Recovering Software Layers from Object Oriented Systems

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Abstract: Recovering the architecture of existing software systems remains a challenge and an active research field in software engineering. In this paper, we propose an approach to recover the layered architecture of object oriented software systems. To do so, our approach first recovers clusters corresponding to the various responsibilities of the system; the challenge in this context is to find the appropriate level of granularity of these responsibilities. Then the recovered clusters are assigned to layers using an optimization algorithm that exploits the principles of the layering architectural style. The approach was validated on five Java open source systems.

1 INTRODUCTION

Software architecture is commonly defined as a set of components and connectors (i.e., interactions between components) that satisfy a set of functional requirements and quality attributes (Shaw and Garlan, 1996); (Bass et al., 2003). It is an abstract representation that encompasses many complementary static, runtime and allocation views of a software system (Buschmann et al., 1996). Software architectures are built by applying architectural styles which describe families of systems (Shaw and Garlan, 1996). Examples of common architectural styles are the layered, pipes and filters, client-server and service-oriented styles; each of these styles has its own vocabulary and constraints and promotes some specific quality attributes.

To appropriately support the evolution of an existing software system, we need to understand its architecture. However the as-built architecture is often insufficiently documented (Stoermer et al., 2003). Moreover, this architecture has often deviated from the initial design because of the changes undergone by the system. Hence, a software architecture recovery process is required to reconstruct and document its architecture. The reconstructed architecture enables to understand the system, to restructure it as needed, and to constrain its future evolution. In the context of this paper, we are interested in recovering layered architectures of object oriented systems.

Several approaches were proposed to support the recovery of layered architectures (e.g., (Laval et al., 2012); (Hassan and Holt, 2002); (Sarkar et al., 2009); (Andreopoulos et al., 2007) and (Scanniello et al., 2010)). Most of these approaches propose some heuristics to cluster elements of the system under analysis into layers. For example, in both (Sarkar et al., 2009) and (Laval et al., 2012), heuristics to resolve cyclic dependencies are proposed, while (Scanniello et al., 2010); (Laval et al., 2012) and (Andreopoulos et al., 2007) propose heuristics that exploit the number of fan-out and fan-in dependencies of a module to assign it to the lowest or highest-level layer. However, these heuristics may result in architectures that are too permissive with layering violations.

In this paper, we propose an approach to recover the layered architecture of object oriented systems. In particular, the approach first attempts to cluster the packages of the system under analysis to build the system's responsibilities. The challenge, in this context, is to find the appropriate level of granularity of the clusters. The resulting responsibility clusters are then assigned to layers so as to minimize the violations to the layered style principles. To do so, we propose a set of layers dependency metrics and we use these metrics to formalize the layering of responsibility clusters as an optimization problem.

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The contribution of this paper is threefold: 1) a clustering algorithm that aggregates software packages in order to recover the responsibilities of the system at a given granularity; 2) a layering recovery process that builds layers from the aggregated packages; and 3) the assessment of our approach using five Java open-source systems.

The remainder of this paper is organized as follows. Section 2 states the problem inherent to the layering recovery techniques. Section 3 describes our layering recovery approach. In section 4, we describe the results of an experiment of our approach on five systems. We discuss related works in section 5 and we conclude in section 6.

2 PROBLEM STATEMENT

The layered style was described in many reference books and papers (e.g., (Shaw and Garlan, 1996); (Buschmann et al., 1996); (Clements et al., 2003) and (Eeles, 2002)). It is a technique for decomposing a software system into groups of subtasks where each group of subtasks is at a particular level of abstraction (Buschmann et al., 1996). In other words, a layered architecture is an organized hierarchy where each layer is providing services to the layer above it and serves as a client to the layer below (Shaw and Garlan, 1996). The OSI reference model (Zimmermann, 1980) is one of the most known layered systems. In OSI, a layer uses services provided by lower layers and adds value to them to provide services needed by higher layers.

In an ideal layered architecture, a layer may only use services of the next lower layer. This is referred to as strict layering in (Buschmann et al., 1996) and as closed layering in (Szyperski, 1998). This strict ordering relation is often violated in practice; i.e., very often, layered systems allow a layer to use services provided by any lower layer. Not restricting the dependence of a layer to its lower adjacent layer is considered as a regular feature in the open layering (Szyperski, 1998) and the relaxed layering (Buschmann et al., 1996). However, it is considered as a violation named a skip-call violation in (Sarkar et al., 2009) and layer bridging in (Clements et al., 2003). Exceptionally, a layer may need to rely on a service offered by an upper layer. These dependencies are called back-calls in (Sarkar et al., 2009) and are discussed in (Clements et al., 2003) under the name “upward usage”. However, the quality attributes promoted by the layered style (e.g., reuse, portability, maintainability, understandability, and exchangeability) are no longer supported when layers are allowed to use services of higher layers without restriction (Clements et al., 2003). Therefore, the structure of a layered architecture must be a directed acyclic graph or at least a directed graph with very few cycles connecting layers.

Many approaches have been proposed to recover the software architecture. Most of them rely on clustering, which is a common used technique to reconstruct architecture (e.g., (Tzerpos and Holt, 2000); (Mitchell et al., 2001); (Maqbool and Babri, 2007); (Lung et al., 2004)). However, these approaches target specific languages and systems and do not use a standard representation of the data of the system under analysis. As a consequence, resulting tools do not interoperate with each other (Ulrich and Newcomb, 2010). Besides, most of the layering recovery approaches attempt to recover the layered architecture by relying on heuristics to resolve cyclic dependencies (e.g., (Sarkar et al., 2009) and (Laval et al., 2012)) or to layer modules according to the number of their fan-in and fan-out dependencies (e.g., (Scanniello et al., 2010); (Laval et al., 2012) and (Andreopoulos et al., 2007)). However, these heuristics are not based on layering principles and may result in architectures that are too permissive with layering violations.

To tackle these issues, we proposed in (Boaye-Belle et al., 2013) a platform and language independent approach which exploits the layering principles to reconstruct the layered architecture of object oriented software systems. For this purpose, we extracted two layering principles from the layered style: the responsibility principle and the abstraction principle. The responsibility principle states that each layer of the system must be assigned a given responsibility (Eeles, 2002); (Buschmann et al., 1996), so that the topmost layer corresponds to the overall function of the system as perceived by the final user and the responsibilities of the lower layers contribute to those of the higher layers (Buschmann et al., 1996). The abstraction principle states that the layers of a system must be ordered according to the abstraction criterion that rules the flow of communication between packages of the system. In (Boaye-Belle et al., 2013), we relied on existing decomposition of object oriented systems into packages that we assumed as being designed according to the responsibility principle and we used the abstraction principle to specify a set of constraints on the layering of these packages. These constraints were used to translate the layering recovery process into an optimization problem that we solved using a heuristic search algorithm. Experimentations with this approach yielded encouraging results.

However, relying on existing decomposition of systems into packages raised some issues when recovering the layers. In fact, when we flatten the packages hierarchy, two children packages that are nested within the same parent package might be assigned to different layers during the recovery process, ending for instance in two consecutive layers. Such an assignment may be wrong depending on the granularity of the parent package's responsibility. The nesting of child packages into the same parent package indicates that they contribute to the same general responsibility, and, depending on its granularity, this responsibility may belong to one layer or may spam several layers. This problem, also encountered by other layering recovery approaches (e.g., (Laval et al., 2012); (Hautus, 2002)), is illustrated by Figure 1. In the latter, layers 3, 2, and 1, are responsible of the system's visualization, logic, and data, respectively. The packages view1.package1 and view1.package2 are part of the package view1 which contributes to layer 3's responsibility. However, in Figure 1, these two packages were assigned to consecutive layers to promote adjacent relationships between layers (i.e., to promote reuse).

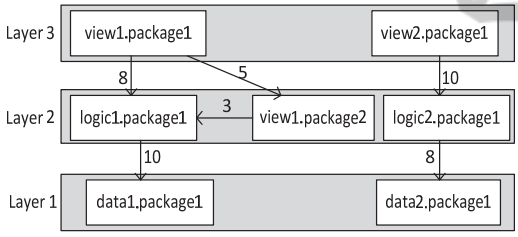


Figure 1: An example of packages' assignment to layers.

To address this issue, each group of packages belonging to the same layer's responsibility should be clustered and assigned to the same level of abstraction (i.e., layer). In Figure 1, it would allow clustering view1.package1 and view1.package2 into a single cluster that would have been assigned to layer 3. Notice that when the responsibility of a layer is complex, it is refined into finer responsibilities in order to handle its complexity and ease its comprehensibility. Each resulting finer responsibility can in turn be recursively refined until basic responsibilities are obtained. The refinement of a layer's responsibility can then lead to different granularities of responsibilities, i.e. to responsibilities with various degrees of complexity. Depending on its granularity, each responsibility can be implemented by a number of packages. Hence, to assign the responsibilities/packages to the right layers, packages should be clustered at the appropriate level of granularity. In fact, if the granularity of the responsibilities is set to a coarse level, the clustering process will produce very few clusters with too many packages (Tzerpos and Holt, 2000). This may lead to a very small number of layers and the resulting architecture will be close to a monolithic one. If the responsibilities' granularity is too fine, then the clustering process will generate many clusters including hardly more than one package. Assigning clusters to layers, in this case, raises the same issues as discussed above and illustrated by Figure 1. Therefore, tackling the issue of clustering the packages at the appropriate level of granularity will enable recovering the as-built layered architecture of object oriented systems.

3 OVERVIEW OF THE PROPOSED APPROACH

To recover the layering organization of a system, we follow the three-step approach illustrated by Figure 2. The first step consists in retrieving the facts from the system under analysis. To extract the system's facts, we analyze its source code and generate platform independent models that are compliant with the Knowledge Discovery Metamodel (KDM). The latter was introduced by the OMG (OMG Specifications, 2013) as a standard representation of legacy systems. The KDM defines a meta-model for representing—at various levels of abstraction—all aspects of existing legacy systems. This meta-model provides a common interchange format to ensure interoperability between tools. In our context, we parse the KDM models that we generated from the source code, to retrieve packages and their relationships. Dependencies between two packages are derived from the dependencies between their respective classes (i.e., class references, inheritance, method invocation and parameters).

Once the system's facts are extracted, we iterate over steps 2 and 3 to recover the layering architecture of the system. The second step of our approach aims at clustering packages to build the responsibilities of the system at a given granularity. To do so, we build a responsibility tree of the system using its packages' namespaces and we define the granularity of a given responsibility as the number of nodes that have to be traversed from the root of the responsibility tree to the node corresponding to that responsibility (i.e., the level of the package representing the responsibility in the tree). Depending on the targeted granularity, clusters of packages are built from subtrees of nodes corresponding to that granularity. Step 2 is described in details in subsections 3.1 and 3.2. In the third step of our approach, clusters obtained in

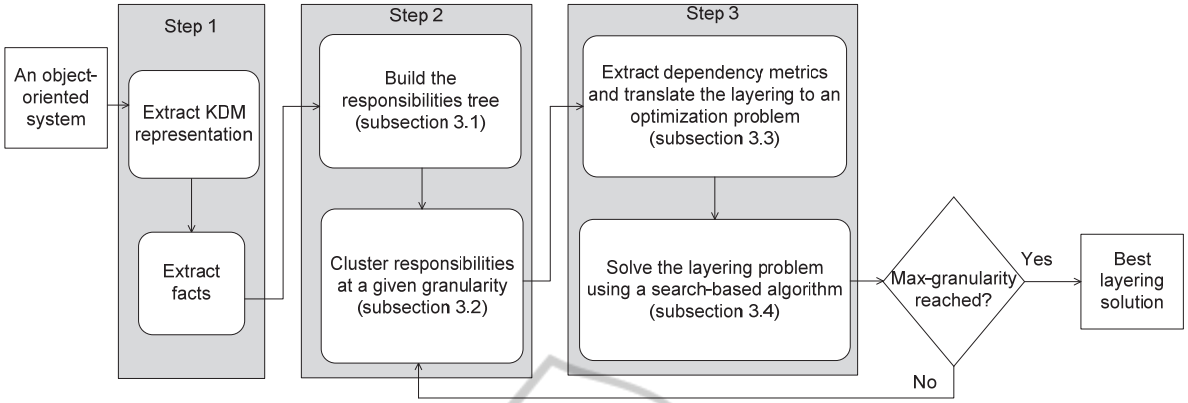


Figure 2: Overview of the proposed approach.

the second step are assigned to layers so as to minimize the layers' dependencies that violate the layered architecture (e.g., skip-calls and back-calls) and maximize dependencies between adjacent layers that we call adjacent dependencies. To do so, we introduce a number of dependency metrics that are derived from the abstraction principle introduced in (Boaye-Belle et al., 2013). We use these metrics to formalize the layering of clusters of packages as an optimization problem that we solve using a search-based algorithm. Step 3 is described in details in subsections 3.3 and 3.4.

At the first iteration of steps 2 and 3, the granularity of the responsibilities is set to 2. At each iteration, the granularity of the responsibilities is increased until it reaches the maximum value (i.e., the height of the responsibilities tree minus one). The layering solution obtained after each iteration is evaluated and it is kept as the best layering solution if its evaluation gives better results than the best solution found at the previous iteration. A layering solution is evaluated using a manual decomposition of the system and a ratio computed as the number of adjacent dependencies over the sum of all the dependencies in the solution. We rely on this ratio to compare two layering solutions instead of the absolute number of adjacent dependencies since the number of these dependencies varies depending on the granularity of responsibilities.

3.1 Building the Responsibilities Hierarchy

Some clustering techniques were proposed to create subsystems that enable managing and understanding the analyzed system (e.g., (Müller et al., 1993); (Hassan and Holt, 2002); (Bowman and Holt, 1998) and (Tzerpos and Holt, 1996)). These techniques rely for instance on a system's documentation, on the development team structure, on the directory structure of a system, and on the naming conventions followed when naming a system's parts. The use of naming information to aggregate packages into subsystems is the most common technique used by these approaches (e.g., (Müller et al., 1993) and (Hassan and Holt, 2002)). In fact, during the naming of packages, the developers usually name each package meaningfully, and they generally rely on the package's functionality to do so. A package's name gives a hint about its role in the system (Clements et al., 2003). Therefore, the so-obtained naming information usually gives some clues about the responsibilities of a system's packages. Of course, naming information can only be useful if the developers of the system have followed naming conventions (Müller et al., 1993).

All programming languages (e.g., SmallTalk, C++ and Java) provide mechanisms to support various kinds of namespaces (e.g., records, dictionaries, objects) (Achermann and Nierstrasz, 2000) allowing to name software entities. A namespace is a sequence of key-words that map labels to values (Achermann and Nierstrasz, 2000) and identifies a software entity (e.g., package). Packages that contribute to the same responsibility usually have namespaces beginning with the same subset of key-words. In our context, we rely on namespaces to reconstitute the hierarchy of a system's responsibilities. This hierarchy can be seen as a responsibilities tree that is built so that its root node is the subset of key-words that appears at the beginning of each package. The root node represents the overall functionality of the system. The other nodes of the tree are recursively built so that each path from the root to a leaf describes the namespace of a package. Concretely, intermediate nodes of the tree correspond to responsibilities/packages with finer granularity than the root node (i.e., responsibilities that have been

refined), while the leaves of the tree correspond to the elementary responsibilities. To get from the root to the nodes located at a given granularity of responsibilities G, we need to cross (G-1) nodes.

Let us consider JHotDraw 7.0.6, a framework developed with Java and whose packages' namespaces are listed in table 1. Figure 3 shows the responsibilities tree obtained using the key-words in the packages namespaces of JHotDraw 7.0.6. The value of the granularity of the root of the tree, which is the sequence "org.jhotdraw", is 1. Each path from the root to a leaf corresponds to a package whose namespace begins with "org.jhotdraw". Packages whose namespaces do not begin with the sequence "org.jhotdraw" (e.g., "nanoxml" and "net.n3.nanoxml") are not included in the tree.

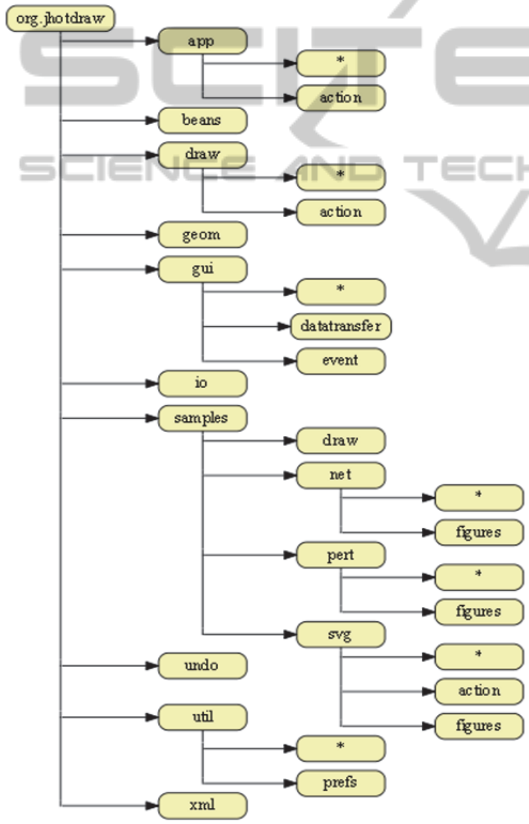


Figure 3: an example of the Responsibilities tree.

3.2 A Responsibilities-based Clustering Algorithm

In order to build responsibilities-based clusters, we rely on the responsibilities tree of the system built using packages namespaces as explained above. We traverse the responsibilities tree to select each sub-tree rooted by a node located at a specified granularity of responsibility. The packages whose namespaces define paths to leaves located in a selected sub-tree are put together in a cluster. Each of the resulting clusters comprises packages contributing to the same granularity of responsibilities. The algorithm describing this clustering process is illustrated by Figure 4. This algorithm takes as input the set of packages of the analyzed system and the targeted granularity of responsibilities at a given iteration. As discussed above, we iterate over all possible levels of granularities in our approach. The algorithm returns the set of clusters of responsibilities corresponding to the given granularity.

Table 1: JHotDraw Packages Namespaces.

No	Packages namespaces	Granularity
1	nanoxml	-
2	net.n3.nanoxml	-
3	org.jhotdraw.app.*	3
4	org.jhotdraw.app.action	3
5	org.jhotdraw.beans	2
6	org.jhotdraw.draw.*	3
7	org.jhotdraw.draw.action	3
8	org.jhotdraw.geom	2
9	org.jhotdraw.gui.*	3
10	org.jhotdraw.gui.datatransfer	3
11	org.jhotdraw.gui.event	3
12	org.jhotdraw.io	2
13	org.jhotdraw.samples.draw	3
14	org.jhotdraw.samples.net.*	4
15	org.jhotdraw.samples.net.figures	4
16	org.jhotdraw.samples.pert.*	4
17	org.jhotdraw.samples.pert.figures	4
18	org.jhotdraw.samples.svg.*	4
19	org.jhotdraw.samples.svg.action	4
20	org.jhotdraw.samples.svg.figures	4
21	org.jhotdraw.undo	2
22	org.jhotdraw.util.*	3
23	org.jhotdraw.util.prefs	3
24	org.jhotdraw.xml	2

The algorithm starts by determining the smallest non-empty namespace common to the majority of packages (line 1). Each package whose namespace do not begin with the smallest namespace is removed from the set of packages and put in a singleton cluster (lines 2 to 8). The latter is added to the set of clusters (line 8). The algorithm then builds the responsibilities tree from the set of remaining packages, considering the smallest common namespace as the root of the tree (line 11). The tree nodes are then recursively computed so that each path from the root to a leaf describes the namespace of a package. During the tree's construction, granularity values are

assigned to tree nodes, the root node having the granularity value of 1. We then consider all nodes whose granularity of responsibility is equal to the input granularity of responsibilities (lines 12 to 13). For each of these nodes, we build a cluster containing all the packages whose namespaces correspond to leaves in the sub-tree rooted by the considered node (line 14). The clustered packages are at the same time removed from the remaining set of packages. Each resulting cluster is added to the set of clusters (line 15). Finally, the packages remaining in the set of packages are put in singleton clusters that are in turn added to the set of clusters (lines 18 to 22).

```
ClusterList :: clusteringByName(List packageSet, int GRANULARITY)
1.  space ← smallerCommonName(packageSet)
2.  for(package in packageSet) {
3.      packageName ← computeSpaceName(package)
4.      if(!packageName.beginsWith(space)) {
5.          packageSet.remove(package)
6.          cluster ← createEmptyCluster()
7.          cluster.add(package)
8.          clusterSet.add(cluster)
9.      }//end if
10. }//end for
11. nameTree ← buildTree(packageSet, space)
12. for(node in nameTree) {
13.     if(node.getGranularity() = GRANULARITY) {
14.         cluster ← clusterLeaves(nameTree , node, packageSet)
15.         clusterSet.add(cluster)
16.     }//end if
17. }//end for
18. for(package in packageSet) {
19.     cluster ← createEmptyCluster()
20.     cluster.add(package)
21.     clusterSet.add(cluster)
22. }//end for
23. return clusterSet
```

Figure 4: A high level view of the clustering algorithm.

3.3 The Layering of Responsibilities as an Optimization Problem

We rely on the abstraction principle introduced in (Boaye-Belle et al., 2013) to assign levels to the clusters obtained from the responsibilities clustering step. In fact, our analysis of the layered style led us to retain two properties that we need to comply with when assigning clusters to layers:

1) The Layer abstraction uniformity property: clusters assigned to the same layer must be at the same abstraction level. The level of abstraction of a component often refers to its conceptual distance from the "physical" components of the system (Buschmann et al., 1996), i.e. hardware, database, files and network.
2) Incremental layer dependency property: a cluster assigned to a layer (*j*) must only rely on services of the layer below (*j-1*). As discussed in the problem statement, this property is the one that is mostly violated, either through back-call or skip-call dependencies between layers. Our analysis of the various descriptions of the layered style and several open source projects led us to conclude that this property should be stated in a way that allows—to some extent—the skip-call and back call violations. Hence, we relaxed this property to "clusters of layer *j-1* are mainly geared towards offering services to clusters of layer *j*". This means that in the event when there is some skip-call and back-call dependencies between layers, the number of these dependencies must be insignificant compared to the number of downward dependencies between adjacent layers.

To ensure compliance with the first property, the clusters of the same layer should be at the same distance from the "physical" or lowest layer clusters. However, the existence of back-call and skip-call dependencies introduces a discrepancy between the clusters' distances, even when they belong to the same layer. Hence, compliance with our first property derives largely from compliance with our second property which we will formalize using a set of metrics and constraints related to the dependencies between layers. These constraints will enable to translate the layering problem into an optimization problem.

We define the index of use of a layer *j* by a layer *i* as the number of dependencies directed from layer *i* to layer *j*. This index is obtained by summing the weights of the dependencies directed from each cluster of layer *i* to each cluster of layer *j*. The dependency between two clusters derives from the dependencies between their respective packages. In what follows, this index is labeled as:

- AdjacencyUse(i,j) when j = i-1. AdjacencyUse(i,j) denotes the number of dependencies directed from layer *i* to its adjacent lower layer *j*.
- SkipUse(i,j) when j < i-1. SkipUse(i,j) is the number of skip-call dependencies directed from layer *i* to layer *j*.
- BackUse(i,j) when i < j. BackUse(i,j) is the number of back-call dependencies directed from layer *i* to layer *j*.
- IntraUse(i) when i = j. IntraUse(i) is the number of the dependencies inside layer *i*.

Figure 5 illustrates the calculation of the layer dependency metrics for a system made of three layers

where all dependencies have the same weight (i.e., a weight of 1). In accordance with the incremental layer dependency property, we want to minimize the number of skip-call and back-call dependencies. This means that, apart from the upper layer adjacent to layer *j*, we must minimize the index of use relating other layers to layer *j*. However, skip-calls are often used for performance reasons and should be more tolerated than the back-calls which lead to a poorly structured system. These restrictions are formalized by the following constraint:

$$\text{For all i, j, k} \mid j<i \text{ and } k<j\text{-}1, \text{BackUse(j,i)} \leq \text{SkipUse(j,k)} \leq \text{AdjacencyUse(j, j-1)} \quad (1)$$

Constraint (1) may be certainly satisfied when the number of the layers of the system is very small (i.e., when layers are merged). However, dependencies between clusters of the same layer are not recommended unless otherwise stated (Bourquin and Keller, 2007) or when some concerns as portability need to be addressed (Clements et al., 2003). Hence, we subjoined to constraint (1) the following constraint that limits the number of intra-dependencies of a layer:

$$\text{IntraUse(j)} \leq \text{AdjacencyUse(j, j-1)} \quad (2)$$

The layer dependency metrics and constraints introduced so far will be used to guide the process of assigning the clusters of a given system to a set of layers while rewarding the adjacency between layers and keeping their intra-dependencies quite low and minimizing the skip-calls and back-calls. For this purpose, we define the individual layering cost (ILC) of a given layer *i* of the system as follows:

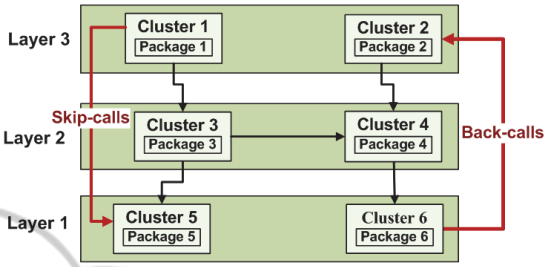
$$\text{ILC(i)} = \alpha\,\text{AdjacencyUse(i, i}-1) + \beta\,\text{IntraUse(i)} + \gamma\sum_{j=i-2}^{1}\text{SkipUse(i, j)} + \delta\sum_{j=i+1}^{N}\text{BackUse(i, j)} \quad (3)$$

Where α, β, γ and δ are respectively the penalties adjoined to the adjacent dependencies, the intra-dependencies, the skip-call dependencies and the back-call dependencies. For instance, in Figure 5, ILC(3) = 2α + γ, as the third layer has two adjacent dependencies and one skip-calls.

In order to penalize the undesired dependencies and satisfy the two constraints defined before, the penalty α must be lower than the other penalties. The global layering cost LC of assigning the clusters of a system to a set of *n* layers is then computed by summing the individual layering cost for each layer *i* of the system:

$$\text{LC} = \sum_{i=1}^{n}\text{ILC(i)} \quad (4)$$

The lower LC is, the better the assignment of clusters to layers is. Attempting to reconstruct a layered architecture while minimizing its LC, is a problem that can be solved by adapting a search-based algorithm to reduce the search space.



Layer Metrics	AdjacencyUse (3, 2) = 1 + 1 = 2 ; AdjacencyUse (2, 1) = 1 + 1 = 2 IntraUse (3) = 0; IntraUse (2) = 1; IntraUse (1) = 0 SkipUse (3, 1) = 1 BackUse (2, 3) = 0; BackUse (1, 2) = 0; BackUse (1, 3) = 1
Individual Layering Costs	ILC(1) = δ ILC(2) = 2α + β ILC(3) = 2α + γ.

Figure 5: Example of the calculation of the layer metrics and the individual layering costs.

3.4 An Algorithm to Assign Responsibilities to Layers

In order to build the optimal layering of software systems, we choose to adapt the steepest ascent hill-climbing technique (Mitchell et al., 2001) using our LC (Eq. 4) as a fitness function. We focused on the hill-climbing algorithm because it performs well in the context of large systems and it has been successfully used in several approaches. The algorithm works in an iterative way. It starts by an initial partition of the system's modules into a set of clusters; usually a randomly generated partition as in (Mitchell et al., 2001). Modules are then moved between clusters to improve the partition according to some criterion. This criterion is based on maximizing or minimizing a fitness function.

Figure 6 shows a high-level view of our adaptation of this technique to the layering problem. It starts with an initial partition consisting of a set of n layers comprising the clusters resulting from the clustering step. The uppermost layer is constituted by the clusters having no incident dependencies; the lowermost layer of this partition contains the clusters having no outgoing dependencies; and the remaining clusters are randomly assigned to intermediate layers. The so-called initial system is then considered as the current solution of the algorithm (line 1). In the following iterations (lines 3 to 20), all the neighboring solutions are created (line 6) and evaluated using their cost (line 8). A neighbor solution is computed by moving a single cluster from a layer A to a layer

B of the current solution, provided these two layers are different. In order to compute the cost of each neighbor, we set the values of α, β, γ and δ prior to the application of the algorithm. The neighbor having the lowest value of LC is considered as the best neighbor of the iteration (lines 9 to 12) and accepted as the current solution if its cost is lower than the one of the current solution (lines 14 to 17). The algorithm stops if the current solution cannot be improved anymore (lines 18 and 19).

```
LayeredSystem :: layeringBycost (LayeredSystem initialSystem,
                                 real MAX_VALUE)
1. currentSolution ← initialSystem
2. currentLC ← computeLC (initialSystem )
3. while (TRUE){
4.          bestLC  ← MAX_VALUE
5.          bestNeighbor  ← NULL
6.          neighborList ← computeAllNeighbors(currentSolution)
7.          for (neighbor in neighborList){
8.               neighborLC ← computeLC(neighbor)
9.               if (neighborLC  < bestLC) {
10.                   bestNeighbor ← neighbor
11.                   bestLC  ← neighborLC
12.              }//end if
13.         }//end for
14.         if (bestLC < currentLC){
15.              currentSolution ← bestNeighbor
16.              currentLC ←bestLC
17.         }//end if
18.         else
19.           return currentSolution
20. }//end while
21. return currentSolution
```

Figure 6: A high level view of our layering algorithm.

4 VALIDATION

The validation of our approach aimed at addressing the two following questions: i) What is the correct granularity of responsibility to consider when clustering packages of a given system? This question is meant to investigate the appropriate granularity of responsibility that will help addressing the issues raised in section 2. ii) What are the values of penalties (α, β, γ and δ) that generate software layers that correspond to the as-built architecture? The user might try many combinations values before finding the ones that best fit the analyzed system. Hence, our goal through the second question is to reduce the set of penalties' values that the user could consider when applying our layering recovery algorithm.

To validate our approach, we implemented a tool within the Eclipse™ environment. This tool is made of three modules. The first one is a fact extractor built atop of the MoDisco open source tool which enables to generate a KDM representation of the system under analysis. The KDM representation is then used by our extractor to retrieve the system's packages and the dependencies between them. The second module implements the clustering algorithm to generate clusters from the extracted packages according to the second step of our approach. In particular, this module builds a module dependency graph where nodes are clusters of packages and edges are dependencies between the clusters which are inferred from the dependencies between packages. The module dependency graph enables the creation of an initial partition (i.e., initial layering solution) that is the input of the third module of our tool. This third module implements our layering algorithm.

4.1 Experiment

To assess our approach and answer the two research questions discussed above, we conducted experiments on five software projects. Some characteristics of these projects are summarized in table 2. We choose these projects because they are open-source systems that are known to be layered systems. Table 3 shows the results of executing the approach on these projects using three different setups. We indicate for each setup the values of the penalties that were used when applying the layering algorithm. During these experiments, we set the adjacency penalty (α) to 0 for all these setups; we reward downward adjacent dependencies. Table 3 shows for each setup, the best ratio (computed as the number of adjacent dependencies over the sum of all the dependencies in the solution as discussed in section 3) found for all the iterations of the approach on a system and the corresponding granularity of responsibilities.

Layered solutions obtained during the experiment and that correspond to the as-built architectures of the analyzed systems are in grayed cells in table 3. Interestingly, we can notice that setup 2 is the one that yields the best results in terms of the ratio of adjacent dependencies. The explanation lies in the fact that since the clustering step has already resolved some cyclic dependencies, a quite high value of the back-call penalty δ (e.g., δ =4) is sufficient to resolve the remaining cyclic dependencies. In this regard, having the intra-dependencies penalty β higher than the skip-calls penalty γ in setup 2, avoids putting the remaining cyclic dependencies in the same layer at the expense of the adjacent dependen-

cies. This answers our second research question regarding the set of values of penalties (α, β, γ and δ) that generate software layers that correspond to the as-built architecture.

Table 2: Projects statistics.

Project	Numb. of files	LOC	Numb. of packages	Package dependencies
JFreeChart 1.0.14	596	209711	37	225
JHotDraw 7.0.6	310	51 801	24	89
JUnit 4.10	162	10 402	28	107
Rhino 1.7	237	132634	15	23
JEdit 4.3	488	138046	28	154

Setting the back-call penalty δ to a very high value as in setup 3, will ensure assigning to the same layer the majority of the clusters involved in cyclic dependencies. Hence, we expected setup 3 to be more appropriate for systems where the number of cyclic dependency remains very high in spite of the clustering step. For instance, JEdit 4.3 has a very high number of cyclic dependencies and we expected that setup 3 would yield the best results for that system. However, the best ratio found for JEdit 4.3 corresponds to setup 2. This discrepancy can be explained by the fact that JEdit 4.3 has some omnipresent packages which bias the recovery process. Among these omnipresent packages is the package with the namespace org.gjt.sp.jedit.* which uses many packages and is in turn used by many other packages.

Regarding the first research question, we observed that the majority of the best ratios of desired dependencies (i.e., the ratios of adjacent dependencies over the sum of all the dependencies in the solution) are obtained when the granularity of responsibilities is assigned a value of 3. In fact, when the granularity of the responsibilities is too coarse (e.g., granularity=1 or 2), the clustering step results in very few clusters (e.g., 2 clusters in the case of Rhino 1.7, JFreeChart 1.0.14 and jEdit 4.3) and the layering step in a too small number of layers (i.e., one to two layers). Furthermore, experimentations also showed that the more the level of responsibilities considered for clustering is far from the root's one (e.g., granularity =5), the more the ratios of desired dependencies decrease.

Table 3: Layering results.

		Rhino	JHotD.	JUnit	JEdit	JFree.
Setup 1: α =0, β =1, γ = 2, δ = 4	Ratio	77%	85.55%	67.32 %	51.78%	53%
	Granularity	3	2	3	4	3
Setup 2: α =0, β =2, γ = 1, δ = 4	Ratio	84%	84.98%	67.32 %	64.00%	59%
	Granularity	3	2	3	4	3
Setup 3: α =0, β =2, γ = 1, δ = 8	Ratio	77%	84.98%	67.32 %	60.08%	55.41%
	Granularity	3	2	3	3	3

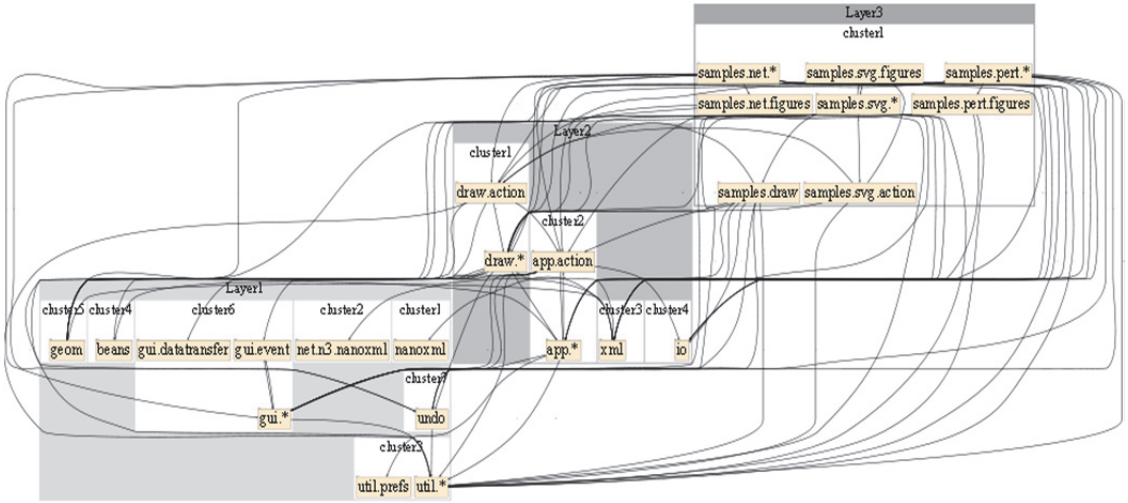


Figure 7: The layering results of JHotDraw 7.0.6.

This is due to the fact that the majority of the generated clusters are singletons (i.e., they contain one package), which weakens and sometimes nullifies the impact of the clustering process on the layering recovery.

In case of JHotDraw 7.0.6, the best layering solution is obtained using setup 1 and for a granularity of responsibilities of value 2. This solution is illustrated by figure 7 and it is pretty close to the one that was built through a manual decomposition of the source code. JHotDraw constitutes an "exception" as it was designed as an example of a well-designed framework. It contains less cyclic dependencies than the other projects and its analysis yields the best desired ratio for all setups when compared to the ratios of the other projects. Another interesting fact that came to our attention is that in the case of JUnit 4.10, a granularity of responsibilities equals to 3 produces the best and an identical layering organization for each of the 3 setups. This indicates that for this system, the clustering step led to a stabilization of the layering results.

4.2 Threats to Validity

To validate our approach, we performed our preliminary experiments on open-source systems that were known to be layered systems. And since it was difficult to find experts to decompose these systems, we manually verified the experimentation results. Nevertheless, as future work, we need to carry out experiments on industrial legacy systems to assess the usefulness of our approach and generalize the results. Besides, the object-oriented systems we analyzed were all developed in Java. However, using the KDM standard to represent them makes our approach language and platform-independent and therefore applicable to other types of systems. Another issue that could hinder the applicability of our approach is its dependence on the MoDisco tool's robustness and scalability. Using other tools to generate the KDM representations of the analyzed systems will help addressing this threat.

5 RELATED WORKS

Many approaches have focused on the architectural reconstruction and they mostly rely on clustering techniques. Various clustering-based approaches are discussed in (Maqbool and Babri, 2007) and (Shtern and Tzerpos, 2012). Most of these approaches aim at finding a clustering of the system that optimizes the modularity of resulting packages (e.g., (Lung et al., 2004), (El Boussaidi et al., 2012)). Our work is more related to the approaches proposed to recover or analyze layered architectures (e.g., (Sarkar et al., 2009); (Lague et al., 1998); (Laval et al., 2012); (Scanniello et al., 2010); (Müller et al., 1993); (Tzerpos and Holt, 1996)).

Laval et al., (2012) proposed an approach, called oZone, which removes undesired cyclic dependencies prior to the decomposition of a system into layers. For this purpose, they rely on two heuristics to resolve dependencies that belong to cycles and impede the finding of layers of a system. These dependencies are tagged by the proposed algorithm and they are ignored when building layers of the system. In (Sarkar et al., 2009), the authors proposed 3 layering principles (skip-call, back-call and cyclic dependency) and a set of metrics that measure the violation of these principles. Although these principles are focused on detecting violations, they are related to the layer abstraction uniformity and incremental layer dependency properties as defined in this paper. Nevertheless, unlike both (Laval et al., 2012) and (Sarkar et al., 2009), we address the layering recovery process without relying on any heuristic to resolve the cyclic dependencies problem.

Scanniello et al., (2010) proposed a semi-automatic approach aiming at recovering software layers. In their approach, the uppermost layer comprises the classes that rely on many other classes, while the lowermost layer is made of the classes that are used by many other classes. The middle layer comprises in turn the remaining classes. In both (Laval et al., 2012) and (Scanniello et al., 2010), it is assumed that a module that does not have fan-out-dependencies belongs to the lowest-level layer and conversely a module that does not have fan-in dependencies belongs to the highest-level layer. However, when a module represents a common subtask exclusive to packages of a middle-level layer, this module will not have any fan-out dependency but still belongs to this middle-level layer. Likewise, a module that starts some specific service of a middle-layer may not have any fan-independency but still belongs to this middle-level layer.

Lague et al., (1998) developed a framework for analyzing layered systems to evaluate the coherence between the description of the architecture given in design documents and the actual source code's structure. Their framework relies on a set of questions for evaluating the properties of a layered system and a set of metrics that help answering these questions. This empirical study has shown that strict layering is not enforced in layered systems as skip-calls are made extensively however there are no back-calls.

Though the framework does not support the recovery of the layered architecture, its results helped us adjust our skip-call cost parameter compared to the intra and back-call cost parameters.

Tzerpos and Holt (1996) propose a "hybrid" process to reconstruct software architectures. This process is based on various steps including: selecting the domain model; retrieving the facts from the source code and from the files' names; clustering the facts into subsystems based on naming conventions, directory structure or automatic clustering techniques; creating successive structural diagrams that are refined by the developers. Müller et al., (1993) propose an approach aiming at supporting users in discovering, restructuring and analyzing subsystem structures using a reverse engineering tool. The proposed process involves the identification of the layered subsystem structures. The layered structure is obtained through the clustering of system's packages into building blocks using composition operations among which the composition by name. Similarly to (Tzerpos and Holt, 1996) and (Müller et al., 1993), our layering recovery process involves a naming-based clustering step. However, our clustering step is focused on the recovery of the layers' responsibilities while theirs targets the ease of the system's manageability and understandability. Besides, in (Tzerpos and Holt, 1996) and (Müller et al., 1993) the maintainer has to intervene in most of the recovery process's steps, while in our approach the maintainer only needs to validate the layering results.

6 CONCLUSION AND FUTURE WORK

In this paper, we proposed an approach that aims at recovering the layered architecture of object oriented systems. This approach attempts to cluster the packages of the system under analysis to build clusters of the system's responsibilities. The resulting clusters are then assigned to layers so as to minimize the layers' dependencies that violate the layered architecture and maximize dependencies between adjacent layers. To do so, we introduced a set of layers dependency metrics and we used these metrics to formalize the layering of clusters of packages as an optimization problem. The challenge in this context is to find the appropriate granularity to consider when clustering responsibilities.

We applied the approach on five open-source systems and we manually assessed the resulting layered architectures. The results were very promising as illustrated in section 4. Our approach has two main advantages: 1) it does not rely on heuristics to resolve cyclic dependencies and 2) it is language and platform independent as it relies on the KDM specification standard. Moreover, it supports the interaction with users and domain experts to refine the layering results.

While we continue to refine the principles and metrics of our approach, we need to perform more experiments and analyses to properly tune the penalties used by our layering algorithm. In this context, we intend to conduct experiments on industrial systems and get the feedback from these systems' experts in order to validate the resulting layered architectures and assess the usefulness of our approach. In the short term, we plan to apply the approach on larger open source systems (e.g., Mozilla and Ant) and to compare our results with other approaches. We also envision improving our fact extractor in order to get a richer and more accurate representation of the analyzed systems.

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