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# Refactoring Object-Oriented Applications for a Deployment in the Cloud:

## *Workflow Generation Based on Static Analysis of Source Code*

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Abstract: Cloud Computing delivers to customers computing/storage resources as services via the internet. It is characterized by its elastic nature and its payment model (pay-as-you-go). To optimize the use of these resources, one of the requirements related to this type of environment is to dynamically configure the applications to reduce the costs of their deployment. The dynamic configuration requires the ability to determine which resources are used, as well as when and where they are utilized. This can be done using workflows. In fact, several works rely on workflows to reduce execution costs in the cloud. Unlike workflows, OO applications have an architecture which exposes little or no behavioral (temporal) aspect. Hence, to execute an OO application in the cloud, the entire application needs to be deployed and all its used resources need to be allocated during its entire execution time. To reduce execution costs, we propose a re-engineering process aiming to restructure these applications from OO architectural style to workflow style. In this paper, we focus on the first step of the process which has as a goal generating a workflow from OO source code.

## 1 INTRODUCTION

Cloud computing is a technology that uses the internet and central remote servers to provide services for its customers on demand (Kaur et al., 2011; Mell et al., 2011). Google App Engine, Amazon EC2, Aneka and Microsoft Azure are some of the prominent cloud computing platforms (Masdari et al., 2016).

Generally, the services provided by the cloud can be classified as SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service) (Wu et al., 2013). SaaS is a software delivery paradigm, where the software is developed by service providers and delivered via internet (Espadas et al., 2013). PaaS provides platforms to develop and deploy applications in cloud infrastructure using programming languages, libraries and so on (Fakhfakh et al., 2014). IaaS providers deliver processing, storage, network and other fundamental computing resources to deploy and run customers' software (Dillon et al., 2010; Mell et al., 2011). In fact, customers can provision resources (e.g. processors, storage space, network, etc.) whenever they want and release them when they are no longer needed (Dillon et al., 2010).

However, based on the "pay-as-you-go" model, customers are usually charged following the resource usage. Consequently, it is important to have the ability to adjust this usage, i.e., allocate resources only when needed and release them when they are no longer used, in order to reduce costs. This can be done by dynamically allocating and releasing resources based on their usage (Fakhfakh et al., 2014; Xu et al., 2009). Nevertheless, the dynamic allocation and release requires determining, for each application, which resources are used, as well as when and where they are utilized.

Object-Oriented (OO) style is one of the most used architectural styles to develop software applications (Taylor et al., 2009; Garlan and Shaw, 1993). However, without any prior restructuring, to execute an OO application in the cloud, the entire application needs to be deployed and all its used resources need to be allocated during its entire execution time. Consequently, a customer will be billed based on the used resources even if some of them were unnecessarily occupied for certain periods (Fakhfakh et al., 2014).

For the data used by certain types of applications such as scientific ones, it is possible to determine the required resources to execute them: storage space,

network, processor, etc. These resources are necessary for the storage, acquisition/transmission and processing of data.

The data flow architectural style is adapted to deploy this kind of applications in the cloud. In fact, this style focuses on how data moves between processing elements of an application (Taylor et al., 2009; Bass, 2007). Hence, these elements and their consumed/produced data are explicitly identified allowing to determine resources needed by each one of them. In addition, it allows to determine when each element can be executed, and therefore when its needed resources are used. Note that, by extending the data flow style with a richer control flow, i.e. a control flow that expresses sequences, conditional branches and loops, an architectural style that represents a workflow (Hollingsworth, 1995), in which each architectural component is a task, can be obtained. Several works rely on the data flow style in order to perform dynamic configuration to optimize resources usage in the cloud, and thus to reduce execution costs (Zhu et al., 2016; Masdari et al., 2016; Fakhfakh et al., 2014; Xu et al., 2009; Lin and Lu, 2011).

In order to deploy OO applications in the cloud while reducing costs, we propose a re-engineering process aiming to restructure these application from OO architectural style to data flow style. In this paper, we focus on the first step of the process which has as a goal generating a workflow description from existing OO application. This generation requires the ability to map OO concepts into the workflow ones. For example, we need to determine what is the mapping of the concept task compared to the OO concepts. Once such a mapping is defined, the refactoring consists, in recovering the constituents of a workflow from a source code, i.e. a set of tasks, a control flow and a data flow.

The originality of our approach can be viewed from two aspects. On the one hand, we use source code refactoring in order to adopt OO application to a deployment in the cloud instead of either executing them with high costs or redeveloping them from scratch. On the other hand, techniques used in our approach allow us to recover the entire workflow while a majority of the existing works (e.g. (Kosower and Lopez-Villarejo, 2015), (Korshunova et al., 2006), (Zou et al., 2004) ) propose to extract only a part of a workflow (i.e. either control flow or data flow). Moreover, although some approaches propose to extract a description of the workflow by analyzing source code, they do not propose to generate the code of this workflow (see section 7).

The remainder of this paper is organized as fol-

lows. Section 2 presents a possible mapping from OO concepts to workflow ones and announces addressed refactoring issues. Section 3 presents a solution for task identification, while section 4 presents control and data flow recovery solutions. Section 5 discusses a workflow implementation. Section 6 evaluates our proposal. Section 7 outlines related works. Finally, section 8 concludes the paper.

## 2 OBJECT-ORIENTED VERSUS WORKFLOW-BASED ARCHITECTURAL STYLES

### 2.1 Background : Workflow-Based Style

The term workflow has been initially defined by the WorkFlow Management Coalition (WFMC) in 1995 (Hollingsworth, 1995) as:

”The computerized facilitation or automation of a business process, in whole or part.”

This standard definition proposes a reference model for the creation, deployment and control of workflow applications. It refers to a workflow as a solution for business processes automation. A process is defined as a coordinated sequence of a set of tasks leading to a determined result. Coordination specifies the sequencing mode of tasks, as well as the data exchanged between them. In other words, a workflow can be seen as an application constructed by a set of tasks, with possibly dependencies specified by following two classical formalisms: data flows and control flows. In this paper, these concepts are defined as follows:

- **Task:** a task is the basic unit of composition of a workflow. It is the smallest execution unit, representing an execution stage in a whole application. Its implementation is independent of other tasks and can be reused in different contexts. A task can define input and output data, where input data represent data required for executing the task and output data, the produced ones. A task can be either primitive or composite. A composite one can be viewed as a sub-workflow enclosing primitive or composite tasks.
- **Control flow:** a control flow describes the execution order of tasks through different constructs such as sequences, conditional branches (if and switch) and loops (for and while).
- **Data flow:** a data flow specifies data dependencies between tasks. If the outputs of a task  $T_i$  are

inputs of a task  $T_j$ , then the execution of  $T_j$  depends on that of  $T_i$ .

Figure 1 shows an example of a workflow consisting of three tasks. On the one hand, the control flow specifies that *Task A* and *Task B* are executed sequentially, whereas *Task C* can be executed only if the condition " $data A > data B$ " is true. On the other hand, the data flow indicates that *Task A* produces three output data *data A*, *data C* and *data D*, while *Task B* produces an output data *data B*. *data D* and *data C* are respectively used by *Task B* and *Task C*, whereas *data A* and *data B* are utilized to evaluate the condition " $data A > data B$ ".

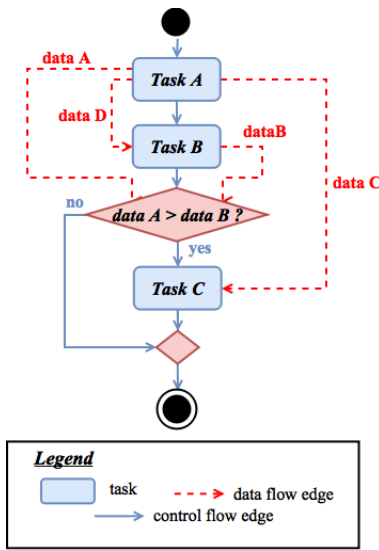


Figure 1: Example of a workflow.

## 2.2 A Mapping from Object-Oriented Code to Workflow

A task is the basic unit of composition of a workflow. It is the smallest execution unit, representing an execution stage in a whole application. Based on this definition, we consider that a method can be mapped to a task in a workflow (see Figure 2). In particular, we assume that a method that contains only assignment statements or invokes only methods provided by a standard library is mapped to a primitive task, a method that includes a sequence of methods invocations and control statements is mapped to a composite task. For methods including both methods invocations, control statements and other statements, the source code has to be refactored to wrap these later in a method. In fact, a workflow, as seen in Figure 2, does not include assignment statements as a unit of composition.

A task can define input and output data, where input data represent data required for executing the task and output data, the produced ones. Due to the fact that a task corresponds to an OO method, task inputs represents data needed to execute the corresponding method, while task outputs is the data produced from this execution. In order to be executed, a method requires a receiving object and its input parameters. Once executed, the method's produced data is its modified inputs (i.e. receiving object and/or input parameters), and/or its output parameter (i.e. returned value). Hence, each method's produced data that represents a modified input corresponds to two data in a workflow, an input and an output data (see Figure 2).

In a workflow, the execution order of tasks is expressed using different control constructs such as sequence, conditional branches and loops. In OO style, the execution order of methods invocations, which corresponds to the execution of tasks, depends on control statements (e.g. if statement, while statement, etc.). Hence, we chose to consider that a control statement can be mapped to a control construct. Thus, the input data of a control construct corresponds to data manipulated in the corresponding control statement, i.e. in the condition and the body of the control statement, while control construct outputs are the data defined in the control statement and used in the following statements.

The explained mapping between OO concepts and workflow ones is illustrated in Figure 2.

## 2.3 Refactoring Process and Issues

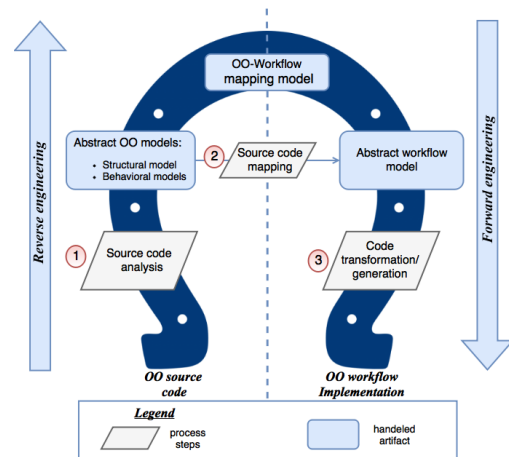


Figure 3: OO versus workflow: the re-engineering process

Our goal is to generate a workflow based on static analysis of OO source code. In order to achieve this

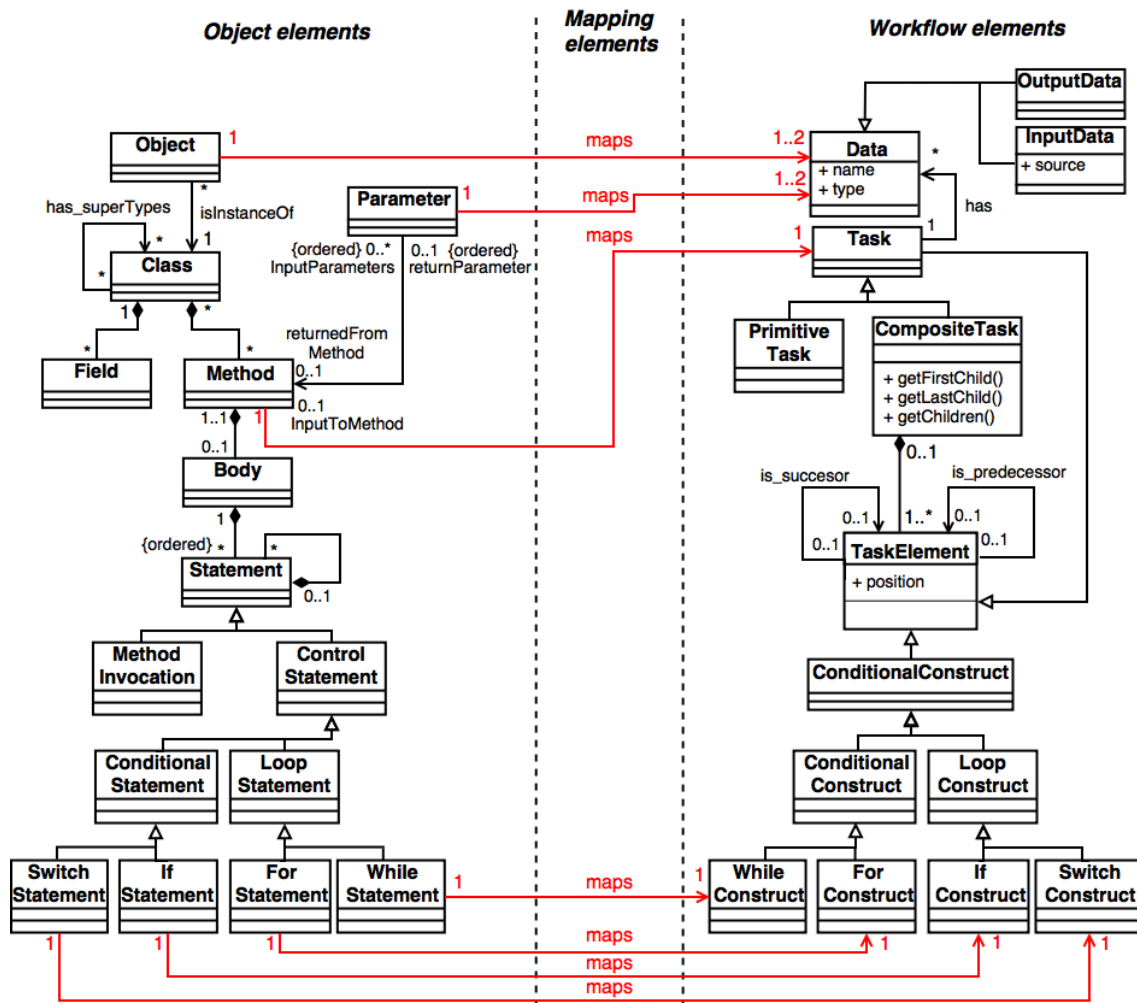


Figure 2: From OO elements to workflow ones: the mapping model.

goal, a refactoring process, that can be seen as a re-engineering horseshoe model (see Figure 3), was proposed. The existing OO system is represented on the left side of the figure and the target system on the right side.

The refactoring process consists of three steps. These steps are represented in Figure 3. In the first step, existing source code is analyzed to identify the application structural elements (classes, methods, etc.) and their links (method calls, class inheritances, etc.). The aim of the second step is to map OO concepts to workflow ones. Starting by, identifying primitive and composite tasks (see section 3), as well as their respective input and output data, and then recovering the control flow and the data flow (see section 4) associated to these tasks to preserve the same behavior then the OO application. The last step of our process consists of transforming the OO source code

to conform to this workflow (see section 5).

For this refactoring process, we chose to preserve the object entities of the original source code to generate the new structure of the application. This means that object instances will not be transformed into primitive elements (i.e. the values of their attributes). Thus, the result of the refactoring is an implementation based on "task" entities connected by input and output data and whose control flow is explicitly represented at the architectural level. In other words, the target source code is composed of task entities, implemented based on the object entities of the original source code.

The realization of this process requires answering the following questions:

- **Q1:** what are the tasks that reflect the workflow corresponding to the analyzed OO application? The answer to this question requires identifying

a matching at the instance level between task entities and OO methods invoked on object instances.

- **Q2:** what is the control flow to be defined between the identified tasks with preservation of the same behavior as the analyzed OO application? The answer to this question requires, among others, to make explicit the implicit control flow due to OO features, for example, polymorphism and dynamic binding.
- **Q3:** what is the data flow to be associated with the identified tasks and control flow? The goal is to define for each task its input and output data in such a way that the application architected as tasks gives the same results as the application architected as objects, i.e. given the same inputs, the two variants of the application produces the same outputs. This is mainly to identify the flow of objects attached to tasks already identified.
- **Q4:** what model of implementation to structure the target application into new object entities that reflect the identified tasks, control flow and data flow while preserving the object entities of the originally crafted application?

whether the statements belong to the same bloc or not. Each fragment is extracted as a new method (method *m1* and method *m2*).

Once statements to be extracted are identified, the extraction begins. Variables acceded (defined or used) but not declared by these statements (i.e. the variables declaration statements do not belong to these statements) should be passed in as input parameters of the new method. Whereas, variables defined by these statements and acceded by following fragments should be passed out as its output parameters. Note that, a variable is considered as defined if its value is modified (i.e. writing access) and it is considered as used if its value is read (i.e. reading access).

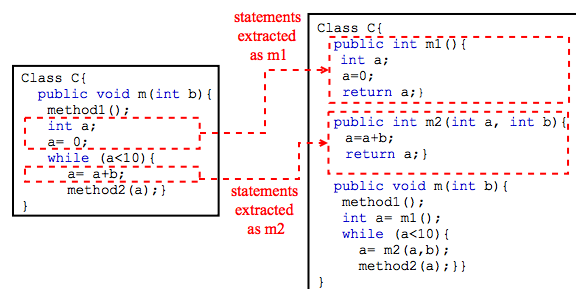


Figure 4: Example of extract method refactoring.

### 3 TASK IDENTIFICATION

Our OO-to-Workflow mapping model establishes a unique mapping for a workflow tasks, a task corresponds to a method in the OO source code (see Figure 2). Thus, we transform all statements that do not represent method invocations in the OO code into method invocations based on code refactoring. Once this refactoring is done, we determine among all the code methods those to transform into primitive tasks from those to transform into composite ones. Finally, we determine the input and output data for each task.

#### 3.1 Extract Method Refactoring

The refactoring of OO source code consists to extract each sequence of statements delimited by user method invocations as a new method and replace the sequence by an invocation of this method. Note that, only statements that belong to the same block can be extracted to ensure that the new method is syntactically correct.

Figure 4 shows an example of extract method refactoring. In this example, the statements delimited by method invocations *method1()* and *method2(a)* do not belong to the same block and thus it is not possible to extract them as a new method. Nevertheless, this sequence can be divided into two fragments based on

Some OO languages, such as Java, imposes that a method can not have more than one output parameter (i.e. returned value). Thus, if a sequence of statements has multiple output values, this sequence will be divided into several fragments. Each one of them is extracted as a new method and return at most one output parameter. This code fragmentation and method extraction do not re-order code statements, which eliminates the possibility of breaking down program semantics.

#### 3.2 Task Identification Based on Analysis of the OO Application Call Graph

A workflow consists of two types of tasks: primitive and composite ones. As a task is mapped to an OO method, then a method that does not include calls to other ones is considered as a primitive task, otherwise, it is a composite one. The identification of primitive and composite tasks is based on the analysis of the OO application's call graph.

Listing 1: Classes *Foo*, *Bar* and *Main*

```

1 class Foo {
2   int x;
3   void setX(int y, boolean isDifferent ){
4     if (isDifferent)
5       initializeX(y); initialize
6     else
7       incX(2*y);}
8   int incX(int y){
9     if (x!=y)
10      setX( y, true);
11    else
12      setX( y, false);
13    return x;}
14   int getX(){
15     return x;}
16   void initializeX(int y) {
17     x=y;}}
18 class Bar{
19   Foo foo= new Foo();
20   void m(){
21     foo.initializeX(1);
22     int x= foo.getX();
23     while (x<20){
24       x=foo.incX(x);}}}
25 class Main {
26   static Bar bar= new Bar();
27   public static void main(String[] args){
28     bar.m();}}

```

In order to build a call graph, the source code is analyzed to determine for each caller method its callees. Call graph leaves are mapped to primitive tasks, whereas the rest of nodes are mapped to composite ones.

A particular case related to the analysis of the call graph concerns direct or indirect recursive calls. Since recursive transitions between tasks (i.e. the ability of a task to invoke itself directly or indirectly during its execution) are not always supported by workflows (Russell et al., 2006), recursive calls between methods are transformed as follows: a method  $M$  in a directed cycle is mapped to a primitive task if all the methods invoked by  $M$  belong to this cycle (see method *Foo.incX* in Listing 1). Otherwise, this method is mapped to a composite task (see method *Foo.setX* in Listing 1).

Figure 5 represents the call graph built from the source code shown in Listing 1. The methods *Main.main*, *Bar.m* and *Foo.setX* map composite tasks, while the methods *Foo.initializeX*, *Foo.getX* and *Foo.incX* correspond to primitive tasks.

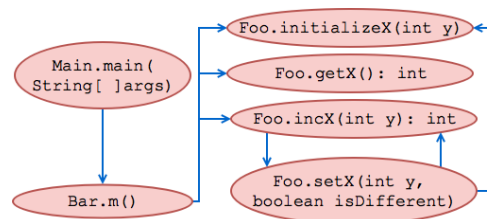


Figure 5: Call graph built from the source code shown in Listing 1.

### 3.3 Identifying Tasks Inputs and Outputs

Each of the identified tasks, primitive or composite, have input and output data. As explained in section 2.2, the inputs correspond to the parameters and the receiving object of the corresponding method, whereas the outputs are the inputs that have been modified and the returned value by the corresponding method. Note that the modified inputs of a task are considered as its outputs because their new values are produced by this task.

To identify which inputs can be modified by a method, we compute for each method  $M$  both its *DEF* and *USE* sets. The *DEF* (resp., *USE*) set contains parameters and attributes defined (resp., used) by  $M$ , i.e. parameters and attributes that their values are modified (resp., read) by  $M$ . An input *INDATA* of a task is considered as modified if either 1) *INDATA* is the receiving object of  $M$  and at least one of its attributes  $\in DEF(M)$  or 2) *INDATA*  $\in DEF(M)$ .

For instance, the inputs of the corresponding task to the method *initializeX* of the class *Foo*, shown in Listing 1, are the receiving object and the parameter  $y$ , whereas the output of this task is the receiving object because its attribute  $x$  is defined in the method *initializeX* (in Line 17).

#### 3.3.1 Computing DEF and USE sets

We consider that assignment on a variable of a primitive type (type which is not a class) is a *DEF* operation. All others operations on primitive variables are considered as *USE* ones (Martena et al., 2002). However, we consider that operations on an object are *DEF* ones in the following cases: 1) this operation defines some of the attributes of the object 2) it is a constructor invocation 3) it is a call of a method that modifies this object (Chen and Kao, 1999). Otherwise, these operations are of *USE* category.

Determining whether an input *INDATA* of a method  $M$  (i.e. a parameter or the receiving object) belongs to *DEF* or to *USE* sets depends on the *DEF*

and *USE* sets of the methods called by *M*. An input *INDATA* of *M* is considered as defined (resp., used) if it is defined (resp., used) by either 1) a statement of *M* which is not a method invocation (e.g. assignment, etc) or 2) at least one of the methods invoked by *M*. More precisely, an input *INDATA* is considered as defined (resp., used) in a called method *CalledM* by *M* in two cases:

- *Case 1:* *INDATA* is the receiving object of the invocation of *CalledM* and the *DEF*(resp., *USE*) set of *CalledM* contains at least one of the attribute of *INDATA*. For example, the receiving object of the invocation of the method *initilizeX* in Line 21 (see Listing 1) is considered as defined because the the method *initializeX* defines the attribute *x* of the receiving object in Line 17.
- *Case 2:* *INDATA* is passed as a parameter in the invocation of *CalledM* and its corresponding formal parameter is in the *DEF*(resp., *USE*) set of *CalledM*. For example, the input *y* passed as parameter in the invocation of the method *initializeX* in Line 21 (see Listing 1) is considered as used because its corresponding formal parameter (i.e. *y*) is used in the method *initializeX* Line 17.

The above constraints related to computing *DEF* sets are formalized below:

$$\left\{ \begin{array}{l}
 \text{-----} \\
 - \text{INDATA is defined in M} \dots\dots\dots 1 \\
 - \exists \text{stat} \in \{\text{Statements}(M) - \text{MethodCalls}(M)\} \\
 \dots\dots\dots 2 \\
 - \text{INDATA is defined in stat} \dots\dots\dots 3 \\
 - \exists \text{call} \in \text{MethodCalls}(M) \dots\dots\dots 4 \\
 - \text{ReceivingObj}(\text{call}) = \text{INDATA} \dots\dots\dots 5 \\
 - \exists \text{attribute} \in \text{AttributeOf}(\text{INDATA}) \dots\dots\dots 6 \\
 - \text{attribute} \in \text{DEF}(\text{CorrespondingMethod}(\text{call})) \\
 \dots\dots\dots 7 \\
 - \text{INDATA} \in \text{ActualParameter}(\text{call}) \dots\dots\dots 8 \\
 - \text{FormalParameter}(\text{INDATA}) \in \\
 \text{DEF}(\text{CorrespondingMethod}(\text{call})) \dots\dots\dots 9 \\
 \text{-----} \\
 1 \Rightarrow (2 \wedge 3) \vee (4 \wedge ((5 \wedge 6 \wedge 7) \vee (8 \wedge 9))) \\
 \text{-----}
 \end{array} \right.$$

Where:

- *Statements*(*M*) denotes the set of statements of *M*.
- *MethodCalls*(*M*) represents the set of method calls in *M*.
- *ReceivingObj*(*call*) specifies the receiving object of a method call.

- *AttributeOf*(*INDATA*) denotes the set of attributes of *INDATA*.
- *ActualParameter*(*call*) specifies the set of actual parameter in a *call*.
- *FormalParameter*(*INDATA*) denotes the corresponding formal parameter of an actual parameter *INDATA*.
- *CorrespondingMethod*(*call*) represents the called method in *call*.

Note that, by replacing the *DEF* set with *USE* set in the former formula, it specifies when an input *INDATA* is considered as used.

To compute *DEF* and *USE* sets, an analysis order of methods is required. For example, to compute *DEF* and *USE* sets of the method *m* (see Listing 1), *DEF* and *USE* sets of the called methods on the attribute *foo* (*initializeX*, *getX* and *incX*) are required to check whether *foo* is defined and/or used.

The built call graph allows the definition of a topological total order of its nodes. Analyzing methods according to this order guarantees that a called method is always analyzed before its caller. The first methods in the total order are the ones that do not invoke others. These methods correspond to the leaves of the graph.

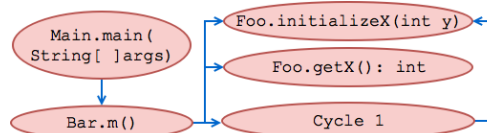


Figure 6: Acyclic call graph.

In the presence of direct or indirect recursion, the call graph contains cycles, and hence it is not possible to determine an order. To tackle this problem, each cycle in the graph is replaced by a representative node allowing the definition of a total order. The call graph nodes are then analyzed following this order. If a node represents a method, then *DEF* and *USE* sets are computed using the former constraints. If the node is a representative, *DEF* and *USE* sets of each method in the cycle represented by this node are computed, firstly, without considering calls to the methods belonging to the cycle, and then these sets are recomputed while taking into account the calls between the methods of the cycle.



Table 1: *DEF/USE* sets of the methods shown in Listing 1

Method	DEF set	USE set
initializeX	{x}	{y}
getX	$\emptyset$	{x}
setX	{x}	{x, y, isDifferent}
incX	{x}	{x, y}
m	{foo}	{foo}
main	{bar}	{bar}

For example, to compute *DEF* and *USE* sets of the methods shown in Listing 1, the cycle containing methods *setX* and *incX* is replaced with a representative node (see Figure 6) allowing the definition of the following order: 1) *Foo.initializeX*, 2) *Foo.getX*, 3) *Cycle1*, 4) *Bar.m* and 5) *Main.main*. Table 1 shows *DEF* and *USE* sets computed for these methods.

## 4 CONTROL AND DATA FLOWS RECOVERY

### 4.1 Control Flow Recovery

The recovery of workflow requires to build the corresponding control flow. This later describes the execution order of tasks. The control flow of composite ones describes the execution order of their enclosed tasks. In our approach, we represent a control flow as a graph, i.e. a Control Flow Graph (CFG). A CFG is a graph where a node represents either a method call, a predicate or a control. A predicate specifies a condition used in a control statement such as if statement.

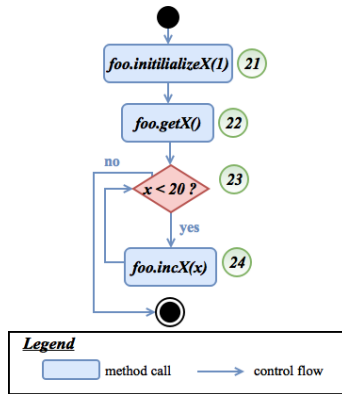


Figure 7: The CFG corresponding to the task mapped to the method *m* of the class *Foo* shown in Listing 1.

Each node representing a method call or a predicate is labeled based on its line number in the source code. Edges of the CFG indicates the execution order of method calls and evaluation of predicates.

A CFG is built incrementally by traversing the statements, which represents the body of the corresponding method to this task (see Figure 7).

In the CFG, a node can represent a method call. If the latter is dynamically dispatched, the exact method to call can not be resolved statically (at compile time). To be able to build a CFG statically, our idea is to refactor each dynamically dispatched call by replacing it with nested if-then statements. In these statements, conditions represent the possible run-time types of the receiving object of the call, while the branches are the different implementations of the called method in each possible receiving object type. Figure 8 shows an example of a CFG recovered in the presence of dynamically dispatched calls. The method *m1* of the class *Bar* invokes the method *incX* of the class *Foo* or the class *FooExp*. Hence, the corresponding CFG contains a path for each possible run-time type of the receiver.

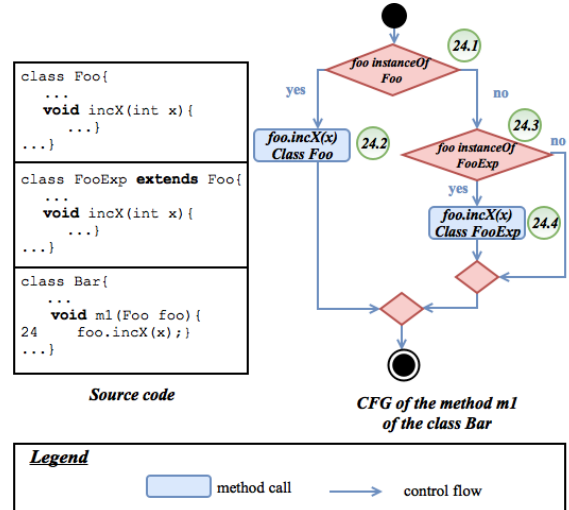


Figure 8: Example a CFG recovered in the presence of dynamic binding.

### 4.2 Data Flow Recovery

In addition to the identification of the tasks and their inputs/outputs (see Section 3.3), the construction of a workflow also requires the identification of dependency links between the data of these tasks (i.e. which output data of a task represents an input data of another one). These dependency links constitute the data flow. We present a data flow as a graph, a Data Flow Graph (DFG) which have the same nodes of a CFG. However, an edge is created between two nodes  $N_i$  and  $N_j$  if a variable  $v$  defined in  $N_i$  is used in  $N_j$ . This edge is then labeled using the name of the variable  $v$  (see Figure 9).

It should be noted that a composite task encloses other primitive and composite ones. Thus, a data flow is recovered for each composite task so as to determine data dependencies between its enclosed tasks.

To build a DFG for a composite task, we compute def-use triplets for the method mapped to this task. Each triplet  $(var, def, use)$  specifies respectively the name of a variable, the line number at which this variable is defined and the line number at which it is used. As explained in section 4.1, CFG nodes are labeled based on the corresponding line numbers in the program. Hence, a data flow edge is created between two nodes denoted by  $k$  and  $l$  if a def-use triplets  $(v, k, l)$  exists.

For example, in Figure 9 an edge is created between nodes denoted by 21 and 22 due to the existence of a triplet  $(foo, 21, 22)$ . In the rest of this section, the process of computing def-use triplets is explained in details.

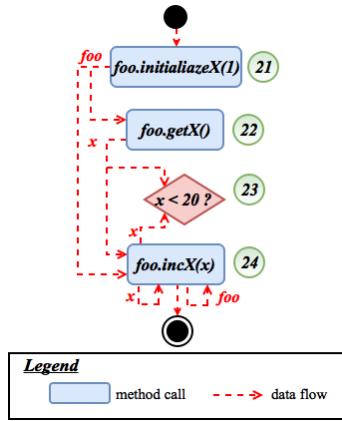


Figure 9: The DFG corresponding to the task mapped to the method  $m$  of the class  $Foo$  shown in Listing 1.

#### 4.2.1 Computing Def-Use Triplets

Computing def-use triplets is performed in three steps. The first step allows to compute  $VarUsed$  sets. It consists in determining variables used in each CFG node. The goal of the second step is to compute  $ReachDef$  sets. It is the specification of definitions that reach each node of the CFG. A definition of a variable  $v$  in a node  $N_i$ , denoted  $(v, N_i)$ , reaches a node  $N_j$  if there is a path in the CFG between  $N_i$  and  $N_j$  without a redefinition of  $v$ . In the third step, def-use triplets are computed using  $VarUsed$  and  $ReachDef$  sets.

**Step1: Computing  $VarUsed$  set:** in order to compute the  $VarUsed$  sets, first we compute  $DEF$  and  $USE$  sets (see section 3.3.1). For each node in the CFG representing a method call, the receiving object

is used if at least one of its attributes is in the  $USE$  set of the invoked method. An effective parameter is used if its corresponding formal parameter is in the  $USE$  set of the invoked method. The  $VarUsed$  of a predicate node contains variables which are used in the corresponding expression.

**Step2: Computing  $ReachDef$  set:** to determine reaching definitions, first we compute  $DEF$  sets, i.e. definitions produced by each node. For each node in the CFG that represents a method call, the receiving object is considered as defined if at least one of its attributes is in the  $DEF$  set of the invoked method. An effective parameter is considered as defined if its corresponding formal parameter is in the  $DEF$  set of the invoked method.

Once definitions produced by each node are specified, reaching definition are determined using the propagation algorithm proposed by Aho Alfred et al. (Aho Alfred et al., 1986).

**Step3: Computing def-use triplets:** for each CFG node  $N$ , a triplet  $(v, def, N)$  is constructed if  $v \in VarUsed(N)$  and  $(v, def) \in ReachDef(N)$ .

Table 2:  $VarUsed$  and  $ReachDef$  computed for each node of the CFG shown in Figure 7

Node	$VarUsed$	$ReachDef$
21	$\emptyset$	$\emptyset$
22	$\{foo\}$	$\{(foo, 21)\}$
23	$\{x\}$	$\{(foo, 21), (foo, 24), (x, 22), (x, 24)\}$
24	$\{x, foo\}$	$\{(foo, 21), (foo, 24), (x, 22), (x, 24)\}$

For example, using  $VarUsed$  and  $ReachInDef$  sets (see Table 2) computed for each node of the CFG shown in Figure 7, def-use triplets constructed are  $(foo, 21, 22)$ ,  $(foo, 21, 24)$ ,  $(foo, 24, 24)$ ,  $(x, 22, 23)$ ,  $(x, 22, 24)$ ,  $(x, 24, 24)$  and  $(x, 24, 23)$ .

## 5 WORKFLOW IMPLEMENTATION

In the previous sections, we showed how elements of the workflow mapping an OO application can be identified. In order to be able to execute the workflow, we present in this section the workflow implementation. The corresponding implementation model is represented in Figure 10. In this model each task is an instance of the class  $Task$ . It has a list of input data and a list of output data. To execute a task, we need to invoke the method  $run$  on the corresponding instance.

If a task is primitive, the method *run* initializes inputs and invokes the method mapped to this task. Otherwise, instances corresponding to the elements of the composite task are created and their methods *run* are executed. These elements can be either control constructs or other tasks. The order of execution of these elements is defined by the attribute task *taskSubelements*.

Similarly, to run a control construct (if construct or while construct), an instance corresponding to this construct is created and its run method is invoked. The run method initializes control construct inputs and evaluates its condition. For example, in the case of while construct, if the condition is true then instances corresponding to the elements of the list *whileElements* are created and their *run* methods are executed.

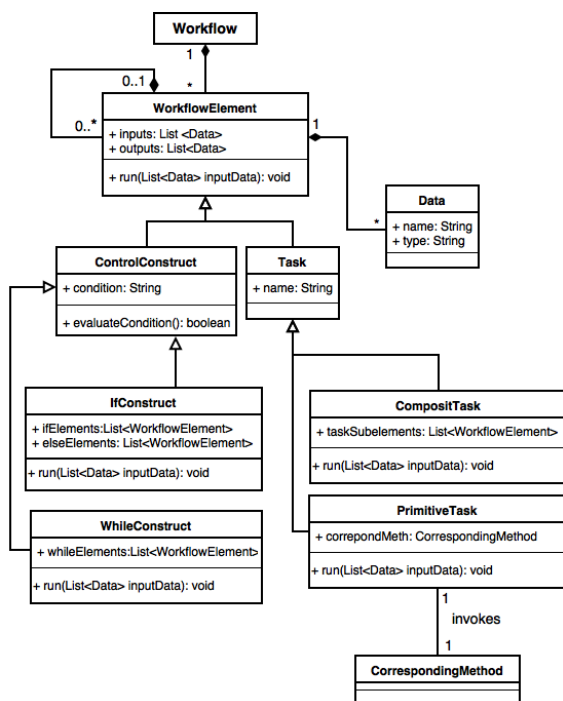


Figure 10: Workflow implementation model

## 6 EXPERIMENTATION AND VALIDATION

### 6.1 Data Collection

As a proof of concept of the proposed refactoring process, we performed a case study on two applications. Table 3 provides insight into the nature of the used applications in our case study.

Table 3: Applications characteristics

Application name	No of classes	No of methods	No of lines of code
eLib	9	80	555
PostOffice	6	57	231

eLib application is a Java program that supports the main functions operated in a library: 1) insert and remove of users/documents, search for users/documents and loan management. Its code is provided in (Tonella and Potrich, 2005).

PostOffice application is also a Java program that computes for each postal item its postage fee and its reimbursement rate. In addition, it prints item information. There are three types of postal items: letters, parcels and express parcels.

### 6.2 Refactoring Results

We applied the workflow refactoring process on the source code of each application in order to generate the corresponding workflow.

As explained previously, the first step in our refactoring process is task identification which requires applying extract method refactoring. Table 4 shows the applications characteristics after applying extract method refactoring using the built in functionality *Extract method* within eclipse IDE.

As we can notice, the number of methods after applying extract method refactoring increased by an average of 27,15% with a standard deviation of 16,61. This can be explained by the fact that new methods were created depending on the number of fragments to be extracted, i.e. fragments consisting of statements delimited by user method invocations that belong to the same block, in the application's source code.

Table 4: Applications characteristics after applying extract method refactoring

Application	No of classes	No of methods	No of lines of code	% of the added methods
eLib	9	115	788	43,75%
PostOffice	6	63	341	10,53%

Once the code is refactored, we analyze it to identify tasks. Table 5 shows the results in term of number of primitive and composite tasks for each application, as well as the total number of identified tasks. This total number equals the number of methods in the OO application since each method is mapped to a task in a workflow.

Table 5: Workflow refactoring results

Application	No of primitive tasks	No of composite tasks	Total
eLib	80	35	115
PostOffice	51	12	63

To demonstrate that the code of the generated workflow preserves the semantic of the original one, we executed both the code corresponding to this workflow and the one corresponding to the analyzed OO application based on the same test suite. We found out that the produced results are the same.

### 6.3 Threats to Validity

#### 6.3.1 Threats to Internal Validity

There are four aspects to be considered regarding the internal validity. These are as follows:

1. Control flow recovery from OO source code in the presence of polymorphism and dynamic binding requires taking into account all the possible run-time types of a receiver, as explained in section 4.1. Therefore, if a method contains  $N$  virtual calls and each one have  $M$  run-time types of a receiver, the CFG will contain at least  $N*M$  paths. Hence, the scalability of our approach is not assured. As a solution, we count to combine dynamic and static analysis. Dynamic analysis is used to determine the exact run-time type of a receiver, while static analysis collect the rest of information, i.e. methods, parameters, etc.
2. In our case studies, we constructed CFGs without considering exception-handling. This requires to extend our control flow recovery method to be able to handle implicit transfers related to exception raising.
3. The presence of aliasing does not affect the applicability of our approach. The only requirement for our data flow recovery in the presence of alias is the availability of some alias analysis (Clarke et al., 2013).
4. In our approach, we used *Extract method refactoring* to restructure code. However, the statements to be extracted are not functionally related. As a perspective, we will restructure the code to obtain methods that have a purpose (Charalampidou et al., 2016) (Kaya and Fawcett, 2016) (Kaya and Fawcett, 2013).

#### 6.3.2 Threats to External Validity

There are two aspects to be considered regarding the external validity. These are as follows:

1. The approach was experimented on applications implemented using Java programming language. However, OO languages (e.g., C++, C#, etc) have the same structure.
2. Only two case studies have been collected in the experimentation. Hence, the approach needs to be validated with a large number of case studies.

## 7 RELATED WORKS

Zou et al. (Zou et al., 2004) proposed an approach to recover a workflow from the source code of an e-commerce application. In order to recover this workflow, the authors identified a set of mapping rules that associates workflow entities to source code entities. However, applying these mapping directly will probably generate a workflow that contains a large number of irrelevant entities that do not map to any entities in the as-specified workflow. To tackle this problem, the authors proposed a set of heuristics to reduce the entities that have been selected. In (Zou and Hung, 2006), Zou et al. proposed an amelioration to their recovery process in order to automate the mapping between source code entities and business process entities. They propose to lift the abstraction level of the extracted control flow because it usually contains more programming language specific control constructs, for example checking whether a variable is *null*.

In addition to previous works that are related to workflow extraction, other works suggested to reverse engineer others abstract models by analyzing source code. In fact, reverse engineering of OO source code have been widely studied in literature. The aim is to generate models which allow the understanding of the structure, such as class diagrams (Budhkar and Gopal, 2011), and behavior, like activity diagrams, interaction diagrams and workflows.

Several tools have been developed to recover an activity diagram from source code. Kosower and Lopez-Villarejo (Kosower and Lopez-Villarejo, 2015) proposed a tool, named Flowfen, to generate a set of interconnected activity diagrams from annotated C++ code. Each diagram represents a method in the source code. In order to recover these diagrams, the authors proposed that developers annotate the C++ code. Mainly, the annotations are used to: specify the statement or the sequence of statements that represents an activity, specify controlling conditions and

return value in a human readable way. The tool uses annotations along with control structures to provide activity diagrams.

Korshunova et al. (Korshunova et al., 2006) proposed a reverse engineering tool, named CPP2XMI, which allows extracting UML class, sequence, and activity Diagrams in XMI format from C++ source code. However, the recovery process of these diagrams had not been explained in details.

In our work, we use the Def-use triplets construction. This technique has been widely used in literature (Chen and Kao, 1999; Buy et al., 2000; Martena et al., 2002). For example, Chen and Kao (Chen and Kao, 1999) proposed an approach to construct two types of def-use triplets: 1) intra-method def-use triplets in which the definition and the use of a variable are in the same method and 2) inter-method def-use triplets in which the definition and the use of a variable are in different methods. The def-use triplets constructed in our approach are intra-method def-use triplets because we are interested in determining data dependencies between the sub-tasks of each composite task, and not between sub-tasks of different composite tasks.

Buy et al. (Buy et al., 2000) identified def-use triplets for a single class. Each triplet specifies the method that defines and the one that uses the same attribute. However, their approach works only on scalar attributes. Martena et al. (Martena et al., 2002) extended this approach so as to handle attributes even if they are objects. Their idea is to classify methods of each class in three categories: modifier, user and user-modifier, based on whether a method defines and/or uses class attributes. When a method is invoked on an object, using this classification, it is possible to determine only whether the object is defined and/or used.

Compared to existing approaches, we proposed a fully automatic approach that generates a workflow, unlike the one proposed by Kosower and Lopez-Villarejo (Kosower and Lopez-Villarejo, 2015). Their approach needs human interactions to add annotations which is not an easy task. Especially for large applications, containing millions of lines of code. Moreover, the generated workflow can be executed contrary to the workflow produced by Zou and al (Zou et al., 2004) which can be used as a documentation only. It is worthy to note that due to the fact that the generated workflow has a hierarchical structure, it can be used for documentation as well. It is up to the one using it (e.g. developer, architect, etc.) to decide at which level of details he wants to stop. In addition, unlike the workflow produced by Zou and al (Zou et al., 2004), data dependencies between tasks are explicitly expressed in our workflow. To the best

of our knowledge, only our approach recovers both data and control flows from source code.

Note that, several works rely on workflows in order to perform dynamic configuration to optimize resources usage in the cloud, and thus to reduce execution costs (Zhu et al., 2016; Masdari et al., 2016; Fakhfakh et al., 2014; Xu et al., 2009; Lin and Lu, 2011). In our future works, we intend either to use these works to run the generated workflow or to propose a new approach inspired from them.

## 8 CONCLUSION

The main contribution of the work presented in this paper is the refactoring of OO source code to generate a workflow. For this purpose, first a mapping model between OO programming concepts and workflow concepts was defined. In order to identify the mapping, a three steps process was proposed. It is worthy to note that the generated workflow can be used to deploy code and data on paying platforms such as the cloud and reducing execution costs. As a part of future work, we plan to apply our approach on real and complex case studies. In addition to this, we intend to improve the generated workflow by enhancing the granularity level of the identified tasks. In fact, some of them are fin-grained. Finally, we plan to propose an approach to run the generated workflow on the cloud while reducing costs.

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