Refactorings of Design Defects using Relational Concept Analysis

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Abstract. Software engineers often need to identify and correct in their programs design defects, i.e., recurring design problems that hinder development and maintenance by making programs harder to comprehend and/or evolve. While detection of design defects is actively researched area, their correction – mainly a manual and time-consuming activity – is yet to be extensively investigated for automation, e.g., by means of refactorings. In this paper, we propose an automated approach for suggesting defect-correcting refactorings based on relational concept analysis (RCA). The added value of RCA consists in exploiting the links between formal objects which abound in a software re-engineering context. We validate our approach on instances of the *Blob* design defect taken from an open-source program, `Azureus`.

Keywords: Design Defects, Formal Concept Analysis, Refactoring, Relational Concept Analysis.

1 Introduction

Design defects are wrongful solutions to recurring design problems that generate negative consequences on the quality characteristics of object-oriented (OO) software artifacts, such as evolvability and maintainability, and therefore increase the cost of software development [16,5]. Design defects, such as antipatterns [28] (the Blob described later is an antipattern), are distinguished from low-level defects, such as code smells [5] (for example, long methods and large classes). Automatic detection and correction of design defects are thus key for the improvement of software quality.

We proposed a systematic method to specify design defects consistently and precisely and to generate detection algorithms from their specifications automatically [17]. We specified a language based on rules that allows to define these specifications with structural, semantic, and measurable properties that characterize a design defect. This method was a first step towards the systematic detection of design defects. Yet both detection and correction of such defects are time-consuming and error-prone activities hence leaving room for automated

techniques and tools. On the one hand, approaches exist to detect design defects by using metrics [15,21], coupled with visualisation tools [13,14] and/or structural data [9]. When applied on large software programs, these approaches contribute to the development and maintenance of programs. On the other hand, to the best of our knowledge, no approach attempts to correct design defects in a semi- or fully automated manner.

Trifu *et al.* [27] propose correction strategies mapping design defects to possible solutions. However, in this context a solution is an example of how the program *should have been implemented* to avoid a defect rather than a list of steps that a software engineer should follow to correct the defect. Huchard and Leblanc [11] use formal concept analysis (FCA) to suggest restructurations of class hierarchies to maximise the sharing of data structure and code through fields and methods and remove code smells from the program (see [6] for a broader discussion on the restructuration of class hierarchies through FCA). These two approaches provide interesting results but none attempts *to suggest refactorings to correct design defects*.

Thus, design defects are still dealt with manually through tedious code analyses and transformations. More specifically, the correction activity splits into three main steps, possibly repeated through trials and errors: (1) Identification of the modifications to correct the design defects, (2) Application of the modifications on the program, (3) Evaluation of the resulting modified program. Step two of correction has been made easier by the recent introduction of *refactorings* [5], i.e., changes performed on the source code of a program to improve its internal structure without changing its external behaviour. Thus, possible transformations are now well understood and documented and the emphasis lies on step one, *i.e.*, the decision of which modifications (or refactorings) to apply.

We propose to apply RCA, a framework that extends core FCA to the processing of several sorts of individuals provided with inter-individual links, on a suitable representation of a program to help identify appropriate refactorings for specific design defects. In particular, we examine the benefits of RCA for the correction of a very common design defect, the Blob [28, p. 73–83], also known as *God Class* [22]. The Blob reveals a procedural design (and thinking) implemented with an OO programming language. It manifests through a large class that plays a God-like role in the program by monopolizing the computation which is surrounded by a number of smaller data classes providing many attributes but few or no methods.

Blobs are common and RCA is particularly well-suited to suggest refactorings to correct them. Indeed, correcting a Blob amounts to splitting the Blob class in smaller chunks by grouping class members that work together, e.g., that collaborate to realize a specific responsibility of the Blob class. Thus, we extract formal concepts to identify the desired chunks whereas both proper characteristics and inter-member links, such as calls between methods, are used in concept formation. Unlike other FCA-based restructuring approaches, we work on whole lattice regions rather than on separate concepts because candidate classes usually stretch over several concepts in the lattice.

We illustrate our approach using a running example of a library and validate it using Azureus version 2.3.0.6, a peer-to-peer program [25] that contains 41 Blobs for 1,626 classes (201,916 lines of code) and show that RCA can suggest relevant refactorings to improve the program. The generalisation of our results to other design defects is briefly discussed. The contributions of the present paper, which extends our previous work [18], are three-fold. First, it describes a more powerful approach based on finer and richer modeling of the problem through RCA. It then proposes enhanced rules for candidate class formation out of concept sets provided with an effective algorithm each. Third, it presents an automated interpretation of the results by suggesting the refactorings to apply.

The paper starts by a short presentation of design defects correction (Section 2). Follow a summary on RCA (Section 3) and the description of our approach (Section 4). Section 5 presents the results of a preliminary empirical study of the approach validity. Related work is summarised in Section 6 while further research directions are given in Section 7.

2 Problem

In the following, we relate design defects to general quality criteria for OO designs using an instance of the Blob as running example. The defects are shown to erode scores on these criteria. The improvement brought by the FCA-based refactorings is discussed in later sections.

2.1 Quality Criteria

Design defects are the results of *bad* practices that transgress *good* OO principles. Thus, we use the degree of satisfaction of those principles before and after the correction as a measure of progress. Technically speaking, we rely on quantification of *coupling* and *cohesion*, which are among the most widely acknowledged software quality characteristics, key for the target maintainability factor [2].

The cohesion of a class reflects *how closely the methods are related to the instance variables in the class* [4] and is typically measured by the LCOM metric (Lack of COhesion Metric) which follows *the number of disjoint sets of methods* [4]. A low LCOM score witnesses a cohesive class whereas a value close to 1 indicates a lack of cohesion and suggests the class might better be split into parts. The coupling of a class to the rest of a program is defined as the degree of its reliance on services provided by other classes [4]. It is measured by the CBO metric (Coupling Between Objects) [3] that counts the classes to which a class is coupled. A well-designed program exhibits *high* average cohesion and *low* average coupling, but it is widely known that these criteria are antinomic hence a trade-off is usually sought.

2.2 Other Design Defects

We choose to illustrate our approach with the Blob because it impacts negatively the two important quality characteristics: such classes show low cohesion and high coupling. Moreover, it is a frequent defect in OO programs. For example, a previous study revealed 1,146 Blobs in the Eclipse IDE [19] even though it is recognised for its quality design.

We observed that an important number of design defects in addition to the Blob are infected by a low cohesion and a high coupling. We count about ten of them such as the Divergent Change [5, page 79], Feature Envy [5, page 80], Inappropriate Intimacy [5, page 85], Lazy Class [5, page 83], Shotgun Surgery [5, page 80], or Swiss Army Knife [28, page 197]. Thus, the approach presented in the following can be applied to these defects in future work.

2.3 Running Example

Our running example (see Figure 1) was inspired by a simple library management system, which includes a Blob described in [28]. The large controller class is the class `Library_Main_Control` which accesses to data of the two surrounded data classes `Book` and `Catalog`.

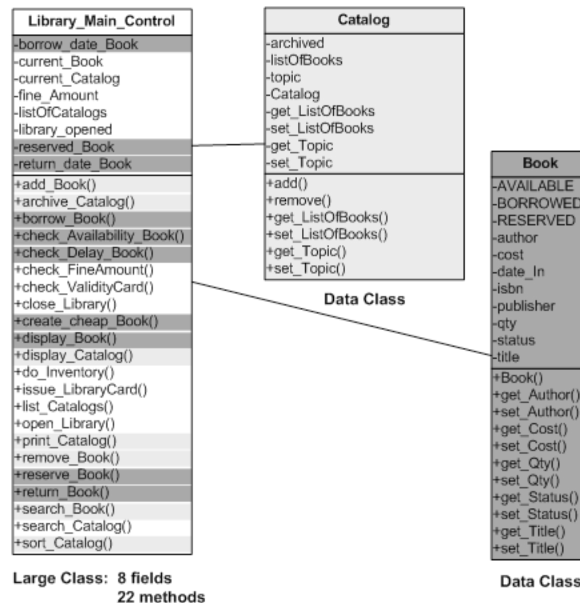

Fig. 1. Library Blob class diagram.

Refactoring a Blob consists in moving class members away from the large controller class to its surrounded data classes or to new classes. For the class

Library_Main_Control, we notice that all methods and fields related to Book or Catalog could be moved to their respective data classes. As a result, data classes gain behaviour and the large class becomes less complex. However, the process of choosing and applying refactoring is long and tedious: Software engineers need to go through all methods and fields of the large class to identify the subsets thereof that form consistent wholes. Yet it is a necessary pain since the result of the process may substantially improve the quality of the program.

3 Relational Concept Analysis

FCA offers a framework deriving conceptual hierarchies from sets of individuals based on the properties these individuals share[4].

3.1 Formal Concept Analysis

FCA describes (formal) concepts both extensionally and intentionally, *i.e.*, as sets of individuals and sets of shared properties, and organizes them hierarchically—according to a generality relation—into a complete lattice, called the concept lattice. The lattice structure allows easy navigation and search as well as optimal representation of information comparable to classical OO requirement of maximal factorisation (each property/individual canonically represented by a unique concept). For instance, the table on the left-hand side of Fig. 2 illustrates a binary context derived from our running Blob class Library_Main_Control. Formal objects are the methods of Blob class whereas formal attributes correspond to method names and the accessed fields[5]. Fig. 3 depicts a simplified (reduced) labeling of the concept lattice derived from this context, yet enriched by additional properties in the way that will be described later in this section.

Formal concepts naturally endow "cohesiveness" because their extents comprise members sharing all the properties from the respective intents. Concept extents are maximal sets for the respective intents because no other individual can be added to an extent without reducing the set of shared properties. When individuals and properties correspond to methods and fields of a given class, the derived concepts represent highly cohesive candidate classes that may replace the original class in order to improve the quality of the OO program. For example, concept ({open_Library(), close_Library()},{W-library_opened}) (concept $c9$ in Fig. 3) could be mapped into a more cohesive class. Furthermore, we would like to consider the links between class members such as method calls (see Fig. 2, on the right) in an attempt to reduce the class coupling in the resulting OO code. For instance, both methods borrow_Book() and reserve_Book() call check_Availability_Book(). Assigning the two first methods to the same class inevitably decreases the class coupling in the OO code. However, grouping

[4] We use *individuals* for *objects* and *properties* for *attributes* to avoid confusion with OO objects and attributes.

[5] The prefixes R- and W- that appear in the field names specify the access mode, *i.e.*, read and write, respectively.

	'add_Book()'	'borrow_Book()'	'check_Availability_Book()'	'check_FineAmount()'	'close_Library()'	'issue_LibraryCard()'	'open_Library()'	'remove_Book()'	'reserve_Book()'	'return_Book()'	'search_Book()'	'sort_Catalog()'	R-current_book	R-fine_amount	W-borrow_date_book	W-library_opened	W-reserved_book	W-return_date_book
add_Book()	X												X					
borrow_Book()		X											X		X			X
check_Availability_Book()			X										X					
check_FineAmount()				X										X				
close_Library()					X											X		
issue_LibraryCard()						X												
open_Library()							X									X		
remove_Book()								X										
reserve_Book()									X								X	
return_Book()										X					X			X
search_Book()											X							
sort_Catalog()												X						

	add_Book()	check_Availability_Book()	check_FineAmount()	remove_Book()
add_Book()				
borrow_Book()		X		
check_Availability_Book()				
check_FineAmount()				
close_Library()				
issue_LibraryCard()			X	
open_Library()				
remove_Book()				
reserve_Book()		X		
return_Book()				
search_Book()				
sort_Catalog()	X			X

Fig. 2. Left: Context of methods. **Right:** Binary relation 'call' between methods.

these two individuals into a formal concept based on the links they share, i.e., the calls of comparable or same methods, is beyond the scope of classical FCA.

3.2 Bringing Relations to Concept Intents

Relational concept analysis (RCA) is an approach for extracting formal concepts from sets of individuals described by properties, called also 'local properties', and links. RCA comes up with formal concepts that are connected in the same way description logics concepts are connected by means of role restrictions involving logical quantifiers. RCA input data are organized within a structure called *relational context family* (RCF) that comprises a set of binary contexts $\mathcal{K}_i = (O_i, A_i, I_i)$ and set of binary relations $r_k \subseteq O_i \times O_j$, where O_i and O_j are the individual sets of $\mathcal{K}_i$ (domain) and $\mathcal{K}_j$ (range), respectively. For instance, the context encoding the access of fields by methods and the binary relation '*call*' that links methods of the Blob with one another form a sample RCF (see Fig. 2). A scaling mechanism is used to translate links into context properties. To that end, relations are interpreted as features whose values are individuals sets, hence the target properties are predicates describing these sets. The predicates are derived from the available concept lattice on the underlying context. Thus, for a given relation seen as a function $r : O_i \rightarrow 2^{O_j}$, new properties, called *relational*, of the form $qr{:}c$, are added to $\mathcal{K}_i$, where c is concept on $\mathcal{K}_j$ and q a scaling operator (comparable to role restriction connectors from description logics). An individual $o \in O_i$ gets a property $qr{:}c$ depending on the relationship between its link set $r(o)$ and the extent of $c = (X, Y)$. The relationship can be either inclusion, *i.e.*, $r(o) \subseteq X$ (called

universal scaling schema, q is $\forall$), or non-empty intersection, *i.e.*, $r(o) \cap X$ (called *existential* scaling schema, q is $\exists$). Formally, given a context $\mathcal{K}_i=(O_i, A_i, I_i)$, a relation $r \subseteq O_i \times O_j$ and the lattice $\mathcal{L}_j$ of $\mathcal{K}_j$, the image of $\mathcal{K}_i$ for the existential scaling operator is: $sc_\exists(\mathcal{K}_i) = (O_i, A_i^+, I_i^+)$, where $A_i^+ = A_i \cup \{\exists r : c | c \in \mathcal{L}_j\}$ and $I_i^+ = I_i \cup \{(o, \exists r : c) | o \in O_i, c = (X, Y) \in \mathcal{L}_j, r(o) \cap X \neq \emptyset\}$). In the present study, as in the vast majority of software engineering applications of RCA, current or anticipated, only the existential scaling is suitable. Hence we shall be systematically omitting the $\exists$ sign in attribute names to keep notations simple.

	call:c0	*call:c2*	*call:c4*	*call:c5*	*call:c6*	*call:c11*
`borrow_Book()`		×	×	×		
`issue_LibraryCard()`				×	×	
`reserve_Book()`		×	×	×		
`sort_Catalog()`	×	×		×		×

Table 1. Scaling of the Blob context along the relation `call`. For space limitation, individuals that are not affected by relational scaling are omitted.

For example, assume methods are scaled along relation *call* regarding the lattice of the context in the left hand side of Fig. 2, which is composed of the concepts $\{c0, c2, c4, c5, c6, c11\}$ and the respective precedence links illustrated in Fig. 3. Since the method `sort_Catalog()` calls the method `add_Book()` which appears in the extent of concepts $c0$, $c2$ and $c5$ and calls the method `remove_-Book()` which belong to the extent of concepts $c11$ and $c5$, the Blob context is extended by the relational properties *call:c0*, *call:c2*, *call:c5* and *call:c11*. Table 1 presents the integration of the relation *call* to the Blob context.

The relational scaling is only one step in the global analysis process which, given a RCF, yields a set of lattices, one per context, called *relational lattice family* (RLF). The RLF is defined as the set of lattices whose concepts jointly reflect *all* the shared properties and links among individuals of the RCF. Its construction is an iterative process because a relational scaling step modifies contexts and thereby the corresponding lattices which in turn may require a new scaling to reflect the newly formed concepts and the link sharing they provoke. Iterations stop whenever a fixed point is reached, *i.e.*, further scaling leaves all the lattices in the RLF unchanged. In the final lattices, a relational property is interpreted as an association between two concepts, the one whose intent it belongs to and the one it refers to explicitly.

Lattice evolution is illustrated within the analysis of the Blob RCF in Fig. 2 using RCA process yields the concept lattice illustrated in Fig. 3. The final lattice of the Blob is different from the initial one due to the relational information inserted into the scaled version of the Blob context. Indeed, the individuals are assigned relational properties that lead to additional property sharing among these. By factoring out the new properties into concept intents, links between

individuals are lifted up to the concept level, yielding relations between concepts[6]. Thus, in Fig. 3, previously existing concepts can be seen getting new properties while completely new concepts emerge. For example, the concept $c16$ which represents the method `sort_catalog()` has been assigned the relational properties *call:c0* and *call:c11* which means that `sort_catalog()` calls methods in the extent of concept $c0$ and $c11$, namely `add_book()` and `remove_book()`. Furthermore, methods `borrow_Book()` (concept $c3$) and `reserve_Book()` (concept $c12$) have top concept as immediate successor in the initial lattice. Their link with the method `check_Availability_Book()` (concept $c4$) has being revealed through scaling. They form a new concept $c19$ (see Fig. 3) which represents the set of methods that call `check_Availability_Book()`.

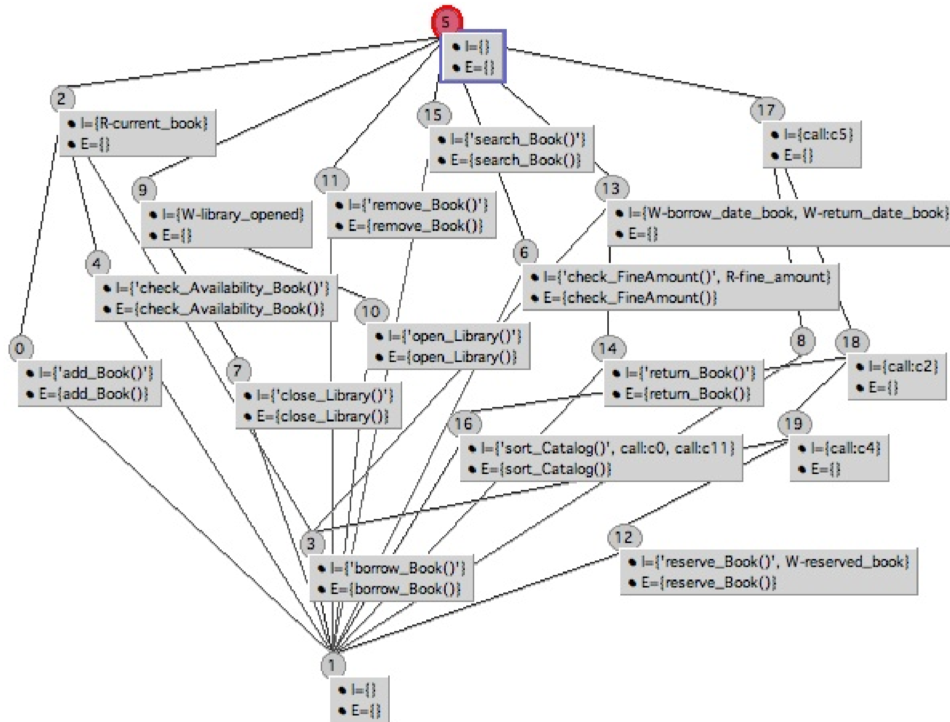

Fig. 3. The lattice of the context of methods shown in Fig. 2.

[6] Observe that for compactness reasons, only non-redundant relational properties are visualized in concept intents, *i.e.*, the ones referring to the most specific concepts.

4 Correction of Design Defects using RCA

Our intuition is that design defects resulting in high coupling and low cohesion could be improved by redistributing class members among existing or new classes to increase cohesion and/or decrease coupling. RCA provides a particularly suitable framework for the redistribution because it can discover strongly related sets of individuals with respect to shared properties and inter-individual links and hence supports the search of cohesive subsets of class members. Fig. 4 depicts our approach for the identification of refactorings to correct design defects in general and the Blob in particular. It shows the tasks of detection of design defects and of correction of user-validated defects.

4.1 Overall process

We define a three-step RCA-based refactoring process that follows a two-step defect detection process. First, we build a model of the program which is simpler to manipulate than the raw source code and therefore eases the subsequent activities of detection and correction. The model is instantiated from a metamodel to describe OO programs. Next, we apply well-known algorithms based on metrics and–or structural data on this model to single out suspicious classes having potential design defects [17]. For each suspicious class, we automatically extract a RCF that encodes relationships among class members from the model of the program. Then, the obtained RCF is fed into a RCA engine which derives the corresponding concept lattices. Finally, the discovered concepts are explored using some simple algorithms, which apply a set of refactoring rules that allow the identification of cohesive sets of fields and methods. The approach suggests a set of refactorings that jointly amount to splitting the Blob into as many classes as there are cohesive sets and merge the content of the surrounding classes with the new classes whenever appropriate.

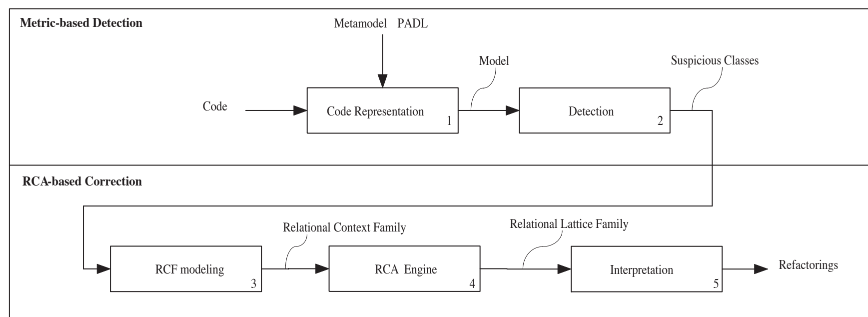

Fig. 4. RCA-based Workflow for the Detection and Correction of Design Defects.

4.2 RCF Extraction

To correct design defects, we need to identify cohesive sets of methods with respect to the mode of usage of fields, *i.e.*, read or write, and call between methods. Hence, the individuals are methods of the large class and properties are its fields. The incidence relation represent the access of fields in read/write mode. In order to differentiate between the two access modes, the prefix -R and -W are added to the name of the fields as illustrated in Fig. 2. Method invocations within the large class are encoded by a dedicated inter-individuals relation denoted *call* (see table in the left hand side of Fig. 2).

The formal attributes were derived from names of methods and added to the method context. These attributes allow the emergence of a single concept for each method, called *method concept*[7], in the corresponding lattice. Beside listing the entire set of properties of a given method, the concept method helps preserving one-to-one invocation between methods. These details can be lost during the scaling step that aims at integrating the relation *call* into the context of the large class by substituting one-to-many invocations for those of type one-to-one.

4.3 Deriving the lattice

Fig. 3 represents the concept lattice obtained by the RCF engine from the context given in Fig. 2. The concepts of the lattice represent the refactoring opportunities of the design defect. Indeed, concepts such as $c9$ exhibit group of methods using the same sets of fields and fields used by cohesive sets of methods. These concepts are considered as class candidates because they are cohesive. In addition, concepts such as $c3$ and $c12$ highlight subsets of cohesive methods, because methods calling the same set of other methods are highly cohesive. A third category of concepts such as $c9$ and $c13$ represent the *use-relationship* between methods of the large class and the surrounding data classes. The study of these concepts allow to assess the coupling between the large class and its surrounding data classes. Thus, we can identify which methods and fields of the large class should be moved to surrounding classes.

4.4 Suggesting Refactorings

The RLF of the Blob is used to interpret the inner structure of the Blob and then suggest refactorings. More specifically, we apply algorithms looking for concepts that reflect the presence of highly cohesive and weakly coupled sets. Intuitively, shared usages of fields and calls of methods is a sign of cohesion whereas coupling is directly expressed by the reliance of a method on a surrounding class (method and/or field). Following these design guidelines, we correct the Blob in two ways. First, we move disjoint and cohesive subsets of methods and/or fields that are related to a data class in that data class. Two refactorings describe such migration between classes: *Move Method* [5, p.142] and *Move Field* [5, p.146].

[7] The smallest extent in the lattice containing this method.

Second, we organise cohesive subsets that are not related to data classes in separate classes. In addition to the two previous refactorings, we use the refactoring *Extract Class* [5, p.149], which consists in creating a new class and moving the chosen fields and methods from the old class to the new class using the two first previous refactorings.

We have specified three refactoring rules to build incrementally cohesive sets by visiting the concept lattice of methods[8]. These rules are applied in a row, i.e., we apply the two first rules that deal with the access of fields by methods in read/write mode and then rule that handle method calls.

Rule 1. Methods accessing in write mode the same set of fields are gathered in a single cohesive set.

Rule 2. Methods accessing in read mode the same set of fields are gathered in a single cohesive set if the number of common fields which they access is higher than the number of fields they access separately.

Note that these two rules are inspired from the object identification approach described in [23] where grouping of methods is based on the accessed fields, with respect to the number of fields they access separately. The obtained cohesive sets are merged according to the following rule:

Rule 3. Methods that call the same set of methods are put in a single cohesive set if the number of jointly called methods is higher than the number of methods called separately.

For instance, applying the three previous rules on the running example of the Library blob class, we obtain several cohesive sets as illustrated in Fig. 5, on the left. The cohesive sets that should be migrate in the data classes are shown in Fig. 5 on the right. This last step is currently performed manually but planned to be automated.

5 Experimental Study

We use PADL [10] to model source code and Galicia, v.2.1, to construct and visualize the concept lattices. PADL is the meta-model at the heart of the Ptidej tool suite (*Pattern Trace Identification, Detection, and Enhancement in Java*) [8]. Galicia is a multi-tool open-source platform for creating, visualizing, and storing concept lattices [20]. Both tools communicate by means of XML files describing data and results. Thus, an add-on to Ptidej generates contexts in the XML format of Galicia, which are then transformed by the tool into lattices and shown on screen for exploration.

In order to validate the proposed approach for the detection and correction of Blob design defects, we consider an open source program: Azureus version

[8] We provide the implementation details of these rules in an Appendix.

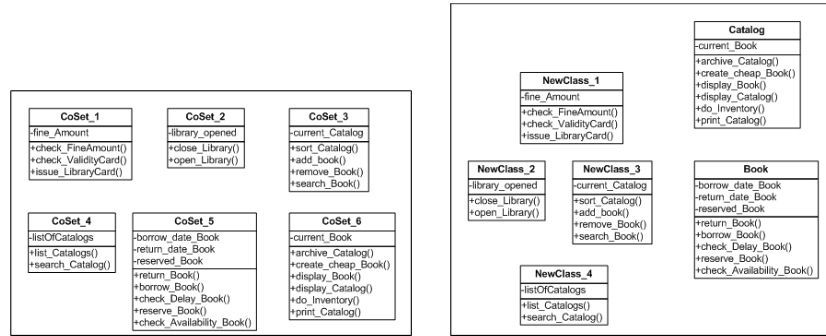

Fig. 5. Left: The cohesive sets obtained from class `Library_Main_Control` depicted in Fig. 1 . **Right:** Moving these cohesive Sets to existing data-classes or new-classes.

2.3.0.6. We use a *freely available* program to ease comparisons and replications of our experiments. Azureus version 2.3.0.6 (201,916 lines of code, 1,626 classes, 561 interfaces) is a peer-to-peer client implementing the BitTorrent protocol with a comprehensive user-interface and extension mechanisms. We choose Azureus because it has been heavily changed and maintained since its first release in July 2003. The addition of new features, optimisations, and bugs fixes have introduced design defects.

We found 41 Blobs in Azureus by applying detection algorithms. We notice that the underlying classes are difficult to understand, maintain, and reuse because they have a large number of fields and methods. For example, the class `DHTTransportUDPImpl` in the package `com.aelitis.azureus.core.dht.-transport.udp.impl`, which implements a distributed sloppy hash table (DHT) for storing peer contact information over UDP, has an atypically large size. It declares 42 fields and 66 methods for 2,049 lines of code. It has a medium-to-high cohesion of 0.542 and a high coupling of 81 (8th highest value among 1,626 classes). The data classes that surround this large class are: `Average`, `HashWrapper` in package `org.gudy.azureus2.core3.util` and `IpFilterManagerFactory` in package `org.gudy.azureus2.core3.ipfilter`. Table 2 provides the results of applying our rules on three different Blobs classes detected in Azureus. It is noteworthy that the results provided by our method have been assessed manually: Among the set of all cohesive sets in the output we identified those whose semantics could be clearly established and it confirmed their cohesiveness. A measure for the precision of our method is the ratio of the really cohesive sets to the total number of sets output by the method. As Table 2 indicates, the precision may vary within a wide range (from 30 to 70 % of correct guesses).

The cohesive sets suggested by our method include an important number of small cohesive sets, which include generally at most one field and one or two methods. This explains why we did not get a good precision. The other concise

sets gather between 10 and 20 fields/methods and are good candidates for the creation of new classes because they define a specific responsibility or semantics.

To increase the robustness of our method, we need to define additional rules related to the access of fields and methods by methods not only within one class but also located in other associated classes. Moreover, our analysis is purely static. Thus, we need to enhance our method with a dynamic analysis to preserve the behavior of the program. Finally, the restructuring should be semi-supervised by an expert because only experts could assess the relevance of grouping elements. The method should be seen as a support for restructuring huge number of data. Thus, we share Snelting's opinion that an interactive restructuring performed by the software engineer is more appropriate.

Blob Class	Size (number of fields and methods)	Lines of code	Cohesion	Coupling	Number of fields and methods moved	Number of cohesive sets	Number of real cohesive sets
`DHTTransportUDPImpl`	(42+66) 108	2,049	0.542	81	(27+32) 59	10	7
`DHTControlImpl`	(47+80) 127	1,868	0.52	67	(35+62) 97	19	11
`TRTrackerBTAnnouncerImpl`	(36+47) 83	1,393	0.948	54	(24+33) 57	16	5

Table 2. Blob Classes in Azureus and the Number of Cohesive Sets

6 Related Works

Few studies have explored the semi-automatic correction of design defects. Thus, we only sketch work related to design defects and to the use of FCA in software maintenance.

Sahraoui et *al.* in [23] describe an approach and algorithms for identifying objects in procedural code. This approach uses artificial intelligence techniques and includes the five following steps: first, some metrics such as the number of routines or the number of global variable are calculated to determine the profile of the application analyzed. The profile allows to choose the abstraction method the most appropriated for the identification of objects such as reference graphs, routine interdependence graphs, or type visibility graphs. Then, objects are identified using different FCA algorithms of graph decomposition and formation of concepts. The third step consists in identifying the methods of these objects. Relations between objects such as associations and generalisations are found in the fourth step. Finally, the procedural program is transformed using the object model determined.

Snelting and Tip [24] proposed a method based on concept analysis for analyzing the usage of a class hierarchy. They studied how the members of a class

hierarchy are used in the executable code of a set of applications by examining relationships between variables and class members, and relationships among class members. This method allows the identification of anomalies in the design of class hierarchies such as class members that are redundant or that can be moved into a derived class. In contrast, we detect design defects at a higher level and specified in the literature. Moreover, we are not only interested in defects that could arise within class hierarchies only, but also among a set of classes with association relationships.

Godin and Mili [7] used gallois lattices for the class hierarchy redesign using the signatures of classes. The starting point in their approach is a set of interfaces of classes. A binary table is built representing for each interface the set of methods supported. The lattice derived from this table shows how the hierarchy of classes implementing these interfaces has to be organised to optimise the repartition of methods in the hierarchy.

Marinescu [16] presented an approach based on metrics for detecting design defects in the form of *detection strategies*. In essence, metrics-based rules capture deviations from good design principles and heuristics. The advantage lies in the combination of different metrics through filtering and composition. However, metrics alone can hardly detect a design flaw because the *structure* of a design is not measurable. In our approach, we combine different metrics for the detection of design defects with a clustering and visualisation technique, FCA, that allows the design structure to be fully comprehended.

Our work is closed to Kirk's *et al.* work [12] but in their work, they use the technique of attribute slicing to refactor large classes. Attribute slicing is a form of decomposition slice based on the attributes or fields of a class. They identify and split a large class on the basis of the usage made by the methods of the attributes, *i.e.*, if there are subsets of methods which use distinct subsets of attributes, then they identify a class composed of different abstractions and should be refactored into a number of smaller classes. They concentrated on identifying only the Large Class code smell and thus, their approach is applied at a local scope, *i.e.*, within a class. They did not interested in defects that involve several classes such as the Blob and relationships or dependencies between methods. However, an interesting advantage of their approach is that attribute slicing can be applied at the method level but also at the intra-method level. An intra-method level attribute slice takes into account the detailed control structure of a method, and thus, returns only the instructions that updates or manipulates the attribute. Their approach needs yet to be implemented and validated into larger examples.

Tonella and Antoniol used FCA to infer recurring patterns in models of programs [26]. They obtained significant results in inferring groups of classes having common structural relations without using any library of patterns. However, their approach seems of limited interest to the detection of design defects, because it can detect only structural relations, whereas design defects are often characterised by measurable properties (*e.g.*, a large class has *a large number* of

fields and methods). FCA is not focused on numerical measurement and hence needs some assistance from metrics-based techniques.

Arévalo *et al.* applied FCA to identify implicit dependencies among classes in program models [1]. They build models from source code and extract contexts from thee models. Concepts and lattices generated from the contexts with the ConAn engine are filtered out to build a set of views at different levels of abstraction. At the class level, views show the access of the state by the methods and the patterns of calls among methods in a class and, hence, help to assess the cohesion of the class. At the class hierarchy level, based on the different dependencies among classes of a hierarchy, views highlight common and irregular forms of hierarchies to deduce possible refactorings. At the program level, they refined and extended the approach of Tonella *et al.* to any (recurring) regularities such as design patterns, architectural constraints, idioms, etc. Our approach is similar in that it uses FCA to detect flaws, but our choices of the elements and properties to be analysed are guided by the descriptions of design defects.

7 Conclusion

We proposed an approach to use RCA to suggest appropriate refactorings to correct certain design defects. In particular, we showed how our approach can help refactoring programs with Blob design defects. Unlike other FCA-based restructuring approaches, we worked on whole lattice regions rather than on separate concepts because candidate refactoring are inferred from several concepts in the lattice. We illustrated our approach using an example of a Library management system and validated it on Azureus v2.3.0.6. We showed that using RCA, our approach could suggest relevant refactorings to improve the program. The generalisation of our results to other design defects is briefly discussed and will be developed in future work. Future work will also include assessing of our approach more programs and discussing the proposed refactorings with their developers and apply them. We also plan to performed quantitative studies on the trade-off between cohesion and coupling.

References

1. Gabriela Arévalo. *High Level Views in Object Oriented Systems using Formal Concept Analysis.* PhD thesis, University of Berne, January 2005.
2. Jan Verelst Bart Du Bois and Serge Demeyer. Refactoring - improving coupling and cohesion of existing code. In *Proceedings of the 11th IEEE Working Conference on Reverse Engineering*, pages 144–151, 2004.
3. Shyam R. Chidamber and Chris F. Kemerer. A metrics suite for object oriented design. *IEEE Transactions on Software Engineering*, 20(6):476–493, 1994.
4. Norman Fenton and Shari Lawrence Pfleeger. *Software metrics (2nd ed.): a rigorous and practical approach.* PWS Publishing Co., Boston, MA, USA, 1997.
5. Martin Fowler. *Refactoring – Improving the Design of Existing Code.* Addison-Wesley, 1st edition, June 1999.

6. R. Godin and P. Valtchev. Formal concept analysis-based normal forms for class hierarchy design in oo software development. In R. Wille B. Ganter, G. Stumme, editor, *Formal Concept Analysis: Foundations and Applications*, chapter 16, pages 304–323. Springer Verlag, 2005.
7. Robert Godin and Hafedh Mili. Building and maintaining analysis-level class hierarchies using galois lattices. In *Proceedings of the eighth annual conference on Object-oriented programming systems, languages, and applications (OOPSLA '93)*, pages 394–410, New York, NY, USA, 1993. ACM Press.
8. Yann-Gaël Guéhéneuc. A reverse engineering tool for precise class diagrams. In Janice Singer and Hanan Lutfiyya, editors, *Proceedings of the* 14th *IBM Centers for Advanced Studies Conference*, pages 28–41. ACM Press, October 2004.
9. Yann-Gaël Guéhéneuc and Hervé Albin-Amiot. Using design patterns and constraints to automate the detection and correction of inter-class design defects. In Quioyun Li, Richard Riehle, Gilda Pour, and Bertrand Meyer, editors, *Proceedings of the* 39th *conference on the Technology of Object-Oriented Languages and Systems*, pages 296–305. IEEE Computer Society Press, July 2001.
10. Yann-Gaël Guéhéneuc and Hervé Albin-Amiot. Recovering binary class relationships: Putting icing on the UML cake. In Doug C. Schmidt, editor, *Proceedings of the* 19th *Conference on Object-Oriented Programming, Systems, Languages, and Applications*, pages 301–314. ACM Press, October 2004.
11. Marianne Huchard and Hervé Leblanc. Computing interfaces in java. In *ASE*, pages 317–320, 2000.
12. Douglas Kirk, Marc Roper, and Neil Walkinshaw. Using attribute slicing to refactor large classes. In David W. Binkley, Mark Harman, and Jens Krinke, editors, *Beyond Program Slicing*, number 05451 in Dagstuhl Seminar Proceedings. Internationales Begegnungs- und Forschungszentrum fuer Informatik (IBFI), Schloss Dagstuhl, Germany, 2006. <http://drops.dagstuhl.de/opus/volltexte/2006/490> [date of citation: 2006-01-01].
13. Michele Lanza. CodeCrawler—Lessons learned in building a software visualization tool. In Mark van den Brand and Tibor Gyimothy, editors, *proceedings of the* 7th *Conference on Software Maintenance and Reengineering*, pages 409–418. IEEE Computer Society Press, March 2003.
14. Michele Lanza. *Object-Oriented Reverse Engineering – Coarse-grained, Fine-grained, and Evolutionary Software Visualization*. PhD thesis, Institute of Computer Science and Applied Mathematics, May 2003.
15. Radu Marinescu. *Measurement and Quality in Object-Oriented Design*. PhD thesis, Politehnica University of Timisoara, October 2002.
16. Radu Marinescu. Detection strategies: Metrics-based rules for detecting design flaws. In *Proceedings of the* 20th *International Conference on Software Maintenance*, pages 350–359. IEEE Computer Society Press, 2004.
17. Naouel Moha, Yann-Gaël Guéhéneuc, and Pierre Leduc. Automatic generation of detection algorithms for design defects. In Sebastian Uchitel and Steve Easterbrook, editors, *Proceedings of the* 21st *Conference on Automated Software Engineering*. IEEE Computer Society Press, September 2006. Short paper.
18. Naouel Moha, Jihene Rezgui, Yann-Gaël Guéhéneuc, Petko Valtchev, and Ghizlane El Boussaidi. Using FCA to suggest refactorings to correct design defects. In Sadok Ben Yahia and Engelbert Mephu Nguifo, editors, *Proceedings of the* 4th *International Conference on Concept Lattices and their Applications*. IEEE Computer Society Press, September 2006. Short paper.
19. Object Technology International / IBM. Eclipse platform – A universal tool platform, July 2001.

20. University of Montreal. Galicia, September 2005. http://sourceforge.net/projects/galicia/.
21. Daniel Raţiu, Stéphane Ducasse, Tudor Gîrba, and Radu Marinescu. Using history information to improve design flaws detection. In Claudio Riva and Gerardo Canfora, editors, *proceedings of the* 8th *Conference on Software Maintenance and Reengineering*, pages 223–232. IEEE Computer Society Press, March 2004.
22. Arthur J. Riel. *Object-Oriented Design Heuristics*. Addison-Wesley, 1996.
23. Houari A. Sahraoui, Hakim Lounis, Walcélio Melo, and Hafedh Mili. A concept formation based approach to object identification in procedural code. *Automated Software Engg.*, 6(4):387–410, 1999.
24. Gregor Snelting and Frank Tip. Understanding class hierarchies using concept analysis. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, 22(3):540–582, 2000.
25. Open source project. Azureus, June 2003.
26. Paolo Tonella and Giulio Antoniol. Object oriented design pattern inference. In Hongji Yang and Lee White, editors, *Proceedings of the* 7th *International Conference on Software Maintenance*, pages 230–240. IEEE Computer Society Press, August 1999.
27. Adrian Trifu and Iulian Dragos. Strategy-based elimination of design flaws in object-oriented systems. In Serge Demeyer, Stéphane Ducasse, and Kim Mens, editors, *proceedings of the* 4th *international Workshop on Object-Oriented Reengineering*. Universiteit Antwerpen, July 2003.
28. Hays W. McCormick III Thomas J. Mowbray John Wiley & Sons Inc. William J. Brown, Raphael C. Malveau. *AntiPatterns – Refactoring Software, Architectures, and Projects in Crisis*. Robert Ipsen, 1998.

Appendix

Implementing Rule 1. We iterate the lattice and record all concepts related to fields with the prefix `'W-'`. We mark all these concepts as visited. We sort this list in reverse order by the number of fields with `'W-'`. Thus, fields that are accessed in write mode by a high number of methods are processed first. For example, the concept $c3$ in Fig. 3 is processed first because of the related concept $c13$. For each concept of the list, we create a new cohesive set and apply the method applyRuleWrite(). This method consists in moving the current(s) field(s) (`borrow_date_book` et `return_date_book` in concept $c13$) with the refactoring *Move Field* and for each method in the intent of the current concept (`borrow_Book()`) that has not yet been included in a set (*i.e.*, not yet visited), we move it to the current cohesive set using the refactoring *Move Method*. Then, recursively, we check the parents of the current concept and the children of a parent if interesting to explore. The children of a parent are interesting to explore if the parent contains at least one `'W-'` field also contained by the current concept. For example, only the children of the parent $c13$ of the concept $c3$ are interesting to explore. We reapply the rule applyRuleWrite() on the children.

Implementing Rule 2. This rule consists in finding the best cohesive set of methods that access to a common set of fields in read mode. For each concept related to common fields in read mode and not yet visited *i.e.*, not processed when applying the rule 1, and thus not included in a set, we calculate a ratio. The ratio corresponds to the number of fields in common with their total number of fields. We calculate the mean of all the ratios corresponding to each concept and retain only groups of concepts that have a mean higher than 0.5 *i.e.*, concepts whose methods accessing a common number of fields is higher than their own number of fields in average. We obtain thus a list of candidate sets of concepts that we sort in reverse order to process first concepts with a better ratio. For each sets of concepts, we create a new cohesive set by moving the methods and fields with the respective appropriate refactorings (*Move Field* and *Move Method*).

Implementing Rule 3. This rule is similar to rule 2. The difference is that we identify common methods called by one or several methods of the resulting cohesive sets built from rules 1 and 2. We calculate also a ratio and select the best candidates, and then merge the cohesive sets according to the value of their ratio.