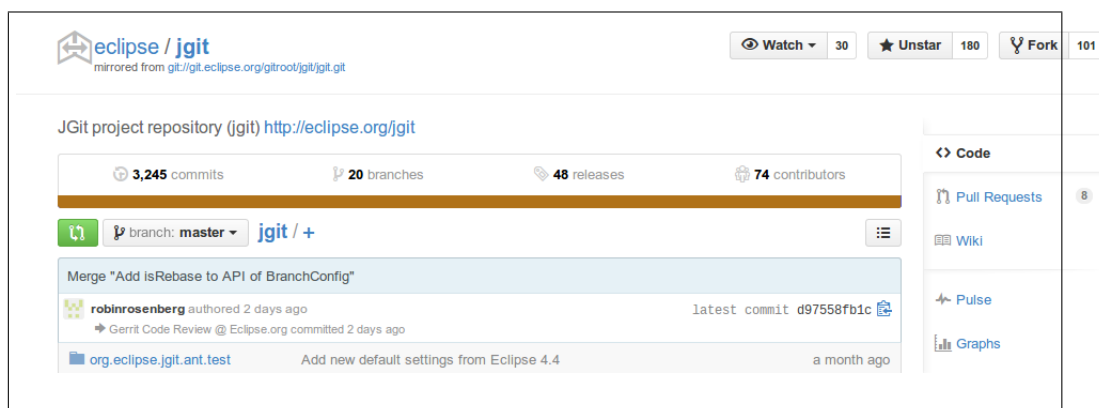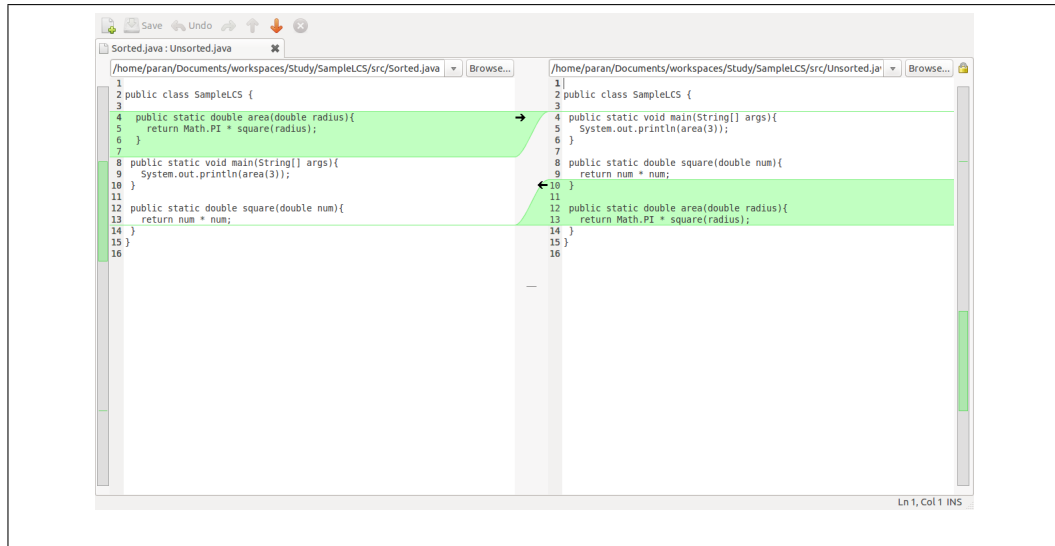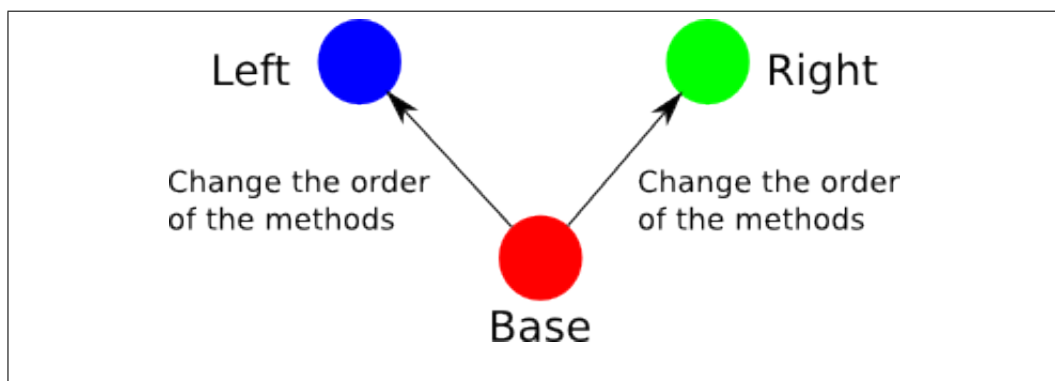**Figure 2.3:** The issue has been updated from a commit message

Figure 2.4: The number of contributers to the JGit project

Figure 2.5: A graphical diff tool showing differences with two equivalent blocks of source code
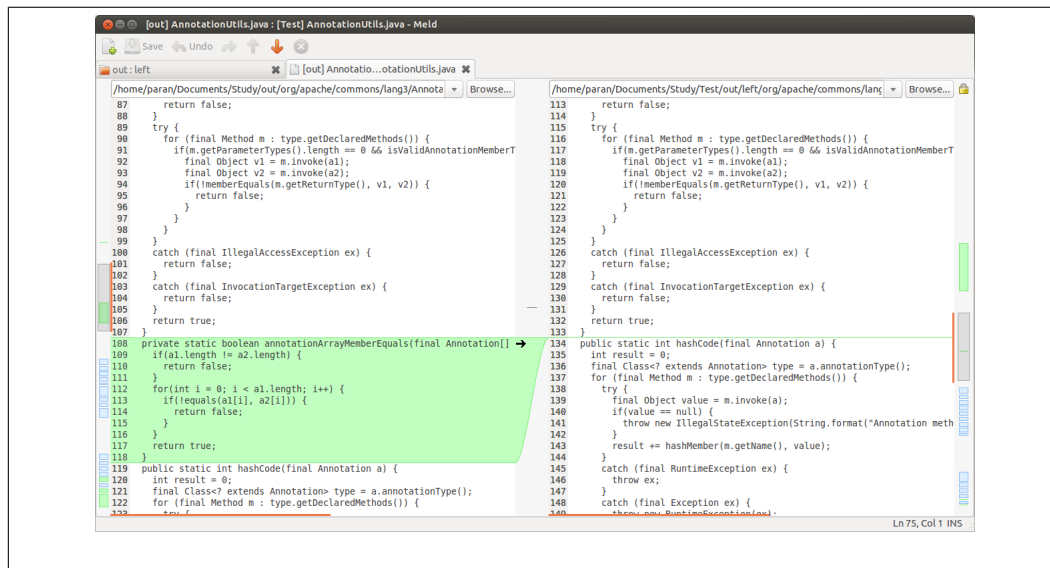

Figure 2.6: The set-up for the test of JDime

**Figure 2.7:** Screen-shot of Meld showing a different method order

Chapter 3

Individual refactored views

In a project with multiple developers situations may arise where you need to make a change to the structure of the source code. This becomes a problem if you also want to limit the impact other developers. Maintaining your own independently refactored view of the source code could be valuable in these circumstances. There is a significant amount of interest already in making diff tools and version control systems refactor aware, some examples of this are MolhadoRef [7] [6] which attempts to incorporate refactoring in version control systems and commerical systems such as Semantic Merge which is a series of stand alone diff tools for different languages.

3.1 The problem

Repeated structure changes for other software developers. Imagine a situation where you are working jointly on a project with other people. Since you want to collaborate on different aspects of the same source code you have set up the project in a merge based version control system. You have checked out your own copy of the code so that you can work on the source code without interfering with any of the changes others are making. You notice that you they are going to
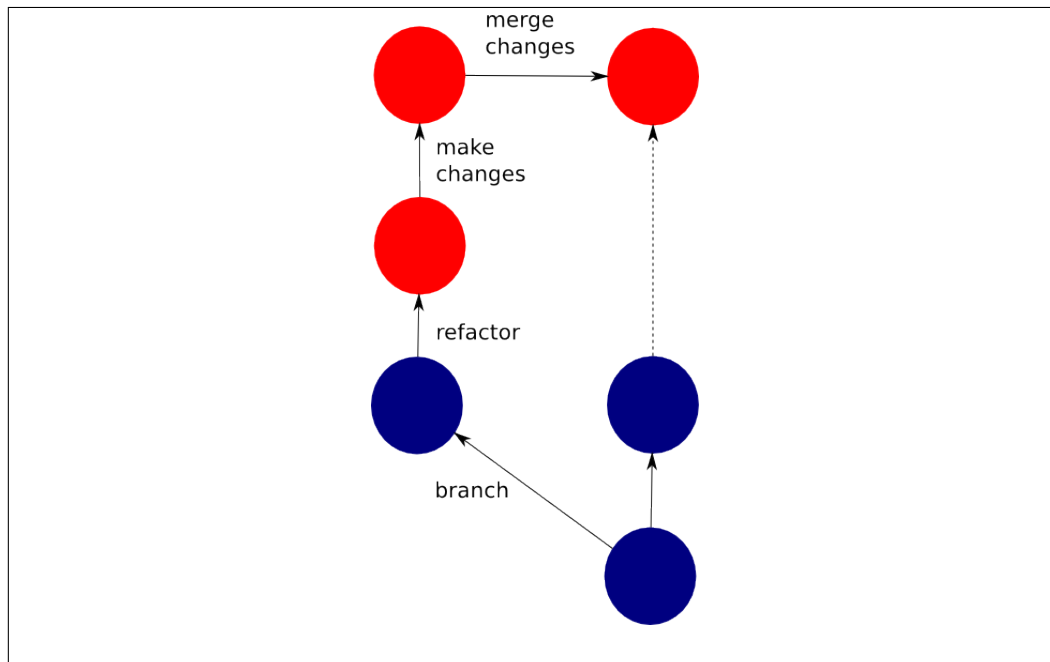
Figure 3.1: Merging changes with refactored code also merges any refactoring

have to refactor the code before you add any of your changes. This would be a fair judgment call as Fowler claims that the main time to do refactoring is before making any changes [9]. You complete your changes and check in your code back into the version control system. While you are doing this other people have been working on the code. If you manage to check in your code before anyone else you will not need to merge any of your changes. Anybody who checks in after you however, could have a merge conflict. Some conflicts that they experience could be because the changes you made directly compete with the changes you have made. Potentially more conflicts would occur between the changes they have made and the refactoring that you have completed. This is because a refactoring often makes a large amount of global changes to the source code.

As shown in figure the difficulty lies in the fact that not only the

functionality that you have added is checked in but also the changes brought about by refactoring. These refactored changes have not changed how the program functions but have simplified and tidied the code to make the addition of your changes easier. There are some occasions where you may want to avoid changing other peoples code in such a dramatic fashion.

In some conditions refactoring is only required to simplify the code to implement a small change as opposed to cleaning up the entire code base. This partial refactoring is likely if the code base is large. According to Melina et. al. [13] refactoring is a challenge when the code base is large. By definition refactoring does not any functionality but changes the source code. This means that the code previous to being partially refactored has the equivalent functionality to the code after the partial refactoring.

By checking in your refactoring code you are forcing others to comply with your vision about how the code should be structured. This occurs even though you could have no awareness about what changes to the code others have made or intend to make. Everyone who attempts to check in their code after you will need to merge into a restructured code source that they are unfamiliar with. The potential for merge based bugs and time wasted doing unnecessary merging increases.

Difficulty if there are multiple check-ins. When there is a large change on a separate branch with many development milestones it is desirable to have the ability to submit your code periodically. This could be done to ensure that there is not too much divergence between the separate branch and other development projects. The desire to regularly merge the code makes the issue we have discussed even worse. Currently if you have a project where there are periodic check-ins for each development milestone there could be a large impact each

time there is a commit. This is because the refactoring for the large refactored project is imposed upon others each time it is merged.

One of the ways this can be dealt with is by creating separate branches for different projects however this has some issues with merging when working on two or more projects simultaneously. In order to minimize the amount of divergence it is advisable to merge each of the branches with the trunk often. If there has been global refactoring changes introduced by one project being merged the merge will be worse for any of the remaining branches when they are checked in. Instead of having an issue merging at the check-in level we now have an issue at the merging of branches. As these changes will occur less often than checking in the code, the code will possibly have more divergence. This divergence is likely to cause more rather than less merge issues at the expense of having to merge less often.

Differences in how code is understood. According to Kerievsky a reason for refactoring code is to better understand it [11]. As proven by [4] the very act of going through the source code and reprocessing it in a clearer form can help with the understanding of it. This would suggest that developers tend to leave the code in a difficult to understand state or that different developers understand things differently. Kerievsky also relates a tale about how the lack of knowledge of patterns making a particular refactoring look a lot more complex [11]. The different perspectives meant that the programmer he refers to as John has a differing opinion that the refactored code was not an improvement. This shows that it is not just different functionality that influences the need to refactor but sometime the knowledge and experience of the developers themselves. It is often the case that two developers could have different views about what is an appropriate refactoring. This could be because each person brings different skills, notices different issues and has a preferred way of visualizing

a problem and solution.

Version control systems not being aware of changes in the order. One of
the changes which is not catered for by current version control sys-
tems is the changes of order. The first person to check-in their code
will have no issue as the version control system assumes that all
the changes are simply a new revision. When the second person
attempts to reconcile their view there is the possibility of having un-
necessary conflicts. A lot of these conflicts will be with refactored
code which although works the same has a different structure.

3.2   Benefits of individual refactored views

We want to be able to maintain private views or separate branches that
can have different but equivalent refactoring. Different structures of code
that function the same way a number of features that could be of interest.

Reduced interference with other software developers. One benefit is that
it is possible to keep the structure of code that each software devel-
oper works on consistent. The location of methods and variables are
more likely to remain in the place the software developer left them
even if a merge occurs. By maintaining two differently refactored
view it allows software developers to work on the same program-
ming project to freely refactor with minimal interference to others. If
two software developers refactor the code that they are able to hold
their own individual refactoring with reduced changes when they
are merged. The reduced changes would also mean that there will
be less unnecessary merge conflicts when merging code.

The number of changes is reduced when merging. The number of changes
when merging is reduced if you omit any changes that don't also
have any change in behaviour. This in turn means that there is less
chance for there to be a merge conflict.

The ability to have comment tied to a specific view. It would be possible
to have comments that are not considered when doing a merge. This
would be a benefit if there are comment that are specific to a branch
and that are not necessary to share. This would allow a programmer
to keep a lot more personal notes. The risk of having so many com-
ments from others that it is hard to see the code is reduced. By being
able to identify that a block of text comment is a new addition

3.3   Ways individual refactored views could be achieved

There are a number of ways we have considered about how to provide
differently refactored views that have the same functionality.

Comparing differences using a non-ordered comparison algorithm. Instead
of using the Longest Common Sub-sequence (LCS) based approach
we could instead use a non-ordered comparison. The easiest way to
consider this concept is that the LCS algorithm compares two lists
whereas a non-ordered algorithm is a bit more like comparing sets
of items. The items within the set will still be ordered.

> **while** *There are elements on both sides that match* **do**
> > Create a histogram of remaining elements;
> > Select one of the elements that occurs in both sides the least but not zero times;
> > **while** *There is an element below the selected one that matches on both sides* **do**
> > > Remove element from list of elements to compare, as it matches;
> >
> > **end**
> > **while** *There is an element above the selected one that matches on both sides* **do**
> > > Remove element from list of elements to compare, as it matches;
> >
> > **end**
> > Remove selected element from list of elements to compare, as it matches;
>
> **end**

Algorithm 1: A non-ordered comparison algorithm

The problems with using this approach to reconcile to different ordered sets is that comparison would not know the difference between what needs to strictly remain in order and what is allowed to be in a different order. If the version control system has an understanding of a particular computer language it is much easier to determine what items can be moved without changing functionality and which ones need to stay in the same order.

Normalizing the source code before placing it in the version control system.
Before placing the item into source control it could be transformed into an agree upon format. Before allowing a merge on a block of code each the views could transform the block of code using the same method and compare it with the equivalent block of code that in the version control system. If the transformed code is the same

then there is no need to merge.

Storing additional information in the version control system. By storing additional information within the version control system different views could be managed and recreated. This concept is very similar to Ekmans plugin for eclipse that maintains a record different refactorings in addition to the source code [8].

The problem with this is that it would have to store information about every view that was differently refactored. In a distributed version control system especially an online one the number of distinct views could be large and change often.

Using regular expressions It could be possible to use regular experssions to control a lot of the merge process. We could eliminate a number of comparisons that contain equivalent functionality in this manner.

Using a tool like JDime solely as a method of comparison. As mentioned earlier there are a number of reasons why JDime cannot currently be used as a method of keeping two different refactored views. If changed however it could still be useful. One idea we had was to attach it to Git and solely use it to detect equivalent pieces of java source code.

3.4   Are comments important?

Although in this thesis we have focused mostly on changes to the behaviour of a program as opposed to astetic changes to the source code we recognise that sometimes changes to comments may be important. If a new comment is inserted in a branch or even if a comment is deleted it is likely that the change is specifc to the task the programmer is trying to implement. However if an existing comment is modified it is more likely that the comment and the task will have some impact on other branches and

should be modified. There could be exceptions where inserted or deleted code should have an impact on other code and where a modification to a comment does not really need to be broadcast to other users during a merge.

Existing comments and even white space can also provide useful information about any changes of order in the code. If a programmer has cut and pasted a block of code the white space and comments are also moved and provide hints to what has occured. Even if some of the code has been modified there could be enough clues left behind to suggest that the most likely event is that the code has moved and then adjusted.

Chapter 4

Refactor categories tool

In order to prove that having individual refactored views would provide
some useful results we created a refactor categories tool. The refactor cate-
gories tool examines the differences between files and arranges them into a
greater variety of categories than used by version control systems or merge
and diff tools. In addition to being able to detect instances of delete, insert
and modify the refactor categories tool can also detect instances where the
code has been relocated and to some extent renamed. It also can differ-
entiate between changes to comments, white space and Java code. This
means it can differentiate between instances where a change to a source
file causes a change in the behaviour of the program and some instances
where it has been refactored. When we use the word refactored here we
refer to the defintion of refactoring presented by Murphy-Hill [14] who
claims that refactoring simply changes the structure of the code but not the
behaviour. Although it does not detect more complex differences beyond
this we intend to show that changes exist in real world software projects
that have no impact on the projects behaviour.

4.1   Overview

The refactor categories tool analyses all the historical changes ever made
on a software project by extracting successive revisions from a Git repos-
itory using JGit. An ordinary text comparison is used as a starting point.
The algorithm used for the text comparison is the histogram LCS one nor-
mally used by JGit with white space ignored. The text comparison returns
the minimal number of text changes in EditList object. The information
about each change that the EditList object retains are:

- the starting line of the change for both revisions being compared

- The ending line of the change for both revisions

- The type of change that is being made

The types of changes that are detected between two files are limited to
inserts, deletes, and modifications. In order to expand this list we need
more information. We obtain information about the meaning of Java files
by parsing both revisions we are comparing into an AST using JastAddJ.
We then need to discover which AST node matches which change to the
source code.

Each of the AST nodes can contain information about the line of source
the AST node starts and ends at. Unlike the EditList object which we have
previously discussed AST node can also hold the column that the AST
node starts and ends at. Using this positional information we can match
the text based changes to a set of AST nodes.

There is likely to be AST nodes that are not included in any of the
change sets and can be safely ignored. In order to find just AST nodes
we are interested in we need to traverse the AST. When we start at the
root of the AST the start position for the root node is the first line and the
first column. The end position for the root node is the last line and last
column. By examining the children of the root however we can determine
which children contain all or part of a text based change.
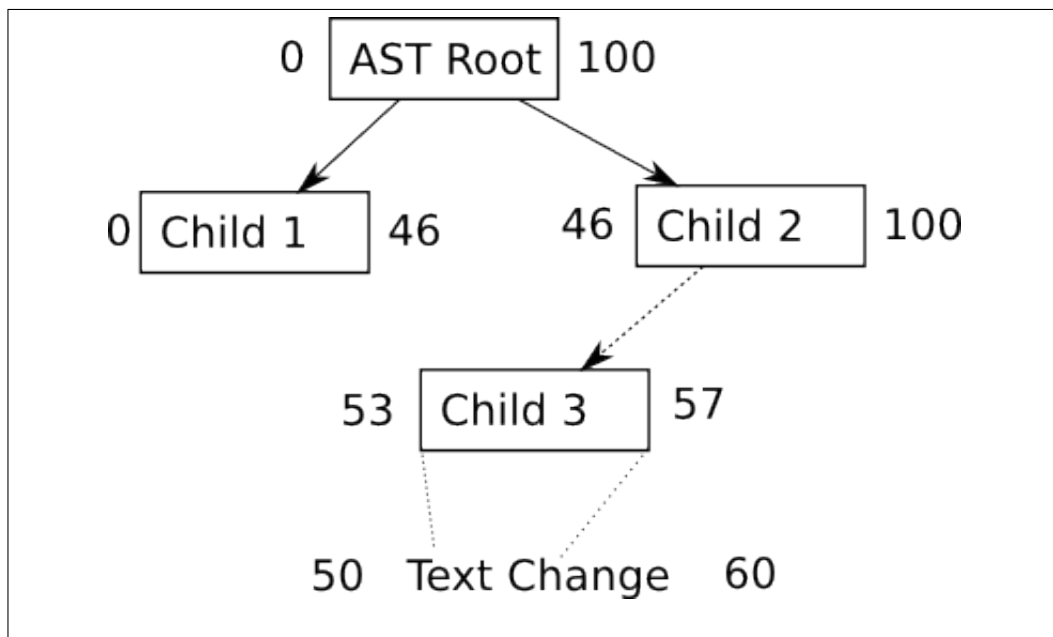
Figure 4.1: Finding an AST node we are interested in

An example of this can be found in figure 4.1. In this figure it is safe to ignore any children of the AST node marked 'Child 1' because 'Child 1' does not contain the text change. The AST Node marked 'Child 3' however is interesting as its location places it within a text change.

In some instances items within the text change will not have a corresponding AST node. These are of interest to us because these are instances where the text may have been changed but it has no impact on the behaviour of the program. The most likely instances of this is when a comment has changed or if white space has been introduced in the middle of source code. Once the AST node for both revisions has been matched with the text change we can compare the AST nodes and their children to discover if they would behave in the same fashion. If they do behave in the same fashion it could indicate that the change is an ascetic one.

Another change we are interested in is if items have been moved. We would notice this if there is a both insert and a delete for similar AST node types within the same scope. If a method has been shifted within a class

we would notice similar AST nodes, one being deleted at one location, the other being inserted at a different location. This is another example of a text based change that does not change the behaviour of the program.

If we find examples of text based changes that do not change the programs' behaviour we have an indication that we can reduce the amount of changes necessary to update another branch. This in turn could indicate that we would have less merge conflicts by reducing the overall number of changes.

4.2   What the tool does

By checking to see if an insert at one point matches a delete at another point it is possible to detect to see if the code block has moved. In order to determine if the move is one that has no impact the matches are only counted if a match can be found within the same container. Here, a container is an enclosing scope within the source code, such as a class or method. For example if a method has been shifted within the same class the program will still act the same. If a method is moved from one class into an inner class there is no guarantee that they will be evaluated to determine if there is a suitable match. If a method is shifted from one class to an inner class however the programs' behaviour could have changed.

To get a good match each possible match is given a score which indicates how much it has changed. This score is set in the configuration and the default for this is 1000. If there is no apparent change such as in the case of changing white spaces or equivalent AST nodes a score of zero is given. For every that change involves a delete or insert the default score is assigned. As modifies or moves can be thought of as both an insert and a delete twice the default score is assigned to them. The score is divided by the total number of items examined. An example of this is if a section of source code is examined and there are four AST nodes that have been identified. If the AST nodes are found to be equivalent apart from the

second one which has been modified the calculation is:

1000 * 2 / 4

This is where 1000 is the default score, it is multiplied by 2 as it is a modification rather than an insert or delete and there are 4 AST nodes to examine.

Once the various matches have been tested we use a greedy algorithm to select the lowest score for each item. Once two items are matched with each other both of them can no longer be matched with anything else. The matched items are removed and the next lowest score for a match is evaluated. To ensure that anything cannot be matched with anything once all good matches are eliminated once the lowest score remaining is greater than the default score of 1000 then any further matches are ignored. The two items that could have otherwise been matched will remain a solitary insert and a delete.

To a limited extent the refactor categories tool can also deal with renaming. It does this by examing the node and seeing if its children have remained the same and its type remain the same but its name has changed. It can not analyse nodes where the name has not changed as these are not picked up by the initial text comparison.

The refactor categories tool first does a cursory examination of the text differences between two files. It then examines both the differences in executable Java code and the differences between comments and whitespace.

4.3   Performance

As we are testing the complete revision history for several projects there is a high number of changes. This means that performance is an issue especially for large software projects that have many changes. This means we have not only had to look at using more memory for the refactor categories tool but also had to make some changes to the code to free up more

memory where required.

By setting object references back to null when they are no longer used.
Once a difference has been detected we attempt to remove any of the
information we are not going to use in the future. This should help
the garbage collector free up memory. We do this by setting the AST
nodes recorded against a difference to null once the difference has
been discovered.

By not analyzing AST node that did not have a text based change. By ig-
noring AST nodes and any of their child nodes that do not have a
text based change comparing all the AST nodes can be avoided. This
will also help to speed up analysis as these nodes do not need to be
analyzed to see if they match.

By comparing only successive changes. There are a greater amounts of
changes if we compare the head against a very old revision. By
checking against successive we reduce the number of changes. This
also could mean that we need to parse fewer files.

matching within only the required scope. If we were not testing for moves
in the same scope we would need to test every deleted AST node
against every inserted AST node for the entire file. By stipulating
that we can only be sure if it is a legal move if it is in the same scope
we not only eliminate a lot of relocations of source code that are il-
legal but also reduce the number of items that need to be compared.
In addition to this the AST node along with its type are recorded in
a hash map. This ensures that only AST nodes that are a similar type
are compared against each other.

4.4   Design decisions

There are a number of design differences between JDime and the refactor categories tool. Instead of doing a text comparison first and only proceeding to analyze the program using an AST if there are conflicts the categorization tool examines all files that have a difference in them. Although this takes longer and is more memory intensive there are some advantages to this. The main advantage is related to the concept of keeping branches as consistent as possible whenever there is a change. An example of this advantage is if a merge was done using an ordinary text comparison and there is a non functional change to only one revision. Examples of a non functional change could include reordering methods or inserting a comment. As the changes were only done to one of the revisions there is no conflict and JDime only does a text based merge. During this text based merge, in addition to any of the changes to functionality that we want, we get the non functional changes that change the source code without changing the programs' behaviour. By examining all changes irrespective of if the text has conflicts means that the refactor categories tool can determine if it is a change that would not affect the behaviour of a program.

As there is a cost overhead with testing all the changes rather than just the conflicting ones the categorization tool needs to be efficient in how it tests changes. Assuming that changes occur in select areas within the file there are portions of the file that have not been changed. We have developed a method that spends a smaller amount time in within the portions that have already been identified as not containing changes. Like JDime we initially do a text based merge. The text based merge we use however uses the histogram merge in JGit. This allows us to use information from the text based merge when we analyze the AST tree. The information used is the ranges of line numbers and operations identified by the histogram merge. The change set has been taken from the original JGit based diff contains the start and end of the change in both files and what type of

change it is (insert delete or modify). By reusing these ranges of line numbers it is possible to figure out which AST items these changes affect. This is done by loading the file into the JastAddJ parser to get an AST tree. Line numbers for each item in the tree are then compared to line numbers from the change set. The line numbers are matched to the position information stored in each AST node using the following method.

The root of the AST is identified as the AST node we need to start at. We only begin any analysis, if the AST node resides completely within a block of text changes. If there are any separate blocks of changes that occur between the start position of the AST node and the end position of the AST node then we recursively examine the AST nodes children.

In some instances there is no position information stored in the JastAddJ AST nodes. This could be because they are generated by the parser to reflect parts of the Java language that are inferred rather than directly mentioned in the code. An example of this would be the use of super in the constructor. Even if it is not written in the code for every constructor has a super. Likewise all methods mentioned in an interface have a public type even if is not in the code.

To get around this problem we have needed to discover the end position of the previous AST Node to determine the position the inferred AST node should occupy. This means that the inferred AST node is in the right position but is not represented by a block of text in the source code.

Comment and white-space are also examined separately as they also could give some indication of where code has been moved from or to. Before being checked to find matches unnecessary white-space is identified and recorded. Any text that remains is examined to determine if its is a comment.

Because of the way we are using the position in the code to identify AST nodes there are circumstances when parts of the Java programming language are identified as being surplus text. These have already been identified and represented as an AST Node. By identifying comments we

can eliminate any of the items falsely recorded as comments.

Rather than comparing everything with each other to determine matches it is more efficient to match just the items that are under the same AST structure. This means that it is more likely that we get a match that is going to be relevant and valid. An example of this is matching methods. If the methods are under the same container (a class) they may be legally swapped without causing issues. If the method has been moved to an inner class from an outer one however it becomes more complicated and we cannot guarantee that the code is equivalent.

4.5 Limitations of the tool

The refactor categories tool focuses only on areas where there has been a change in the source code. It is harder to investigate any change that has causes side effects in unchanged code. Fortunately it is not often that this type of side effect will be purposely placed in the code as it reflects bad design decisions. This may however be an issue with bugs, which are unintentionally placed in the code. This also means that the refactor categories tool will not be able to tell when some code has been copied but the original remains unchanged. Instead it will assume that it is a completely new insertion of code.

If a change of a variable name is noticed the program still retains the same behaviour if the rename operation has worked on all instances where the old name was previously used. As we do not examine parts of the code that have not experienced a text based change we cannot guarantee that a rename operation is a valid one. We have an indication that it might be if the code still compiles without error. If a variable name is changed to that of an already existing variable however the behavior of the program could change. This is known as a *semantic conflict*. This issue already exists in a text based merge and Fan [**?**], Shao [**?**] and others address this issue.

Chapter 5

Experimental Results

The data sets in table 5.1are complete git repositories which have been examined to discover the proportion of changes to behavior compared to ascetic changes that do not affect the behaviour of the program.

- Jasm - this a a Java bytecode assembler written for use with the Whiley programming language. https://github.com/Whiley/Jasm

- Jpp - this is a preproccessor for Java based on Bash shell script. https://github.com/ma

- AST Java - a small parser wriiten to transform Java into an AST. https://github.com/klangner/ast-java

- Java Object Diff - allows two Java objects to be compared https://github.com/SQiShER object-diff

Table 5.1: Complete git repositories that are tested

Jasm	this a a Java bytecode assembler written for use with the Whiley programming lang
foo	bar

- DiffJ - a diff tool which in addition to ignoring white space ignores changes of ordering in package names for a Java file https://github.com/jpace/diffj

Chapter 6

Future Work

Chapter 7

Conclusions

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