

Towards Automated Merging of Code Clones in Object-Oriented Programming Languages

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Abstract

This should be done when most of the rest of the document is finished. Be concise, introduce context, problem, known approaches, your solution, your findings.

Duplication in source code can have a major negative impact on the maintainability of source code. There are several techniques that can be used in order to merge clones, reduce duplication, improve the design of the code and potentially also reduce the total volume of a software system. In this study, we look into the opportunities to aid in the process of refactoring these duplication problems for object-oriented programming languages.

We first look into redefinitions for different types of clones that have been used in code duplication research for many years. These redefinitions are aimed towards flagging only clones that are useful for refactoring purposes. Our definition defines additional rules for type 1 clones to make sure two cloned fragments are actually equal. We also redefined type 2 clones to reduce the number of false positives resulting from it.

We have conducted measurements that have indicated that more than half of the duplication in code is related to each other through inheritance, making it easier to refactor these clones in a clean way. Approximately a fifth of the duplication can be refactored through method extraction, the other clones require other techniques to be applied.

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Chapter 1

Introduction

Context: what is the bigger scope of the problem you are trying to solve? Try to connect to societal/economical challenges. Problem Analysis: Here you present your analysis of the problem situation that your research will address. How does this problem manifest itself at your host organisation? Also summarises existing scientific insight into the problem.

Refactoring is used to improve quality related attributes of a codebase (maintainability, performance, etc.) without changing the functionality. There are many methods that have been introduced to help with the process of refactoring [fowler2018refactoring, wake2004refactoring]. However, most of these methods still require manual assessment of where and when to apply them. Because of this, refactoring takes up a significant portion of the development process [lientz1978characteristics, mens2004survey], or does not happen at all [mens2003refactoring]. For a large part, refactoring requires domain knowledge to do it right. However, there are also refactoring opportunities that are rather trivial and repetitive to execute. In this thesis, we take a look at the challenges and opportunities in automatically refactoring duplicated code, also known as “code clones”. The main goal is to improve maintainability of the refactored code.

Duplication in source code is often seen as one of the most harmful types of technical debt. In Martin Fowler’s “Refactoring” book [fowler2018refactoring], he exclaims that *“Number one in the stink parade is duplicated code. If you see the same code structure in more than one place, you can be sure that your program will be better if you find a way to unify them.”*.

In this research, we focus on formalizing the refactoring process of dealing with duplication in code. We will measure open source projects from the We will show the improvement of the metrics over various open source and industrial projects. Likewise, we will perform an estimation of the development costs that are saved by using the proposed solution. We will lay the main focus on the Java programming language as refactoring opportunities do feature paradigm and programming language dependent aspects [choi2011extracting]. However, most practises used in this thesis will also be applicable with other object-oriented languages, like C#.

1.1 Problem statement

1.1.1 Research questions

Code clones can appear anywhere in the code. Whether a code clone has to be refactored, and how it has to be refactored, is dependent on where it exists in the code (it’s context). There are many different contexts in which code clones can occur (in a method, a complete class, in an enumeration, global variables, etc.). Because of this, we first must collect some information regarding in what contexts code clones exist. To do this, we will analyze a set of Java projects for their clones, and generalize their contexts. To come to this information, we have formulated the following research question:

Research Question 1:

How can we group and rank clones based on their harmfulness?

As a result from this research question, we expect a catalog of the different contexts in which clones occur, ordered on the amount of times they occur. On basis of this catalog, we have prioritized the further analysis of the clones. This analysis is to determine a suitable refactoring for the clone type that has been found at the design level. For this, we have formulated the following research question:

Research Question 2:

To what extent can we suggest refactorings of clones at the design level?

As a result, we expect to have proposed refactorings for the most harmful clone patterns. On basis of these design level refactorings we will build a model, which we will proof using Java, that applies the refactorings to corresponding methods. For building this model, we have formulated the following research question:

Research Question 3:

To what extent can we automatically refactor clones?

As a result from this research question, we expect to have a model to be able to refactor the highest priority clones.

1.1.2 Research method

1.2 Contributions

Our research makes the following contributions:

1. We deliver several novel measurements regarding code clones on a large corpus of Java projects.
2. We deliver a novel clone detection tool that finds refactorable clones in Java.
3. We deliver a novel clone refactoring tool that suggests refactorings to be applied, and applies these refactorings.
4. We give further recommendations in how refactoring can be automatically applied to improve maintainability in software projects.

1.3 Scope

In this research we will look into code clones from a refactoring viewpoint. There are several methods that detect code clones using a similarity score to match pieces of code. This similarity is often based on the amount of tokens that match between two pieces of code. The problem with similarity based clones is that it is hard to assess the impact of merging clones that have different tokens, but what exactly this token is is unknown. Because of this, we will not focus on similarity based clone detection techniques, but rather on exact matches and predefined differences.

It is very disputable whether unit tests apply to the same maintainability metrics that applies to the functional code. Because of that, for this research, unit tests are not taken into scope. The findings of this research may be applicable to those classes, but we will not argue the validity.

1.4 Outline

In Chapter 2 we describe the background of this thesis. Chapter ?? describes ... Results are shown in Chapter 6 and discussed in Chapter 7. Chapter 8, contains the work related to this thesis. Finally, we present our concluding remarks in Chapter 9 together with future work.

Chapter 2

Background

This chapter will present the necessary background information for this thesis. Here, we define some basic terminology that will be used throughout this thesis.

2.1 Clone Class

As code clones are seen as one of the most harmful types of technical debt, they have been studied very extensively. A survey by Roy et al [roy2007survey] states definitions for various important concepts in code clone research. In this survey, he mentions the concept “clone pair”, which is *a set of two code portions/fragments which are identical or similar to each other*. Furthermore, he defined “clone class” as *the union of all clone pairs*. Apart from this, we use the definition “clone instance”, which is a single code portion/fragment that is part of either a clone pair or clone class.

Figure 2.1 displays an example of a clone pair or clone class. In this case, both cloned fragments, are found in the same class. Each of the cloned fragments can be defined as a “clone instance”.



Figure 2.1: Example of a clone pair, as found in the ardublock project.

Figure 2.2 displays two clone classes. These clone classes are separated by a single line that is different. The first clone class spans over both the constructor and a method of this class.

Figure 2.2: Example of two clone classes.

2.2 Clone Types

?? Duplication in code is found in many different forms. Most often duplicated code is the result of a programmer reusing previously written code [haefliger2008code, baxter1998clone]. Sometimes this code is then adapted to fit the new context. To reason about these modifications, several clone types have been proposed. These clone types are described in Roy et al [roy2007survey]:

Type I: Identical code fragments except for variations in whitespace (may be also variations in layout) and comments.

Type II: Structurally/syntactically identical fragments except for variations in identifiers, literals, types, layout and comments.

Type III: Copied fragments with further modifications. Statements can be changed, added or removed in addition to variations in identifiers, literals, types, layout and comments.

Type IV: Two or more code fragments that perform the same computation but implemented through different syntactic variants.

A higher type of clone means that it's harder to detect and refactor. There are many studies that adopt these clone types, analyzing them further and writing detection techniques for them [sajnani2016sourcerercc, kodhai2010detection, van2019novel].

2.2.1 Type 2 clones

Relating this to the clone class example of 2.2, the complete class would be flagged as a type 2 clone. This is displayed in figure 2.3. Considering such clones displays the opportunity to refactor the class as a whole.

Figure 2.3: The clone displayed in figure 2.2 as a type 2 clone.

2.2.2 Type 4 clones

For this thesis we have chosen not to consider type 4 clones for refactoring, because they are both hard to detect and hard to refactor (how to choose the best alternative for a certain computation could be a thesis in itself). A study by Kodhai et al [kodhai2013method] looks into the distribution of the

different types of clones in several open source systems (see table 6 of his study). It becomes apparent that type 4 clones exist way less in source code than all of the other types of clones. For instance, for the J2sdk-swing system he finds 8115 type 1 clones, 8205 type 2 clones, 11209 type 3 clones and only 30 type 4 clones. Because of that, we can conclude that type 4 clones are relatively less relevant to study.

2.3 Clone Contexts

Code clones can be found anywhere in the code. The most commonly studied type of clone is the method-level clone. Method-level clones are duplicated blocks of code in the body of a method. Many clone detection tools only focus on method-level clones (like CPD¹, Siamese², Sysiphus³). The reason for this is that with method-level clones it's most likely that the clones are harmful, and they are more straight-forward to refactor.

A paper by Lozano et al [lozano2007evaluating] discusses the harmfulness of cloning. In this paper the author argues that 98% are produced at method-level. However, the paper that is cited to support this claim [bergman2004ethnographic] does not conclude this same information. First of all, the study that is referenced uses a very small dataset (460 copy & paste instances by 11 participants). Secondly, the group of subject only consists of IBM researchers (selection bias). Thirdly, it only focuses on copy and paste instances, as opposed to other ways clones can creep into the code. Finally, the "98%" is not stated explicitly, but is vaguely derivable from one of the figures (figure 1) in this paper. Because of this, there is no reliable overview of how many clones there are in different contexts.

This thesis will focus on measuring how many clones there are per context. This way we can determine the impact of focusing our search on a specific context, like the analysis of only method-level clones. Our hypothesis is that the 98% claim is not true (we think this should be far less). We also hypothesize that clones in different contexts than method-level are less likely to be harmful and less straight forward to refactor.

2.3.1 Clone refactoring in relationship to its context

How to refactor clones is highly dependent on their context. Method-level clones can be extracted to a method [kodhai2013method] if all occurrences of the clone reside in the same class. If a method level clone is duplicated among classes in the same inheritance structure, we might need to pull-up a method in the inheritance structure. If instances of a method level clone are not in the same inheritance structure, we might need to either make a static method or create an inheritance structure ourselves. So not only a single instance of a clone has a context, but also the relationship between individual instances in a clone class. This is highly relevant to the way in which the clone has to be refactored.

2.4 Code clone harmfulness

There has been a lot of discussion whether code clones should be considered harmful.

Most papers view clones as harmful regarding program maintainability. *"Clones are problematic for the maintainability of a program, because if the clone is altered at one location to correct an erroneous behaviour, you cannot be sure that this correction is applied to all the cloned code as well. Additionally, the code base size increases unnecessarily and so increases the amount of code to be handled when conducting maintenance work."* [ostberg2014automatically]

However, the harmfulness of clones depends on a lot of factors. A paper by Kapser et al [kapser2006cloning] describes several patterns of cloning that may not be considered harmful. In this paper Kapser names examples where eliminating clones would compromise other important program qualities. Another study by Jarzabek et al [jarzabek2010clones] categorized "Essential clones": clones that are essential because of the solution that is being modelled by the program. Overall, many of the benefits of code clones do not apply to most modern object-oriented programming languages.

¹CPD is part of PMD, a commonly used source code analyzer: <https://github.com/pmd/pmd>

²Siamese is an Elasticsearch based clone detector: <https://github.com/UCL-CREST/Siamese>

³Sisyphus crawls the Java library for existing implementations of parts of a codebase: <https://github.com/fruffy/Sisyphus>

2.5 Related work

There have been some papers that take some steps towards code clone refactoring. Most research towards refactoring code clones has been conducted by Y. Higo et al. In a 2008 study [**higo2008metric**] the authors look at the refactoring of class-level, method-level and constructor-level clones in Java.

Chapter 3

Addressing problems with clone type definitions

For each of type 1-3 clones [roy2007survey] we list our solutions to their shortcomings (see chapter ?? for these definitions) to increase the chance that we can merge the clone while improving the design. Due to the serious challenges involved in their detection and refactoring, type 4 clones are not considered in this study.

3.1 Type 1R clones

Type 1 clones are identical clone fragments except for variations in whitespace and comments. However, when two clone fragments are textually identical, it does not yet indicate that they are functionally identical. Although textually equal, method calls can still refer to different methods, type declarations can still refer to different types and even variables can be of a different type. In such cases refactoring opportunities could be invalidated. Therefore, we propose an alternative definition of type 1 clones. We have named it “type 1R clones”. The “R” stands for refactoring-oriented (and may be less suitable for other analyses). Type 1R clones differ from type 1 clones as follows:

- **Compare the equality of the fully qualified method signature for method references.** If an identifier is fully qualified, it means we specify the full location of its declaration (e.g. `com.simonbaars.fruitgame.Apple` for an `Apple` object). This way we can validate whether two method references, like method calls, are functionally equal. In the method signature, not only the fully qualified identifier of the method should be considered, but also the type of all its arguments. This way we can be sure that two potentially cloned method references do not point to overloaded variants (in a case that the data type of arguments is overloaded).
- **Compare the equality of the fully qualified identifier for type references.** This way we can be sure that two referenced types are actually equal, and that they are not just two types with the same name.
- **Compare the equality of the fully qualified identifier for variable usages.** Two cloned lines might use a variable with the same name, but different types. This might pose serious challenges on refactoring, as the variables might not concern the same object or primitive. To check this, we need to track the declaration of variables and from this infer the fully qualified identifier of its type.
- **Compare the equality of the fully qualified identifier for method references and call signatures.** This is to prevent a change in functionality after merging the clone, as methods with equal names/parameters can still contain different functionality.

The problem with the clone shown in ?? is that this could invalidate a refactoring opportunity for such a code fragment (especially when we automate it). Because of that, we recommend redefining type-1 clones for refactoring. We propose to:

- **Compare the equality of the fully qualified method signature for method references.** This way we can validate whether two method references, like method calls, are actually equal. In the method signature, not only the fully

Figure 3.1: A wrapped figure going nicely inside the text.



qualified identifier of the method should be considered, but also of the type of all its arguments. This way we can be sure that two potentially cloned method references do not point to overloaded variants (in a case that the data type of arguments is overloaded).

- **Compare the equality of the fully qualified identifier for type references.** This way we can be sure that two referenced types are actually equal, and that they are not just two types with the same name.
- **Compare the equality the fully qualified identifier for variable usages.** Two cloned lines might use a variable with the same name, but different types. This might pose serious challenges on refactoring, as the variables might not concern the same object or primitive. To check this, we need to track the declaration of variables and from this infer the fully qualified identifier of its type.

3.2 Type 2R clones

Type 2 clones allow any change in identifiers, literals, types, layout, and comments. For refactoring purposes, this definition is unsuitable; if we allow any change in identifiers, literals, and types, we cannot distinguish between different variables, different types and different method calls anymore. This could render two methods that have an entirely different functionality as clones. Merging such clones can be harmful instead of helpful.

We tackle these problems with type 2R clones to be able to detect such clones that can and should be merged. Our definition ensures functional similarity by applying the following changes to type 2 clones:

- **Considering types:** Type 2 clones do not consider types. However, this can make a code fragment very hard to refactor, as different types can describe different functional concepts. Because of this, we propose that type 2R clones should consider types like type 1R clones do.
- **Having a distinction between different variables:** For type 2 clones, no identifiers would be taken into account. We agree that a difference in identifiers may still result in a harmful clone, but we should still consider the distinction between different variables. For instance, if we call a method like this: `myMethod(var1, var2)`, or call this method like this: `myMethod(var1, var1)`. Even if the variables have the same type, the distinction between the variables is important to ensure the functionality is the same after merging.
- **Defining a threshold for variability in literals:** For type 2 clones no literals would be taken into account. We agree, as when merging the clone (for example by extracting a method), we can turn the literal into a method parameter. However, we would argue that thresholds matter here. How many literals may differ for the segment still to be considered a clone with another segment? We need to define a threshold to be sure that, by merging, we are not replacing a code fragment by a worse maintainable design.
- **Consider method call signatures and define a threshold for variability in method calls:** As type-2 clones allow changes in identifiers, also the names of called methods may vary. However, because of this, completely different methods can be called in cloned fragments as a result. This poses serious challenges on refactoring and makes it more disputable whether such a clone is harmful for the maintainability of the code. This is because different method identifiers can describe a completely different functionality. Therefore, we suggest considering the call signatures of cloned methods when they are compared. We can allow variability in the rest of method identifiers by passing the function as a parameter. To limit the amount of parameters required we also recommend defining a threshold for variability in method call expressions, so only a limited number of method calls can vary.

3.3 Type 3R clones

Type 3 clones are even more permissive than type 2 clones, allowing added and removed statements. For these clones, thresholds matter a lot to make sure that not the whole project is detected as a clone

of itself. The main question for this study regarding type 3 clones is: *“how can we merge type 3 clones while improving the design?”*.

Clone instances in type 3 clones are almost always different in functionality. As we have to ensure equal functionality after merging the clone, we have to wrap the difference in statements between the clone instances in conditional blocks. We can then pass a variable to indicate which path should be taken through the code (either a boolean or an enumeration). Such a refactoring would make added statements that are contiguous less harmful for the design than added statements that are scattered throughout the cloned fragment.

We also argue that statements that are not common between two clone instances, should not count towards the size of the clone (and thus towards the threshold which determines whether the clone will be taken into account). As for the detection of type 3 clones, we think the easiest opportunity to detect these clones is to consider it as a postprocessing step after clone detection. By trying to find short gaps between clones, we can find opportunities to merge clone classes into a single type 3 clone class. The amount of statements that this “short gap” can maximally span should be dependent on a threshold value.

3.4 The challenge of detecting these clones

To detect each type of clone, we need to parse the fully qualified identifier of all types, method calls and variables. This comes with serious challenges, regarding both performance and implementation. Also, to be able to parse all fully qualified identifiers, and trace the declarations of variables, we might need to follow cross file references. The referenced types/variables/methods might even not be part of the project, but rather of an external library or the standard libraries of the programming language. All these factors need to be considered for the referenced entity to be found, on basis of which a fully qualified identifier can be created.

CloneRefactor uses JavaParser [tomassetti2017javaparser]. JavaParser has a built-in symbol solver, which can automatically resolve types, method calls and variables. However, because of this, CloneRefactor does require all libraries that the software project requires (apart from the Java Standard Library). If these are not available, CloneRefactor will estimate types on basis of the information that is available.

Chapter 4

Relation, Location and Content Analysis of Clones

To be able to refactor code clones, it is very important to consider the context of the clone. We define the following aspects of the clone as its context:

1. The relation of clone instances among each other through inheritance (for example: a clone instance resides in a superclass of another clone instance in the same clone class).
2. Where a clone instance occurs in the code (for example: a method-level clone is a clone instance that is in a method).
3. The contents of a clone instance (for example: the clone instance spans several methods).

Figure 4.1: Abstract representation of clone classes and clone instances.

Figure 4.1 shows an abstract representation of clone classes and clone instances. The relation of clones through inheritance is measured on clone class level: it involves all child clone instances. The location and contents of clones is measured on clone instance level. A clone's location involves the file it resides in and the range it spans (for example: line 6 col 2 - line 7 col 50). A clone instance contents consists of a list of all statements and declarations it spans.

We analyzed the context of clones in a large corpus of open source projects. For these experiments, we used our CloneRefactor tool. These experiments follow the structure of the context: The relation between clone instances is explained, measured and discussed in chapter 4.3; the location of clone instances is explained, measured and discussed in chapter 4.4; the content of clone instances are explained, measured and discussed in chapter 4.5.

4.1 The corpus

For our measurements we use a large corpus of open source projects [githubCorpus2013]. This corpus has been assembled to contain relatively higher quality projects. Also, any duplicate projects were removed from this corpus. This results in a variety of Java projects that reflect the quality of average open source Java systems and are useful to perform measurements on.

As indicated in chapter 3.4 CloneRefactor requires all libraries of software projects we test. As these are not included in the used corpus [githubCorpus2013], we decided to filter the corpus to only include Maven projects. Maven is a build automation tool used primarily for Java, and works on basis of an `pom.xml` file to describe the projects' dependencies. As no `pom.xml` files are included in the corpus, we cloned the latest version of each project in the corpus. We then removed each project that has no `pom.xml` file. As a final step, we collected all dependencies for each project by using the `mvn dependency:copy-dependencies -DoutputDirectory=lib` Maven command, and removed each project for which not all dependencies were available (due to non-Maven dependencies being used or unsatisfiable dependencies being referenced in the `pom.xml` file).

Some general data regarding this corpus is displayed in Table 4.1.

Table 4.1: General results for GitHub Java projects corpus [githubCorpus2013].

Amount of projects	1,361
Amount of lines (excluding whitespace, comments and newlines.)	1,414,996
Amount of statements/declarations	1,212,189
Amount of tokens (excluding whitespace, comments and newlines.)	11,643,194

4.2 Clone detection results

Currently, we have implemented two clone detection algorithms into CloneRefactor. The first one finds clones by comparing tokens (excluding whitespace, comments and newlines), equal to the definition of type 1 clones in literature [roy2007survey]. The second algorithm implements our type 1R, as explained in chapter 3.1. The differences between the clones found for these algorithms is displayed in Table 4.2.

Table 4.2: CloneRefactor clone detection results for the two different algorithms.

	Type 1	Type 1R
Amount of lines cloned	200,362	129,519
Amount of statements/declarations cloned	182,466	118,980
Amount of tokens cloned	1,582,845	973,596

Looking at Table 4.2, it becomes apparent that the type 1R algorithm finds significantly less clones than the type 1 algorithm. This indicates that about a third of the clones have textual equality, but are not actually equal when considering the types of expressions. This makes these clones less suitable for automated refactoring.

4.3 Relations Between Clone Instances

When merging code clones in object-oriented languages, it is very important to consider the relation between clone instances. This relation has a big impact on how a clone should be merged, in order to improve the software design in the process. In this chapter, we display measurements we conducted on the corpus introduced in chapter 4.1. These measurements are based on an experiment by Fontana et al. [fontana2015duplicated], which we will briefly introduce in chapter 4.3.1. We use a vastly different setup, which is explained in chapter 4.3.2. We then show our results in chapter 4.3.3.

4.3.1 Categorizing Clone Instance Relations

Fontana et al. [fontana2015duplicated] describe measurements on 50 open source projects on the relation of clone instances to each other. To do this, they first define several categories for the relation between clone instances in object-oriented languages. A few of these categories are shown in Figure 4.2. These categories are as follows:

1. **Same method:** All instances of the clone class are in the same method.
2. **Same class:** All instances of the clone class are in the same class.
3. **Superclass:** All instances of the clone class are children and parents of each other.
4. **Ancestor class:** All instances of the clone class are superclasses except for the direct superclass.
5. **Sibling class:** All instances of the clone class have the same parent class.
6. **First cousin class:** All instances of the clone class have the same grandparent class.
7. **Common hierarchy class:** All instances of the clone class belong to the same hierarchy, but do not belong to any of the other categories.

8. **Same external superclass:** All instances of the clone class have the same superclass, but this superclass is not included in the project but part of a library.
9. **Unrelated class:** There is at least one instance in the clone class that is not in the same hierarchy.

Figure 4.2: Abstract figure displaying some relations of clone classes. Arrows represent superclass relations.

Please note that none of these categories allow external classes (except for “same external superclass”). So if two clone instances are related through external classes but do not share a common external superclass, it will be flagged as “unrelated”. The main reason for this is that it is (often) not possible to refactor to external classes.

4.3.2 Our setup

We use a similar setup to that used by Fontana et al. (Table 3 of Fontana et al. [fontana2015duplicated]). Fontana et al. measure clones using their own tool (DCRA). As explained in chapter ??, we chose to implement our own tool, CloneRefactor. Therefore, the setup for our measurements differs as follows from Fontana et al.:

- We consider clone classes rather than clone pairs. The rationale for this is given in chapter ??.
- We use different thresholds regarding when a clone should be considered. Fontana et al. seek clones that span a minimum of 7 source lines of code (SLOC). We seek clones with a minimum size of 6 statements/declarations. This is explained detail in chapter ??.
- We seek duplicates by statement/declaration rather than SLOC. This makes our analysis depend less on the coding style (in terms of newline usage) of the author of the software project.
- We test a broader range of projects. Fontana et al. use a set of 50 relatively large projects. We use the corpus as explained in 4.1, which contains a diverse set of projects (diverse both in volume and code quality).

4.3.3 Our results

Table 4.3 contains our results regarding the relations between clone instances. In this table, “T1” stands for the type 1 algorithm from literature and “1R” stands for our type 1R definition as explained in chapter 3.1.

Table 4.3: Clone relations

Relation	# T1	% T1	# 1R	% 1R
Unrelated	6,134	35.48	4,762	38.14
Same Class	4,772	27.60	3,131	25.07
Sibling	2,680	15.50	1,949	15.61
Same Method	2,247	13.00	1,685	13.49
External Superclass	794	4.59	558	4.47
First Cousin	269	1.56	197	1.58
Superclass	237	1.37	118	0.94
Common Hierarchy	123	0.71	73	0.58
Ancestor	35	0.20	14	0.11

The most notable difference when comparing it to the results of Fontana et al. [fontana2015duplicated] is that in our results most of the clones are unrelated (38.14% with type 1R), while for them it was only 15.70%. This might be due to the fact that we consider clone classes rather than clone pairs, and mark the clone class “Unrelated” even if just one of the clone instances is outside a hierarchy. It could also be that the corpus which we use, as it has generally smaller projects, uses more classes from outside the project (which are marked “Unrelated” if they do not have a common external superclass). About a fourth of all clone classes have all instances in the same class, which is generally easy to refactor. On the third place come the “Sibling” clones, which can often be refactored using a pull-up refactoring. There are no noteworthy differences between type 1 and type 1R clones.

4.4 Clone instance location

After mapping the relations between individual clones, we looked at the location of individual clone instances. A paper by Lozano et al. [lozano2007evaluating] discusses the harmfulness of cloning. The authors argue that 98% are produced at method-level. However, this claim is based on a small dataset and based on human copy-paste behavior rather than static code analysis. We validated this claim over our corpus. The results for the clone instance locations are shown in Table 4.4. We chose the following categories:

1. **Method/Constructor Level:** A clone instance that does not exceed the boundaries of a single method or constructor (optionally including the declaration of the method or constructor itself).
2. **Class Level:** A clone instance in a class, that exceeds the boundaries of a single method or contains something else in the class (like field declarations, other methods, etc.).
3. **Interface Level:** A clone that is (a part of) an interface.
4. **Enumeration Level:** A clone that is (a part of) an enumeration.

Please note that these results are measured over each clone instance rather than each clone class, hence the higher total amount in comparison to the results of chapter 4.3.3.

Table 4.4: Clone instance locations

Location	# T1	% T1	# 1R	% 1R
Method Level	32,861	66.02	19,075	58.23
Class Level	15,069	30.27	12,207	37.27
Constructor Level	1,391	2.79	1,080	3.30
Interface Level	282	0.57	247	0.75
Enum Level	171	0.34	147	0.45

Our results indicate that around 58% of the clones are produced at method-level. About 39% of clones either span several methods/constructors or contain something like a field declaration. Another 3% of the clones are found in constructors. The amount of clones found in interfaces and enumerations is very low. Regarding the differences between type 1 and type 1R, it seems that there are relatively less method level clones and more class level clones for type 1R. This is probably due to that the main reason for variability between type 1 and type 1R is variable references, which occur more at method level than class level.

4.5 Clone instance contents

Finally, we looked at the contents of individual clone instances: what kind of declarations and statements do they span. We selected the following categories to be relevant for refactoring:

1. **Full Method/Class/Interface/Enumeration:** A clone that spans a full class, method, constructor, interface or enumeration, including its declaration.

2. **Partial Method/Constructor:** A clone that spans a method partially, optionally including its declaration.
3. **Several Methods:** A clone that spans over two or more methods, either fully or partially, but does not span anything but methods (so not fields or anything in between).
4. **Only Fields:** A clone that spans only global variables.
5. **Includes Fields/Constructor:** A clone that spans a combination of fields and other things, like methods.
6. **Method/Class/Interface/Enumeration Declaration:** A clone that contains the declaration (usually the first line) of a class, method, interface or enumeration.
7. **Other:** Anything that does not match with above-stated categories.

The results for these categories are displayed in Table 4.5.

Table 4.5: Clone instance contents

Contents	# T1	% T1	# 1R	% 1R
Partial Method	32,214	64.72	18,791	57.37
Several Methods	10,542	21.18	8,514	25.99
Includes Constructor	1,772	3.56	1,213	3.70
Includes Field	1,681	3.38	1,487	4.54
Partial Constructor	1,389	2.79	1,078	3.29
Only Fields	962	1.93	888	2.71
Full Method	647	1.30	284	0.87
Includes Class Declaration	263	0.53	258	0.79
Other Categories	304	0.61	243	0.74

Unsurprisingly, most clones span a part of a method. More than a quarter of the clones (for type 1R) span over several methods, which either requires more advanced refactoring techniques or indicates a non-harmful clone.

Chapter 5

Merging duplicate code through refactoring

The most used technique to merge clones is method extraction (creating a new method on basis of the contents of clones). However, method extraction cannot be applied in all cases. Sometimes a clone spans a statement partially (like a for-loop of which only its declaration and a part of the body is cloned). Merging the clones can be harder in such instances. Also, the cloned code can contain statements like `return`, `break`, `continue`. In these instances, more conditions may apply to be able to conduct a refactoring, if beneficial at all.

We measured the amount of clones that can be refactored through method extraction (without additional transformations being required). Our results are displayed in Table 5.1. In this table we use the following categories:

- **Can be extracted:** This clone is a fragment of code that can directly be extracted to a method. Then, based on the relation between the clone instances, further refactoring techniques can be used to merge the extracted methods (for instance “pull up method” for clones in sibling classes).
- **Complex control flow:** This clone contains `break`, `continue` or `return` statements.
- **Spans part of a block:** This clone spans a part of a statement.
- **Is not a partial method:** If the clone does not fall in the “Partial method” category of Table 4.5, the “extract method” refactoring technique cannot be applied.

Table 5.1: Refactorability through method extraction

	# T1	% T1	# 1R	% 1R
Is not a partial method	5,917	34.22	4,806	38.49
Complex control flow	5,511	31.87	3,158	25.29
Spans part of a block	3,989	23.07	3,152	25.24
Can be extracted	1,874	10.84	1,371	10.98

From Table 5.1, we can see that approximately ten percent of the clones can directly be refactored through method extraction (and possibly other refactoring techniques based on the relation of the clone instances). For the other clones, other techniques or transformations will be required. Looking into these techniques and transformations will be one of our next steps.

Chapter 6

Results

In this chapter, we present the results of our experiment.

Chapter 7

Discussion

In this chapter, we discuss the results of our experiment(s) on ...

Finding 1: Highlight like this an important finding of your analysis of the results.

Refer to Finding 1.

Chapter 8

Related work

We divide the related work into ... categories: ...

Chapter 9

Conclusion

In the research we have conducted so far we have made three novel contributions:

- We proposed a method with which we can detect clones that can/should be refactored.
- We mapped the context of clones in a large corpus of open source systems.
- We mapped the opportunities to perform method extraction on clones this corpus.

We have looked into existing definitions for different types of clones [roy2007survey] and proposed solutions for problems that these types have with regards to automated refactoring. We propose that fully qualified identifiers of method call signatures and type references should be considered instead of their plain text representation, to ensure refactorability. Furthermore, we propose that one should define thresholds for variability in variables, literals and method calls, in order to limit the number of parameters that the merged unit shall have.

The research that we have conducted so far analyzes the context of different kinds of clones and prioritizes their refactoring. Firstly, we looked at the inheritance relation of clone instances in a clone class. We have found that more than a third of all clone classes are flagged unrelated, which means that they have at least one instance that has no relation through inheritance with the other instances. For about a fourth of the clone classes all of its instances are in the same class. About a sixth of the clone classes have clone instances that are siblings of each other (share the same superclass).

Secondly, we looked at the location of clone instances. Most clone instances (58 percent) are found at method level. About 37 percent of clone instances were found at class level. We defined “class level clones” as clones that exceed the boundaries of a single method or contain something else in the class (like field declarations, other methods, etc.). Thirdly, we looked at the contents of clone instances. Most clones span a part of a method (57 percent). About 26 percent of clones span over several methods.

We also looked into the refactorability of clones that span a part of a method. Over 10 percent of the clones can directly be refactored by extracting them to a new method (and calling the method at all usages using their relation). The main reason that most clones that span a part of a method cannot directly be refactored by method extraction, is that they contain `return`, `break` or `continue` statements.

9.1 Threats to validity

We noticed that, when doing measurements on a corpus of this size, the thresholds that we use for the clone detection have a big impact on the results. There does not seem to be one golden set of thresholds, some thresholds work in some situations but fail in others. We have chosen thresholds that, according to our manual assessment, seemed optimal. However, by using these, we definitely miss some harmful clones.

9.2 Future work

Acknowledgements

Thanks to you, for reading this :)

Appendix A

Non-crucial information