Improving Software Maintainability through Automated Refactoring of Code Clones

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Host Company: Software Improvement Group

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Location: Amsterdam

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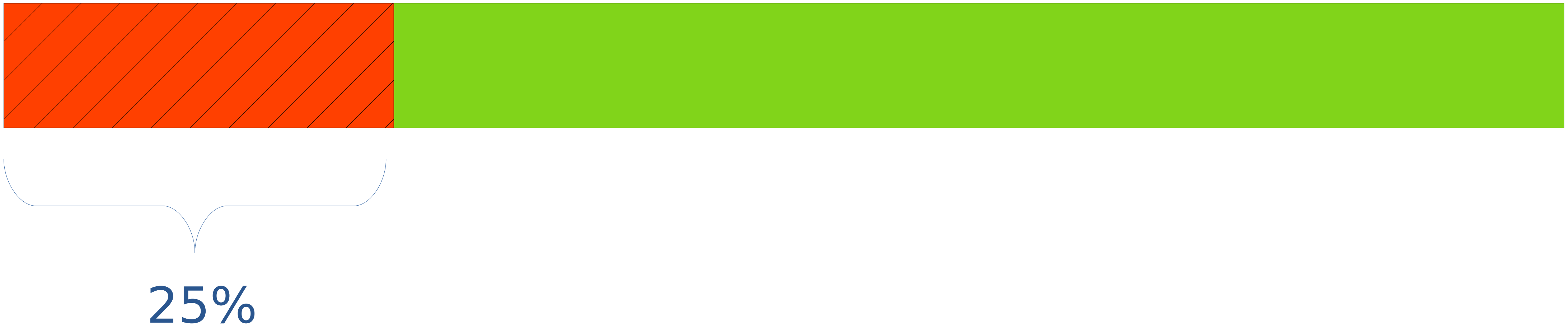
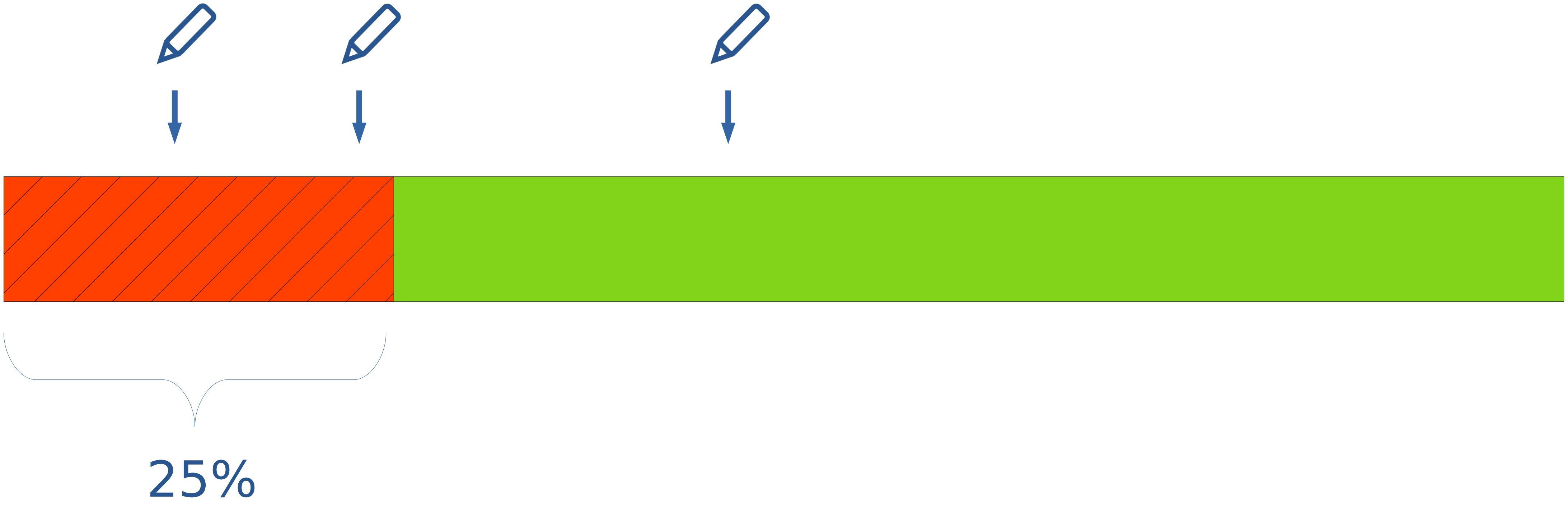


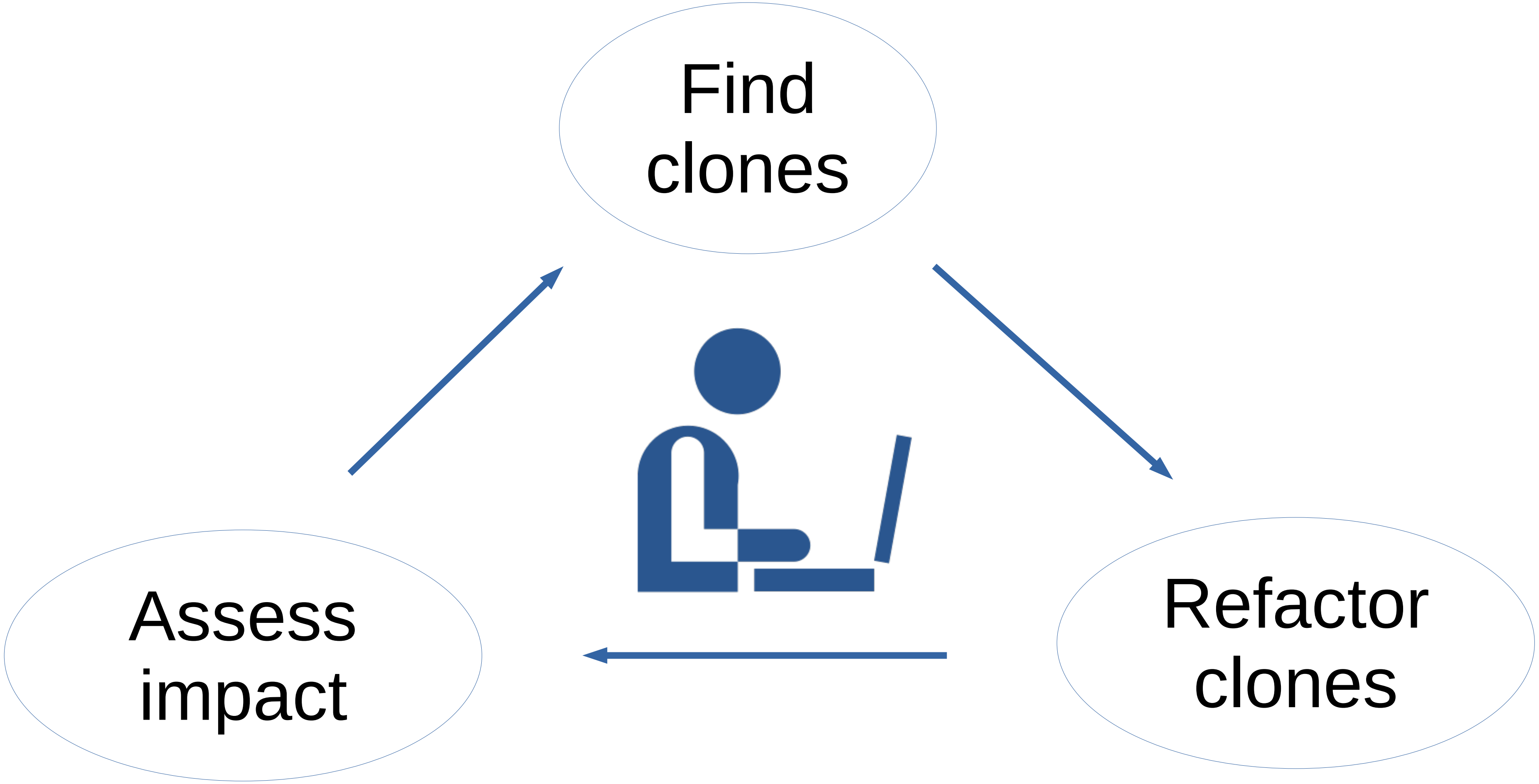
25%

One “simple” change...



*“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”*

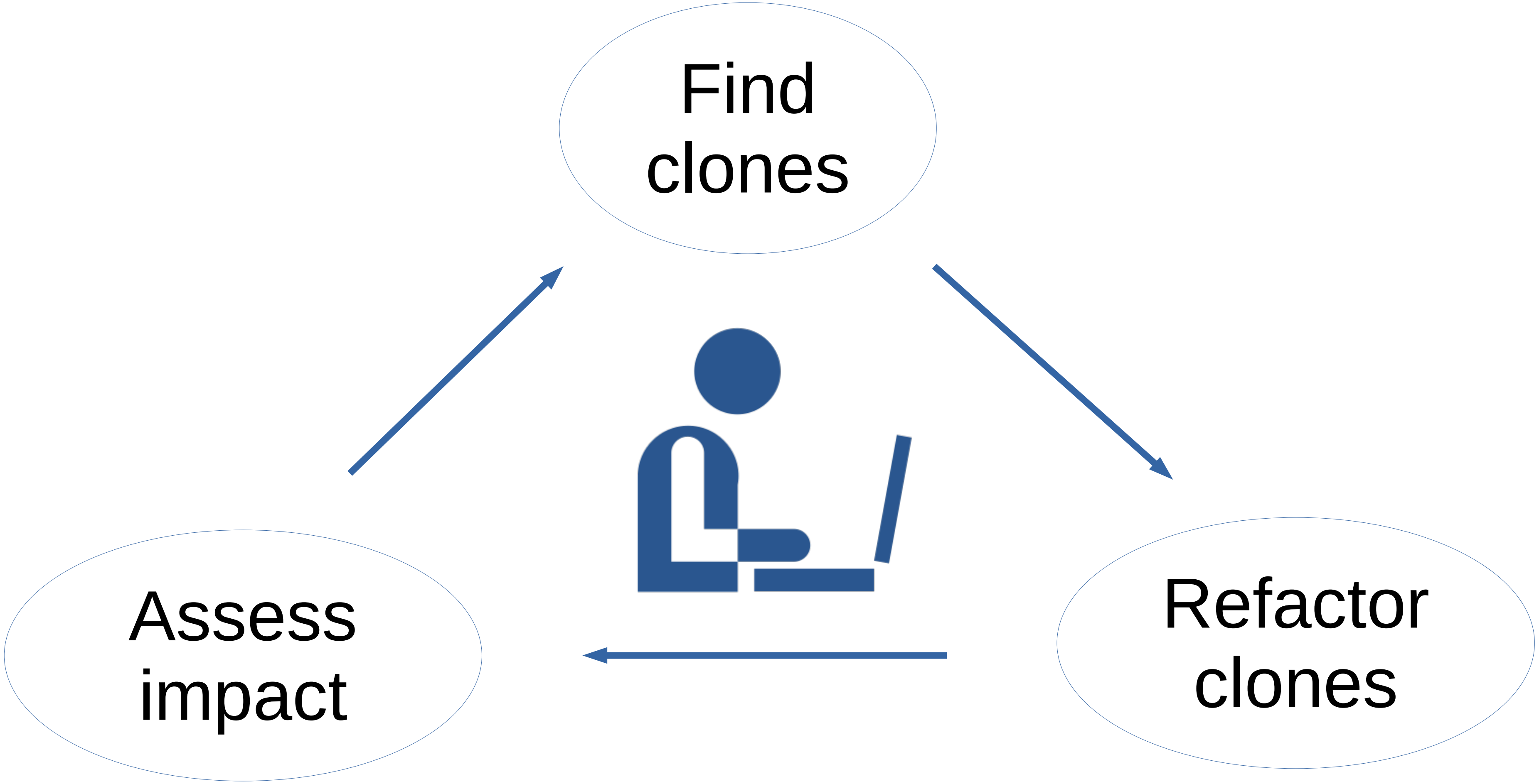
~ Martin Fowler & Kent Beck in *Refactoring*



Find clones

Refactor clones

Assess impact



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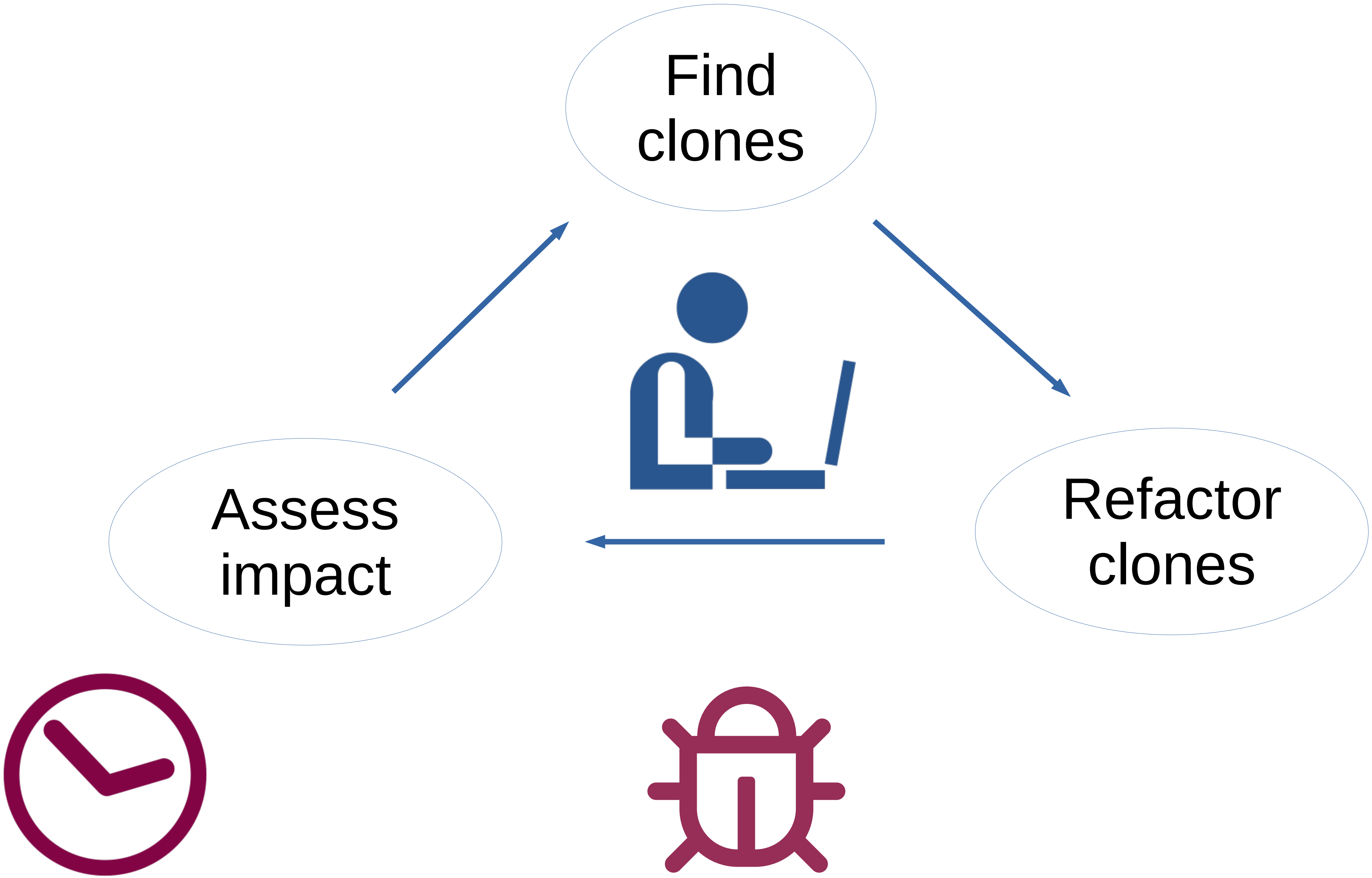

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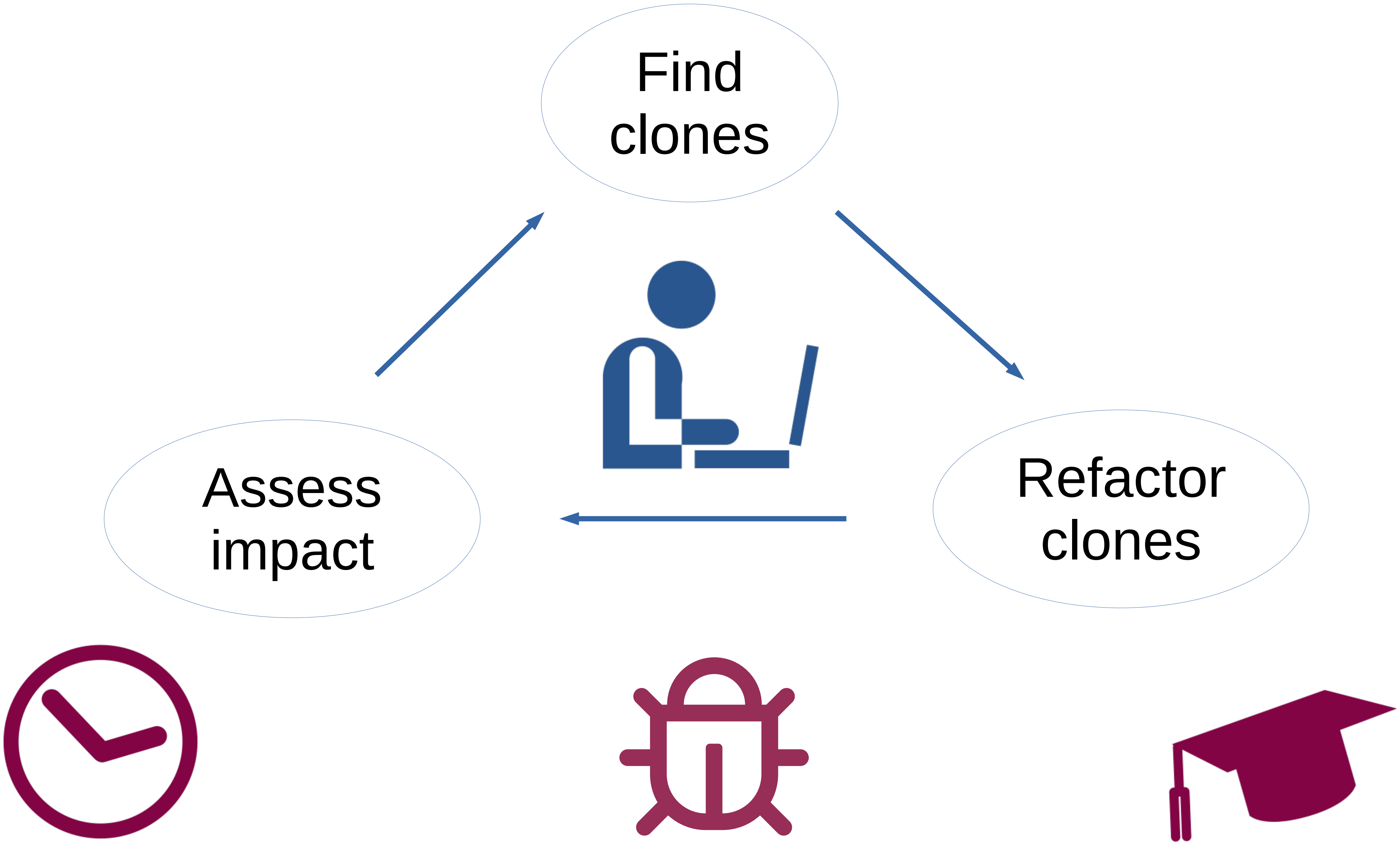

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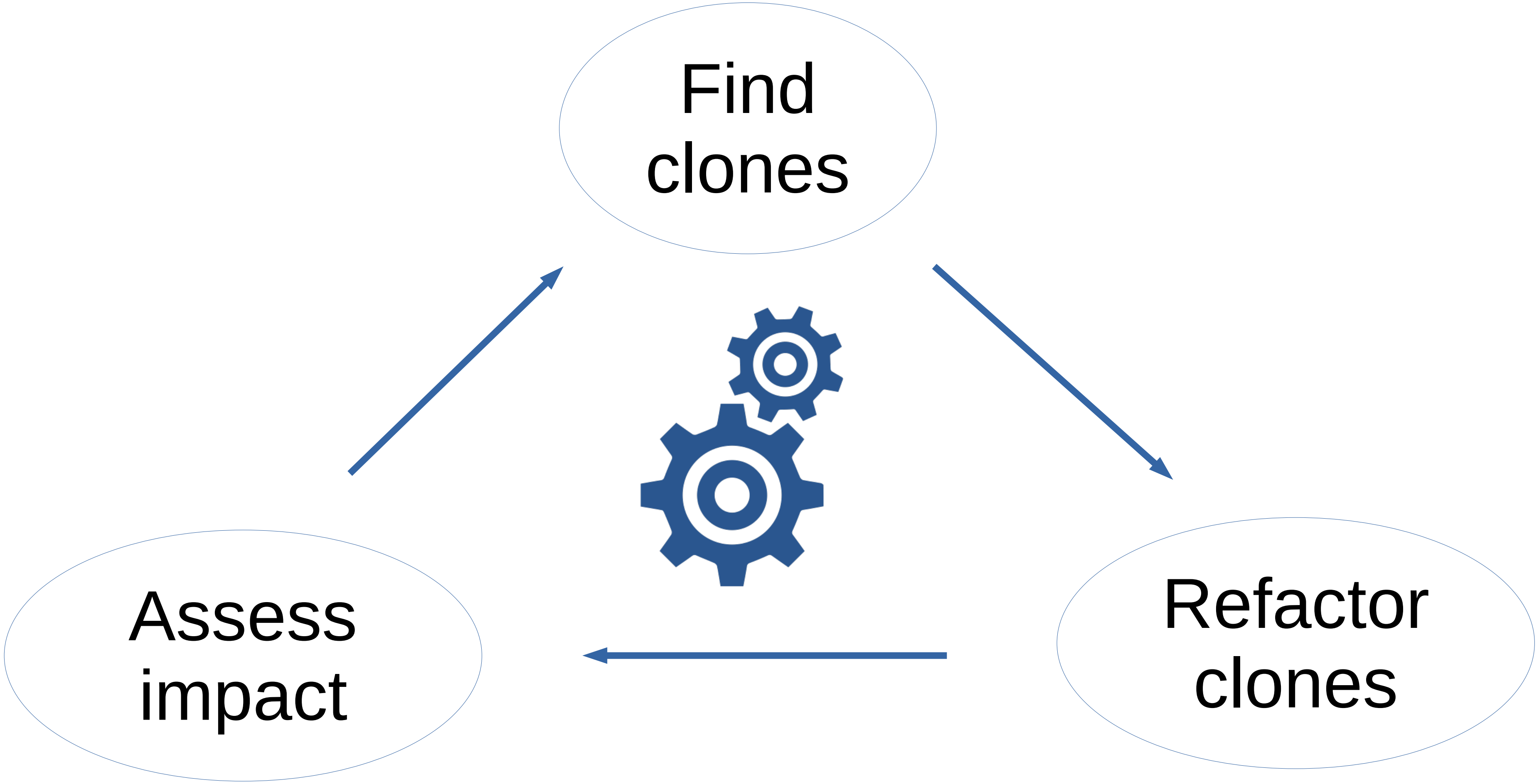

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Refactor clones

Assess impact

RQ1.

How can we define clone types such that they ***can*** *be automatically refactored?*

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How can we prioritize refactoring opportunities based on the ***context*** *of clones?*

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RQ3.

What are the discriminating factors to decide when a clone ***should*** *be refactored*

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How can we define clone types such that they ***can*** *be automatically refactored?*

RQ2.

How can we prioritize refactoring opportunities based on the ***context*** *of clones?*

RQ3.

What are the discriminating factors to decide when a clone ***should*** *be refactored*

Clone Types

Each clone type allows more variance between cloned fragments.

$$\text{Type 1} \subseteq \text{Type 2} \subseteq \text{Type 3}$$

Type 1.

Textually identical code fragments except for variations in whitespace and comments.

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```java
package com.sb.cryo.addition;

import com.notificationlib.*;
import java.util.List;

public class AdditionUtils {
    public void addToList(List l) {
        l.add(getClass().getName());
    }

    public int addTen(int x) {
        x = x + 10; // add number
        Notifier.notifyChanged(x);
        return x;
    }
}
```

```java
package com.sb.cryo.util;

import com.sb.cryo.notifier.*;
import java.awt.List;

public class StringUtils {
    public void addToList(List l) {
        l.add(getClass().getName());
    }

    public String concatTen(String x) {
        x = x + 10; // concat number
        Notifier.notifyChanged(x);
        return x;
    }
}
```

Type 1R.

Contextually & textually identical code fragments except for variations in layout and comments.

```
package com.sb.cryo.addition;

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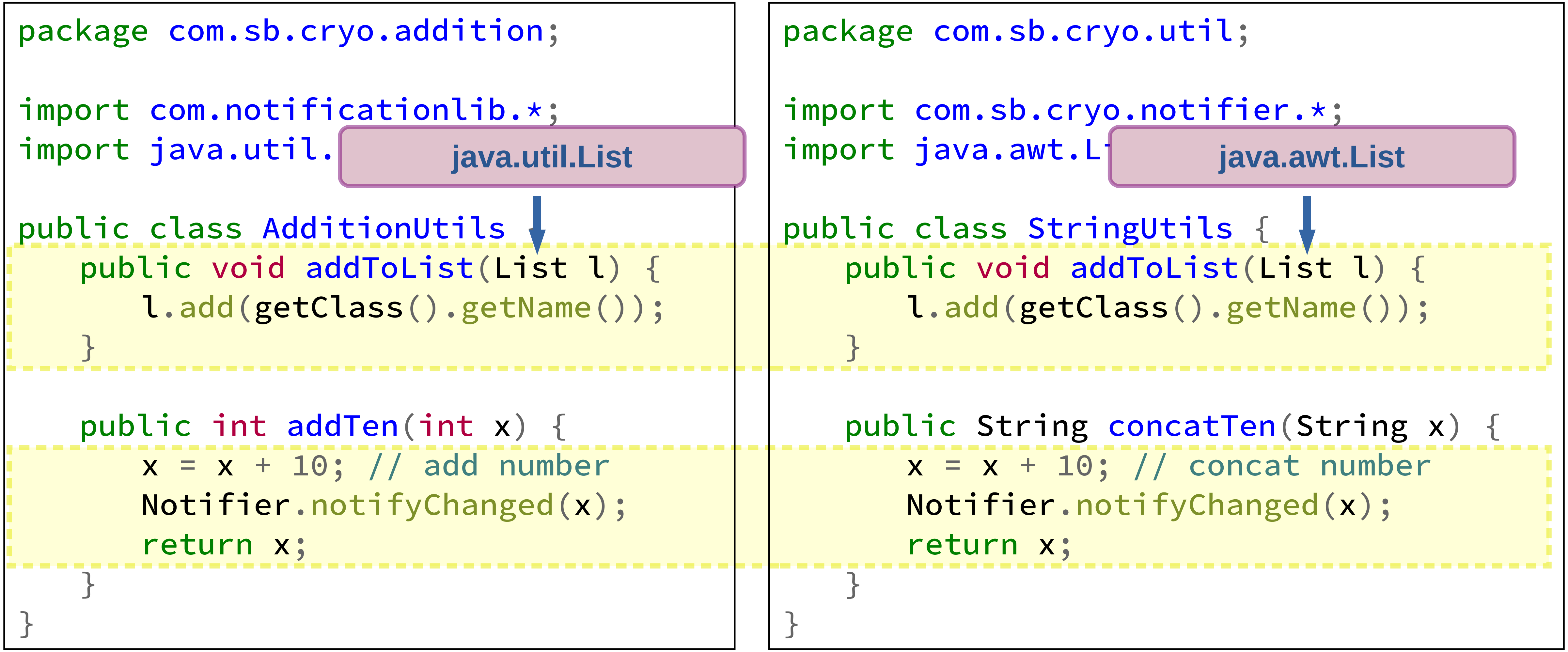

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package com.sb.cryo.addition;

import com.notificationlib.*;
import java.util.

public class AdditionUtils
    public void addToList(List l) {
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java.util.List

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java.awt.List

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Contextually & textually identical code fragments except for variations in layout and comments.

java.util.List.add(java.lang.Object)

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package com.sb.cryo.addition;

import com.notificationlib.*;
import java.util.List;

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    public int addTen(int x) {
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        return x;
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}
```

java.awt.List.add(java.lang.String)

```
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import java.awt.List;

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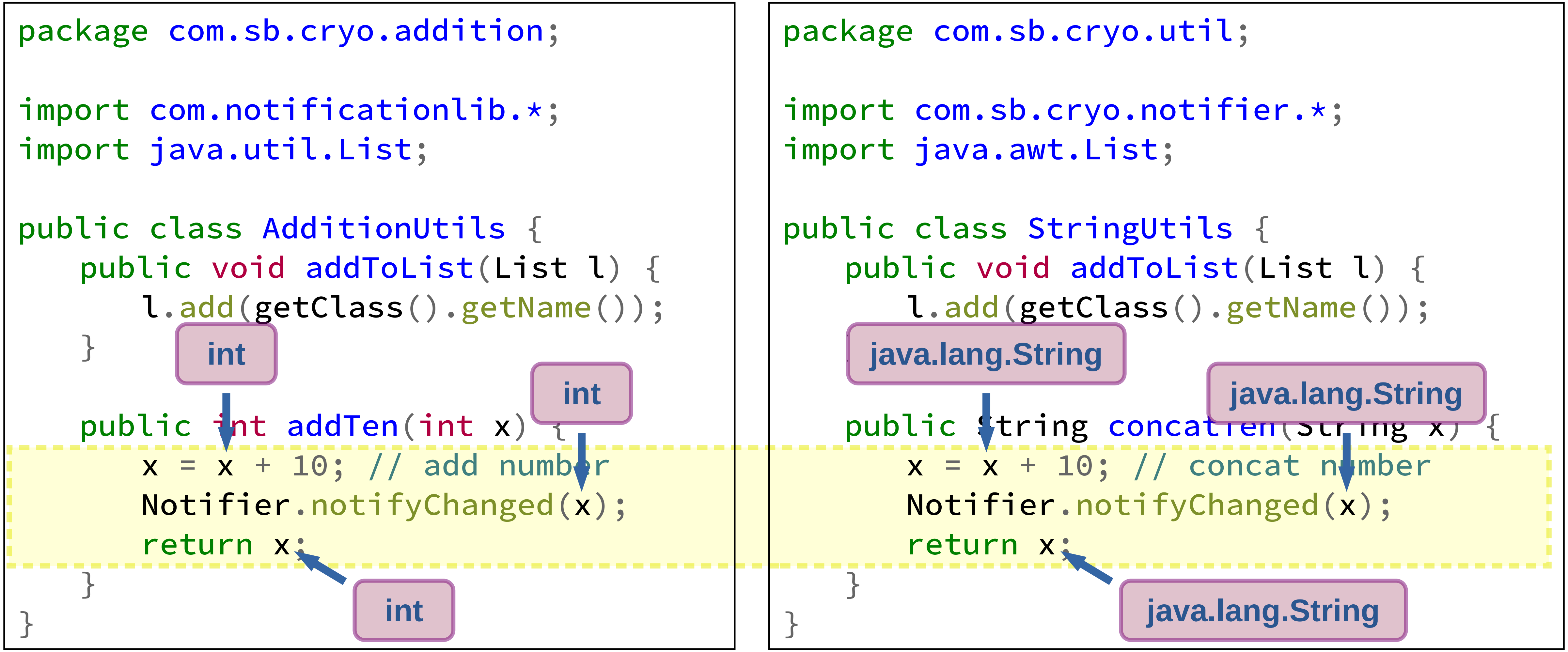

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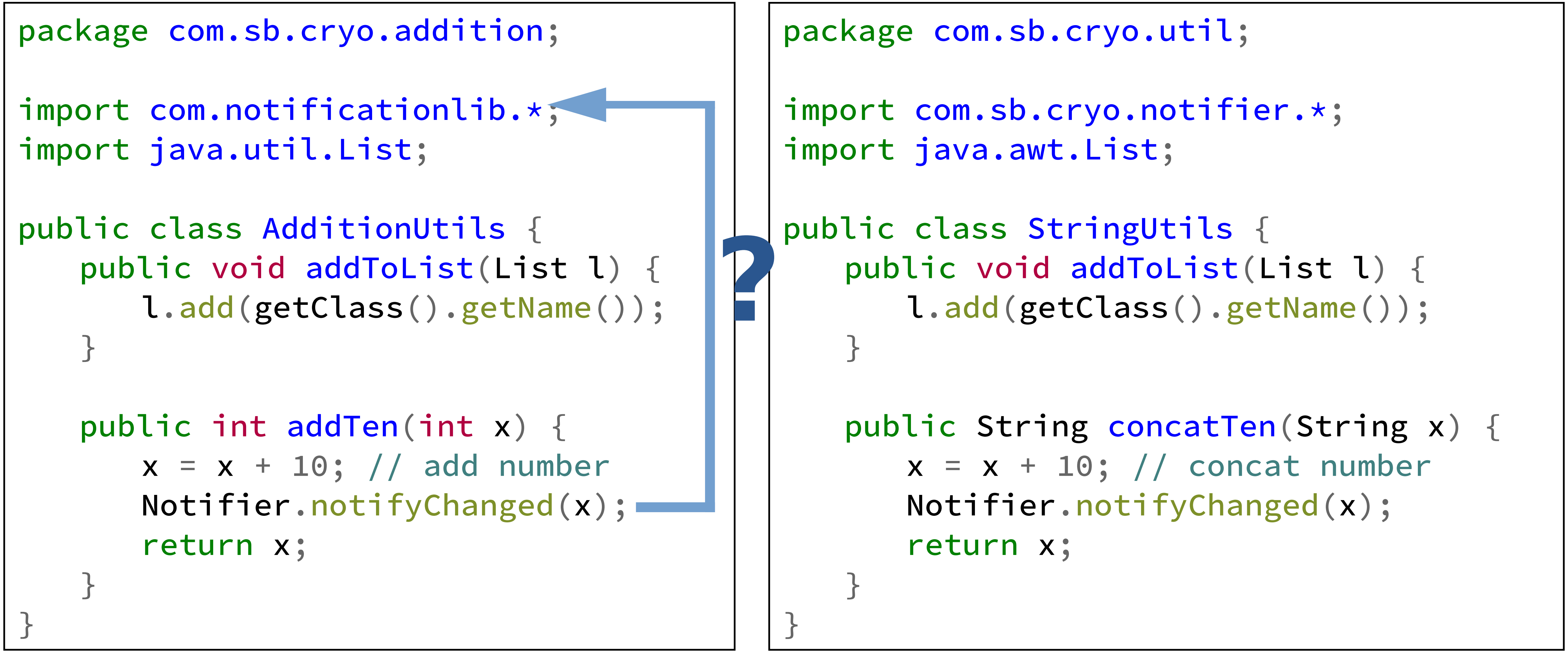
}
```

Type 1R.

Retrieving contextual information can be challenging!



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    public String concatTen(String x) {
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        Notifier.notifyChanged(x);
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    }
}
```

Type 1R Summarized

In addition to type 1 rules, we compare contextual information of:

1. Type references (Fully Qualified Identifier)
2. Variable references (type)
3. Method references (Fully Qualified Signature)

Retrieving fully qualified identifiers/signatures can be challenging!

Type 2.

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

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

```java
public boolean containsOnlyRedCircles(List<Circle> circles){
  return circles.stream().allMatch(Shape::isRed);
}
```

```java
public Apple getEdibleApple(FruitBasket<Apple> basket){
  return basket.getFruit().getApple(Fruit::notEaten);
}
```

Type 2R.

Type 1R clones except for variations in a controlled set of expressions.

No design tradeoff

- Type declaration names
- Method names
- Variable names/references (sometimes)

Design tradeoff

- Literals (of the same type)
- Variable references (sometimes)
- Called methods (same type & parameters)

Type 2R clones

> No design tradeoff

- **Type declaration names**
- **Method names**
- Variable names/references (sometimes)

> Design tradeoff

- Literals (of the same type)
- Variable references (sometimes)
- Called methods (same type & parameters)

```
public class A {
   public void doA() {
      print("hello");
   }
}

public class B {
   public void doB() {
      print("hello");
   }
}
```

Type 2R clones

> No design tradeoff

- Type declaration names
- Method names
- **Variable names/references (sometimes)**

> Design tradeoff

- Literals (of the same type)
- Variable references (sometimes)
- Called methods (same type & parameters)

```
public void doA() {
    String message = "hello";
    print(message);
}

public void doB() {
    String hello = "hello";
    print(hello);
}
```

Type 2R clones

> No design tradeoff

- Type declaration names
- Method names
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> Design tradeoff

- **Literals (of the same type)**
- Variable references (sometimes)
- Called methods (same type & parameters)

```
// Original
void doABC(){
   doA();
   doB("abc");
   doC();
}

void doDEF(){
  doA();
  doB("def");
  doC();
}
```

```
// Refactored
void doABC(){
   doThis("abc");
}

void doDEF(){
   doThis("def");
}

void doThis(String letters){
  doA();
  doB(letters);
  doC();
}
```

Type 2R clones

> No design tradeoff

- Type declaration names
- Method names
- Variable names/references (sometimes)

```
// Original
String abc = "abc";
String def = "abc";
void doABC(){
   doA();
   doB(abc);
   doC();
}
void doDEF(){
  doA();
  doB(def);
  doC();
}
```

> Design tradeoff

- Literals (of the same type)
- **Variable references (sometimes)**
- Called methods (same type & parameters)

```
// Refactored
String abc = "abc";
String def = "abc";
void doABC(){
   doThis(abc);
}
void doDEF(){
   doThis(def);
}
void doThis(String letters){
  doA();
  doB(letters);
  doC();
}
```

Type 2R clones

> No design tradeoff

- Type declaration names
- Method names
- Variable names/references (sometimes)

```
// Original
void doABC(){
   doA();
   doB();
   doC();
}

void doADC(){
  doA();
  doD();
  doC();
}
```

> Design tradeoff

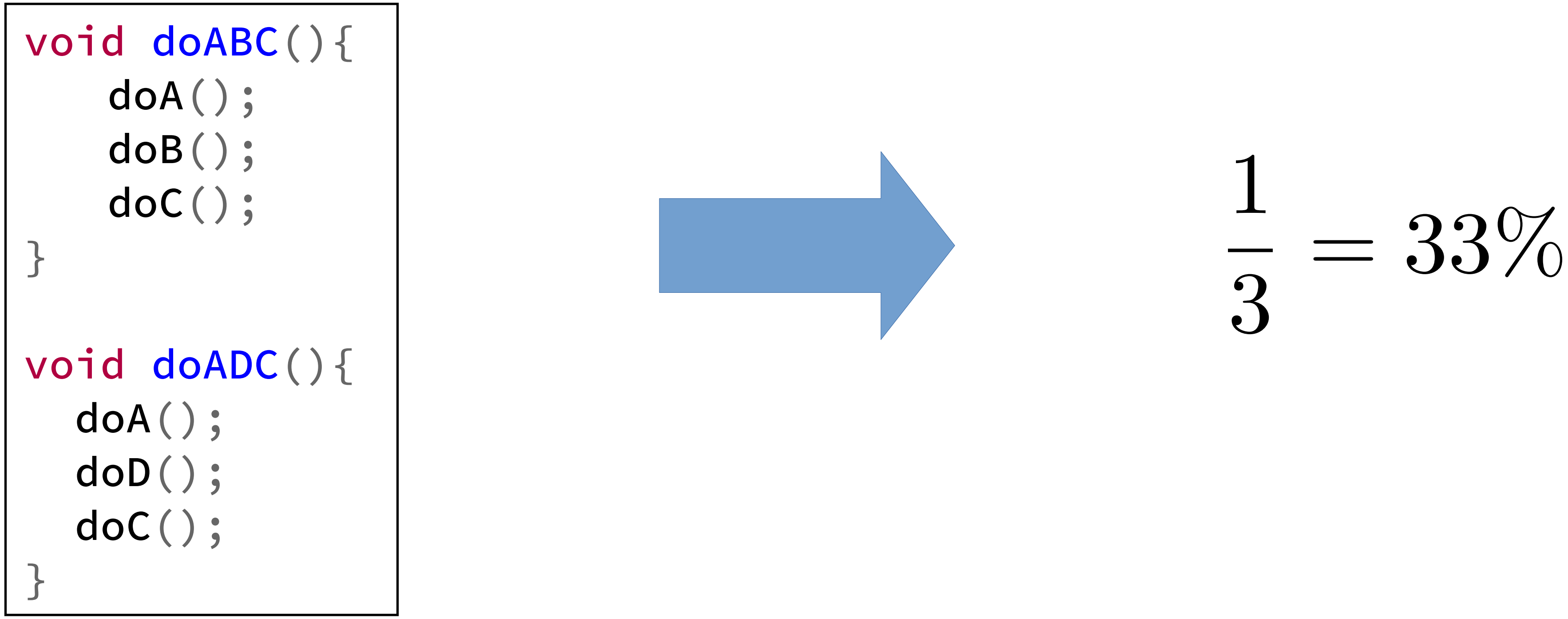
- Literals (of the same type)
- Variable references (sometimes)
- **Called methods (same type & parameters)**

```
// Refactored
void doABC(){
   doThis(this::doB);
}

void doADC(){
   doThis(this::doD);
}

void doThis(Runnable r){
  doA();
  r.run();
  doC();
}
```

$$\text{T2R Variability} = \frac{\text{Number of different expressions}}{\text{Total number of expressions in clone instance}} * 100$$



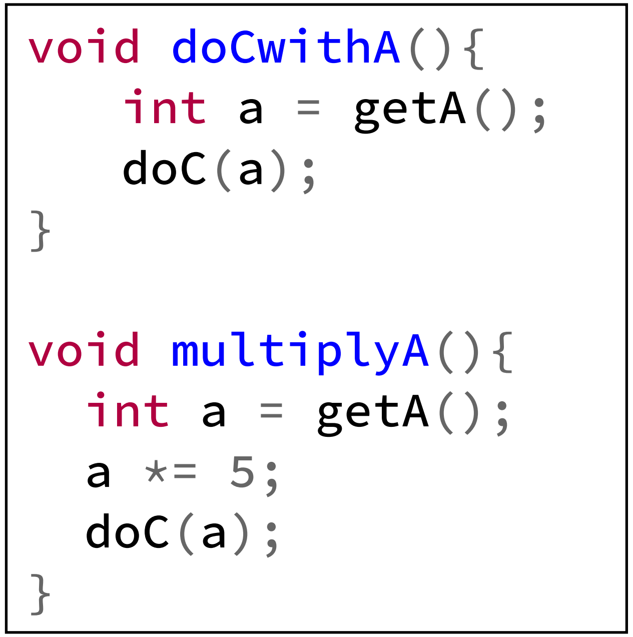
```
void doABC(){
    doA();
    doB();
    doC();
}

void doADC(){
  doA();
  doD();
  doC();
}
```

$$\frac{1}{3} = 33\%$$

Type 3.

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



```
void doCwithA(){
   int a = getA();
   doC(a);
}

void multiplyA(){
  int a = getA();
  a *= 5;
  doC(a);
}
```

Type 3R.

Type 2R clones with optional gaps of non cloned statements.

```
// Original
void doCwithA(){
    int a = getA();
    doC(a);
}

void multiplyA(){
  int a = getA();
  a *= 5;
  doC(a);
}
```

```
// Refactored
void doCwithA(){
    modifyA(false);
}

void multiplyA(){
    modifyA(true);
}

void modifyA(boolean
multiply){
  int a = getA();
  if(multiply) a *= 5;
  doC(a);
}
```

$$\text{T3R Gap Size} = \frac{\text{Number of statements in gap}}{\text{Number of statements in clones}} * 100$$

```
// Original
void doCwithA(){
    int a = getA();
    doC(a);
}

void multiplyA(){
   int a = getA();
   a *= 5;
   doC(a);
}
```

$$\frac{1}{2} = 50\%$$

Summarized

Type 1R.

Contextually & textually identical code fragments except for variations in layout and comments.

Type 2R.

Type 1R clones except for variations in a controlled set of expressions.

Type 3R.

Type 2R clones with optional gaps of non cloned statements.

$$\text{Type 1R} \subseteq \text{Type 2R} \subseteq \text{Type 3R}$$

Clone Context

Determining how a clone should be refactored.

Relation

- Common Class
- Common Hierarchy
- Common Interface
- Unrelated

Location

- Method Level
- Class Level
- Interface Level
- Enum Level

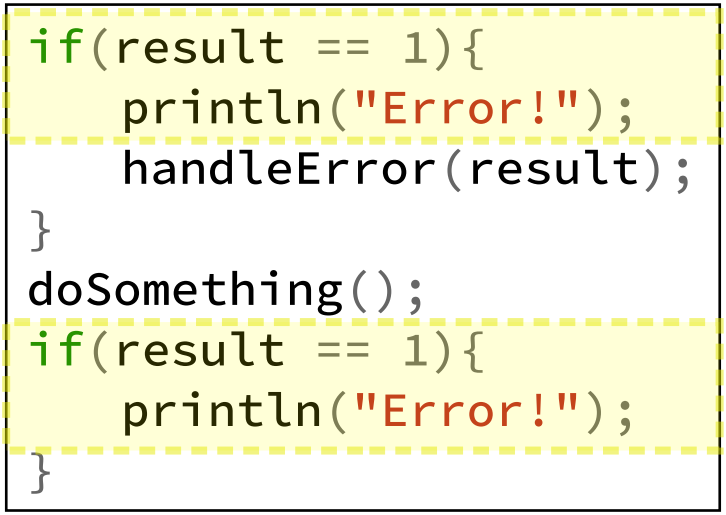
Contents

- Full Declaration
- Partial Body
- Only Fields
- Several Methods
- Other

Refactorability

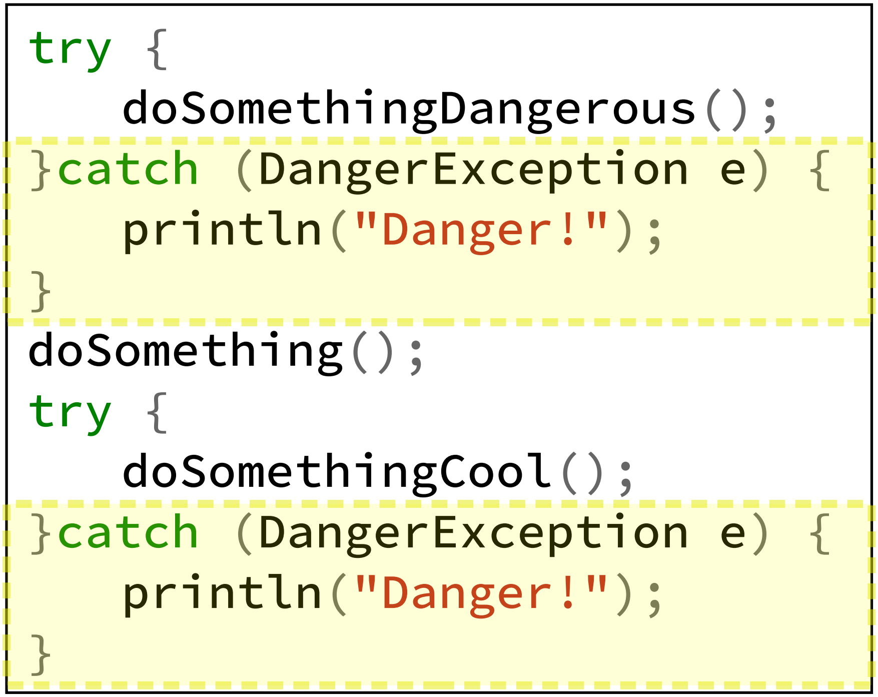
Determining whether a clone can be refactored using “Extract Method”.

Partial Block



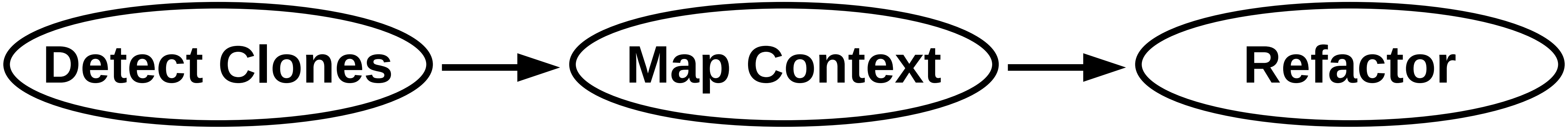
```
if(result == 1){
    println("Error!");
    handleError(result);
}
doSomething();
if(result == 1){
    println("Error!");
}
```

Top-Level Node is not a Statement



```
try {
    doSomethingDangerous();
}catch (DangerException e) {
    println("Danger!");
}
doSomething();
try {
    doSomethingCool();
}catch (DangerException e) {
    println("Danger!");
}
```

CloneRefactor



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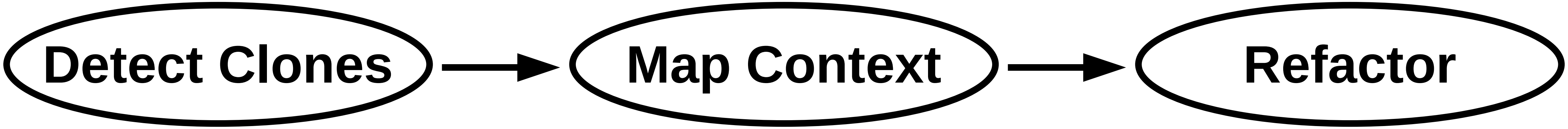


Detect Clones

Map Context

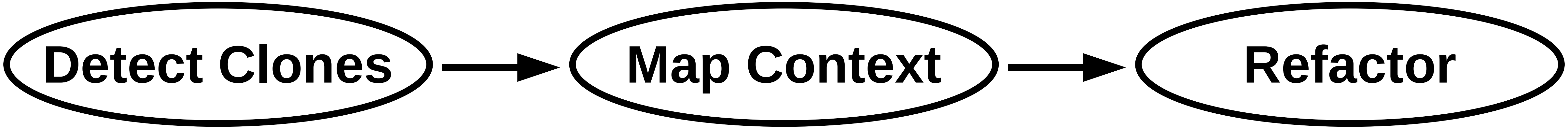
Refactor

- Type 1R-3R
- Type 1-3

- Relation
- Location
- Contents

- Determine Refactorability
- Apply Transformations
- Measure Impact

CloneRefactor



Detect Clones

Map Context

Refactor

- Type 1R-3R ✓
- Type 1-3 ✓

- Relation ✓
- Location ✓
- Contents ✓

- Determine Refactorability ✓
- Apply Transformations
- Measure Impact

Refactoring

Determining the impact of refactoring the clone.

Characteristics

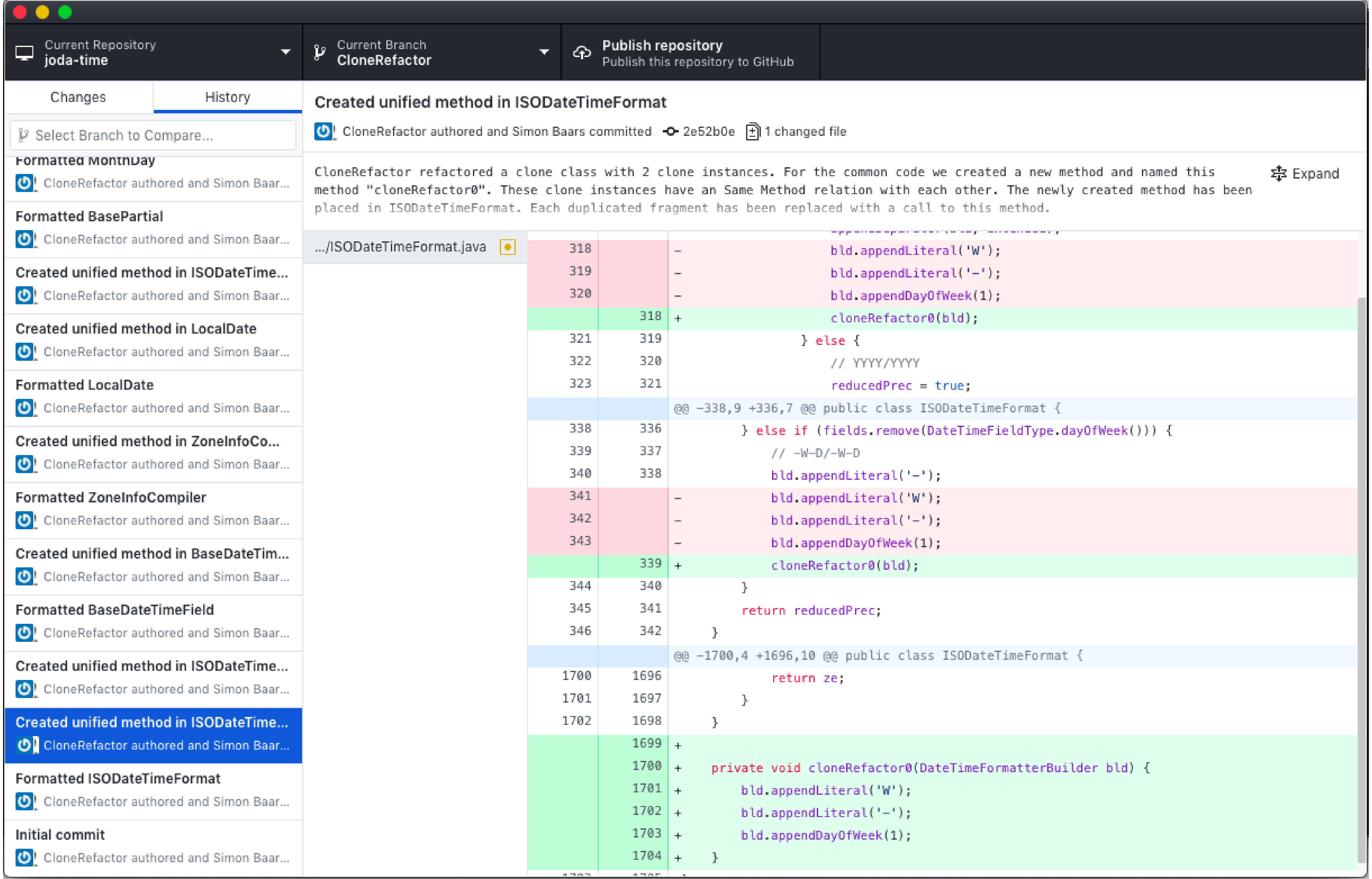
- Clone Size
- Relation
- Return Category
- Parameters

Metrics

- Duplication
- Volume
- Complexity
- Number of Parameters

Risk Profiles

- Low Risk
- Moderate Risk
- High Risk
- Very High Risk



Formatted MonthDay
CloneRefactor authored and Simon Baar...

Formatted BasePartial
CloneRefactor authored and Simon Baar...

Created unified method in ISODateTime...
CloneRefactor authored and Simon Baar...

Created unified method in LocalDate
CloneRefactor authored and Simon Baar...

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CloneRefactor authored and Simon Baar...

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Created unified method in ISODateTime...
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Created unified method in ISODateTime...
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CloneRefactor authored and Simon Baar...

Initial commit
CloneRefactor authored and Simon Baar...

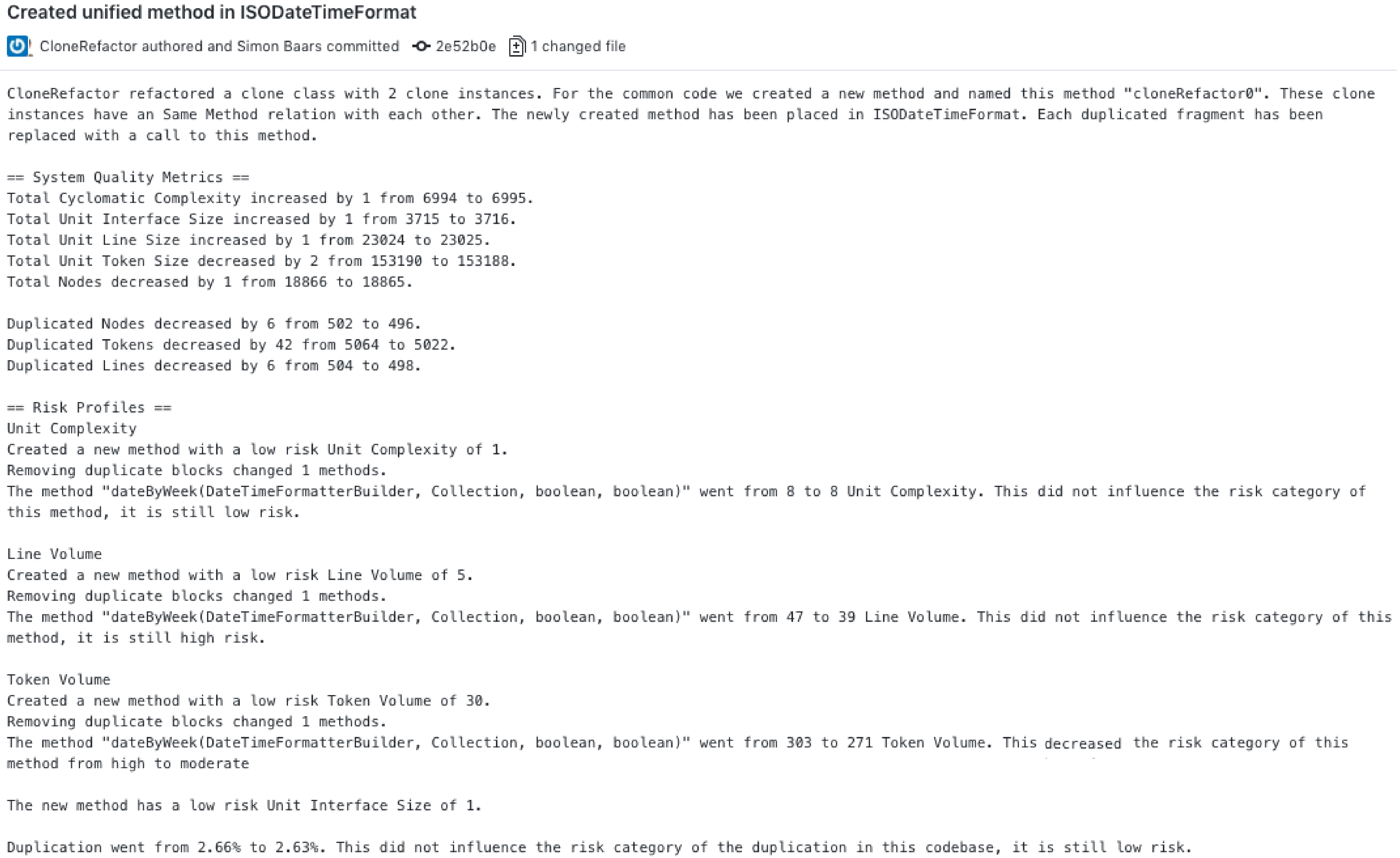
Created unified method in ISODateTimeFormat

CloneRefactor authored and Simon Baars committed 2e52b0e 1 changed file

```
CloneRefactor refactored a clone class with 2 clone instances. For the common code we created a new method and named this
method "cloneRefactor0". These clone instances have an Same Method relation with each other. The newly created method has been
placed in ISODateTimeFormat. Each duplicated fragment has been replaced with a call to this method.
```

.../ISODateTimeFormat.java

```diff
-                    bld.appendLiteral('W');
-                    bld.appendLiteral('-');
-                    bld.appendDayOfWeek(1);
+                    cloneRefactor0(bld);
                } else {
                    // YYYY/YYYY
                    reducedPrec = true;
@@ -338,9 +336,7 @@ public class ISODateTimeFormat {
        } else if (fields.remove(DateTimeFieldType.dayOfWeek())) {
            // -W-D/-W-D
            bld.appendLiteral('-');
-           bld.appendLiteral('W');
-           bld.appendLiteral('-');
-           bld.appendDayOfWeek(1);
+           cloneRefactor0(bld);
        }
        return reducedPrec;
    }
@@ -1700,4 +1696,10 @@ public class ISODateTimeFormat {
            return ze;
        }
    }
+
+   private void cloneRefactor0(DateTimeFormatterBuilder bld) {
+       bld.appendLiteral('W');
+       bld.appendLiteral('-');
+       bld.appendDayOfWeek(1);
+   }
```



Created unified method in ISODateTimeFormat

CloneRefactor authored and Simon Baars committed 2e52b0e 1 changed file

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== System Quality Metrics ==
Total Cyclomatic Complexity increased by 1 from 6994 to 6995.
Total Unit Interface Size increased by 1 from 3715 to 3716.
Total Unit Line Size increased by 1 from 23024 to 23025.
Total Unit Token Size decreased by 2 from 153190 to 153188.
Total Nodes decreased by 1 from 18866 to 18865.

Duplicated Nodes decreased by 6 from 502 to 496.
Duplicated Tokens decreased by 42 from 5064 to 5022.
Duplicated Lines decreased by 6 from 504 to 498.

== Risk Profiles ==
Unit Complexity
Created a new method with a low risk Unit Complexity of 1.
Removing duplicate blocks changed 1 methods.
The method "dateByWeek(DateTimeFormatterBuilder, Collection, boolean, boolean)" went from 8 to 8 Unit Complexity. This did not influence the risk category of
this method, it is still low risk.

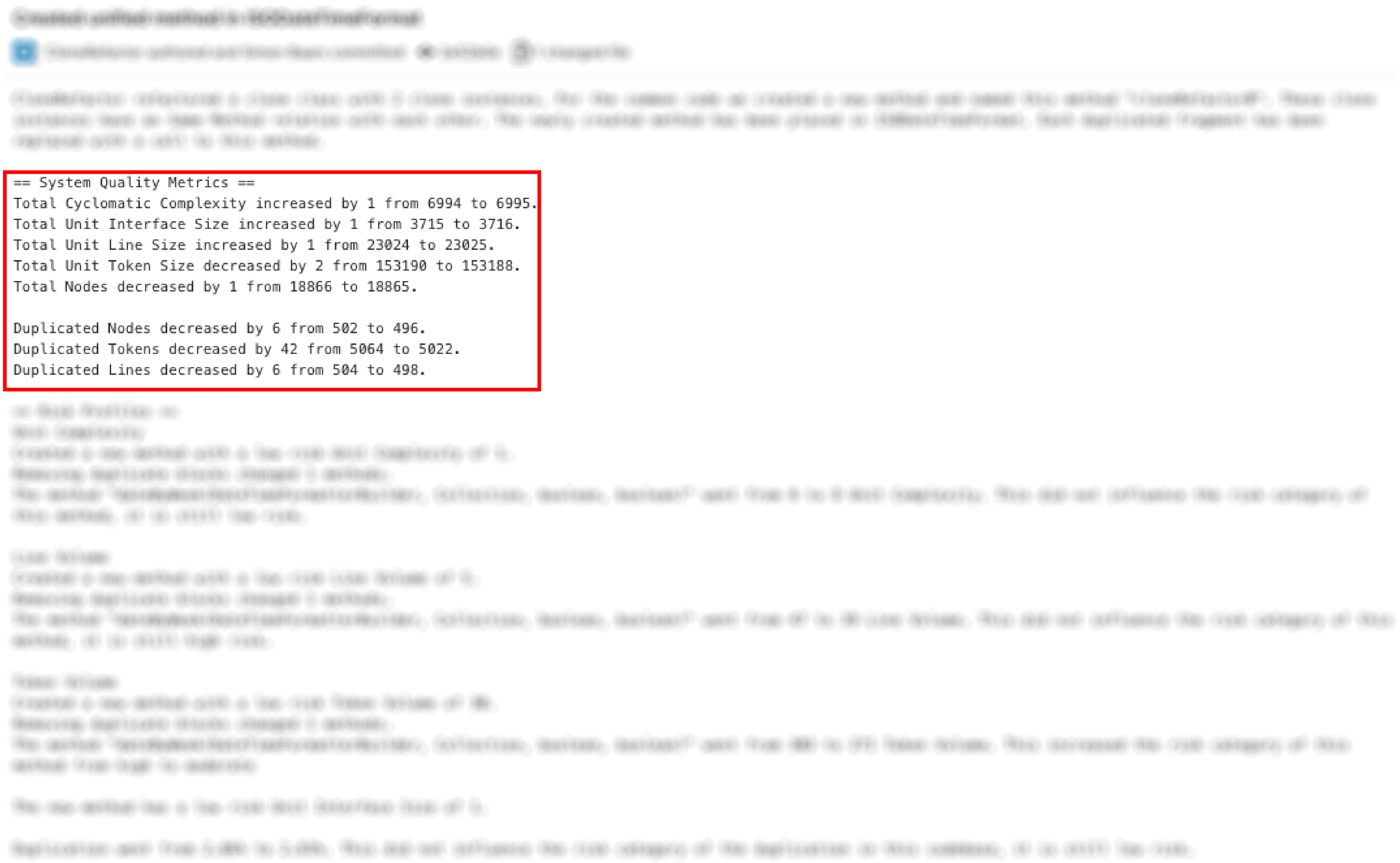
Line Volume
Created a new method with a low risk Line Volume of 5.
Removing duplicate blocks changed 1 methods.
The method "dateByWeek(DateTimeFormatterBuilder, Collection, boolean, boolean)" went from 47 to 39 Line Volume. This did not influence the risk category of this
method, it is still high risk.

Token Volume
Created a new method with a low risk Token Volume of 30.
Removing duplicate blocks changed 1 methods.
The method "dateByWeek(DateTimeFormatterBuilder, Collection, boolean, boolean)" went from 303 to 271 Token Volume. This decreased the risk category of this
method from high to moderate

The new method has a low risk Unit Interface Size of 1.

Duplication went from 2.66% to 2.63%. This did not influence the risk category of the duplication in this codebase, it is still low risk.
```

have an Same Method relation with each other.



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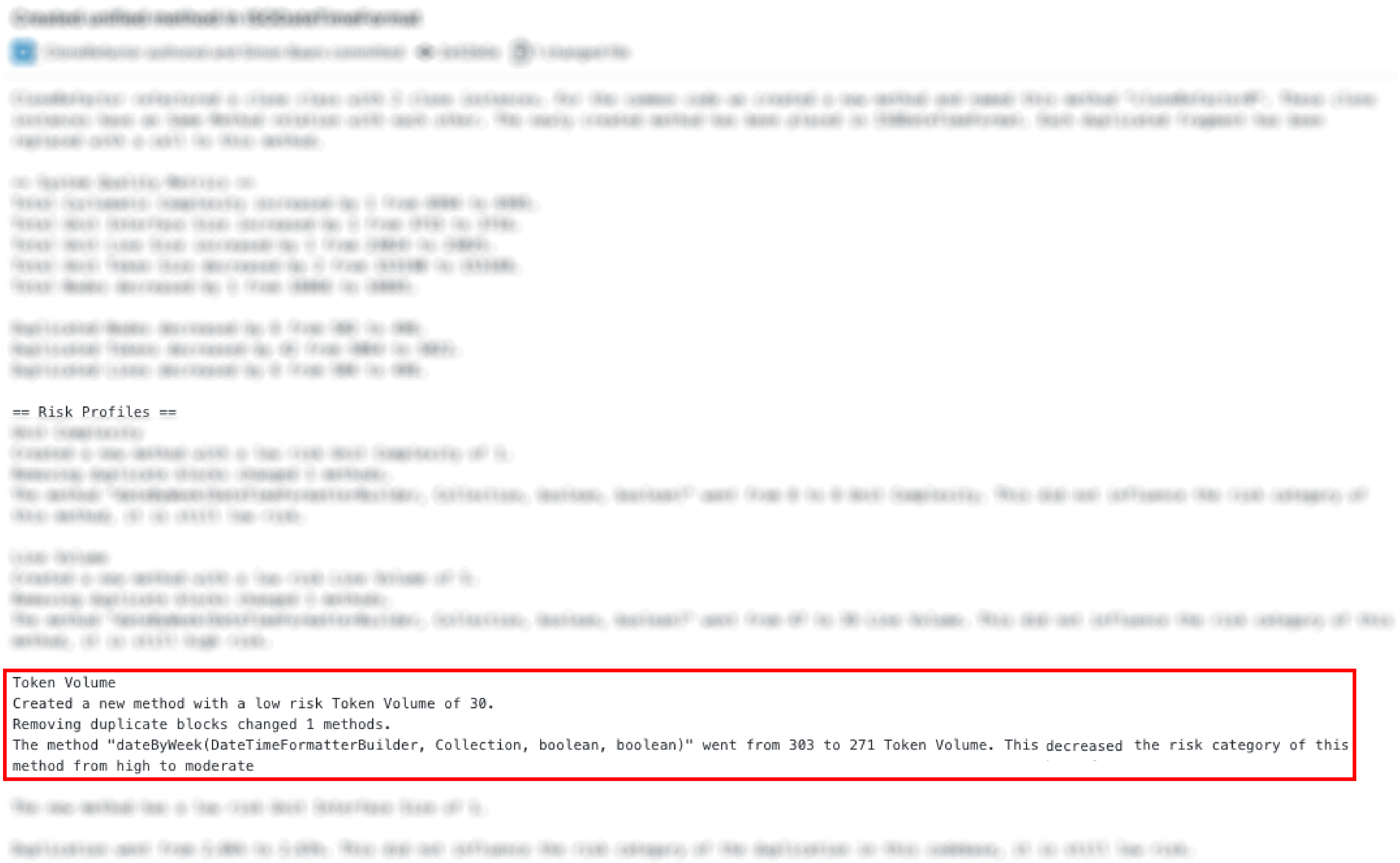

```
== Risk Profiles ==
```

```
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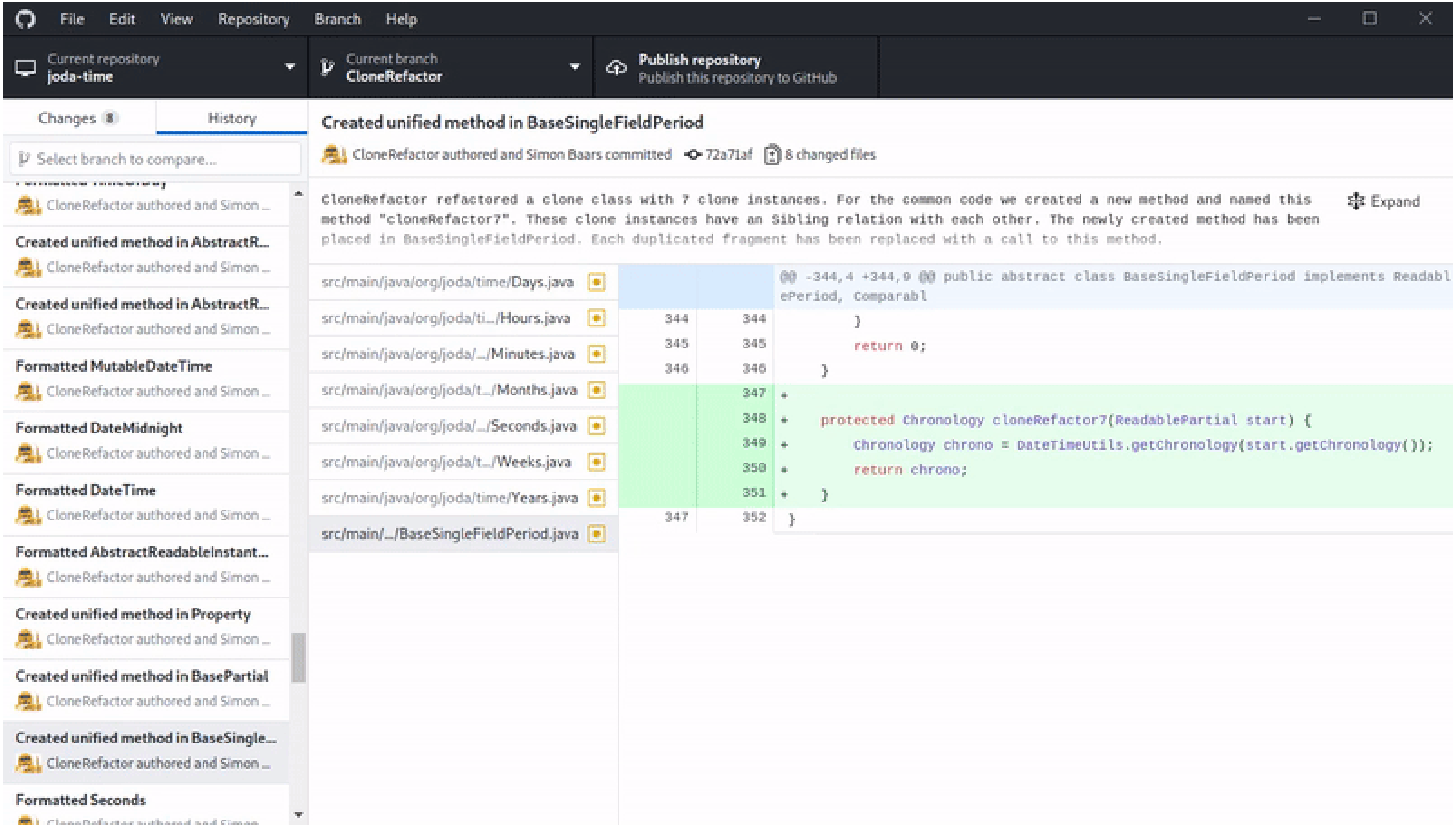
Created a new method with a low risk Token Volume of 30.
Removing duplicate blocks changed 1 methods.
The method "dateByWeek(DateTimeFormatterBuilder, Collection, boolean, boolean)" went from 303 to 271 Token Volume. This decreased the risk category of this
method from high to moderate
```



CloneRefactor authored and Simon ...

Created unified method in AbstractR...
CloneRefactor authored and Simon ...

Created unified method in AbstractR...
CloneRefactor authored and Simon ...

Formatted MutableDateTime
CloneRefactor authored and Simon ...

Formatted DateMidnight
CloneRefactor authored and Simon ...

Formatted DateTime
CloneRefactor authored and Simon ...

Formatted AbstractReadableInstant...
CloneRefactor authored and Simon ...

Created unified method in Property
CloneRefactor authored and Simon ...

Created unified method in BasePartial
CloneRefactor authored and Simon ...

Created unified method in BaseSingle...
CloneRefactor authored and Simon ...

Formatted Seconds

Created unified method in BaseSingleFieldPeriod

CloneRefactor authored and Simon Baars committed 72a71af 8 changed files

```
CloneRefactor refactored a clone class with 7 clone instances. For the common code we created a new method and named this
method "cloneRefactor7". These clone instances have an Sibling relation with each other. The newly created method has been
placed in BaseSingleFieldPeriod. Each duplicated fragment has been replaced with a call to this method.
```

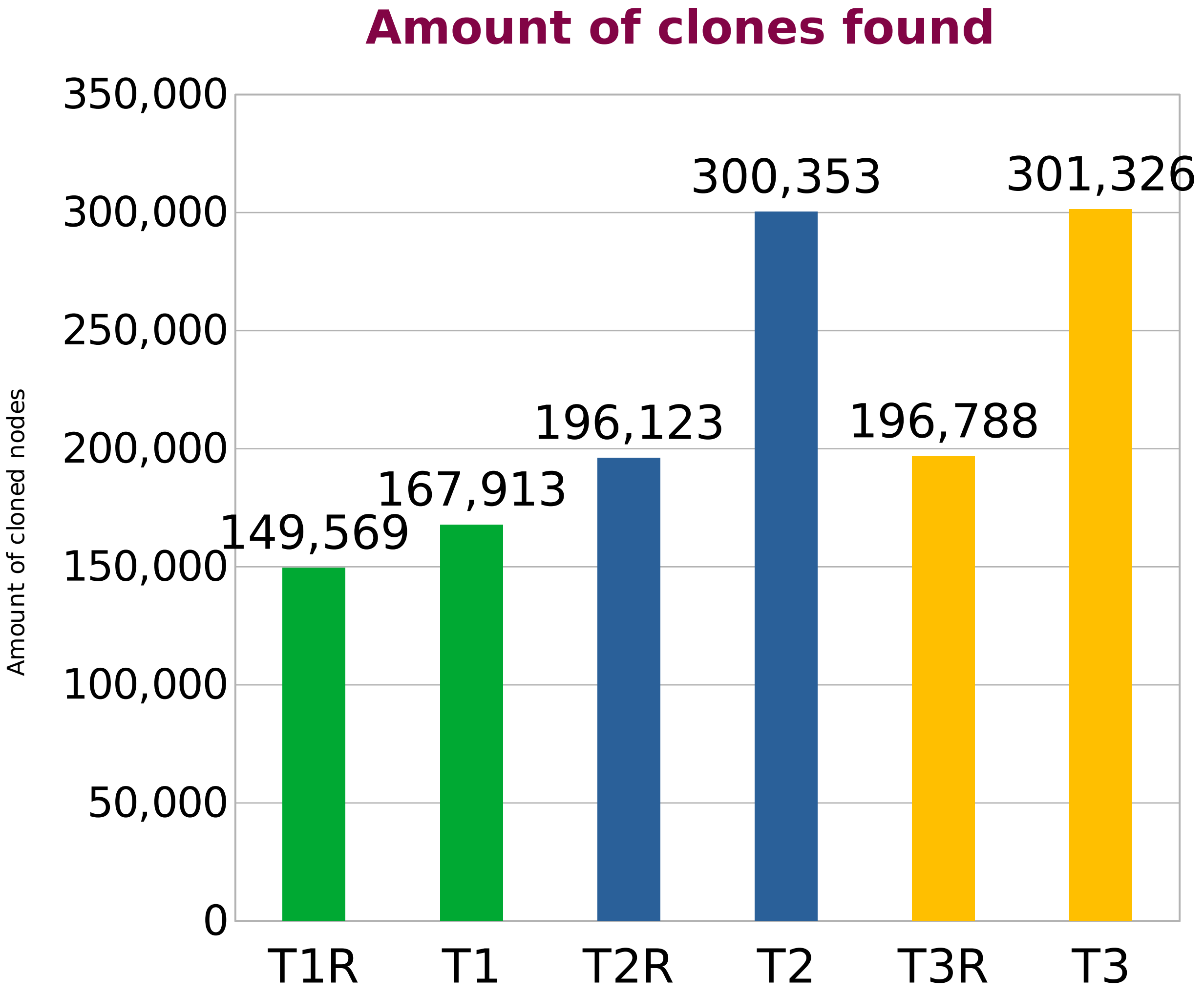
src/main/java/org/joda/time/Days.java
src/main/java/org/joda/ti.../Hours.java
src/main/java/org/joda/.../Minutes.java
src/main/java/org/joda/t.../Months.java
src/main/java/org/joda/.../Seconds.java
src/main/java/org/joda/t.../Weeks.java
src/main/java/org/joda/time/Years.java
src/main/.../BaseSingleFieldPeriod.java

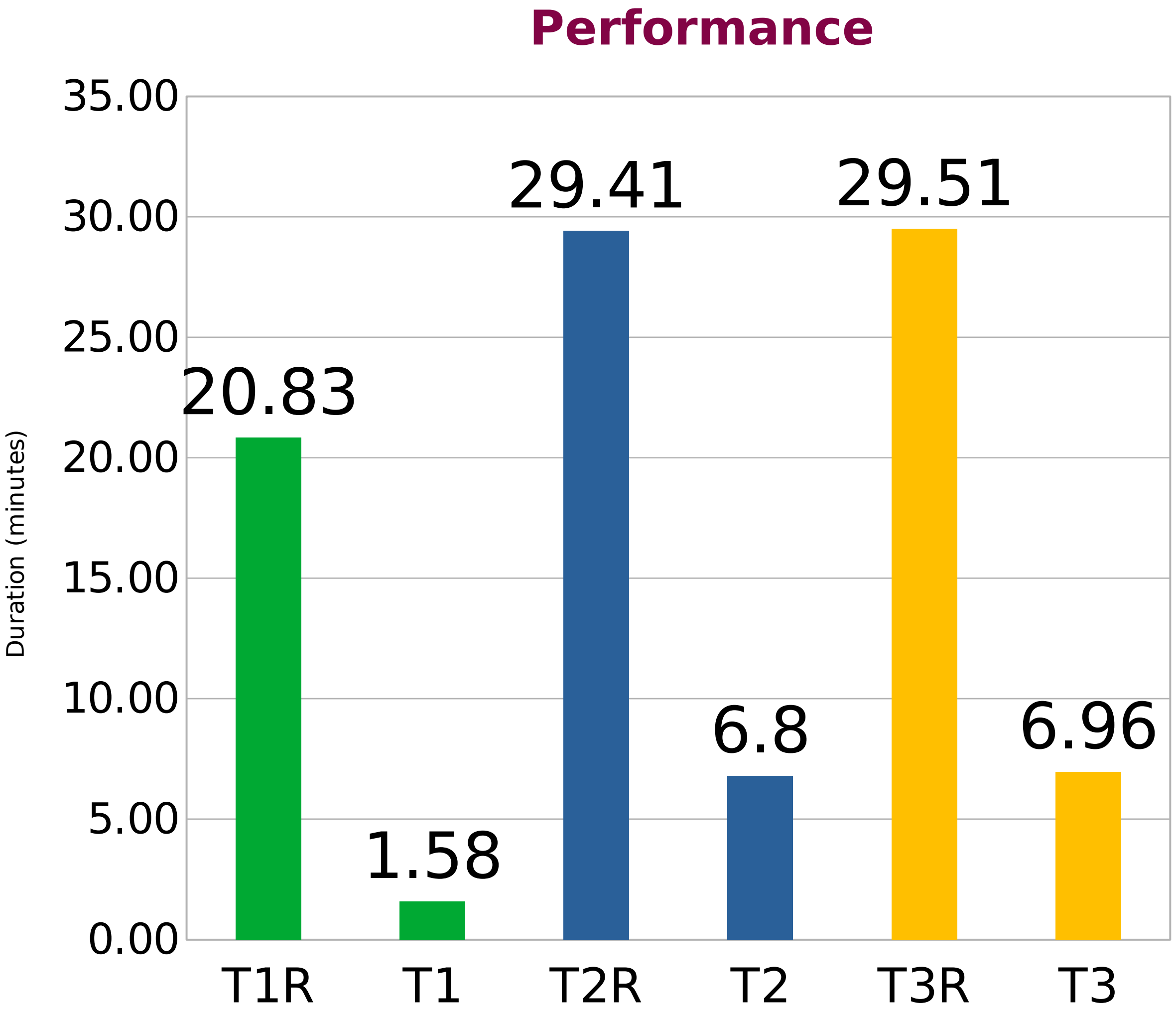
```
@@ -344,4 +344,9 @@ public abstract class BaseSingleFieldPeriod implements ReadablePeriod, Comparabl
            }
            return 0;
        }
+
+   protected Chronology cloneRefactor7(ReadablePartial start) {
+       Chronology chrono = DateTimeUtils.getChronology(start.getChronology());
+       return chrono;
+   }
 }
```

Experiments

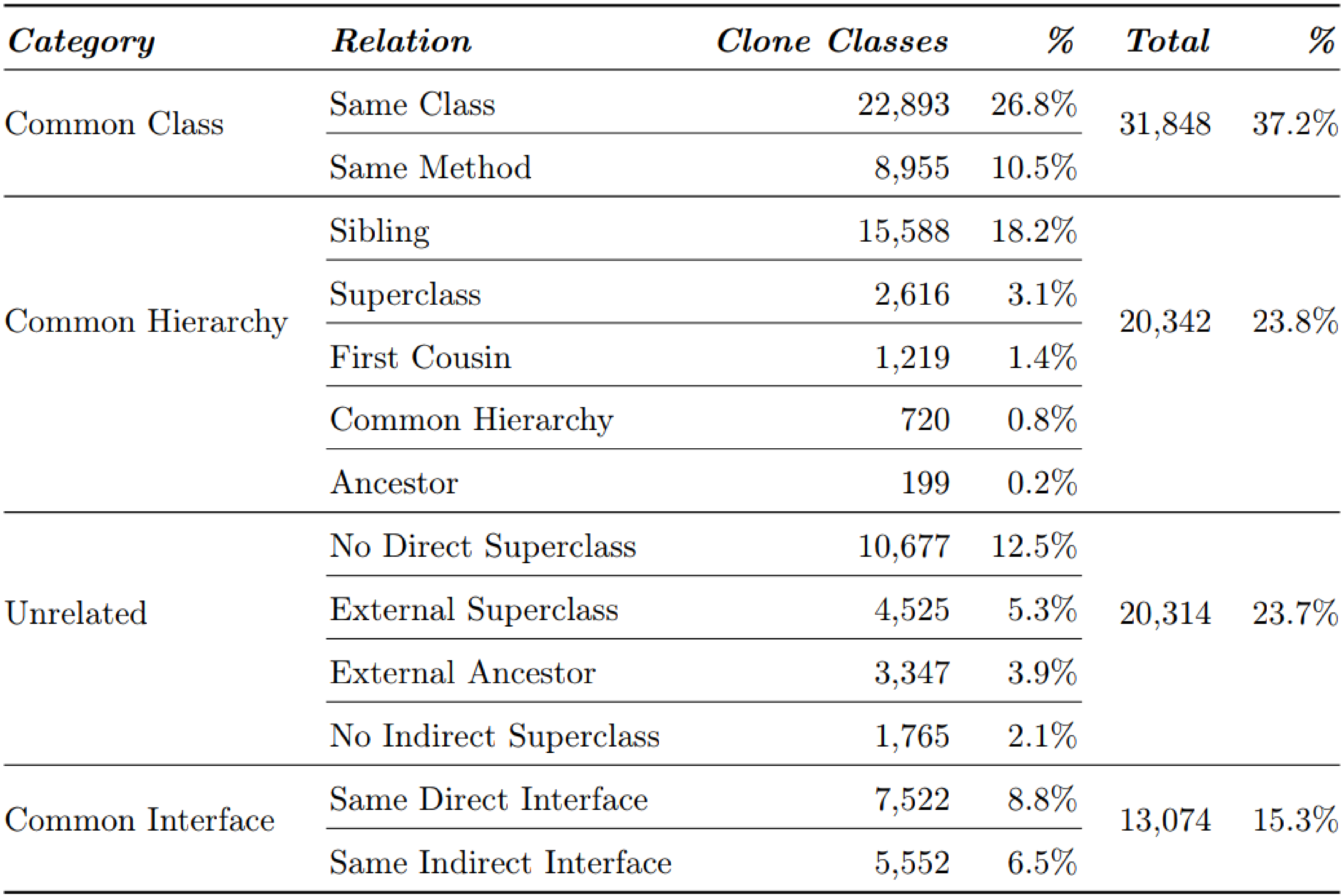
- GitHub Corpus with 2.267 Java projects
- Experiments:
  - Clone Types
  - Context
  - Refactorability
  - Thresholds

Clone Types


Amount of clones found
Amount of cloned nodes
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
149,569
167,913
196,123
300,353
196,788
301,326
T1R
T1
T2R
T2
T3R
T3

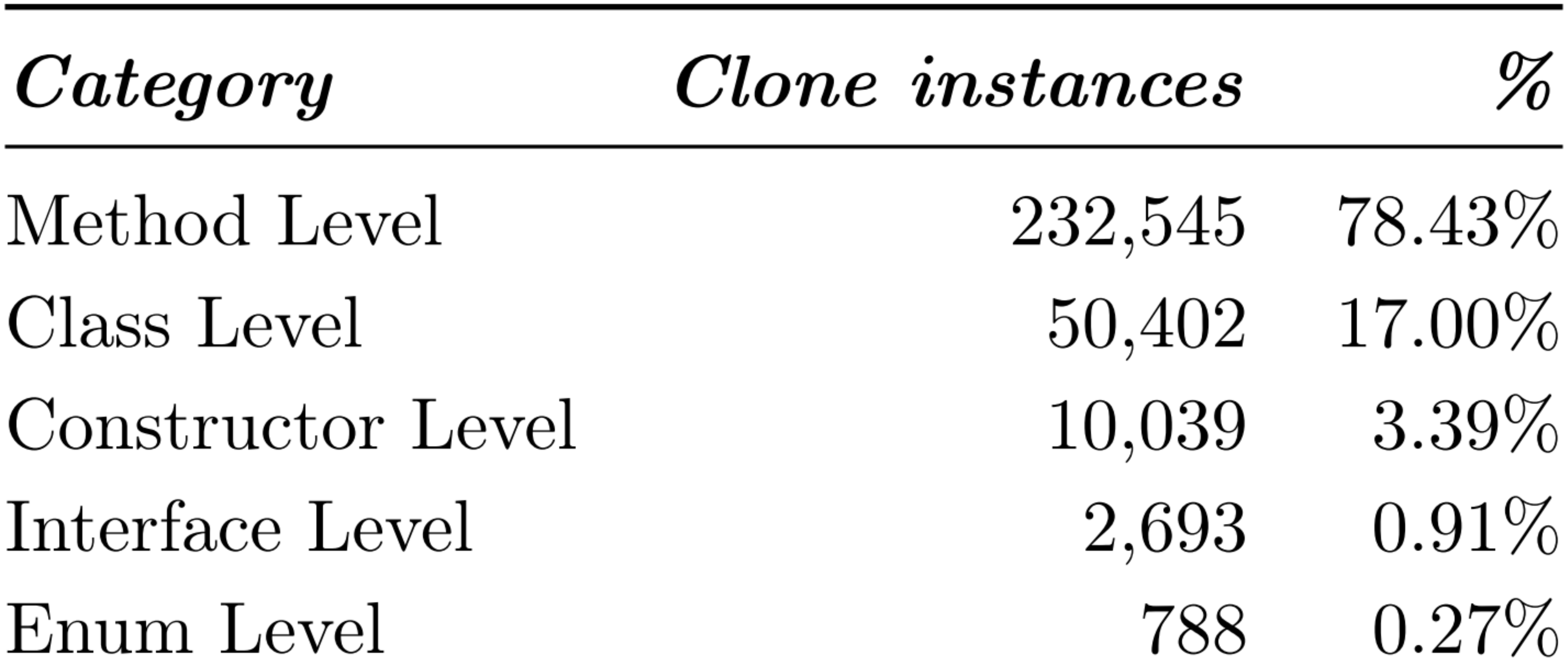

Performance
Duration (minutes)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20.83
1.58
29.41
6.8
29.51
6.96
T1R
T1
T2R
T2
T3R
T3

Relation



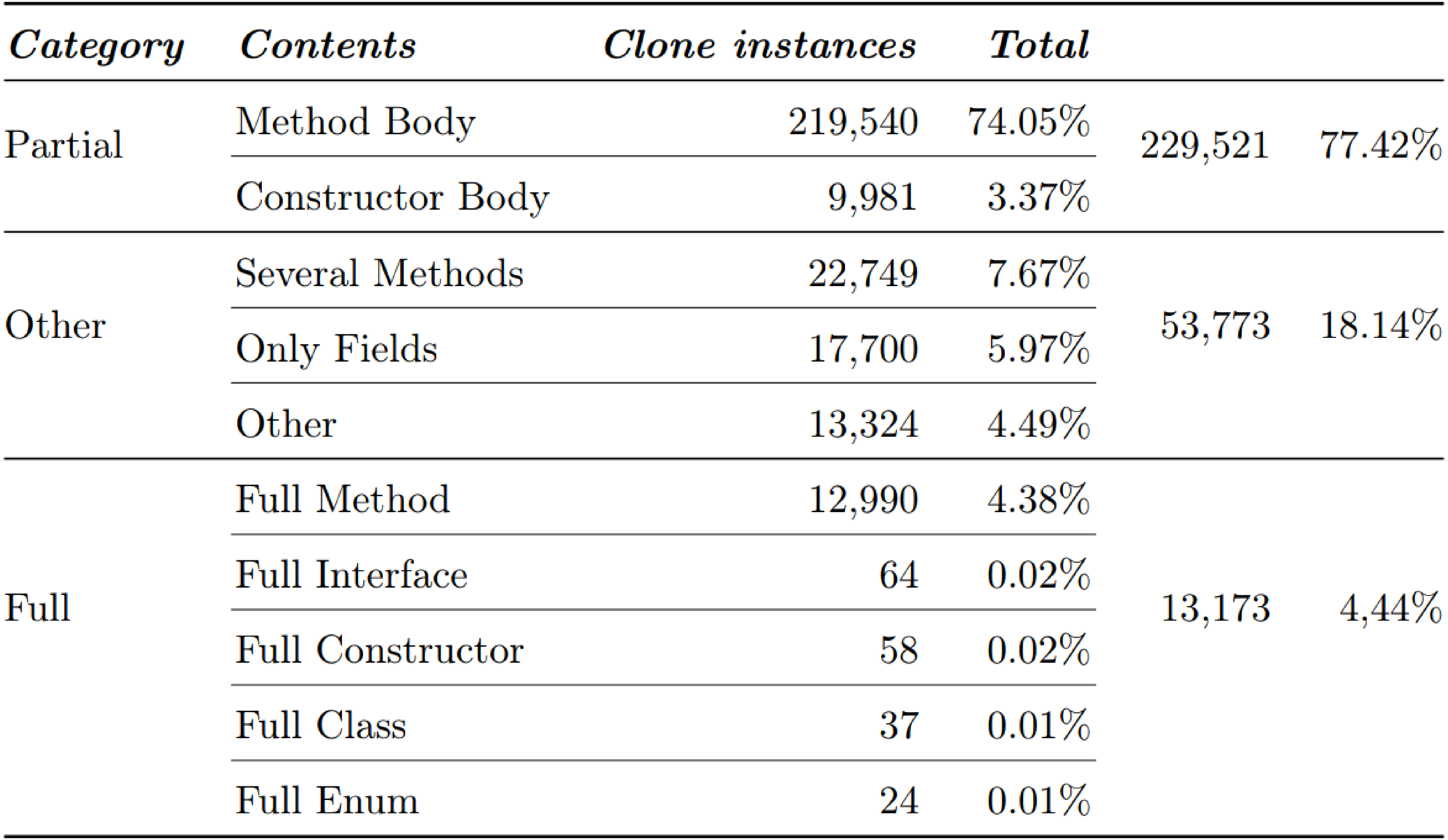
Category	*Relation*	*Clone Classes*	*%*	*Total*	*%*
Common Class	Same Class	22,893	26.8%	31,848	37.2%
	Same Method	8,955	10.5%		
Common Hierarchy	Sibling	15,588	18.2%	20,342	23.8%
	Superclass	2,616	3.1%		
	First Cousin	1,219	1.4%		
	Common Hierarchy	720	0.8%		
	Ancestor	199	0.2%		
Unrelated	No Direct Superclass	10,677	12.5%	20,314	23.7%
	External Superclass	4,525	5.3%		
	External Ancestor	3,347	3.9%		
	No Indirect Superclass	1,765	2.1%		
Common Interface	Same Direct Interface	7,522	8.8%	13,074	15.3%
	Same Indirect Interface	5,552	6.5%		

Location



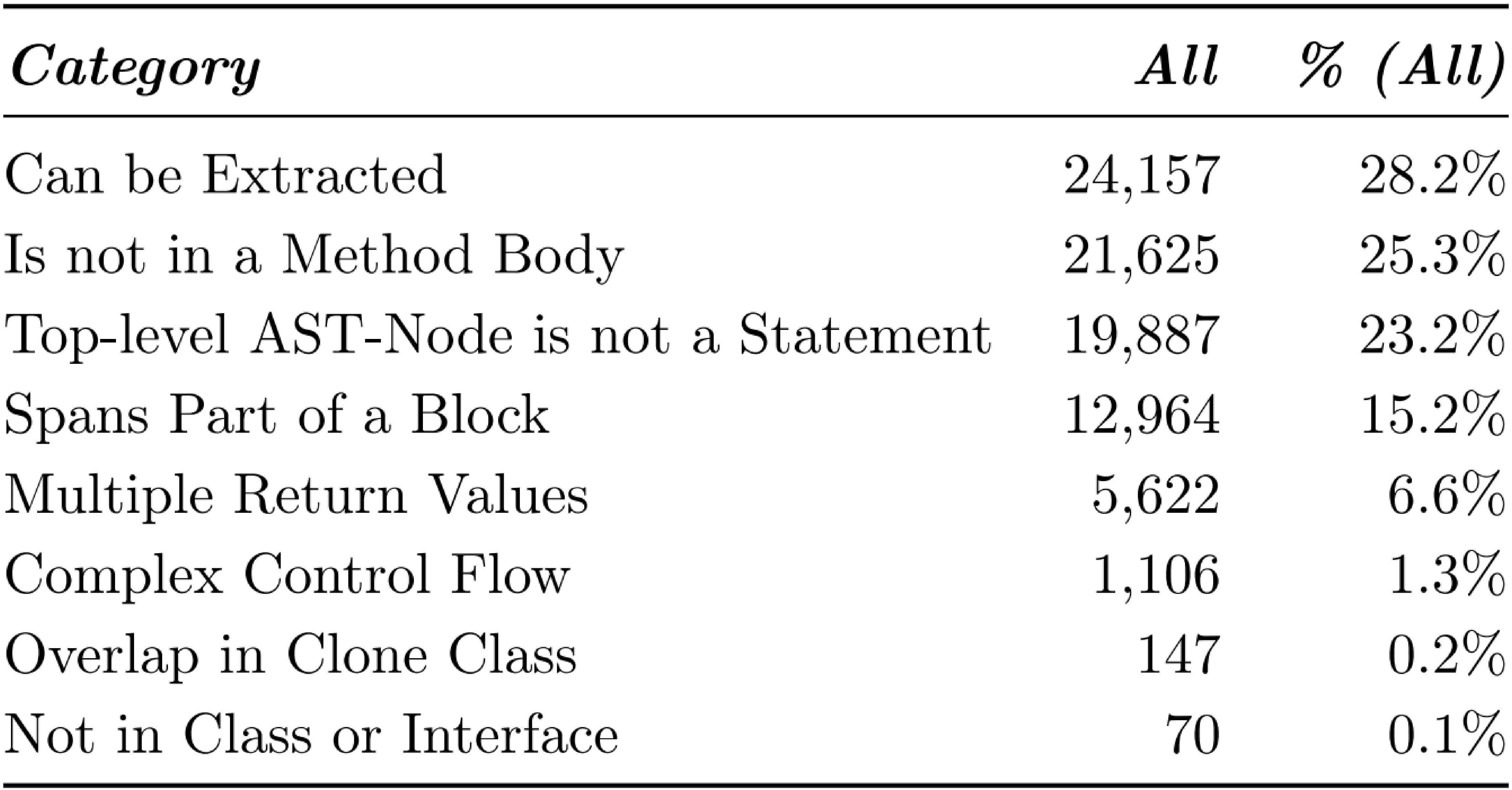
Category	*Clone instances*	*%*
Method Level	232,545	78.43%
Class Level	50,402	17.00%
Constructor Level	10,039	3.39%
Interface Level	2,693	0.91%
Enum Level	788	0.27%

Contents



Category	*Contents*	*Clone instances*	*Total*		
Partial	Method Body	219,540	74.05%	229,521	77.42%
	Constructor Body	9,981	3.37%		
Other	Several Methods	22,749	7.67%	53,773	18.14%
	Only Fields	17,700	5.97%		
	Other	13,324	4.49%		
Full	Full Method	12,990	4.38%	13,173	4,44%
	Full Interface	64	0.02%		
	Full Constructor	58	0.02%		
	Full Class	37	0.01%		
	Full Enum	24	0.01%		

Refactorability



Category	***All***	***% (All)***
Can be Extracted	24,157	28.2%
Is not in a Method Body	21,625	25.3%
Top-level AST-Node is not a Statement	19,887	23.2%
Spans Part of a Block	12,964	15.2%
Multiple Return Values	5,622	6.6%
Complex Control Flow	1,106	1.3%
Overlap in Clone Class	147	0.2%
Not in Class or Interface	70	0.1%

Refactoring Experiments

- 12.683 refactorings performed
- Characteristics:
  - Clone Size
  - Relation
  - Return Category
  - Parameters
- Metrics
  - Δ Duplication
  - Δ Volume
  - Δ Complexity
  - Δ Number of Parameters

Calculate Maintainability Score

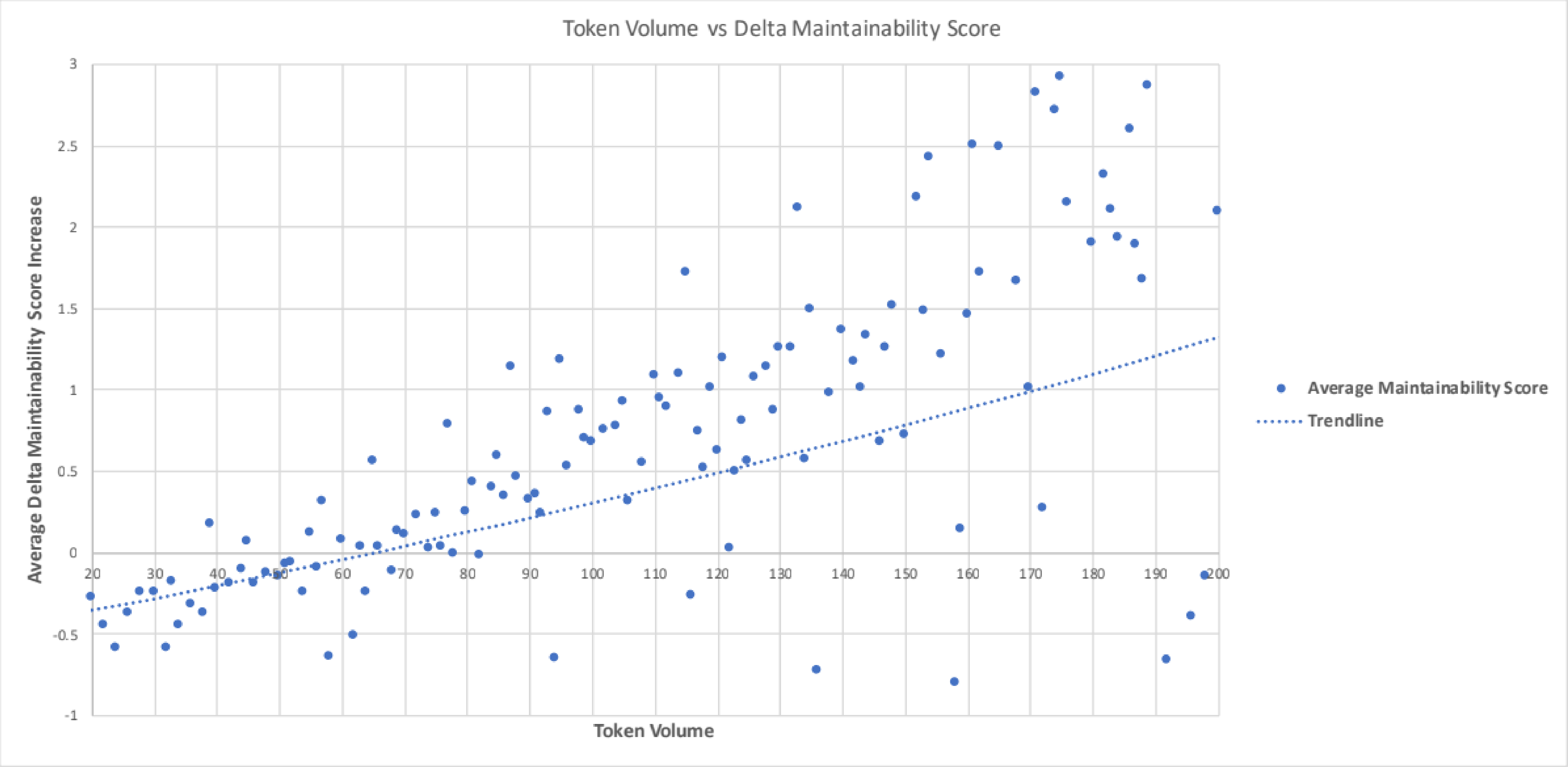
Aggregating the used maintainability metrics to give each refactoring a score.

- Δ Duplication
- Δ Volume
- Δ Complexity
- Δ Number of Parameters

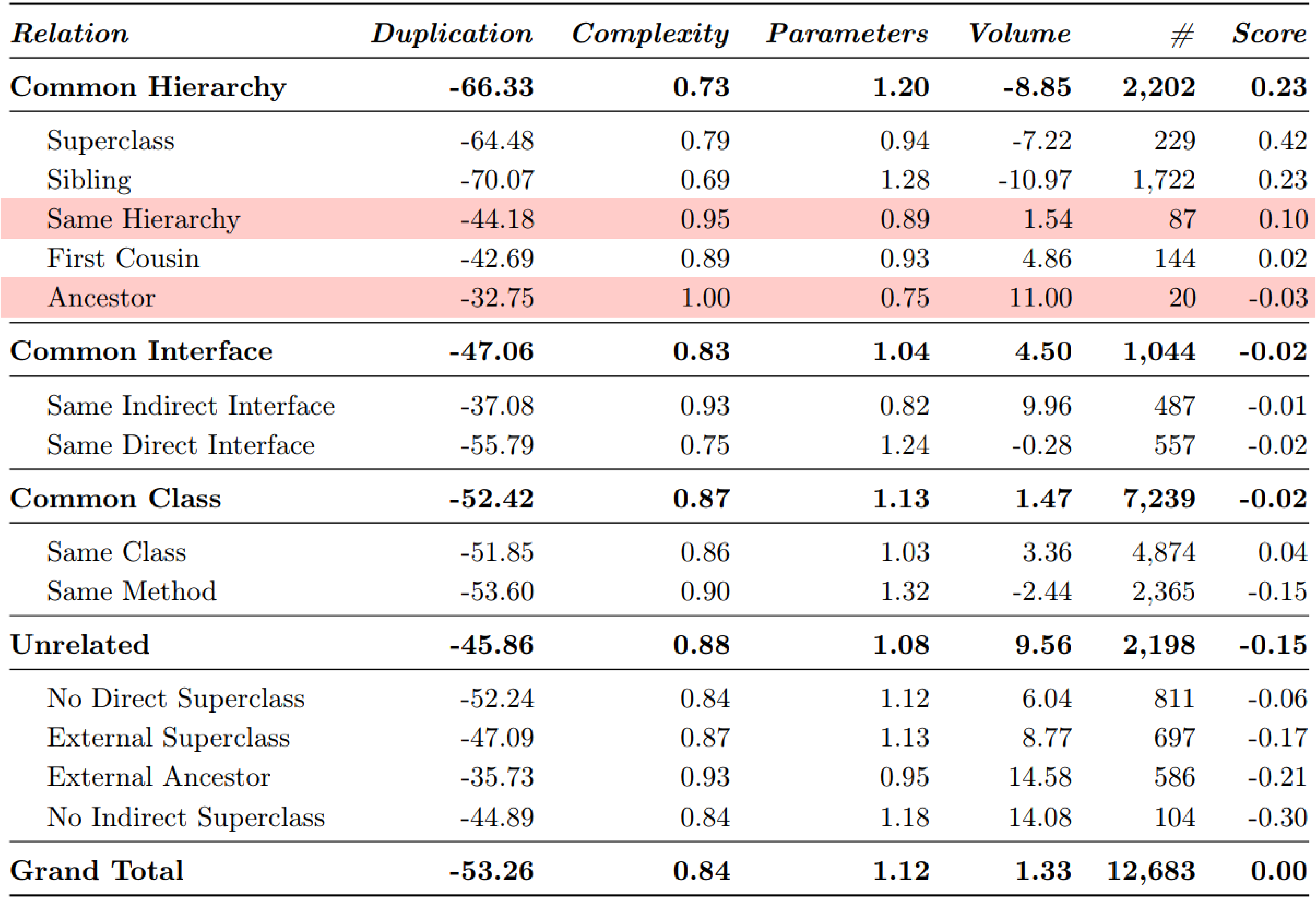
$$N_{metric} = \frac{\Delta X - \mu}{\sigma}$$

$$\text{Maintainability Score} = N_{duplication} + N_{complexity} + N_{volume} + N_{parameters}$$

Token Volume

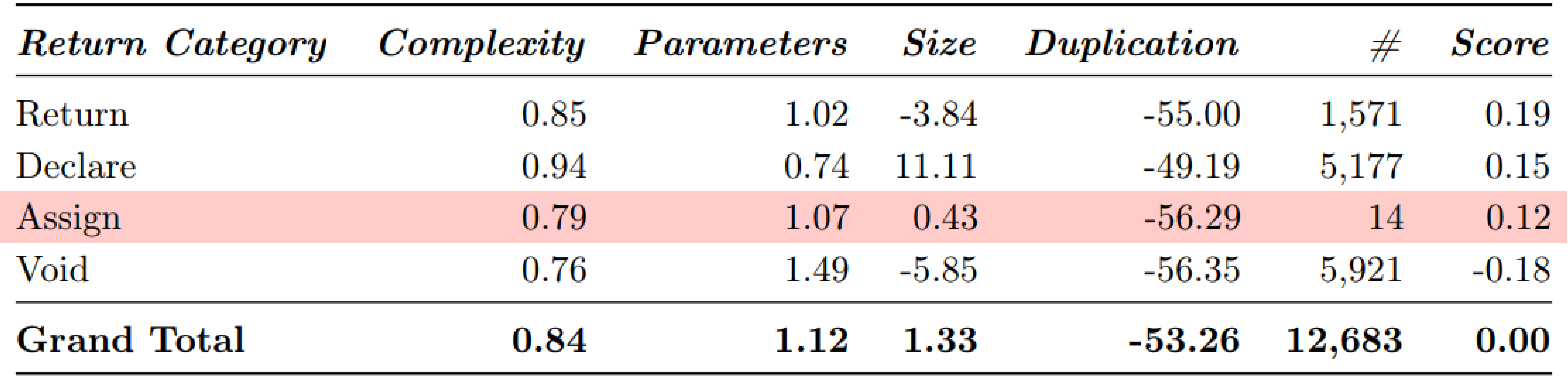


Relation



Relation	*Duplication*	*Complexity*	*Parameters*	*Volume*	*#*	*Score*
Common Hierarchy	**-66.33**	**0.73**	**1.20**	**-8.85**	**2,202**	**0.23**
Superclass	-64.48	0.79	0.94	-7.22	229	0.42
Sibling	-70.07	0.69	1.28	-10.97	1,722	0.23
Same Hierarchy	-44.18	0.95	0.89	1.54	87	0.10
First Cousin	-42.69	0.89	0.93	4.86	144	0.02
Ancestor	-32.75	1.00	0.75	11.00	20	-0.03
Common Interface	**-47.06**	**0.83**	**1.04**	**4.50**	**1,044**	**-0.02**
Same Indirect Interface	-37.08	0.93	0.82	9.96	487	-0.01
Same Direct Interface	-55.79	0.75	1.24	-0.28	557	-0.02
Common Class	**-52.42**	**0.87**	**1.13**	**1.47**	**7,239**	**-0.02**
Same Class	-51.85	0.86	1.03	3.36	4,874	0.04
Same Method	-53.60	0.90	1.32	-2.44	2,365	-0.15
Unrelated	**-45.86**	**0.88**	**1.08**	**9.56**	**2,198**	**-0.15**
No Direct Superclass	-52.24	0.84	1.12	6.04	811	-0.06
External Superclass	-47.09	0.87	1.13	8.77	697	-0.17
External Ancestor	-35.73	0.93	0.95	14.58	586	-0.21
No Indirect Superclass	-44.89	0.84	1.18	14.08	104	-0.30
Grand Total	**-53.26**	**0.84**	**1.12**	**1.33**	**12,683**	**0.00**

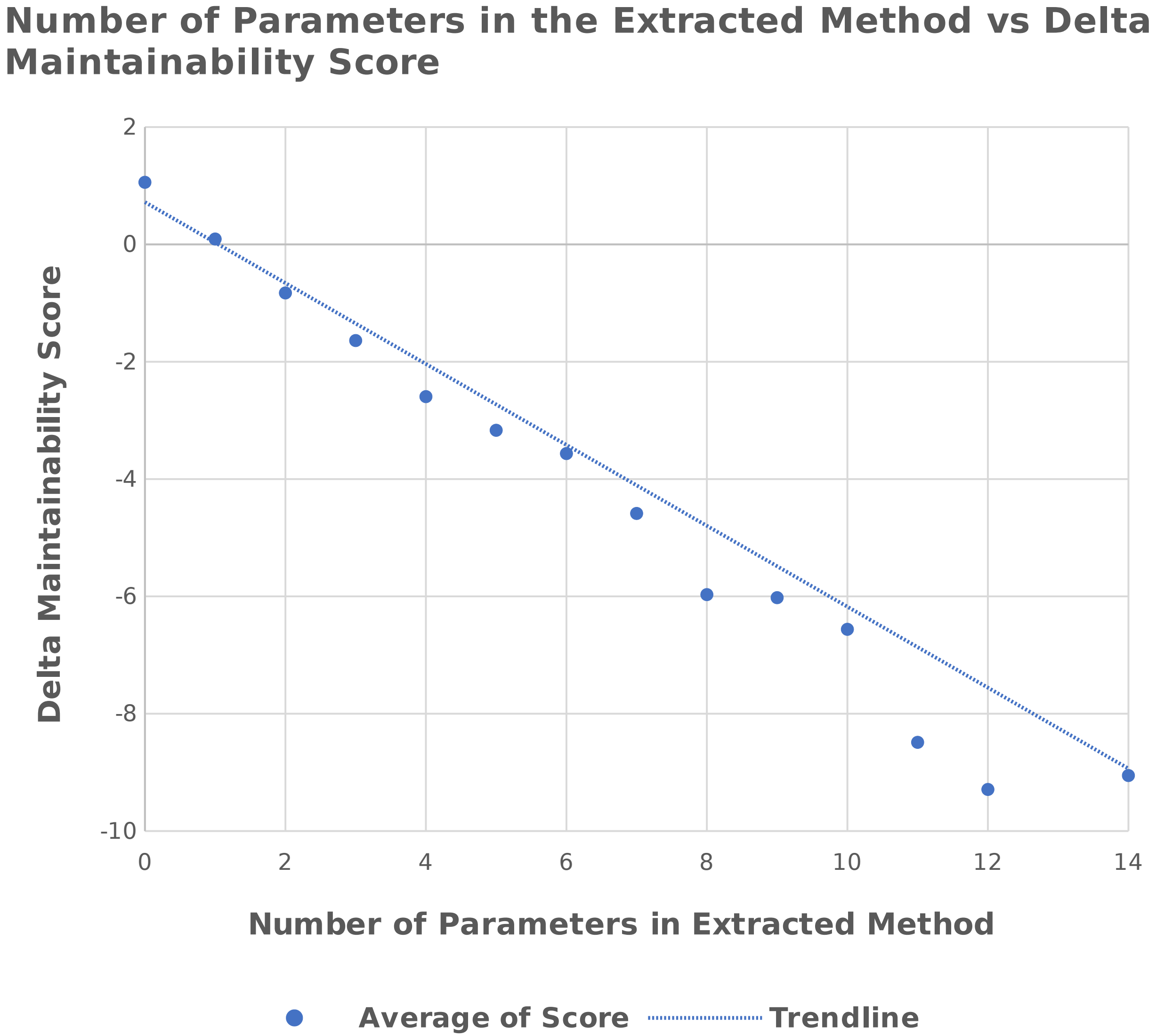
Return Category



Return Category	*Complexity*	*Parameters*	*Size*	*Duplication*	#	*Score*
Return	0.85	1.02	-3.84	-55.00	1,571	0.19
Declare	0.94	0.74	11.11	-49.19	5,177	0.15
Assign	0.79	1.07	0.43	-56.29	14	0.12
Void	0.76	1.49	-5.85	-56.35	5,921	-0.18
Grand Total	**0.84**	**1.12**	**1.33**	**-53.26**	**12,683**	**0.00**

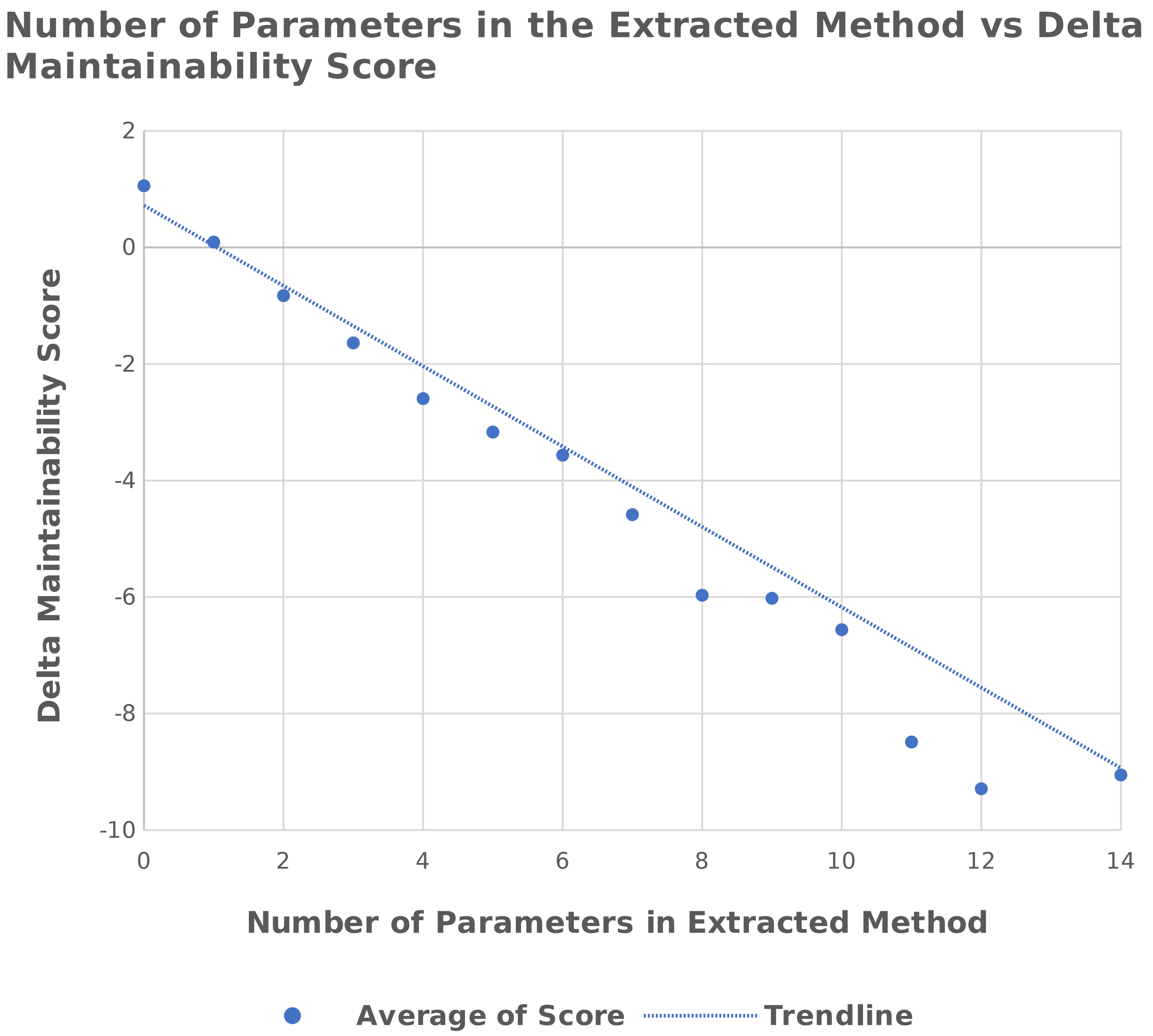
Parameters

Any Token Volume

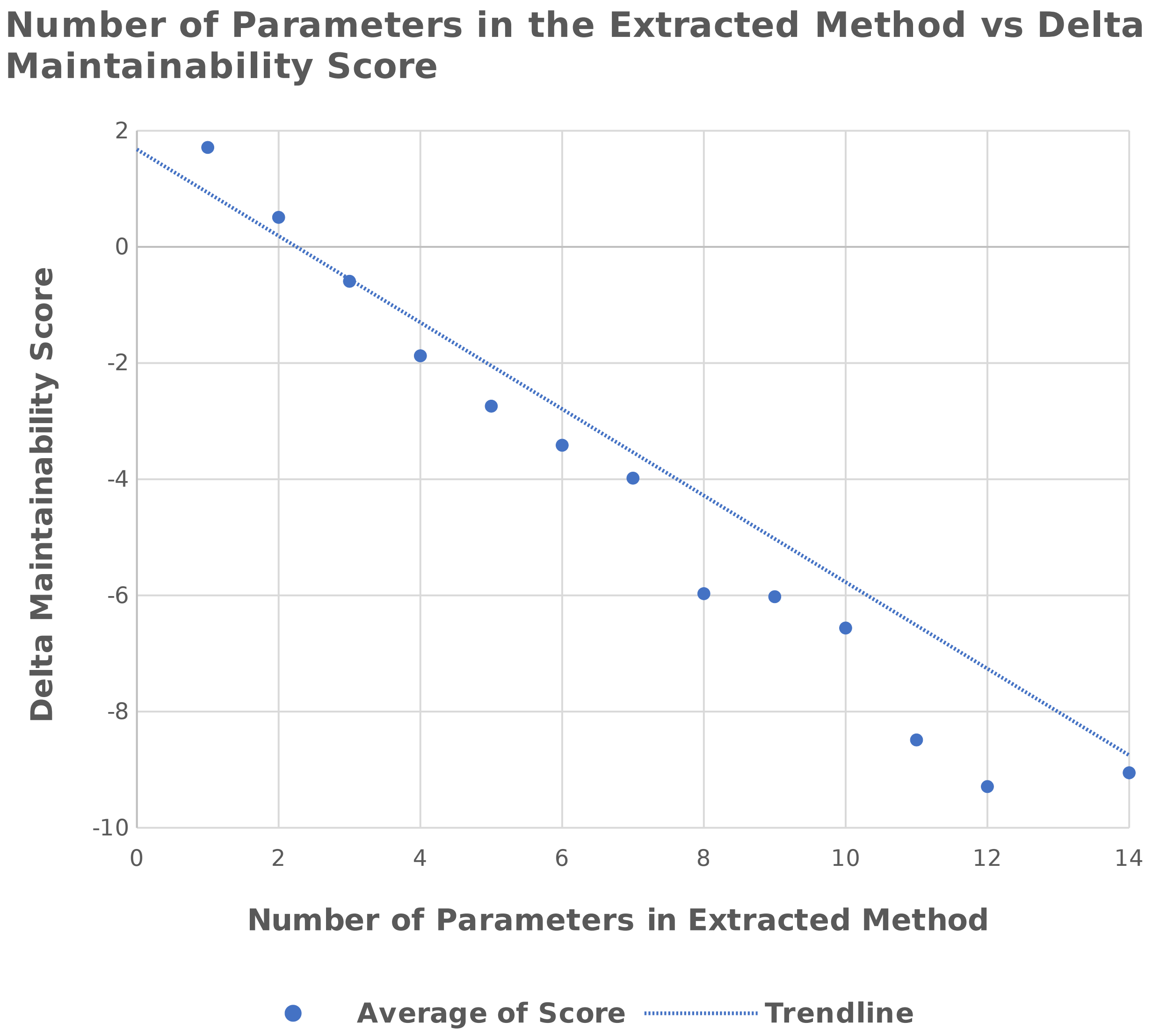


Parameters

Any Token Volume



63+ Token Volume



RQ1.

*How can we define clone types such that they **can** be automatically refactored?*

RQ2.

*How can we prioritize refactoring opportunities based on the **context** of clones?*

RQ3.

*What are the discriminating factors to decide when a clone **should** be refactored*

Summary

- **T1R.** Textually identical code fragments except for variations in whitespace and comments.
- **T2R.** Type 1R clones except for variations in a controlled set of expressions.
- **T3R.** Type 2R clones with optional gaps of non cloned statements.

- **Relation.** 37% Same Class, 24% Same Hierarchy, 24% Unrelated and 7% Same Interface
- **Location.** 78% Method Level, 17% Class Level, 4% Constructor Level and 1% Other
- **Contents.** 74% Method Body (77% including constructor), 8% Several Methods, 6% Only Fields and 4% Full Method.

- **Refactorability.** 28% can be extracted, 25% is not in a method body, 23% top-level AST-node is not a statement, 15% spans part of a block and 6% multiple return values.

- **Token Volume.** Clone classes with a Token Volume higher than 63 results in refactorings that, on average, improve maintainability.
- **Number of Parameters.** When an extracted method has more than two parameters , it is more likely to decrease maintainability.
- **Relation and Return Category.** These two factors have a minor influence on maintainability.