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Migrating Large Object-Oriented Applications into Component-Based Ones

Instantiation and Inheritance Transformation

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Abstract

Large object-oriented applications have complex and numerous dependencies, and usually do not have explicit software architectures. Therefore they are hard to maintain, and parts of them are difficult to reuse. Component-based development paradigm emerged for improving these aspects and for supporting effective maintainability and reuse. It provides better understandability through a high-level architecture view of the application. Thereby migrating object-oriented applications to component-based ones will contribute to improve these characteristics (maintainability and reuse). In this paper, we propose an approach to automatically transform object-oriented applications to component-based ones. More particularly, the input of the approach is the result provided by software architecture recovery: a component-based architecture description. Then, our approach transforms the object-oriented source code in order to produce deployable components. We focus in this paper on the transformation of source code related to instantiation and inheritance dependencies between classes that are in different components. We experimented the proposed solution in the transformation of a collection of Java applications into the OSGi framework. The experimental results are discussed in this paper.

Categories and Subject Descriptors D.2.3 [Software Engineering]: Coding Tools and Techniques; D.2.7 [Software Engineering]: Distribution, Maintenance, and Enhancement; D.2.2 [Programming Techniques]: Design Tools and Techniques; D.2.13 [Programming Techniques]: Reusable Software; D.1.2 [Programming Techniques]: Automatic Programming

General Terms Algorithms, Languages, Design

Keywords Component, Object, Code Transformation, Refactoring, Inheritance, Encapsulation, Class Instantiation, Java, OSGi

1. Introduction

Most existing large legacy applications are object-oriented (OO) [19]. These applications have complex and numerous internal dependencies. Usually, they do not have explicit architectures, in which coarse-grained high-level entities and their dependencies are described. This makes these applications hard to maintain (understand and change), and hard to reuse.

Conversely, component-based (CB) applications have coarse-grained high-level architecture views [1]. They have loosely coupled and highly cohesive entities that have explicit dependencies. Therefore, these applications are easy to understand through their architecture views, and it is easy to reuse their coarse-grained entities [5,9]. Thus migrating these OO applications to CB ones contributes to improve their maintainability, in addition to their reusability by feeding existing component repositories [12].

The migration process is composed of two main steps [1]: the first step is CB architecture recovery where components and their dependencies are identified. The second step is code transformation where OO code is transformed into equivalent CB one.

The step of CB architecture recovery was largely treated in the literature [2-4,7,9]. Most of these works aim to identify components as clusters of classes. They use clustering algorithms, among other techniques, aiming at maximizing intra-component cohesion and minimizing inter-component coupling to identify the architectural elements (components and connectors). CB architecture recovery aims to identify components and connectors but not to create them. It does not transform these clusters of classes into a concrete component model. Moreover, the dependencies between clusters remain OO ones.

Code transformation (The second step) aims at creating programming level components by transforming OO code. It aims at creating components based on given clusters of classes. Component encapsulation (i.e., Interaction through explicit provided and required interfaces) is a main characteristic of components and therefore a major difference between the component and object concepts [15]. Thus, object to component transformation consists on transforming OO dependencies between classes belonging to different clusters to interactions through interfaces to avoid component encapsulation violation. It needs the transformation of OO mechanisms used at the implementation level (i.e. instantiation, inheritance, exception handling, etc.) into ones related to CB (interface-based connections) [12].

This paper proposes a method that automatically transforms an OO application code to a CB one. We assume that an existing CB architecture recovery method provides us architecture descriptions as an input to our method. Based on the taxonomy of component models proposed in [11], we chose, as the target of our transformation, an object-based component model (i.e. components implemented based on OO source code). These component models are implemented as an extension of mainstream OO programming lan-
guages (e.g. OSGI is an extension of Java [13], CCM is an extension of C++ [11]. This choice allows us to reuse the OO source code to be migrated. In this work, we experimented the proposed solution on the transformation of Java applications into the OSGi framework.

The remainder of this paper is organized as follows. Section 2 presents the migration process and its related issues. Section 3 explains the proposed solution to transform class instantiation dependencies. Section 4 describes our solution to transform OO inheritance relationships. Section 5 presents implementation and experimental results. Before concluding, we present the related work in Section 6.

2. Problem Statement

To better illustrate the problem and solutions related to the OO-to-component migration, we introduce an example of a simple Java application. This application simulates the behavior of an information screen (e.g. a software system which displays on a bus’s screen information about stations, time, etc.).

In Figure 1, ContentProvider class implements methods which send text messages (instances of Message), and time information obtained trough Clock instances based on the data returned by TimeZone instances. The DisplayManager is responsible for viewing the provided information through a Screen.

2.1 Component-Based Architecture Recovery

Architecture recovery was largely studied in the literature [3]. In these works a software component is recovered as a cluster (set) of classes that collaborate with each other to provide the component functionalities [6]. In most of these works, a cluster is identified based on the definition of a fitness function and a clustering algorithm. For example, in our previous works [4, 9], we have proposed an approach which aims to recover component-based architectures based on a fitness function and a search-based algorithm. The fitness function is based on quality measurements on the component-based architecture (i.e. maintainability, reliability, autonomy, specificity and composability). The search-based algorithm aims to maximize this fitness function.

Figure 2 shows the result of architecture recovery step applied on our example. The recovery step identifies five clusters, each cluster contains one or several classes. For example Component1 is responsible for displaying information on the screen through the collaboration of its classes, Screen and DisplayManager. A cluster is composed of two types of classes: internal classes and boundary classes. Internal classes are classes that do not have dependencies (e.g. a method invocation or an inheritance relationship) with other classes placed into other clusters (e.g. GpsLocation and Screen). And the boundary classes are classes that have dependencies with classes placed into other clusters (e.g. TimeZone and Clock). We consider a component-based architecture as a set of components connected via interfaces, where interfaces are identified from boundary classes.

2.2 Code Transformation

In this paper we use clusters of classes obtained based on recovery approaches as an input of the source code transformation step. To transform clusters of classes to components we need to solve two main problems:

1) Explicit component encapsulation violation: the component must hide its internal structure and behavior [16]. It should provide its services without exposing the classes that implement it. Two source code expressions fall under this category. First, “class instantiation”, where a class (in one component) creates an instance of another class (residing in a different component). For example, Clock class creates an object of TimeZone class, while these classes belong to two different clusters. Second, “method invocation”, where a method defined in a given class of a cluster invokes a method defined in a class placed in another cluster.

2) Implicit component encapsulation violation: It is related to implicit dependency between components caused by OO mechanisms, such as inheritance, exception handling and event handling. For instance, for the inheritance mechanism, a class and its subclasses cannot be necessarily placed in the same cluster. This is the case in Figure 2 for Clock and Message subclasses of Content Class. In this case, the inheritance relationship between
these classes crosses component boundaries, facing an implicit depen-
dency between the underlying components. Since component
models do not all support inheritance (e.g. ComponentJ, COM,
etc.) [13], source code related to inheritance need to be trans-
formed.

In this paper we focus on solutions related to source-code trans-
formations of explicit component encapsulation violation (instanti-
ation and method invocation) and OO inheritance which is a case
of implicit component explicit violation.

3. Instance Handling Transformation

Considering the result of the recovery step, a class belonging to a
component (cluster) can be instantiated in a method of class be-
longing to another component by using directly this class construc-
tors. This causes a violation of the principle of component encapsu-
lation. Our approach proposes two steps to transform direct instan-
tiation dependencies: (i) Uncoupling classes belonging to different
components (clusters) by creating object interfaces. (ii) Defining
specific component interfaces playing the role of object factories.

3.1 Creating Object Interfaces: Uncoupling Boundary

Classes

We transform direct references (method calls) between classes of
different components to interface-based calls. Thus when a class A
uses class B where A and B are parts of two different components,
we create a couple of the same provided and required interfaces
(IB). The provided one will be defined in the component of the
class B and the required one in the component of the class A. Theses
interfaces define the same methods of all public methods of class
B. In addition they define other methods to access public attributes
of this class (i.e. setter and getter methods). Each direct use of class
B in the class A will be refactored as a use of the required interface
(IB) added to the component of A.

To illustrate this, consider our illustrative example, where Clock
creates an instance of TimeZone. This is depicted in Listing 1. We
create ITimeZone interface for class TimeZone. ITimeZone specifies
the signatures of all public methods in TimeZone. Moreover, it
declares setter and getter methods for its public attribute (time).
Listing 2 shows the result of our transformation in both Clock and
TimeZone classes.

Listing 1. Instanctiation dependency in Java code.

```java
public class Clock extends Content{
  public Clock() {
    TimeZone timeZone = new TimeZone();
    String time = timeZone.getTime();
  }
}
```

```java
public class TimeZone {
  public String getTime();
  public String setTime();
}
```

Listing 2. Creating object interfaces.

```java
public class Clock extends Content{
  public Clock() {
    ITimeZone timeZone = new ITimeZone();
    String time = timeZone.getTime();
  }
}
```

```java
public class TimeZone implements ITimeZone{
  public String getTime();
  public String setTime();
}
```

3.2 Using Component Interfaces through the Factory Pattern

The second step of this transformation is based on the Factory
design pattern. Thus the expression in the source code related to
the instantiation of a class B by a class A where these classes are
parts of two different components is transformed to a use of
a component interface playing the role of an object factory. This
interface is defined as provided by the component of class B. It
contains methods that return objects instantiated from classes of
the component of class B. Each method of this interface corresponds
to an existing class constructor. The methods of this interface are
implemented in a factory class which is added to the classes of
the component of the class B.

![Figure 3. Transforming class instantiation based on the factory
pattern.](image)

In Figure 3, we create a provided factory interface whose meth-
ods are implemented in the factory class. It has a method create-
TimeZone() that returns a new ITimeZone() instance. The Clock
class invokes this method instead of creating the instance. It does
not expose the class that implements the interface, but exposes only
the interface. Thereby, client code does not know the internal struc-
ture of Component5. Listing 3 shows how Clock class gets a new
instance of type ITimeZone using the Factory class.

Listing 3. Transforming class instantiation based on the factory
pattern in OSGi code.

```java
public class Clock extends Content{
  public Clock() {
    ITimeZone timeZone = Factory.createTimeZone();
    String time = timeZone.getTime();
  }
}
```

public interface ITimeZone {
  public String setTime();
  public String getTime();
}

4. Inheritance Transformation

Inheritance links between classes belonging to different compo-
nents need to be transformed. Our solution to transform these in-
heritance dependencies is based on the delegation pattern [18]. In
the case of object-oriented code, delegation pattern related to two objects A and B corresponds to an explicit transfer (forward) for all method invocations received by A (called delegator) to B (called delegatee) through methods of B. All internal method invocations in methods of B related to this transfer must be transferred to delegator. This avoids the problem of the lost of the initial receiver [8, 10].

4.1 Replacing Inheritance by Delegation

Our solution to transform the inheritance link consists in implementing the delegation pattern, but at component level (see Figure 4). Thus, inheritance link between two classes A and B (A subclass of B) which belong to two different components is transformed as follows. From the one hand, all methods invoked on the class A are transferred (delegated) to the component of B (considered as the delegatee) through a required interface. The required interface is implemented by the component of A (considered as the delegator) which is connected to a provided interface defined by the delegator component. The provided interface defines all methods of the superclass B. From the other hand, all internal method invocations in the superclass B must be transferred to the delegator component through a required interface. This interface is implemented by the delegator component and connected to a provided interface defined by the delegator component. This interface defines all methods of the subclass A.

![Figure 4. Implementation of the delegation pattern at level of component.](image)

At class level, the transfer of method invocations between delegator and delegatee components and vice versa is realized by creating an instance of superclass B in the subclass A and by invoking the concerned method in this instance. This instance is created each time the class A is instantiated. Attributes of the instance of the class B are initialized using values given in the constructor of class A. The transfer of a method invocation from the delegatee to the delegator is realized in the same way by invoking this method on the instance of A. The reference of the instance of A is communicated to the instance of B as an additional parameter in each method invocation transferred from delegator to delegatee.

![Figure 5. Replacing inheritance by delegation.](image)

Listing 4 describes the result of transforming inheritance to delegation. As we mentioned before, the transformation concludes into three steps: (i) create new interfaces IMessage and IContent; (ii) Message is composed of an instance of type IContent as super interface; (iii) IContent is composed of an object interface of type Message as this interface.

```java
public class Message implements IMessage{
    public void getContent(){...}
    ...
}

class Message implements IMessage{
    private IContent this;
    public Content(IContent initReceiver) {
        _this = initReceiver;
    }
    public void getContent(){...}
    ...
}
```

Our solution transforms inheritance dependency but produces another dependency which is instantiation, where a subclass creates an instance of its superclass. So we apply here the solution proposed in the previous section (cf. Section 4).

4.2 Handling Subtyping

This section proposes a solution for the problem of breaking the supertype chain. In particular, a variable of superclass type can be assigned a reference to an instance of subclass type (polymorphic assignment), but the necessary assignment compatibility (subtyping) is removed by replacing inheritance with delegation. Another case occurs when a casting to superclass or a type test (casting) is removed by replacing inheritance with delegation. Another case occurs when a casting to superclass or a type test (instanceof in Java) exists in the program. For example, a variable (content) in class ContentProvider is typed with Content. It can be assigned an instance of Message or Clock. However, after transformation, this variable can not be assigned Message nor Clock instances.

Our solution suggests to use interface inheritance, which is the most common way to form subtypes between components [16]. We introduce subtyping by adding inheritance between component interfaces providing methods of the subclass and its the component interface providing methods of the superclass. In the example of Figure 5, IMessage interface must inherit IContent interface. In the same way, IObserver interface inherits from IContent interface. Therefore, a type of IContent can be assigned an instance of both types IMessage and IObserver. Moreover, fields defined in IContent are now available in both IMessage and IObserver by setter and getter methods (e.g. setContent(c: String) in class Message).

4.3 Dealing with Abstract Superclasses

As we explained before, a delegator is composed of an instance of a delegatee to delegate method invocations. However, what if the superclass is abstract? An abstract class cannot be instantiated, so no delegatee can be created.
Our solution is based on the proxy pattern. We use a third class as a proxy that breaks the inheritance between the subclass and its superclass when the latter is abstract. Thus the subclass inherits from this proxy, the proxy class inherits the abstract superclass. The proxy class defines the same methods with the same signatures of the abstract superclass. These methods are considered as proxy methods. Each of these methods delegates the received message to the abstract class when this class provides a concrete implementation of this method. In the case of an abstract method on the superclass, the corresponding method on proxy reforwards the message to subclass.

Actually, in our example (see Figure 1) `Content` is an abstract class and has an abstract method `getContent()`. `Factory` interface can not return an instance of this class. So we need to apply proxy pattern before applying delegation pattern. In Figure 6 we create a Proxy class that inherits from `Content` abstract class and implements `IContent` interface. Then `Factory` class provides an object interface of type `IContent` to `Message` which is placed in Component. This enabled us to decouple the inheritance dependency between the abstract superclass `Content` and its subclass `Message` that is placed in a different component.

![Figure 6. Handling abstract superclass based on proxy classes.](image)

Listing 5 shows the result of transforming inheritance that have abstract superclass to proxy pattern. ProxyContent class was created to break the inheritance between Message and Content. The new class implemented all abstract methods inherited from its superclass (Content). The calling of these methods are backward delegated to its caller using our initial receiver variable `this`. The non-abstract methods is called usually under the inheritance relationship between ProxyContent and Content and the composition between Message and ProxyContent. Consequently, the inheritance relationship that has an abstract superclass is transformed by using proxy pattern.

```
Listing 5. Handling abstract superclass based on proxy classes.
public class ProxyContent extends Content implements IContent {
    IContent _this = new Content(this);

    public ProxyContent(IContent initReceiver) {
        _this = initReceiver;
    }

    public void getContent() {
        _super.getContent();
    }
}
```

5. Experimental Evaluation

This section reports on some experiments we conducted to evaluate our approach.

5.1 Experiment Design and Planning

Research Questions

**RQ1:** Does the transformation result avoid component encapsulation violation?

Our approach transforms the OO code to avoid component encapsulation violation by making the dependencies between components explicit. The transformation aims at creating and using component interfaces to achieve component encapsulation. Thus, the aim of this research question is to measure the contribution of our approach to transform OO dependencies to CB ones.

**RQ2:** To which extent does the automatic transformation reduce the developer’s effort?

The aim of this research question is to measure the saved efforts of developers when using our automatic transformation approach instead of using manually one.

Evaluation Methods

To answer RQ1, we need to evaluate how much the OO dependencies are transformed to interface-based ones. This can be measured by the ratio of number of interface-based dependencies to the total number of dependencies between components after transformation. The Abstractness metric proposed by Martin is used for evaluating OO software fulfill this goal. This metric represents the ratio of abstract types (interfaces and abstract classes) in a package to the total number of types in that package. The range for this metric is 0.0 indicating a completely concrete package to 1.0 indicating a completely abstract package. In the context of CB software, this metric has been adapted to measure the quality of a component’s interfaces, where the classes that represent the component’s provided interfaces are grouped in a package to compute Abstractness. Therefore, we used this metric in the same way as to answer RQ1. Based on this metric, a well designed component is supposed to provide only interfaces. Therefore, a component with high Abstractness means a high component encapsulation (i.e., it avoids the component encapsulation violation).

To answer RQ2, we compared the estimated efforts expressed by time spent by developers through manual transformation to the time made by our automatic transformation. We compute the time for each type of transformation, instance handling and both inheritance with and without an abstract superclass transformations.

Data Collection

We have conducted our transformation approach on 9 Java projects in order to validate our approach. The projects have been selected from Qualitas Corpus. In order to guide project selection in such a way that the coverage of a sample is maximized, we have followed the following selection criteria:

i. **project size:** We have selected projects with different sizes.

ii. **Domain:** We have selected projects from different domains to avoid the influence on experimental results of characteristics associated to a specific domain.

iii. **Development team:** We have selected projects that have been developed by different teams to avoid the characteristics related
to programming team habits to influence on experimental results.

Table 1 provides some descriptive measures about these projects. It provides each project name and its version. We can observe the differences of these projects through its sizes and domains. We can infer the differences of development teams by the differences of owned company, where each project developed by different companies.

### Table 1. Data collection.

<table>
<thead>
<tr>
<th>Application</th>
<th>Version</th>
<th>Domain</th>
<th>No of classes</th>
<th>Code Size (KLOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomcat</td>
<td>7.0.71</td>
<td>middleware</td>
<td>1339</td>
<td>196</td>
</tr>
<tr>
<td>Ant</td>
<td>1.9.4</td>
<td>parse/generators/make</td>
<td>1233</td>
<td>135</td>
</tr>
<tr>
<td>Checkstyle</td>
<td>6.5.0</td>
<td>IDE</td>
<td>897</td>
<td>63</td>
</tr>
<tr>
<td>Freecol</td>
<td>0.11.3</td>
<td>games</td>
<td>669</td>
<td>113</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>1.0.19</td>
<td>tool</td>
<td>629</td>
<td>98</td>
</tr>
<tr>
<td>HyperSQL</td>
<td>2.3.2</td>
<td>database</td>
<td>539</td>
<td>168</td>
</tr>
<tr>
<td>Colt</td>
<td>1.2.0</td>
<td>SDK</td>
<td>288</td>
<td>35</td>
</tr>
<tr>
<td>Log4j</td>
<td>1.2.17</td>
<td>testing</td>
<td>220</td>
<td>24</td>
</tr>
<tr>
<td>Galileo</td>
<td>0.0.0-b7</td>
<td>3D/graphics/media</td>
<td>137</td>
<td>26</td>
</tr>
</tbody>
</table>

**Protocol**  For architecture recovery, we used our method called ROMANTIC which enables to identify a component-based architecture from an existing Java application. We applied ROMANTIC on our selected Java projects (Table 1). ROMANTIC clusters each project as a set of disjoint clusters (components).

For code transformation, we developed a tool (an Eclipse plugin) that automatically transforms the result of architecture recovery (clusters of java code) to OSGi components (bundles). Our tool parses the source code using the Abstract Syntax Tree (AST) generated by Eclipse’s JDT. After that, it makes transformations on this AST for the instantiation, method invocation and inheritance dependencies between components.

We conducted two experiments to answer our two research questions respectively. In the first experiment we compare the Abstractness between the recovered components before transformation (i.e., OSGi components with direct OO dependencies) and the same components after transformation (i.e., OSGi components with dependencies though provided and required interfaces). We voluntarily limited the number of types to those which are provided and required by components that depend each from the other. In the second experiment, we compare developers’ efforts (time) between manual transformation with automatic transformation. It is obvious that the automatic transformation provides better results (small values for the transformation time), but what we would like to show here is the estimated average time to perform transformations manually on a whole Java project. The time to do it automatically is measured to estimate the multiplying factor between the two transformation processes.

In this evaluation we firstly computed Abstractness for components (clusters) that resulted from architecture recovery step. To compute Abstractness for a component C, we start by searching for classes of C that are used by classes of other components (provided types). Then we compute the ratio of the number of interfaces and abstract classes that belong to provided types to the total number of provided types (see Equation 1). After that, we used our transformation tool to transform Java clusters into OSGi components (bundles) with provided and required interfaces. Then we recompute Abstractness as described in equation 1 for OSGi components. Finally, we compare the Abstractness values to answer our research question RQ1.

\[
Abstractness(C) = \frac{Na}{Np}
\]

where \( Na \) is the number of interfaces and abstract classes that belong to provided types of component C, and \( Np \) is the number of provided types of component C.

In the second experiment, we performed the transformation manually. To this end, we selected from our data collection three projects that have different sizes. We chose Log4j as a small project, JFreeChart as a medium project and Tomcat as a large project. We selected just three representative projects from the nine composing our data collection (cf. Table 2). We do this selection to adapt the manual experimentation to the available resources (persons and time). We invited 15 developers to transform Java source code. To make sure that we obtain a relatively fair valuation, we split this group of persons into three groups, five persons for each. Table 2 provides descriptive information about these persons. Before starting the experimentation, we checked that these persons have well understood the steps presented in our approach to applied for transforming OO to CB code. In each group, we provided each person the source code. In addition, we gave them the information about three components with different sizes (small, medium and large) in each project (9 components in total). Then we asked them to randomly select three classes from each project and from different components. The selected classes must be transformed by satisfying our condition: selected instantiation and/or inheritance dependencies that must be transformed must be related to classes belonging to other component(s). We measured the time for three types of transformation: instantiation, inheritance and inheritance with an abstract superclass.

### Table 2. Information about persons involved in the experiment.

<table>
<thead>
<tr>
<th>Persons</th>
<th># persons</th>
<th>Group</th>
<th>Experience in Java</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph.D Students</td>
<td>5</td>
<td>1</td>
<td>3-6 years</td>
</tr>
<tr>
<td>Developers</td>
<td>5</td>
<td>2</td>
<td>4-6 years</td>
</tr>
<tr>
<td>M.S. Students</td>
<td>5</td>
<td>3</td>
<td>2-4 years</td>
</tr>
</tbody>
</table>

#### 5.2 Results

##### 5.2.1 Architecture Recovery Results

Table 3 provides some descriptive statistics about architecture recovery results (on the whole data collection, and not on the three projects selected for manual transformation). It displays the number of components recovered from each project (16-129). Moreover, it shows the nature of the components: average number of classes per component (8.5-20.7) and how strongly components are related to each other using Afferent Couplings (10.33-24.85). Afferent Couplings (also known as Outgoing Dependencies) is a metric that measures the number of types outside a component that depend on types inside the component. According to the obtained results, we observed that the number of components is almost directly proportional to the project size except in case of Tomcat and Freecol projects.

##### 5.2.2 Code Transformation Results

Table 4 provides descriptive statistics about transformation types for our data collection. It describes the number of transformations that must be performed according to our approach for each
The results show that instantiation is the most transformation type with an average of 69.9% from all transformation types in all projects. Then transforming inheritance that have abstract superclass with an average of 16.3% (except for HyperSQL, Colt and Galleon, where transforming inheritance is slightly bigger than transforming abstract superclass). Finally, transforming inheritance with an average of 13.8%.

**Table 3.** Architecture recovery results.

<table>
<thead>
<tr>
<th>Application</th>
<th># components</th>
<th>AVG. number of classes per component</th>
<th>AVG. Efferent coupling per component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomcat</td>
<td>125</td>
<td>10.8</td>
<td>13.87</td>
</tr>
<tr>
<td>Ant</td>
<td>129</td>
<td>9.5</td>
<td>10.33</td>
</tr>
<tr>
<td>Checkstyle</td>
<td>63</td>
<td>14.5</td>
<td>13.98</td>
</tr>
<tr>
<td>Freecol</td>
<td>36</td>
<td>18.5</td>
<td>22.47</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>40</td>
<td>15.7</td>
<td>15.63</td>
</tr>
<tr>
<td>HyperSQL</td>
<td>26</td>
<td>20.7</td>
<td>24.85</td>
</tr>
<tr>
<td>Colt</td>
<td>23</td>
<td>12.5</td>
<td>10.70</td>
</tr>
<tr>
<td>Log4j</td>
<td>23</td>
<td>9.5</td>
<td>10.74</td>
</tr>
<tr>
<td>Galleon</td>
<td>16</td>
<td>8.5</td>
<td>15.56</td>
</tr>
</tbody>
</table>

**Table 4.** Statistics of transformation types.

<table>
<thead>
<tr>
<th>Application</th>
<th># instantiation transformations</th>
<th># inheritance transformations</th>
<th># inheritance with abstract class transformations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomcat</td>
<td>350</td>
<td>49</td>
<td>79</td>
</tr>
<tr>
<td>Ant</td>
<td>364</td>
<td>50</td>
<td>54</td>
</tr>
<tr>
<td>Checkstyle</td>
<td>249</td>
<td>37</td>
<td>41</td>
</tr>
<tr>
<td>Freecol</td>
<td>164</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>116</td>
<td>22</td>
<td>38</td>
</tr>
<tr>
<td>HyperSQL</td>
<td>99</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Colt</td>
<td>70</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Log4j</td>
<td>62</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>Galleon</td>
<td>56</td>
<td>18</td>
<td>14</td>
</tr>
</tbody>
</table>

According to the obtained results in Table 3 we observed that the number of transformations is (in most cases) directly proportional to the number of components. As can be seen in Figure 7 the relationships between the transformation types and the number of components for our data collection. However, a small exception of that relationship occurred in case of Tomcat and Freecol projects.

**Figure 7.** Relation between number of transformations with number of components.

**Abstractness Results** Table 5 shows the difference of Abstractness values between the components before and after transformation. Moreover, it gives the multiplying factor between the two Abstractness measures. The improvement factor ranges from 2.93 for Tomcat, which basically has a good design from the abstractness point of view, to 7.33 for HyperSQL. The improvement of the level of abstractness depends thus on the analysed software system. On average in the considered data collection, our approach improved Abstractness by 4.33 times (answer to RQ1).

**Table 5.** Improvement of abstractness after transformation.

<table>
<thead>
<tr>
<th>Application</th>
<th>Abstractness before transformation</th>
<th>Abstractness after transformation</th>
<th>Improvement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomcat</td>
<td>0.28</td>
<td>0.82</td>
<td>2.93</td>
</tr>
<tr>
<td>Ant</td>
<td>0.18</td>
<td>0.83</td>
<td>4.61</td>
</tr>
<tr>
<td>Checkstyle</td>
<td>0.12</td>
<td>0.84</td>
<td>7.00</td>
</tr>
<tr>
<td>Freecol</td>
<td>0.17</td>
<td>0.81</td>
<td>4.76</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>0.22</td>
<td>0.81</td>
<td>3.68</td>
</tr>
<tr>
<td>HyperSQL</td>
<td>0.12</td>
<td>0.88</td>
<td>7.33</td>
</tr>
<tr>
<td>Colt</td>
<td>0.26</td>
<td>0.83</td>
<td>3.19</td>
</tr>
<tr>
<td>Log4j</td>
<td>0.19</td>
<td>0.87</td>
<td>4.58</td>
</tr>
<tr>
<td>Galleon</td>
<td>0.21</td>
<td>0.88</td>
<td>4.19</td>
</tr>
<tr>
<td>AVG.</td>
<td>0.194</td>
<td>0.841</td>
<td>4.33</td>
</tr>
</tbody>
</table>

We can observe that the Abstractness for all applications is significantly improved. This improvement lies behind our transformation approach, where we transform OO direct dependencies into component interface dependencies. Another observation is that the values of Abstractness does not reach the optimal value (1.0). That because we have not yet transformed all OO direct dependencies between components to interface-based ones (e.g. exception and event handling, etc.). For example, we improve the Abstractness of Tomcat at 82%. The remaining unimproved value, which is 18%, is caused by the others dependencies that must be transformed but were not presented in this paper.

**Manual vs. Automatic Transformation Results** The results of the second experiment are presented in Table 6. It shows the results of manual transformation for the three selected projects. The first two columns present the selected projects (Tomcat, JFreeChart and Log4j) and the transformation types. The number of needed transformations that must be achieved according our approach are presented in the third column. Then the fourth and the fifth columns show the number of the transformations that were performed manually. The values of the fourth column shows all these transformation while the values of the fifth column present only the number of unique transformations (i.e. transformations on dependencies done only buy one developer). For instance, the number of manually transformed instantiation in Tomcat is 35. But the number of different manual transformation is 20. That mean 15 classes from 35 were repeatedly transformed by different persons. For example, class Walldlader that belong to Tomcat was transformed three times. We note that the ratio of the number of realized manual different transformations to the number of all transformations automatically achieved is about 22%. This ratio constitutes a good base to compare results of manual and automatic transformations.

The sixth column shows the number of wrong manual transformations. A wrong transformation corresponds to a case where this transformation is not properly done. For example, it is the case when a person transformed OO inheritance between two classes which belong to the same component. As we have noted before, the persons manually transformed source code have highly understood our approach before we did the experiments. Therefore, the wrong transformations are not the result of misunderstanding of our approach. The ratio of the number of wrong transformations to the number of total number manual transformations is about 18%. This means that approximatively one fifth manual transformations was wrong.

The transformation time is presented in the rest of the table (last four columns). The first three ones represent statistics about the manual transformation time in seconds for each selected project presented following the type of transformation. We can observe
that the mean time for each type of transformation realized in different selected projects (AVG. time column) is approximately the same. For example, the mean time taken to transform inheritance is ranged from 1053 to 1106, where the difference is just 53 seconds which is a small value compared with the transformation time (i.e. 1053 or 1106). The Min/Max time shows the minimum and the maximum time for the corresponding types of manual transformations which indicates to the variation of the transformations time. Moreover, a standard deviation is provided in the column STD time to better illustrate the amount of variation or dispersion of the manual transformation time. The little standard deviation values compared to the mean reflect a small amount of variation of the transformations time values.

The mean of the estimated time in hours to manually realize a type of transformation for each selected project is presented in the last column (AVG. estimated time). We compute these values by multiplying the number of the needed transformations for each project by the mean values of manually transformation time. The conclusion related to this column is that the manual transformation is not an easy task. For example, to completely transform Tomcat, JFreeChart and Log4j manually, we need 79.48, 31.82 and 18.86 hours respectively. For example, in the case of Tomcat, this corresponds to more than two weeks of work compared to French work laws. In addition, we did not compute the cost caused by wrong transformations that have an error percentage about 18%.

On the contrary, our tool transforms Tomcat for example in a few minutes (about 6 minutes) without any wrong transformation. The ratio between the manually and the automatically transformation times for Tomcat is 795. Thus, we can answer RQ2 that our automatic approach effectively reduces the developer’s efforts especially on large projects.

5.2.3 Threat to Validity

**Internal threats:** one internal threat needs to be considered when interpreting our experimentation results. This is related to the used architecture recovery approach in our experiment. For example, we observed that the number of the needed transformation depends on the number of the recovered components. The number of components depends on the used architecture recovery approach. Consequently, the improvement ratio of Abstractness and the saved transformation efforts obtained by our approach can be affected following the architecture recovery approach that are used (ROMANTIC approach [2]). For example, Tomcat have 350 instantiation dependencies that must be transformed (see Table 6). As the architecture recovery approach is responsible for identifying components (i.e., find clusters of classes), the number of dependencies between these components differs depending on the used recovery approach. Thus, the 350 instantiation dependencies that must be transformed in Tomcat may be less or more depending on this architecture recovery used approach.

**External threats:** External validity refers to generalizability of the results. In this study, we have two threats to external validity to generalize our results. The first one is related to our data collection and the second one is related to the types of persons whom applied our approach manually.

### Data Collection

We performed our experiments on nine different-sizes, several-domains, well-known and open-source Java projects. Moreover, the projects are selected from different development teams. Because the variety of our data collection, we can say that our results can be generalized to involve most Java projects.

### Types of Persons

We experimented our approach manually on three groups, five person in each group. The groups are PhD students, Java developers and master students (MS). By reference to Table 2, all these groups have an experience in Java development ranging from 2 to 6 years. Additionally, the experiments were applied on the three groups under the same conditions. In this threat we need to validate that the time consumed by manually transformation does not affected by the persons types if they know Java development. In addition, we need to validate that the errors caused by manually transformation does not affected by the persons types also. The time consumed by each group for each transformation type. We can see that the transformation times are closed to each other for the three groups. For transforming instantiation, the manual transformation time ranged between 315 to 397 seconds. For transforming inheritance, the manual transformation time ranged between 1073 to 1106. For transforming inheritance that has abstract superclass, the manual transformation time ranged between 1231 to 1258. Consequently, the differences of time consumed by the three groups is negligible. Thus we can emphasize that the time consumed to manual transformation is independent from person type.

Table 6 shows the error percentage caused by manual transformation for each group. We can observe that the results is almost the same. The percentages of error transformation were 15%, 16% and 17% for PhD students, developers and MS respectively. Thus, we can emphasize that the error caused by manual transformation is independent from person type.

### Related Work

Migrating OO applications to CB ones has two types of related works. The first relates to CB architecture recovery, and the second relates to code transformation. Many works have been proposed for recovering CB architectures from OO legacy code. A survey on these works is presented in [7] and [3]. However, only few works have proposed a transformation from OO code to CB one.

The approach proposed by [1] applies in transforming Java applications to OSGi. The approach uses OO concepts to implement

<table>
<thead>
<tr>
<th>Application</th>
<th>Transformation type</th>
<th># needed transformation</th>
<th># manual transformation</th>
<th># different manual transformation</th>
<th># wrong transformation</th>
<th>AVG. estimated time (s)</th>
<th>Min/Max time (s)</th>
<th>STD time (s)</th>
<th>AVG. estimated time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomcat</td>
<td>Instansation</td>
<td>350</td>
<td>35</td>
<td>20</td>
<td>2</td>
<td>367</td>
<td>230/1008</td>
<td>126</td>
<td>35.68</td>
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<td>Inheritance</td>
<td>49</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>1106</td>
<td>928/1380</td>
<td>241</td>
<td>15.05</td>
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<td>Abstract superclass</td>
<td>79</td>
<td>16</td>
<td>9</td>
<td>2</td>
<td>1310</td>
<td>1019/1803</td>
<td>195</td>
<td>28.75</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>Instansation</td>
<td>116</td>
<td>37</td>
<td>16</td>
<td>0</td>
<td>395</td>
<td>192/901</td>
<td>169</td>
<td>12.73</td>
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<td></td>
<td>Inheritance</td>
<td>22</td>
<td>16</td>
<td>15</td>
<td>2</td>
<td>1053</td>
<td>862/1301</td>
<td>148</td>
<td>6.44</td>
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<tr>
<td></td>
<td>Abstract superclass</td>
<td>38</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>1198</td>
<td>1012/1405</td>
<td>135</td>
<td>12.65</td>
</tr>
<tr>
<td>Log4j</td>
<td>Instansation</td>
<td>62</td>
<td>34</td>
<td>17</td>
<td>0</td>
<td>377</td>
<td>248/869</td>
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<tr>
<td></td>
<td>Inheritance</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td>11</td>
<td>1054</td>
<td>892/1401</td>
<td>188</td>
<td>4.68</td>
</tr>
<tr>
<td></td>
<td>Abstract superclass</td>
<td>28</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>989</td>
<td>982/1106</td>
<td>64</td>
<td>7.69</td>
</tr>
</tbody>
</table>
components. They use the Facade design pattern to implement component required interfaces and the Adapter design pattern to implement component provided interfaces. But in contrast to this work, in our approach we deal with inheritance. In addition, in the transformation of instantiations, we take into consideration argument passing (by creating customized Factory methods), while in their work they do not deal with this aspect. Besides, in their approach, for a single connector between components, they create an adapter class, a facade class and a provided interface, with many duplicated code. In our approach, only a factory class and its provided interface are created.

Another method for transforming Java applications into the J-Beans framework is proposed in [19]. They developed an automatic refactoring method that can identify components from OO programs using a graph which models class relations. After that, their method modifies the surrounding parts of the extracted components in the original programs. The modification solves the dependencies appeared into class relation graphs, using the Facade interface and other code refactoring. This approach did not treat all dependencies in an OO application. They solve a subset of these dependencies (e.g. instantiation and method invocation), while in our work we deal, in addition, with other dependencies that exist in OO applications, such as inheritance.

In the context of distributed computing, Eli et al. [27] proposed a distributed one. J-Orchestra is a semiautomatic transformation process that composed two steps. In the first step, a partitioning tool takes as input a centralized Java program and location information supplied by a user for the program. The tool divides the program code into parts that can run in the desired location (supplied by the user). In the second step, J-Orchestra transforms any communication between parts (resulted from the first step) at different locations into remote one by using Java RMI. It transforms constructor calls, method calls, direct references and inheritance. Constructor calls replaced with call to factory methods. Booth method calls and direct references replaced by proxy pattern and proxy references respectively. Finally, transforms inheritance hierarchy between classes into the same inheritance hierarchy but between proxy classes. The transforming of constructor calls, method calls and direct references fit with target transformation (distributed computing). But in contrast, this work transforms inheritance but by inventing new one (inheritance between proxy classes). Thus, the inheritance between parts still used. Moreover, it did not propose a solution for abstract superclass.

In the context of OO software engineering, many works have been proposed for refactoring instantiation and inheritance. For refactoring instantiation, Friedrich et al. [20] developed a new refactoring approach for the extraction of interfaces in order to decouple classes. The extracted interface infers from the type of variable declarations (interface-as-type) and automatically inserts it into the code. The refactoring approach is applied on Java that is available as an Eclipse plugin. Tip et al. [21] proposed an approach that extracts interfaces for replacing the access to a class via a newly created interface. The approach uses type constraints to verify the preconditions as well as to determine the allowable modifications on source code. The approach is implemented in the standard distribution of Eclipse. These two approaches aim to decouple classes by using interface-as-type instead of class-as-type. However, they did not have preconditions or scenarios (on our approach is the direct dependencies between components) to apply the refactoring on all project automatically. The developer decides which types of variable declarations should be refactored.

For refactoring inheritance, Hauck [22] proposed an approach to replace inheritance by a special kind of aggregation. The approach introduces two kinds of fields, super and self fields. The super field is placed in the subclass and points to an instance of the superclass. The self field is placed in the superclass and points to the instance of the subclass. Inherited methods are called via delegation and reverse delegation using super and self fields, respectively. However, the approach did not analyses all inheritance cases. For example it did not provide a solution for abstract super class. Genssler et al. [23] presented a refactoring approach that transforms inheritance to delegation (or, as they call it, composition). The approach introduces certain design patterns (namely Bridge, Strategy, and State) to replace inheritance with composition. INTELLIJ IDEA [24] introduces a refactoring tool that replaces inheritance with delegation for Java. The tool performs a program analysis and refactors inheritance to delegation using inner classes. However, the refactoring introduces delegation by adding an inner class into a subclass. The inner class delegates inherited methods to delegatee. It does not introduce reverse delegation therefore it prevents overridden methods in a subclass from being called.

7. Conclusion

In this paper, we proposed an approach to automatically transform object-oriented applications to component-based ones. We targeted the transformation of applications which are built using object-oriented languages into applications built with an object-based component model. We focus on the transformation of source code in order to produce decoupled components that are compliant
with the architecture recovered in a previous step. We proposed a solution for dealing with instantiation, method invocation and inheritance dependencies.

The experimentation results shows that our approach improves Abstractness and as consequence reduce the violation of component encapsulation. Moreover, it effectively reduces the developer’s transformation efforts especially on large projects.

As a future work, we plan to deal with others object-oriented mechanism’s transformations, like exception and event handling transformation. The ultimate goal is to produce a code which will be completely based on connections of component interfaces.

References


