Graph Theoretical Algorithms For Structural Comparison Of Java Source And Byte Code

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Submitted By

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Legal Declaration

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Abstract

TODO:

This should be a 1-page (maximum) summary of your work. What environment for development has been used, experimental results An abstract is a summary in your own words of the Thesis It is not evaluative and must not include your personal opinions. The purpose of an abstract is to give a reader sufficient information for him or her to decide whether it would be worthwhile reading the entire article or book. An abstract should aim at giving as much information as possible in as few words as possible.

Goal of this work is to search out the most optimal ways to compare different pieces of code. So far there are two techniques for code comparison: a normal text comparison and visual compare. Normal text-compare can be not sufficient to analyse two pieces of code, or to find a similarity between them. For that reason a structural/graph compare opens a doors to discover more possibilities of comparison.

Acknowledgments

I would like to take this time to thank Frankfurt University of Applied Sciences for all of the resources which they provided me in order to pursuing my master study in computer science and make this thesis possible.

I would like to express my sincere gratitude to Prof. Dr. Sergej Alekseev and Prof. Dr. Matthias Wagner for their patient guidance, encouragement and advice which they provided me throughout this thesis work.

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Abbreviations

TDMC	**T**op **D**own **M**ax **C**ommon
BUMC	**B**ottom **U**p **M**ax **C**ommon
BCV	**B**yte **C**ode **V**isualizer
SCV	**S**ource **C**ode **V**isualizer
CFGF	**C**ontrol **F**low **G**raph **F**actory
TC	**T**ext **C**ompare
MBM	**M**aximum **B**ipartite **M**atching

Chapter. 1

Introduction

Modern methods to compare of programming pieces of code are used to analyze code's changing, to explore development process and so on. Basically in current tools or plug-ins only text compare methods are used, that is not full sufficient to define code compare. Sometimes another techniques can be very helpful for such purposes. One of them is a structural code compare, based on building a trees, and methods to compare any similar or same structures.

TODO START: You can't write a good introduction until you know what the body of the paper says. Consider writing the introductory section(s) after you have completed the rest of the paper, rather than before. Be sure to include a hook at the beginning of the introduction. This is a statement of something sufficiently interesting to motivate your reader to read the rest of the paper, it is an important/interesting scientific problem that your paper either solves or addresses. You should draw the reader in and make them want to read the rest of the paper.

REDO: Code duplication or copying a code fragment and then reuse by pasting with or without any modifications is a well known code smell in software maintenance. Several studies show that about 5 to 20 percent of a software systems can contain duplicated code, which is basically the results of copying existing code fragments and using then by pasting with or without minor modifications. One of the major shortcomings of such duplicated fragments is that if a bug is detected in a code fragment, all the other fragments similar to it should be investigated to check the possible existence of the same bug in the similar fragments. Refactoring of the duplicated code is another prime issue in software maintenance although several studies claim that refactoring of certain clones are not desirable and there is a risk of removing them. However, it is also widely agreed that clones should at

least be detected. REDO

Tips: A statement of the goal of the paper: why the study was undertaken, or why the paper was written. Do not repeat the abstract.

Chapter. 2

Description of problem

In this chapter an issue of the master work is being explained. As usual a compare of two code fragments consider comparison of classes, functions or methods. Thereby a compare can be counted as examinations of two pieces of code, in the best case a methods or functions. They can have a similar implementation or alike syntax, however these two pieces of code are different.

There are many purposes to compare a code, to find out a similarity or determine a difference between them. One of the option is to search for plagiarism in case a code can be taken from external source and a variables have been changed. In addition to general search can be improved to look out a similar code in big projects.

Structural compare stands for comparing two graphs. There are many possibilities how to create a graph from java source or byte code. In order to find some structural similarities this two created graphs must be compared. For this purpose there are existing algorithms to figure out graph isomorphism. For example the maximum common sub-tree isomorphism algorithms. The purpose of them to seek out the largest common sub-tree between two trees. These algorithms are used not only to investigate code difference but also they are a fundamental problem with multiplicity of applications in nature sciences and engineering. But unfortunately it is possible only for trees but not for graphs. If two graphs are being isomorphic compared with each other, then it is an NP - complete problem and takes much times and efforts to be done.

In the complex theory the worst case running time of all known algorithms is of exponential order, and just for certain special types of graphs, polynomial-time algorithms have been devised[7].Maximum common sub-graph isomorphism is an optimization problem that is known to be NP-hard. The formal description of

the problem is as follows: There are two input graphs, respectively the maximum common sub-graph isomorphism MCSGI(G_1, G_2):

- Input: Two graphs G_1 and G_2.
- Question: What is the largest sub-graph of G_1 isomorphic to a sub-graph of G_2 can be found?

The associated decision problem, i.e., given G_1, G_2 and an integer k, deciding whether G_1 contains a sub-graph of at least k edges isomorphic to a sub-graph of G_2 is NP-complete[7].This type of graph comparison is very expensive from a computational point of view and thus, and some action must be taken into account to reduce the domain of comparison before performing the actual comparison. Therefore this problem must to be reduced. Luckily, a tree comparison is able to executed in polynomial time and moreover there are some existing algorithms to compare trees.

Thus there are no deterministic algorithms to compare them because of loops in graphs. In this case the input code can be transformed into graph firstly, after the graph creation, it must be converted into tree, using simple techniques removing back edges. The back edges in the input graph are edges, which point from a node to one of its ancestors. Under those circumstances the following techniques are searched and deployed in the paper. After all a few questions can be asked:

1. How to transform code into tree by optimal way?
2. How to compare these trees to get reasonable results?
3. How to reference code pieces and nodes, respectively how to put the code difference?

Regards to the first question, the concept of idea is described in chapter **Graphs Transformation** 5. The second question comprehends existing algorithm and their combination and improvements in chapter **Existing algorithms** 3. The very last issue is about how to lead back the result of the code and is stated in chapter.

Possible result of this thesis is development of concept to find out code difference using graph theory, in the best case a tool in Project Dr. Garbage [1]. Can be implemented that highlights similarity/difference of input code snippet and represented respective graph.

To get started with a small example demonstrating, what kind of result gives text compare (text-to-text compare):

```
public void method1(){
if(i > 1) i++;
```

```
}

public void method2(){
   if(i > 1)
   i++;
}
```

In this example, two pieces of code there one enter symbol after line (i ¿ 1). The result therefore the codes look different. Using simple text compare approach, only these gap will be found, however this difference does not play any role regards business-logic. In Abstract Syntax View, these two graphs will be same, and no discrepancy will have been discovered.

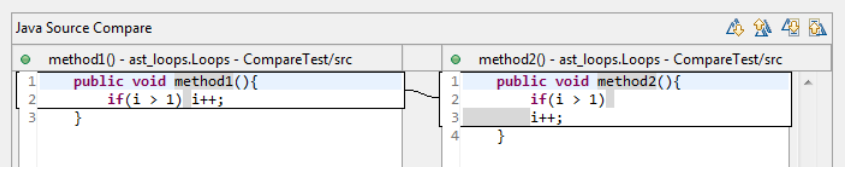


Figure 2.1: The simplest example of text-to-text comparison indicating that text compare sometimes is not enough to investigate code difference, however there are no changes regards the application logic

Since this article includes comparison not only of source code, but also Java byte code, where there is no syntax. Basically to have a look at byte code example, there are no bounds to hold a functions or methods. Based on this, control flow graph can be derived from byte code, that represents a graph, but not a spanning tree. Every node has a reference to byte code address.

To investigate code comparison, two algorithms of structural compare are required, in fact top-down maximum common sub-tree and bottom-up maximum common sub-tree algorithms. To make a contribution into development of structured code compare, the following tasks should be explored:

1. The existing algorithms must be investigated (The text-compare method is not sufficient to find a similarity in code)
2. The algorithms for the structured compare(Abstract syntax trees, Control flow graphs) must be explored
3. New methods and algorithms find a place to tried out. A prototypes of combination text-compare and structure-compare can be implemented.
4. Experimental results of compare must be derived.

Chapter. 3

Tree isomorphism algorithms

This chapter is concerned with the issue of an important generalization of tree isomorphism, mostly known as Maximum Common Sub-tree isomorphism. The goal of these algorithms is finding a largest common sub-tree between two trees. It plays a major role either in scientific fields or in fundamental problems. The trees can be searched for most common sub-tree from top to down, correspondingly form the head of tree till leaves, or from bottom to up, that means the search for largest sub-tree starts from leaves upwards. The algorithms are provided by Gabriel Valiente [3]. In his book *Algorithms on Trees and Graphs* he presented detailed information about Top Down Max Common Sub-tree and Bottom Up Max Common Sub-tree isomorphism. The algorithms have been implemented in dr. Garbage tools for plugin eclipse integrated development environment.

Further research in this area may include not only the implementation of algorithms but also their application field. On this grounds, that the algorithms can be very helpful for tree similarity investigation. The current chapter includes an explanation of how these two algorithms have implemented in the project, about auxiliary algorithms and how they can be helpful for code comparison.

3.1 Top-down maximum common sub-tree isomorphism algorithm

There are two types of top-down maximum common sub-tree isomorphism algorithms. One of them finds the largest common ordered sub-tree T between T_1 and T_2 such can found in both trees, by that when the sequence of edges from parent node does make a sense. On the contrary, the second type is the same top-down algorithm that takes into account the order of edges of parent node, during the

algorithm execution.

A top-down common sub-tree of two unordered trees T_1 and T_2 is an unordered tree T such that there are top-down unordered sub-tree isomorphisms of T into T_1 and into T_2. A maximal top down common sub-tree of two unordered trees T_1 and T_2 is a top-down common sub-tree of T_1 and T_2 which is not a proper sub-tree of any other top-down common sub-tree of T_1 and T_2. A top-down of two unordered trees T_1 and T_2 is a top-down common sub-tree of T_1 and T_2 with the largest number of nodes [3].

Definition 3.1. *A **top-down common sub-tree** of an unordered tree $T_1 = (V_1, E_1)$ to another unordered tree $T_2 = (V_2, E_2)$ is a structure (X_1, X_2, M), where $X_1 = (W_1, S_1)$ is a top down unordered subtree of T_2 and $M \subseteq W_1 \times W_2$ is an ordered tree isomorphism of X_1 to X_2. A top-down common sub-tree (X_1, X_1, M) of T_1 to T_2 is **maximal** if there is no top-down common sub-tree of (X_1', X_2', M') of T_1 to T_2 such that X_1 is a proper top-down common sub-tree of X_1' and X_2' is a proper top-down sub-tree of X_2', and it is **maximum** if there is no top-down common sub-tree (X_1', X_2', M') of T_1 to T_2 with the $size[X_1] < size[X_1'][3]$.*

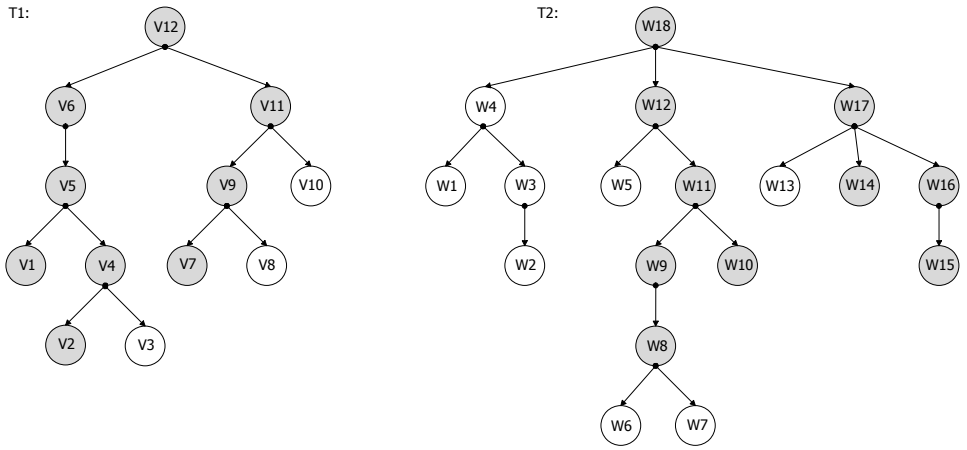
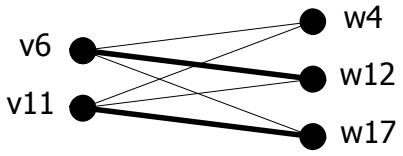


Figure 3.1: Top-down maximum common ordered sub-tree of two unordered trees T1 and T2. Nodes are numbered according to the order in which they are visiting during a post order traversal. The gray highlighted nodes are shaped maximum common sub-tree starting from the root [3].

The figure 3.1 demonstrates a partial injection $M \subseteq W_1 \times W_2$ among trees $T_1 = (V_1, E_1)$ and $T_2 = (V_2, E_2)$ where $M = \{(v1, w10), (v2, w8), (v4, w9),$ $(v5, w11), (v6, w12), (v7, w15), (v9, w16), (v10, w14), (v11, w17), (v12, w18)\}$ is unordered top-down maximum common sub-tree isomorphism T_1 and T_2 [3].

Important to realize that the injection $M \subseteq W_1 \times W_2$ can contain different pairs of nodes, as a result there are is only one unique maximum common sub-tree available. Nevertheless the number of pairs of nodes is constant and always maximal.

If nodes v is leaf T_1 and w is leaf of T_2 accordingly mapped to each other,



	w4	w12	w17
v6	3	5	3
v11	4	5	4

Figure 3.2: The solution MBM of bipartite graph brings $5+4=9$ weight from previous solutions

then the maximum common sub-tree gains size 1. Let suppose that p is number of children of T_1 and q is number of children of T_2 respectively. Consequently $v_1, ..., v_p$ and $w_1, ..., w_q$ are children of v and w[3]. Solving the algorithm needs to build a bipartite graph $G = (\{v_1, ..., v_p, w_1, ..., w_q\}, E)$ on $p+q$ vertices, with edge $v_i, w_i \in E$ if and only if the size of maximum common sub-tree of the sub-tree T_1 rooted at node v_i and the sub-tree of T_2 rooted at node w_i is non zero[3]. The bipartite graphs are built recursively the algorithm in one of trees T_1 or T_2 a leaf reaches. Let the leaf node of v_i of tree T_1 is found, then a bipartite graph can be formed with node w_i from T_2 at the same hierarchy level. Using the algorithm of *Maximum Bipartite Matching* the corresponding parent nodes w_{i+1} and v_{i+1} gains weight one plus *Maximum Bipartite Matching*(shortly named MBM)of current bipartite graph.

	w2
v1	1
v4	1

Figure 3.3: The v_1 and v_4 are leaf nodes of the left branch of T_1, and leaf node w_2 of T_2. The edge (v_1, v_4) is selected with *MBM* algorithm.

As an example can be taken from figure 3.2. As said, the nodes are being traversed until leaf node in the trees T_1 or T_2 is found. Let consider the left branch of T_1, namely leaves v_1 and v_4 and respectively the left branch of T_2, namely leaf w_2. A created bipartite graph is depicted at figure 3.3. The corresponding table shows weights of edges. Since these two are leaves they equal one. With algorithms *MBM* the edge v_1 and w_2 is being selected. Once the selection is done, the algorithm take their parent nodes, accordingly v_5, w_3 and v_3. The appropriate bipartite graph is constructed. The edges v_5 and w_3 have weight equal to one initially in table 3.5, but since from previous solution 3.3 the node v_1 has a parent v_5, the edge (v_5, w_3) gets weight equal to two. Likewise the edge (v_6, w_4) in table

Figure 3.4:

	w1	w3
v5	1	2

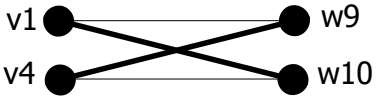
Figure 3.5: The edge (v_5, v_3) gains weight equal to two from previous solution3.3, due to the parent node

3.2 has a value three based on previous result.

By the same way all entries in table 3.2 have been built. Passing through the tree T_1 at another left branch until leaves v_2 and w_3 the similar bipartite graph can be formed 3.6. As said before, the current edges get same weight equal to one. The edge (v_2, w_8) is selected regards the *MBM* algorithm. Under those circumstances the next bipartite graph can be built 3.7. Based on previous solution the edge (v_4, w_9) obtains weight equal to two.

	w8
v2	1
v3	1

Figure 3.6: Starting from leaves select of both trees select edges with maximum weight. According to the algorithm the connection (v_2, w_8) has been selected.



	w9	w10
v1	1	1
v4	2	1

Figure 3.7: Since previous decision was (v_2, w_8), and they respectively are parents of (v_4, w_9) its weight of edge gains one plus the decision equal to one.

	w5	w11
v5	1	4

Figure 3.8: The the sum maximum matched edges from 3.7 equal to 3, in the same manner the edge (v_5, w_{11}) gains $3 + 1 = 4$ weight

Having a look at table in 3.2 in cell (v_6, w_{12}) where the value is 5. This has been formed due to the solution from table 3.8, because nodes (v_6, w_{12}) are direct parents of (v_5, w_{11}). likewise all other leaves in both trees are investigated and on-fly the tables with weight are filled out. The table in 3.2 is completed by the same way as described above. At the end the maximum bipartite matching algorithm selects the edges (v_6, w_{12}) and (v_{11}, w_{17}) because they bring the maximum weight of the bipartite graph. In this case two branches in 3.1 are picked and the corresponding nodes are grey highlighted forming the maximum common sub-tree from the bottom. Pseudo code is represented below:

```
list<node, node> topDownMaxCommonSubtreeIsomorphism(const TREE T1, const TREE T2){
node r1 = root(T1);
node r2 = root(T2);
traverse(node r1, node r2);
M = list<node, node>
reconstruct(r1, M);
}
```

This method goes recursively simultaneously through T1 and T2 till leaves of them are founded.

```
void traverse(node v, node w){
int p = v.getNumberOfChildren();
int q = w.getNumberOfChildren();
if(p == 0 or q == 0) return 1;

Array matrix = new Array[p][q];

for(i = 0; i < p; i++){
   for(j = 0; j < q; j++){
      node vChild = v.getChild();
      node wChild = w.getChild();
      matrix[i][j] = <vChild, wChild, -1>
   }
}

int res = 1;
if(p != 0 and q != 0){
bipartiteGraph bg = createBipartiteGraphFromMatrixEntry(matrix);
if (bg.numberOfEdges == 0) return 0;

list<edge> L = MaxWeightedBipartiteMatching(bg);
forall(e, L){
result += e.getCounter();
}
matching(list<edge> L);
return res;
}
}
```

This method reconstructs the top-down max common unordered sub-tree isomorphism mapping.

```
reconstruct(node r1, list<node, node> M){
M[r1] = r2;
list<node> L;
preorder-tree-traversal(L, T1);
forall(node v, L){
   forall(node w, B[v]){
   if(M[T1.parent(v)] == T1.parent(w)){
      M[v] = w;
      break;
   }
}
}
```

Puts into list B matched edges for further reconstruction

```
matching(list<edge> L){
forall(e, L){
B[r1].insert(r2);
}
}
```

3.2 Bottom-Up maximum common sub-tree isomorphism algorithm

There are two types of bottom-up maximum common sub-tree isomorphism algorithms. One of them finds the largest common ordered sub-tree T between T_1 and T_2 such can found in both trees, by that when the sequence of edges from parent node does make a sense. On the contrary, the second type is the same top-down algorithm that takes into account the order of edges of parent node, during the algorithm execution.

A bottom-up common sub-tree of two unordered trees T_1 and T_2 is an unordered tree T such that there are top-down unordered sub-tree isomorphisms of T into T_1 and into T_2. A maximal bottom-up common sub-tree of two unordered trees T_1 and T_2 is a bottom-up common sub-tree of T_1 and T_2 which is not a proper sub-tree of any other bottom-up common sub-tree of T_1 and T_2. A bottom-up of two unordered trees T_1 and T_2 is a bottom-up common sub-tree of T_1 and T_2 with the largest number of nodes [3].

Definition 3.1. *A **bottom-up common sub-tree** of an unordered tree $T_1 = (V_1, E_1)$ to another unordered tree $T_2 = (V_2, E_2)$ is a structure (X_1, X_2, M), where $X_1 = (W_1, S_1)$ is a bottom-up unordered subtree of T_2 and $M \subseteq W_1 \times W_2$ is an ordered tree isomorphism of X_1 to X_2. A bottom-up common sub-tree (X_1, X_1, M) of T_1 to T_2 is **maximal** if there is no bottom-up common sub-tree of (X_1', X_2', M') of T_1 to T_2 such that X_1 is a proper bottom-up common sub-tree of X_1' and X_2' is a proper bottom-up sub-tree of X_2', and it is **maximum** if there is no bottom-up common sub-tree (X_1', X_2', M') of T_1 to T_2 with the size$[X_1] <$ size$[X_1']$[3].*

The figure 3.9 demonstrates a partial injection $M \subseteq W_1 \times W_2$ among trees $T_1 = (V_1, E_1)$ and $T_2 = (V_2, E_2)$ where $M = \{(v1, w10), (v2, w6), (v3, w7),$ $(v4, w8), (v5, w9), (v6, w11), (v7, w5), (v8, w12)\}$ is unordered bottom-up maximum common sub-tree isomorphism T_1 and T_2 [3].

The problem of finding a maximum common sub-tree isomorphism between two trees T_1 and T_2, where T_1 has n_1 nodes and T_2 has n_2 respectively can be reduced to the problem of partitioning $V_1 \bigcup V_2$ into equivalent classes of bottom-up sub-tree isomorphism. Two nodes are equivalent if and only if the bottom-up unordered sub-tree rooted at them are isomorphic.

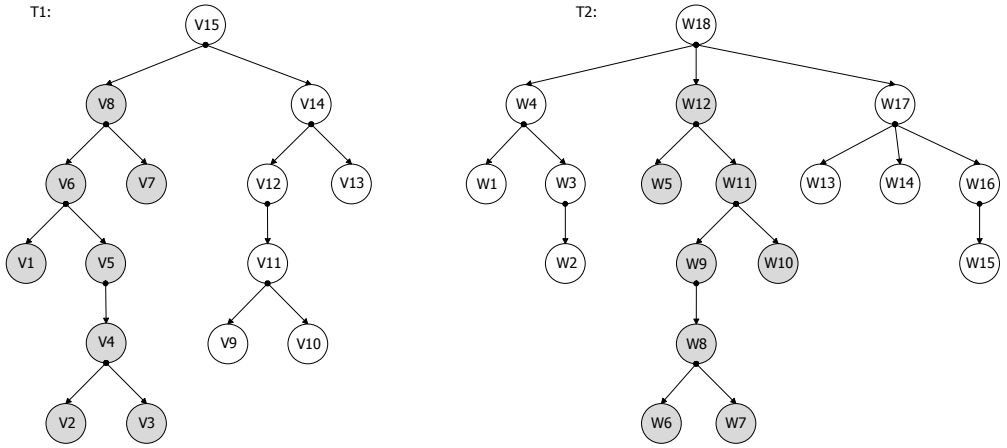


Figure 3.9: Bottom Up maximum common ordered sub-tree of two unordered trees T1 and T2. Nodes are numbered according to the order in which they are visiting during a post order traversal. The gray highlighted nodes are shaped maximum common sub-tree starting from the leaves [3].

The algorithm start with a partition a tree into bottom-up equivalence classes. Let the number of known equivalence classes be initially equal to 1, corresponding to the equivalence class of all leaves in the trees. For all nodes v of T_1 and T_2 in post-order, set the equivalence class of V to 1 if node v is a leaf. Otherwise, look up in the dictionary the ordered list of equivalent classes to which the children of node v belong. If the ordered list (key) is found in the dictionary then set the equivalence class off node v to the value (element) found. Otherwise, increment by one the number of known equivalence classes, insert the ordered list together with the number of known equivalence classes in the dictionary, and set the equivalence class of node v to the number of known equivalence classes.

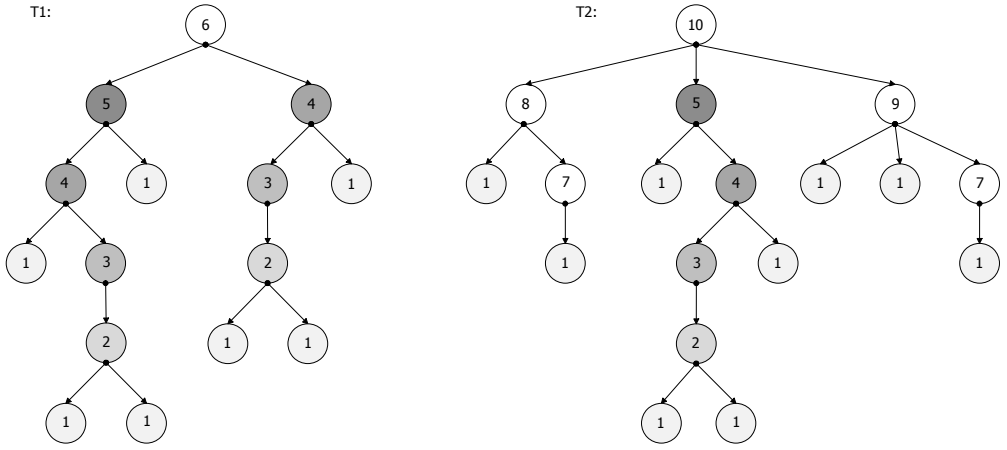


Figure 3.10: Bottom Up maximum common equivalence classes reflected to the figure 3.9. The node are numbered according to the equivalence class to which they belong and the equivalence classes are shown highlighted in the different shades of gray[3].

Chapter. 4

Code compare experiments

4.1 Introduction to experiments

For better understanding of possible "code compare" concept, possible ideas of implementation and following development an amount of experiments are required. In order to build a proper tool or at least a concept, in Eclipse plugins at Dr. Garbage Community® some hand experiments in code should be fulfilled.

All these test cases are performed in Eclipse IDE [10] and divided into blocks. These steps can be approached by following:

1. Research on Java source code using existing methods to compare:
   (a) Normal text compare
   (b) Spanning trees transformed from control flow graphs
2. Research on Java source code using existing methods to compare:
   (a) Normal text compare
   (b) Abstract syntax trees
3. Research on Java byte code using existing methods to compare:
   (a) Normal text compare
   (b) Control flow graphs

All test set are investigated under Java methods and functions. Playing around with the patterns of code changing variables, names, sequences of commands, adding loops or conditions and apply the simple "text to text" compare. This "text compare" is already implemented in Eclipse IDE [10], so-called command

"compare with each other by member". This type of comparison provides a pop-up window, where two pieces of code are compared, line by line.

In parallel a control flow graphs or source graphs from the functions are being created and compared using implemented algorithms Top-Down and Bottom-Up(following called: TD& BU). The further task is to figure out the difference/similarity from graphical visual comparison. Consequently these both results must be matched and recorded for succeeding research.

The derived results from can be as follows:

1. Text compare and TD & BU have same difference
2. Text compare and TD & BU give similar difference
3. Text compare and TD & BU five full difference

Hence, as it was declared in section description of problem, based on these results can be decided what kind of tool in Dr. Garbage Eclipse plug-ins can be built.In case similar or full difference results, a combination of both methods can be used for optimal comparison.

Small example can be demonstrated: there are two functions that look very similar but nevertheless they have different number of string and different functionality. The abstract results can be following:

1. Text compare shows that strings 1 and 5 are different
2. Graph compare shows that string 7 is different

Conclusion: a combination of two methods can explicit that strings 1,5 and 7 are distinguished and much more distinction has been found. Thus it provides an optimal way of investigation.

4.2 Experiments on Java source code Flowcharts

A flowchart is a type of diagram that represents an algorithm, workflow or process, showing the steps as boxes of various kinds, and their order by connecting them with arrows. This diagrammatic representation illustrates a solution model to a given problem. Flowcharts are used in analyzing, designing, documenting or managing a process or program in various fields[4].

Dr. Garbage tools[1] provides a solution how to represent sequential flowchart alongside to Java source code(see figure 4.1).

A depicted flowchart can be easily extracted into control flow graph (see figure 4.2). If there is another similar function, it can be transformed into next control flow graph. These two graphs are being compared using existing TDMC[3.1] and BUMC[3.2] algorithms.

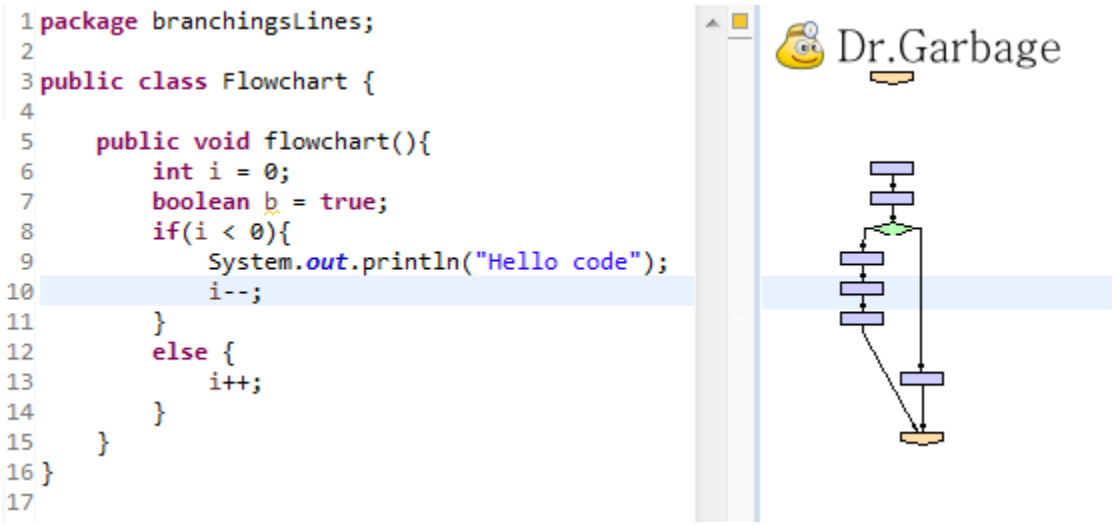


Figure 4.1: Example of source code visualizer

Unfortunately these two algorithms are applicable only for tree structures. For this reason this problem can be reduced, removing minimum number of edges to get a spanning tree. Thus the the edges in the input graphs are reduced by Spanning Tree Algorithm[5.1]. The removed edges are red highlighted, hence this for this structure TDMC and BUMC[3] can be easily applied.

To conduct an experiments a sequence of actions and following statistic are needed. After conducted experiments, taking into account the derived statistic, a conclusion takes place. The steps are carried through sequence of action:

- Write two similar functions in Eclipse IDE
- Apply for them text-to-text comparison
- Declare the statistic, respectively how many lines are different
- Create a source-code graph for both
- Apply TD & BU algorithms to get structural difference
- Declare the statistic, respectively how many nodes are different

In this section all experiments have been executed by hand using plug-in tool "Graph Comparison" in Eclipse from dr. Garbage project. Before starting, a several rules how to evaluate code difference in text and in graph must be established. It is one of the crucial moment, because followed data statistic are used in further tool development.

For the estimation of structural difference there are criteria listed:

- Each java operator is considered as simple node

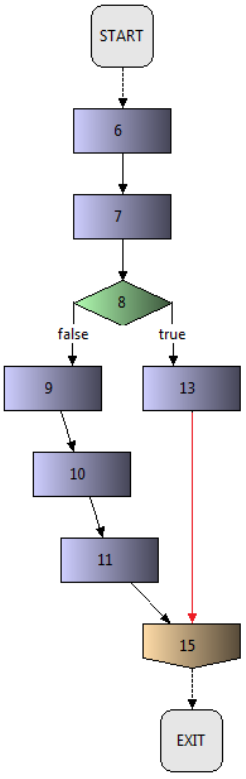


Figure 4.2: Extracted control flow graph from Java source code

- Changing a conditions of block on the contrary issues 100% difference of business logic, however the structure stays unchangeable.
- Availability of extra variables in second piece of code is calculated by division of number of extra variables to amount of all variables.

Mostly all calculations are performed by roughly, because there are many criteria how to evaluate the logic and structure difference. But from this perspective these rules are enough to examine graph's similarity.

For the text difference found via Eclipse tool a criteria to evaluate can be added:

- Percentage is computed by number of
- If in one line of code only one symbol has been covered as found, then it is division of one to amount of symbols in this line.

And after generation of two graphs, these both are compared(see the figure 4.4) using existing TDMC and BUMC[3] algorithms.

The table 4.1 shows results of java source code experiments. Existing algorithms [3] and Eclipse text-to-text comparison have been used to reveal the best approach of code comparison. As it said above, the difference code can be figured out either structurally or simple text comparison. Based on the table 4.1 the apparent conclusion are composed:

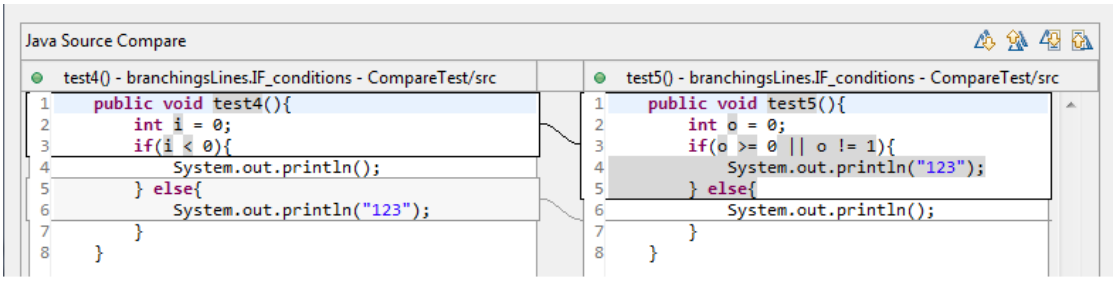


Figure 4.3: Two pieces of code are being compared with Eclipse Text Comparison

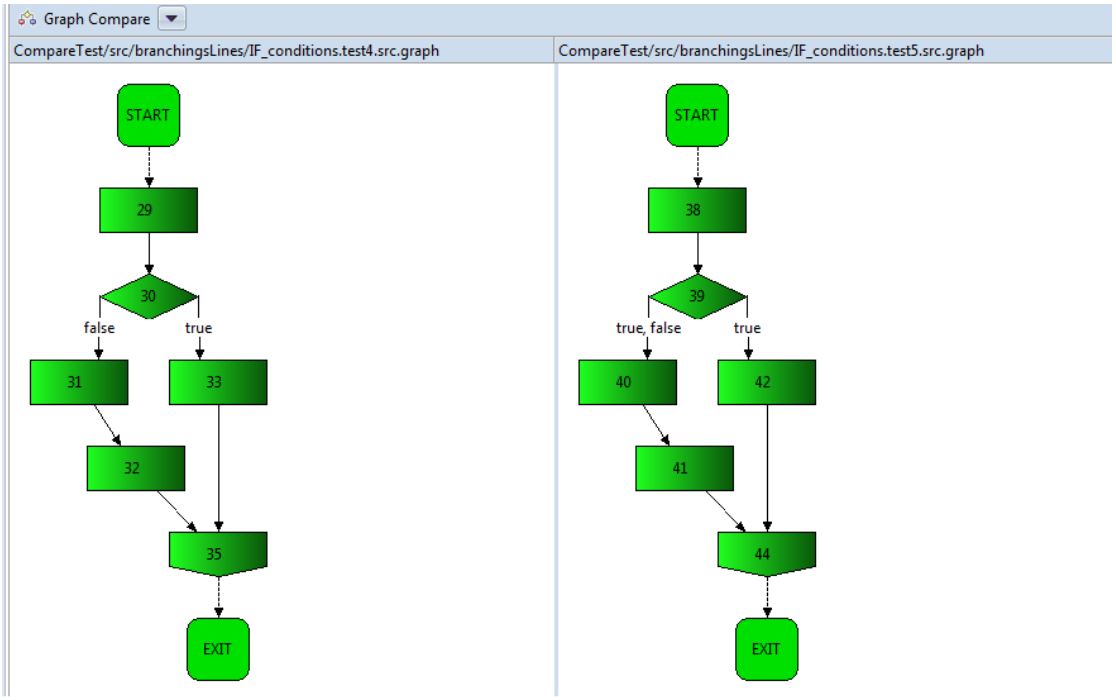


Figure 4.4: Compared source code graphs using TDMC algorithm

Compare experiments			Text -to-text compared	Graphcompared
Test id	Name of functions	Real code difference %	Layout difference % found	TD&BU similarity % found
1	t1() and t2()	50	100	100
2	t1() and t3()	50	100	75
3	t1() and t4()	50	100	100
4	t1() and t2()	50	100	80
5	t1() and t5()	50	100	100
6	t6() and t7()	33	33	100
7	ti1() and ti2()	10	100	0
8	ti2() and ti3()	16	100	100
9	ti3() and ti4()	25	100	66
10	ti4() and ti5()	50	100	0
11	ti6() and ti7()	90	100	42

Table 4.1: The table demonstrates results of Java Source comparison using text-to-text compare method and application of algorithms to their source code graphs

- If the application logic is totally different (For example **if conditions**) then Eclipse Text Compare finds the difference, thus condition itself is highlighted. The graphical comparison with TD& BU are not able to see this distinction. It is obvious since graph theory in this case is able to find how similar structure of code fragments. The conducted example 4.4 above can testify this conclusion. In this way graph theory is not applicable to differentiate logic of application.

- In opposite said above, the graphical compare is quite useful instrument to investigate a code structure. For example, if another third party person has changed local variables, the structure remains same, thus TDMC& BUMC (especially TDMC) find high level of similarity. Unfortunately this approach is not enough to build a new concept allowing to investigate the difference more precisely.

- The graph is totally bound to lines of codes. If one brace is shifted, then it's considered one more block in the graph(Dr. Garbage Source Code Visualizer [1] generates extra node for each code operator). Hence TDMC is not able to find following branch where there an extra node and generated Java source code graph is not optimized for comparison.

- Text-to-text compare is enough to investigate a text difference because this tool finds every different sub-string in code line. But as stated above, changing variables, sequence of operators or even production same loops with different operators the text-to-text compare find too much unmatched strings. Eventually the result of text compare looks like a disorder with same and unmatched sub-strings.

4.3 Experiments using Abstract Syntax Tree graphs

In this section the abstract syntax trees are generated from Java source code using Dr. Garbage plugins [1]. The most notable advantage of building AST trees is a direct converting Java source code into AST tree, thereby avoiding graphs with cycles. Thus there is no need to delete back edges(see Spanning tree algorithms).

TODO: short explanation about AST how it looks like and we need them;

In this section all experiments have been executed by hand using plug-in tool "Graph Comparison" in Eclipse from dr. Garbage project [1]. Before starting, a several rules how to evaluate code difference in text and in graph must be established. It one of the crucial moment, because followed data statistic are used in further tool development.

TODO: after this compares write a conclusion what is better to compare

4.4 Experiments on JavaByte Code

In this section an investigation regards java byte-code comparison is expound. Unlike Java source code, the corresponding byte code has practically no application logic. In spite of this the topic must be researched for the clone detection.

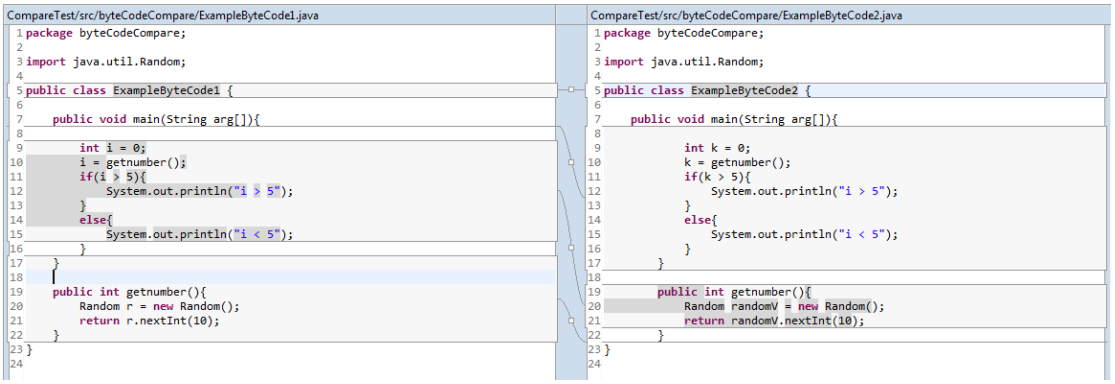


Figure 4.5: Java source code compared using text-to-text

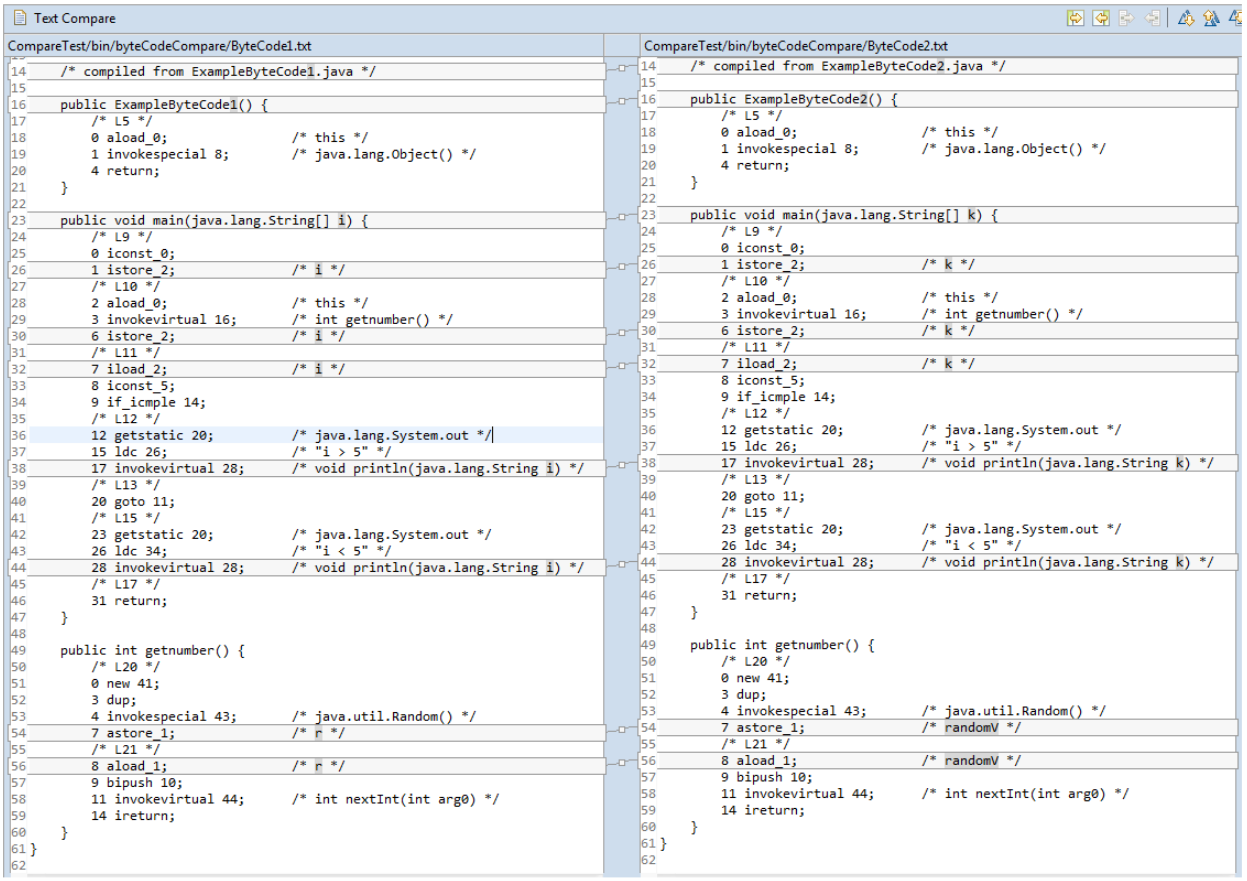


Figure 4.6: Java byte code compared using text-to-text

Chapter. 5

Graph transformation algorithms

5.1 Introduction to the graph transformation

TODO: explain how graph is generated, which libraries are used, plugins

5.2 Techniques to normalize AST improving structural comparison

Researches show that many big development projects have duplicate code, which is generally result of copying and pasting existing pieces of code. Moreover the code can be completely redone, changing name of variables, in some cases replace lines of code. But the most sophisticated part comes when a similar command can be in code substituted. It is known, that from programming perspective, for instance, a loop can be differently organized. There three fundamental ways to reproduce the iteration statements, namely: *pre - condition*, *post - conditions* and so-called *for-loop*. The function can be reworked by so delicate way, that none of any text-to-text compare finds similarity. However the functions execute the same application logic. And this can be found almost everywhere, the most notable example is clone pair between FreeBSD and Linux. In the following example these function are similar and have taken from

```
public void test1(){
     int frameGroupLine = 10;
     for(int Cnt = 1; Cnt < frameGroupLine; Cnt =+ 2)
     {
        if(Cnt*4 != 2){
           frameGroupLine++;
        }
     }
```

```
  }

public void test2(){
     int frameGroupLine = 10;
     for(int Counter = 1; Counter < frameGroupLine; Counter =+ 2)
     {
        if(Counter*4 != 2){
           frameGroupLine = frameGroupLine + 1;
        }
     }
  }
```

Listing 5.1: Text

If this line `frameGroupLine = frameGroupLine + 1;` will be converted into one format of sub-tree, that indicates the same as `frameGroupLine++;`. Thus this sub-tree can be found with TDMC or BUMC algorithms. Consequently it brings more covered nodes that signalize more similarity.

```
  public void test3(){
     int frameTeamLine = 10;
     for(int i = 1; i < frameTeamLine; i =+ 2)
     {
        if(i*4 != 2){
           frameTeamLine++;
        }
     }
  }
```

The code fragments test1() and test2() have the same application logic but different variables. However in the second one the increment of variable "frameTeamLine" is differently written. From text to text compare the functions are different at this point. If the text code similarity will be calculated, then these two fragments are not same(probably 90% similarity). Using Abstract Syntax Trees Optimization, this types of structure can be converted in the same sub-tree of whole AST tree. Thereby these two different text structures are represented as same sub-tree.

On figure 5.1 the example demonstrated how these two functions are compared using Eclipse Text comparison window. After creation and comparison these two AST trees, it can be easily seen that sub-trees (the increment) are different.

From the figure 5.2 TDMC algorithm finds incomplete code similarity since not all nodes have been covered. From statistical point of view using simple math, the percentage of similarity is figured out: 37 nodes in the test2() and 3 of them are not covered. Thus, the calculation indicates $\left(1 - \left(\frac{3}{37}\right)\right) \cdot 100 = 91\%$ code similarity

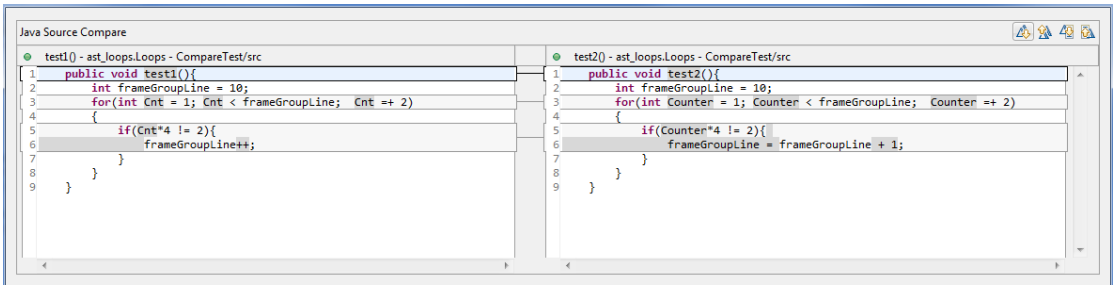


Figure 5.1: Example of standard text-to-text comparison of Java code

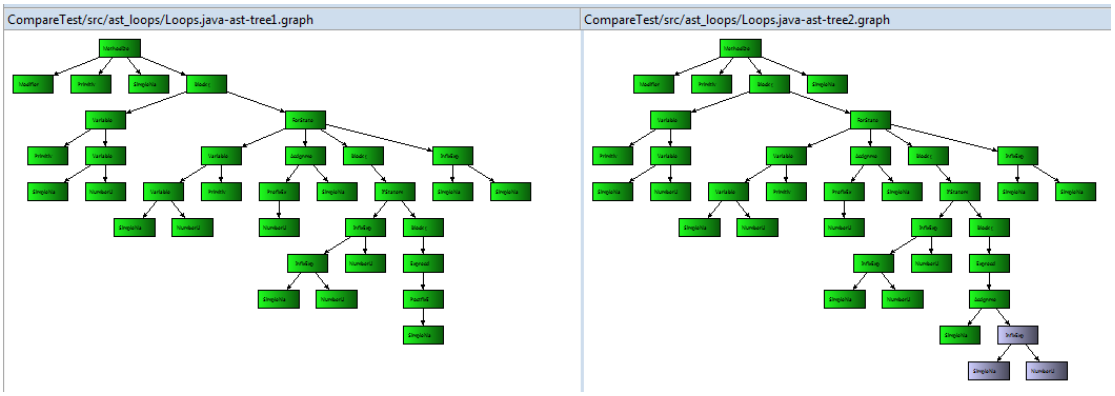


Figure 5.2: Graph comparison of function test1() and test2() using TDMC algorithm 3.1

according to AST trees and applied TDMC algorithm.

This mismatch can be optimized during AST tree production. These two lines of code `frameGroupLine++;` and `frameGroupLine = frameGroupLine + 1;` must be built as a same sub-tree, accordingly same structure and same number of nodes. Using this simple replacement it allows to built a similar AST trees, when logic is same but the source code text is different. Consequently the converted AST trees to some extent are independent from source code and can be compared to explicit the difference.

5.3 Convert graph to tree

TODO: decribe here how to remove edges in order to get spanning tree, DO WE NEED IT HERE??

5.4 Possible ideas

IDEA: how search for precise difference using AST trees and reflect this to text

This example 5.3 demonstrates how text compare is not available to notice the string difference in case some operators have been simply replaced. Namely the operators: `case 0:` and `case 4:` from figure 5.3 have been replaced but text

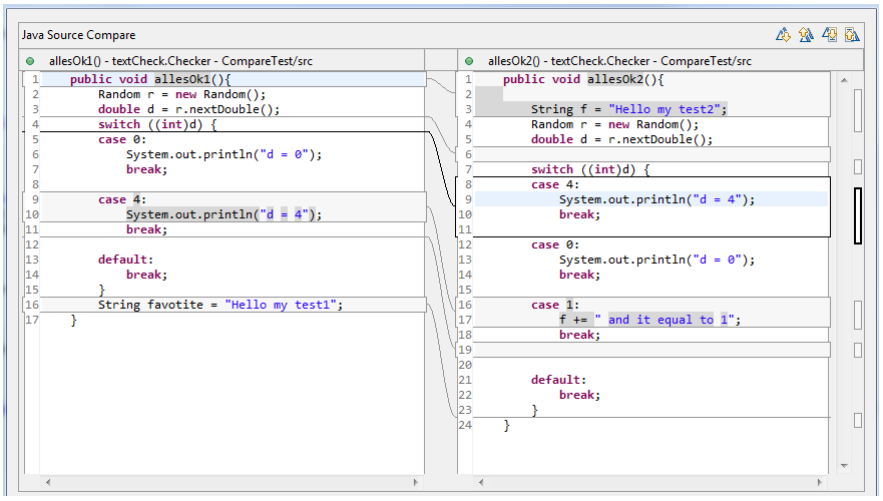


Figure 5.3: Example of standard text-to-text comparison of Java code

compare find this difference. Moreover when this code mostly changed, namely the names of variable, line position in code, thereby not impacting on the application logic of function then it is much more difficult to clarify the code difference. Thus comparing two function using text to text compare, it can be that the result is totally mixed, however this functions almost identical.
Why text-to-text cannot find these obvious differences? Before text comparison starts the preparation of code includes following steps:

1. Comments Removal: Ignores all kinds of comments in the source code depending on the language of interest.

2. Whitespace Removal: Removes tabs, and new line(s) and other blanks spaces.

3. Normalization: Some basic normalization can be applied on the source code

First, some detectors are based on lexical analysis. For instance, Baker's Dup [8] uses a sequence of lines as a representation of source code and detects line-by-line clones. Dup removes tabs, white spaces and comments; replaces identifiers of functions, variables, and types with a special parameter; concatenates all lines to be analyzed into a single text line; hashes each line for comparison; and extracts a set of pairs of longest matches using a suffix tree algorithm[6].

General idea of this suffix tree comparison algorithm: the code is splitted into strings, from these strings a suffix tree is being built, then using sub-suffix algorithm performs a search for substring from one code fragment to another. Building such kind of tree allows to find a sub-string in given string within $O(m)$ complexity, where m is the length of the sub-string (but with initial $O(n)$ time required to build the suffix tree for the string). According to research of Roy, Chanchal Kumar [6] there are some disadvantages that can interpret the issue described above on picture 5.3 where some sub-strings are not found described in following citation:

This tools does not support exploration and navigation through the duplicated code. Detection accuracy is low e.g., cannot detect code clones written in different coding styles. For example "{" position of if-statement or while-statement. Cannot detect code clones using different variable names, e.g., we want to identify the same logic code as code clones even if variable names are different[6].

Hypothesized that tree suffix algorithm is more negatively related to proper code compare in case if clone detection is being searched. This can be improved with help of tree algorithms techniques; As prerequisites let us take the following

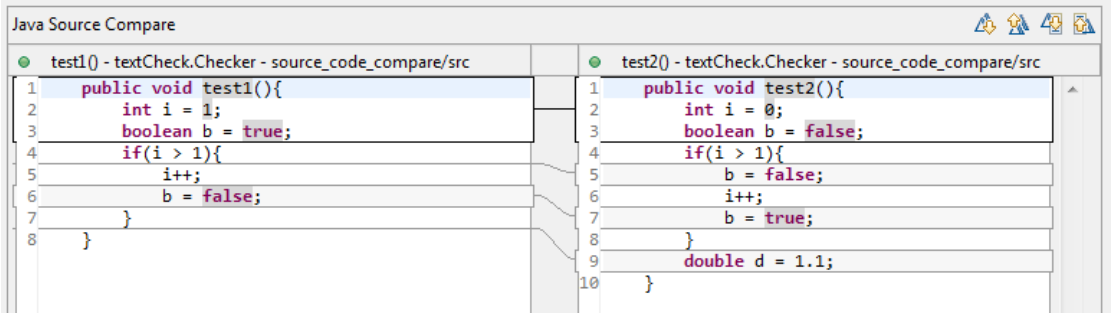


Figure 5.4: Example of text-to-text demonstrating the code difference using sub-suffix algorithm

example depicted on the picture5.4. Considering the example very carefully, line by line, it is easy to get an idea how these two peaces of code organized. In line 2 the obvious mismatch variable `o: 0` to `1` and `false` to `true` are gray highlighted. Up next comes the `if` operator, where there are two and three blocks. They make almost the same logic however the ae The last difference on line 11: function `test2()` contains extra command `b = true;`. At the end of function `test2()` there is additional operator. Notice that, the example is relatively small and has not some much different commands and operators. It can be that two functions are so complex modificated, thereby text compare yields a mix of various lines. To improve this, a code can be transformed into Abstract Syntax Tree(next AST tree) and both tree are traversed synchronously checking matched nodes. The biggest advantage of method that AST trees are built independently of sequence of commands. The difference in this trees is unordered range of nodes. It means that these AST trees are taken into consideration as unordered trees.

The picture 5.5 shows how AST tree from function `test1()` is being built from the source code. As said above the presented AST tree 5.5 is unordered, thus the replaced lines of code and the nested operators and independent from each other. The trees traversal enables to identify the concrete difference in source code, independent how the code is organized. The evident mismatch must be referred to the source code. The idea is to keep the current command or operator in the tree

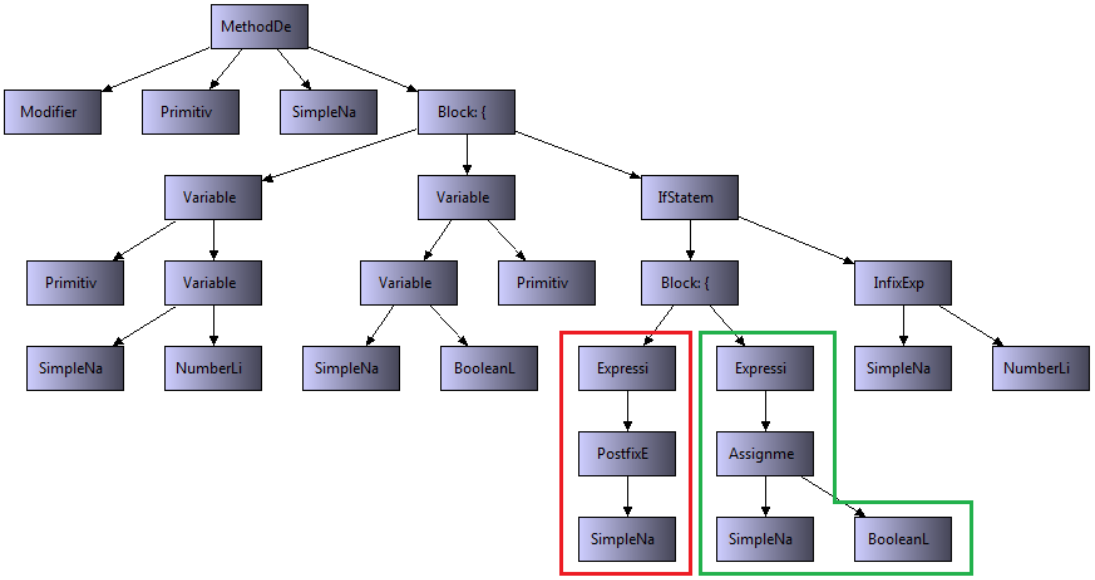


Figure 5.5: Abstract Syntax Graph of function `test1()`.

node, i.e. to keep to current text position of command in the corresponding node. Obviously the proper node forming is kept during the AST tree convert process. After complete parallel tree traversal similar to Breadth-first search, the nodes of i level are compared for matched content, in this case operators and command. If in the level i a match if not found, the mismatched nodes are marked as mismatch. Each node contains information about text location of command or operator. During the second tree traversal on trees when mismatched node is visited, the corresponding text is highlighted in text compare. Therefore it helps to improve standard text-to-text compare.

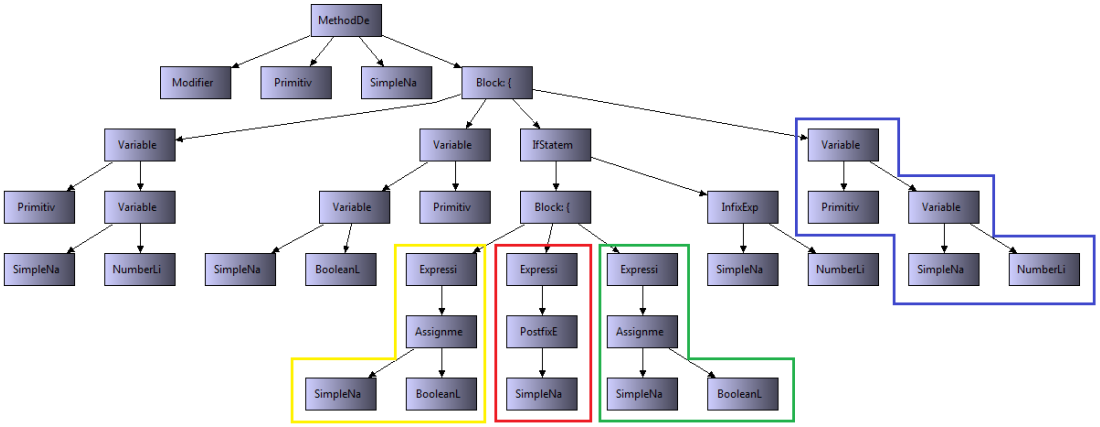


Figure 5.6: Abstract Syntax Graph of function `test2()`.

Example 5.4 and derived AST trees 5.5 and 5.6 indicate similarity and differ-

ence: the red and green framed branches are same(`i++` and `b = false` respectfully), therefore the nodes in this branch are marked *matched*. The yellow frame marks out `b = true;` line, that is redundant in `test1()`. Since the trees are unordered and running over all nodes in *test*1() and *test*2() tree structure at same node depth level i using Cartesian Product among nodes search for different or missed nodes and mark them as mismatch.
TODO: write math formula taking i nodes and Cartesian set

The blue frame in picture 5.6 denotes a new command line, namely `double d = 1.1;`. In Cartesian product this parent node must be not matched, hence the whole branch is marked as mismatch.
TODO: example which strings must be highlighted in text as a reflex to mismatched nodes.
Possible IDEA 2 After second tree traversal to see the mismatch, a non-trivial statistic takes a place: Show in what parts of code the changes has been detected, For example:

- Conditions have been changed (percentage)
- Code added /removed (percentage)

Chapter. 6

Existing Comparison methods

6.1 Plagiarism detection methods

Task of plagiarism detection is an identification of text's similarity. Thus a research of existing methods is useful for this work regards code's comparison.

> Plagiarism detection is the process of locating instances of plagiarism within a work or document. The widespread use of computers and the advent of the Internet has made it easier to plagiarize the work of others. Most cases of plagiarism are found in academia, where documents are typically essays or reports. However, plagiarism can be found in virtually any field, including scientific papers, art designs, and source code [5].

Mostly the task of plagiarism detection is considered for many fields, like text documents, software and source code. In this chapter source code plagiarism is being reviewed.

According to the article of Chanchal Kumar Roy and James R. Cordy [6], source-code similarity detection algorithms can be classified as following:

- Text-based Techniques
- Token-based Techniques
- Tree-based Techniques
- PDG-based Techniques
- Metrics-based Techniques

6.2 Text-based Techniques

How text to text works:(49) Prepare first the fragment of code: 1. Comments Removal: Ignores all kinds of comments in the source code depending on the language of interest. 2. Whitespace Removal: Removes tabs, and new line(s) and other blanks spaces. 3. Normalization: Some basic normalization can be applied on the source code (c.f.,Table 3)

First, some detectors are based on lexical analysis. For instance, Baker's Dup [8] uses a sequence of lines as a representation of source code and detects line-by-line clones. Therefore, it uses a lexer and a line-based string matching algorithm on the tokens of the individual lines. Dup removes tabs, white spaces and comments; replaces identifiers of functions, variables, and types with a special parameter; concatenates all lines to be analyzed into a single text line; hashes each line for comparison; and extracts a set of pairs of longest matches using a suffix tree algorithm.

Conclusion:
+presented on text, every small details is there, see
-code mixed, too much mismatches

6.3 Token-based Techniques

6.4 Tree-based Techniques

6.5 PDG-based Techniques

Chapter. 7

Conclusion

based on experimental results and own opinion, write here what results were derived From time to time write here combined conclusions or improvements

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