

# Real-time management of code clones in an IDE environment

Jakob Hansen

April 16, 2022

# Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
<b>2</b>	<b>Background</b>	<b>3</b>
2.1	Software quality and duplicated code . . . . .	3
2.2	Code clones . . . . .	4
2.2.1	The clone relation . . . . .	4
2.2.2	Code clone types . . . . .	5
2.2.3	Code clone detection process and techniques . . . . .	5
2.2.4	Clone aware development . . . . .	7
2.2.5	IDE-based clone management . . . . .	7
2.3	The Language Server Protocol . . . . .	9
<b>3</b>	<b>The way forward</b>	<b>9</b>
3.1	LSP for IDE-based clone management . . . . .	10
3.2	Architecture of tool . . . . .	11
3.3	Exploring clone management techniques . . . . .	11
3.4	Evaluation . . . . .	11
3.4.1	Performance . . . . .	13
3.4.2	Effectiveness in managing clones . . . . .	13
3.4.3	Using LSP for refactoring and clone management . . . . .	13

# 1 Introduction

Refactoring is the process of restructuring code in order to improve the internal behavior of the code, without changing the external behavior[6, 9]. Refactoring is often done in order to eliminate instances of bad design quality in code, otherwise known as code smells.

A study conducted by Diego Cedrim et al. has shown that while developers tend to refactor smelly code, they are rarely successful at eliminating the smells they are targeting[4]. A large portion of refactorings even tend to make the code smellier. Therefore, automated tools to help developers make better refactorings and perform code analysis is an important field of research.

Duplicated code is a code smell which occurs in practically every large software project. Code clone analysis has recently become a highly active field of research and many tools have been developed to detect duplicated code[8, 7]. However, few of these tools reached and see use in the industry and few have the capability of detecting more intricate types of duplicated code and managing them in a real-time IDE environment.

This thesis will present a tool and possibly techniques for industry viable clone detection and management. It will explore the topics of finding and managing clones in real-time, refactoring-oriented clone management and providing clone management tools in a modern IDE environment.

## 2 Background

### 2.1 Software quality and duplicated code

Software quality is hard to define. The term “quality” is ambiguous and is in the case of software quality, multidimensional. Quality in itself has been defined as “conformance to requirements”[5, 8]. In software, the simplest measure of “conformance to requirements” the software can have is a lack of bugs. However, software quality is often measured in other metrics, including metrics which are not directly visible in the functionality[9, 29]. These metrics often include maintainability, analyzability and changeability.

All of these stated metrics are affected negatively by duplicated code, code which

is more or less copied to different locations in the software. Multiple studies have consistently shown that software projects typically have 10 – 15% duplicated code[1]. Therefore, research into tools and techniques which can reduce duplicated code, will be of benefit to almost all software.

As stated, duplicated code damages software quality software projects. Duplicated code can lead to a plethora of antipatterns, for example shotgun-surgery, and will often lead to an increase in technical debt for the project[6, 99]. The shotgun-surgery antipattern occurs when a developer wants to implement a change, but needs to make the same change in many places for the change to take effect. This is a typical situation which slows down development when a software project contains a lot of duplicated code.

## 2.2 Code clones

We define a code snippet or code fragment as a piece of software code in a larger software system. A code clone is then defined as a code snippet which is equal to or similar to another code snippet. The two code snippets are both code clones, and together they form a code clone pair.

### 2.2.1 The clone relation

The clone relation defines a relation between code snippets where snippets which are code clones are related to each other. The clone relation is reflexive and symmetric, but not always transitive. The transitive property depends on the threshold for similarity when identifying code clones. Given

$$a \xrightarrow{\text{clone}} b \xrightarrow{\text{clone}} c$$

where  $a, b, c$  are code snippets and  $\xrightarrow{\text{clone}}$  gives the clone relation,  $a$  is a clone of  $b$ , but not necessarily similar enough to be a clone of  $c$ , depending on the threshold for similarity.

### 2.2.2 Code clone types

Code clones are generally classified into four types[8]. These types classify code snippets as code clones with an increasing amount of leniency. Therefore, Type-1 code clones are very similar, while Type-4 clones are not necessarily similar at all. However, all code clones do still have the same functionality, it is the syntactic and structural differences which distinguish the types. The set of code clones classified by a code clone type is also a subset of the next type, meaning all type-1 clones are also type-2 clones, but not vice versa.

The code clone types are defined as follows:

**Type-1** clones are syntactically identical. The only differences allowed are elements without meaning, like comments and white-space.

**Type-2** clones are structurally identical. Possible differences include identifiers, literals and types.

**Type-3** clones are required to be structurally similar, but not equal. Differences include statements which are added, removed or modified. This clone type relies on a threshold  $\theta$  which determines how structurally different snippets can be to be considered Type-3 clones[8].

**Type-4** clones have no requirement for syntactical or structural similarity. Therefore, the only requirement is having the same functionality.

Type-1 clones are often referred to as “exact“ clones, while Type-2 and Type-3 clones are often referred to as “near-miss“ clones[14, 1].

### 2.2.3 Code clone detection process and techniques

**The Code clone detection process** is generally split into (but is not limited to) a set of steps to identify clones[12]. This process is often a pipeline of input-processing steps before finally comparing fragments against each other and filtering. The steps are generally as follows:

1. **Pre-processing:** Removing uninteresting parts which we do not want to check for clones, for example generated code. Then partitioning code into a set of fragments, depending on granularity. Granularity which one partitions fragments into could be entire files, methods or lines.

2. **Transformation:** Transforming the fragments into an intermediate representation.
  - (a) **Extraction:** Transforming source code into the input for the comparison algorithm. Can be tokens, AST, dependency graphs, etc.
  - (b) **Normalization:** Optional step which removes superficial differences such as comments, whitespace and identifier names. Often useful for identifying type-2 clones.
3. **Match detection:** Performing the comparisons which outputs a set of candidate clone pairs.
4. **Formatting:** Convert from candidate clone pairs from the transformed code back to clone pairs in the original source code.
5. **Post-processing/Filtering:** Ranking and filtering manually or with automated heuristics
6. **Aggregation:** Optionally aggregating sets of clone pairs into clone classes

As stated, not all clone detection techniques will necessarily follow all these steps.

**Code clone detection techniques** are techniques which can be applied to detect clones, with various advantages and disadvantages. Some of the most popular techniques are as follows:

*Text-based* approaches do very little processing on the source code before comparing. Simple techniques such as fingerprinting or incremental hashing have been used in this approach. Dot plots have also been used in newer text-based approaches, placing the hashes of fragments in a dot plot for use in comparisons.

*Token-based* approaches transform source code into a stream of tokens, similar to lexical scanning in compilers. The token stream is then scanned for duplicated subsequences of tokens. Since token streams rarely include superficial differences such as whitespace, indentation and comments, this approach is more robust to such differences. Concrete names of identifiers and values are abstracted away when comparing the token-stream, therefore type-2 clones can easily be identified. Type-3 clones can also be identified by comparing the fragments tokens and keeping clone pairs with a lexical difference lower than a given threshold. This can be solved with dynamic programming[2].

*Syntactic* approaches transform source code into either parse trees or abstract syntax trees and find clones using either tree matching algorithms or structural

metrics. For tree matching, the common approach is to find similar subtrees in the parse tree / AST, which are then deemed as clones. One way of finding similar subtrees is to hash subtrees into buckets and compare them with a tolerant tree matching algorithm. Variable names, literal values and other source may be abstracted to find type-2 clones more easily. Metrics-based techniques gather metrics for code fragments in the parse tree / AST and uses the metrics to determine if the fragments are clones or not. One way is to use fingerprinting functions where the fingerprint includes certain metrics, and compare the fingerprints of all fragments to find clones.

*Chunk-based* approaches decompose chunks of source code into signatures which are compared. Chunk-size is based on selected granularity, which can be functions, blocks, etc. Signatures can for example be based on some software metrics. Machine learning has been used in this approach ...

*Hybrid* approaches combine multiple approaches in order to improve detection. For example Zibran et al.[14] developed a hybrid algorithm combining both token-based suffix trees for type-1 and type-2 clone detection, with a k-difference dynamic programming algorithm for type-3 clone detection.

#### **2.2.4 Clone aware development**

Developers are often not aware of the creation of clones in their code. Clone aware development involves having clone management as a part of the software development process. Since code clones can be hard to keep track of and manage, tools which help developers deal with clones are useful. However, Mathias Rieger et al. claims that a problem with many detection tools is that the tools “report large amounts data that must be treated with little tool support.”[11, 1]. Existing tools which partly solves this problem are presented below.

#### **2.2.5 IDE-based clone management**

There are many existing clone management tools, however the most useful tools for clone aware development are the tools which are integrated into an IDE and offer services to the programmer while developing in real-time.

The IDE-based tools which exist can be categorized as follows[13, 8]:

- *Copy-paste-clones*: This category of tools deals only with code snippets which are copy-pasted from another location in code. These tools therefore only track clones which are created when copy-pasting, and does not use any other detection techniques. Therefore, this type of tool is not suitable for detecting clones which are made accidentally, since developers are aware that they are creating clones when pasting already existing code snippets.
- *Clone detection and visualization tools*: This category of tools has more sophisticated clone detection capabilities and will detect code clones which occur accidentally.
- *Versatile clone management*: This category of tools covers tools which provide more services than the above. Services like refactoring and simultaneous editing of clones fall under this category.

There are a few existing IDE-tools which have seen success in real-time detection of clones:

- Minhaz et al. introduced a technique for performing real-time focused searches, i.e. searching only for code clones of a given code snippet. This technique can also detect Type-3 clones[14]. This technique was later used in the tool *SimEclipse*[13]. Since this tool can only detect clones of a code snippet which the developer actively selects, this tool is not well suited for finding accidental clones.
- Another tool, SHINOBI can detect code clones in real-time without the need of the developer to select a code snippet, however it can only detect type-1 and type-2 code clones[10].
- The modern IDE IntelliJ has a built-in duplication detection and refactoring, it's able to detect type-1 and type-2 code clones at a method granularity and refactors by replacing one of the clones with a method call. This tool also requires the user to actively select the method which will be checked for clones.

No tools which we are aware of have the capability of both reporting code clones in real-time without fragment-selection and reporting type-3 clones.



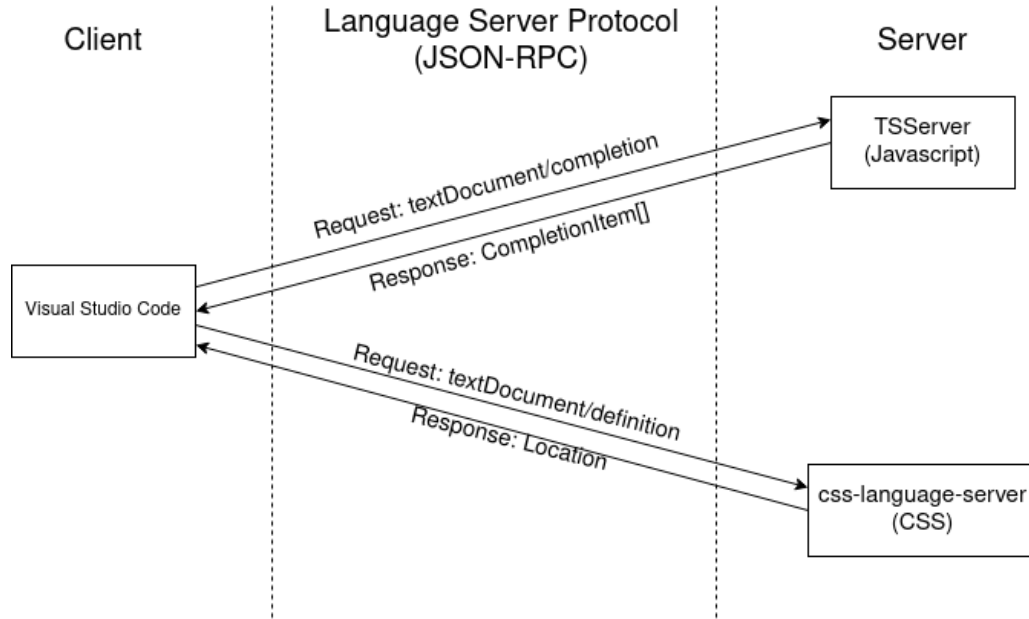


Figure 1: Example client-server interaction using LSP

## 2.3 The Language Server Protocol

The Language Server protocol (LSP) is a protocol which specifies interaction between a client (IDE) and server in order to provide the client with tooling support. The goal of the protocol is to avoid multiple implementations of the same language tools for every IDE and every language. Servers which implement LSP will be able to offer IDE's code-completion, diagnostics, go-to-definition and much more. LSP also specifies generic code-actions and commands, which the LSP server provides to the client in order to perform custom actions defined by the server.

Figure 1 shows a sample interaction between client and server using LSP. The client sends requests to a server in the form of JSON-RPC, and the server sends a corresponding response, also in the form of JSON-RPC.

## 3 The way forward

This thesis will present and evaluate a modern tool which provides clone management capabilities in a real-time IDE environment. The main goal will be to create a tool which fits well into the development cycle and works in a real-time IDE

environment. Areas of focus will therefore be:

- Real-time detection and management of code clones
- Code clone refactoring and detection of refactoring-oriented clones
- IDE tooling and IDE agnostic tooling like LSP.
- Clone ranking, which clones are allowed to stay?

### 3.1 LSP for IDE-based clone management

The tool will give programmers the ability to manage clones in their IDE. We will utilize many feature of LSP, especially code-actions, in order to provide functionality for clone management to any editor which implements LSP.

The interaction with the LSP server is modelled as user stories as follows:

- A programmer wants to see code clones for a single file, the programmer opens the file in their IDE and is displayed diagnostics in the code wherever there are detected clones.
- A programmer wants to see all code clones for the current project. The programmer opens the IDE's diagnostic view and will see all code clones detected as diagnostics there. The diagnostic will contain information like where the clone exists, and percentage of duplicated code.
- A programmer wants to jump to the corresponding match of a code clone in their editor. The programmer moves their cursor to the code clone diagnostic, invokes a request to see code actions, and invokes the "Jump to matching clone" code action. This moves the cursor to the relevant file with the matching code clone selected.
- A programmer wants to merge a code clone pair. The programmer moves their cursor to one of the code clones, invokes a request to see code actions, and invokes one of the "Merge code clone with strategy x" actions. The strategies presented to the user is dependent on the context of the code clone pair, the programmer will only see the useful / realizable merging strategies.

## 3.2 Architecture of tool

Figure 2 shows the architecture of the tool. The server communicates with the IDE and delegates the work of managing clones to the detection engine and the merge engine. The tool also stores an index of all source code files in the current project.

## 3.3 Exploring clone management techniques

During development of the tool, different techniques for detecting and merging clones will be explored. The goal will be to find a fitting technique for both detecting and merging clones in a real-time IDE environment.

Detection techniques explored will include:

- A modified version of Zibran et al. hybrid algorithm[14]
- AST-based technique with incremental parsing. Using Tree-sitter, a generator of incremental parsers[3].
- More techniques ...

Merging techniques explored will include:

- Refactoring-oriented clone merging[7]

The tool will be modular in how techniques are applied for clone management. This means that the tool will be capable of plugging in different detection engines, merging engines and file indices. This will be used extensively in our research in order to test multiple techniques for detection and merging.

## 3.4 Evaluation

We will evaluate this tool based on different criteria, which together will provide a basis for evaluating the tool as a whole.

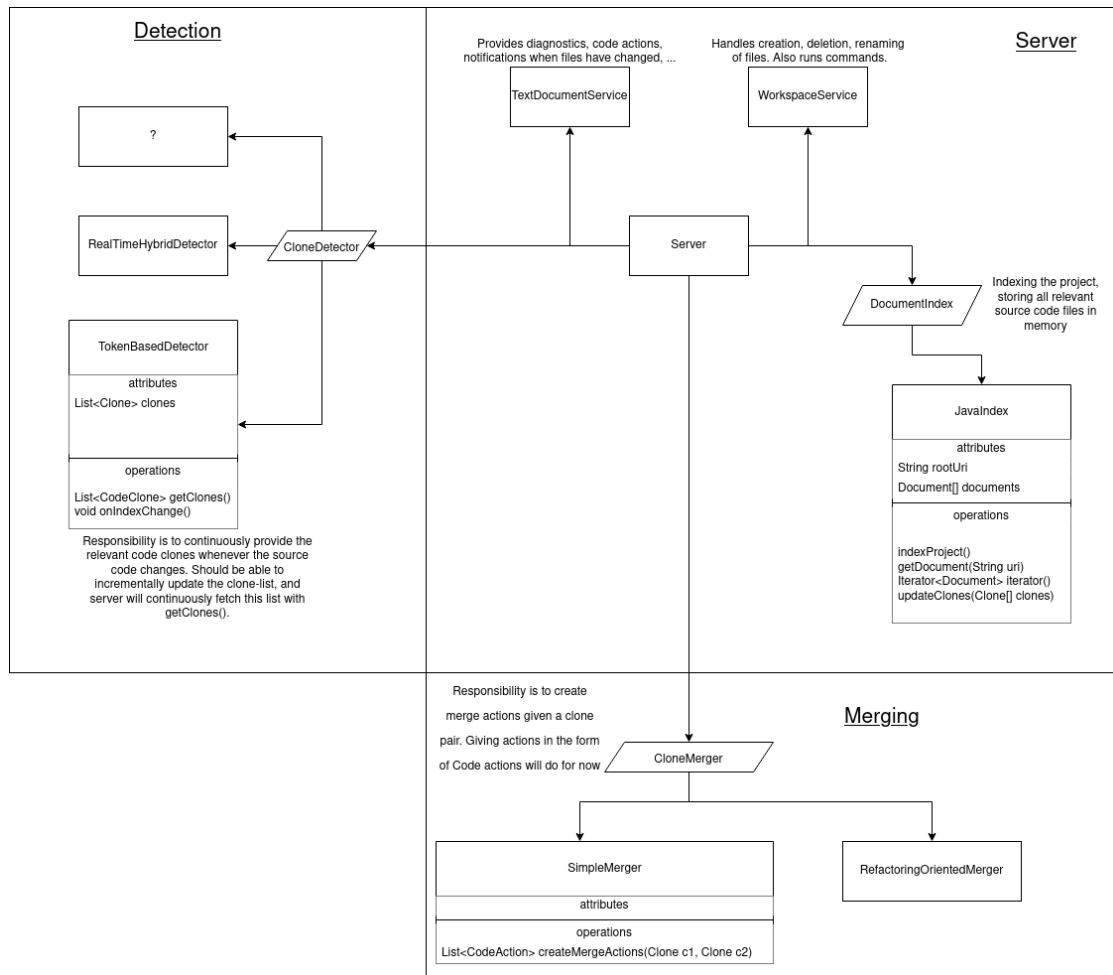


Figure 2: Tool architecture

### **3.4.1 Performance**

Since the tool is focused on efficient detection and management of code clones, real-time performance of the tool will be a big priority in its evaluation. The tool will implement different techniques of detecting and merging clones. These will be empirically compared against each other. The tool will also be evaluated against existing tools empirically.

### **3.4.2 Effectiveness in managing clones**

The tool will also be evaluated based on its effectiveness in managing clones. Can we determine if this tool is better than existing tools at managing or eliminating clones in the software development cycle?

### **3.4.3 Using LSP for refactoring and clone management**

Finally, we will evaluate if LSP is a suitable tool for use in clone management and refactoring in general. Can LSP provide all the features one would want in a modern clone management tool? What is missing, and how could the LSP protocol be extended in order to facilitate this? We believe that if LSP is an appropriate tool to use for clone management, LSP will also be an appropriate tool for refactoring tools in general.

## References

- [1] R. Al-Ekram, C. Kapser, R. Holt, and M. Godfrey. Cloning by accident: an empirical study of source code cloning across software systems. In *2005 International Symposium on Empirical Software Engineering, 2005.*, pages 10 pp.–, 2005.
- [2] Brenda S. Baker and Raffaele Giancarlo. Sparse dynamic programming for longest common subsequence from fragments. *Journal of Algorithms*, 42(2):231–254, 2002.
- [3] Max Brunsfeld. Tree-sitter. <https://tree-sitter.github.io/tree-sitter/>. Accessed: 2022-04-16.
- [4] Diego Cedrim, Alessandro Garcia, Melina Mongiovi, Rohit Gheyi, Leonardo da Silva Sousa, Rafael Maiani de Mello, Balduino Fonseca, Márcio Ribeiro, and Alexander Chávez. Understanding the impact of refactoring on smells: a longitudinal study of 23 software projects. In Eric Bodden, Wilhelm Schäfer, Arie van Deursen, and Andrea Zisman, editors, *Proceedings of the 2017 11th Joint Meeting on Foundations of Software Engineering, ESEC/FSE 2017, Paderborn, Germany, September 4-8, 2017*, pages 465–475. ACM, 2017.
- [5] P.B. Crosby. *Quality is Free: The Art of Making Quality Certain*. New American Library, 1980.
- [6] Martin Fowler. *Refactoring - Improving the Design of Existing Code*. Addison Wesley object technology series. Addison-Wesley, 1999.
- [7] Yoshiki Higo. *Identifying Refactoring-Oriented Clones and Inferring How They Can Be Merged*, pages 183–196. Springer Singapore, Singapore, 2021.
- [8] Katsuro Inoue. *Introduction to Code Clone Analysis*, pages 3–27. Springer Singapore, Singapore, 2021.
- [9] Stephen H. Kan. *Metrics and Models in Software Quality Engineering*. Addison-Wesley Longman Publishing Co., Inc., USA, 2nd edition, 2002.
- [10] Shinji Kawaguchi, Takanobu Yamashina, Hidetake Uwano, Kyohei Fushida, Yasutaka Kamei, Masataka Nagura, and Hajimu Iida. Shinobi: A tool for automatic code clone detection in the ide. pages 313–314, 01 2009.
- [11] M. Rieger, S. Ducasse, and M. Lanza. Insights into system-wide code duplication. In *11th Working Conference on Reverse Engineering*, pages 100–109, 2004.

- [12] Chanchal Kumar Roy, James R. Cordy, and Rainer Koschke. Comparison and evaluation of code clone detection techniques and tools: A qualitative approach. *Sci. Comput. Program.*, 74(7):470–495, 2009.
- [13] Md Sharif Uddin, Chanchal K. Roy, and Kevin A. Schneider. Towards convenient management of software clone codes in practice: An integrated approach. In *Proceedings of the 25th Annual International Conference on Computer Science and Software Engineering*, CASCON '15, page 211–220, USA, 2015. IBM Corp.
- [14] Minhaz F. Zibran and Chanchal K. Roy. Ide-based real-time focused search for near-miss clones. In *Proceedings of the 27th Annual ACM Symposium on Applied Computing*, SAC '12, page 1235–1242, New York, NY, USA, 2012. Association for Computing Machinery.