Identifying Architectural Problems through Prioritization of Code Smells

Santiago Vidal*, Everton Guimaraes†, Willian Oizumi‡, Alessandro Garcia§, J. Andres Díaz-Pace¶ and Claudia Marcos||
*ISISTAN-CONICET, Argentina
Email: svidal@exa.unicen.edu.ar
†UNIFOR, Brazil
Email: eguimaraes@unifor.br
‡PUC-Rio, Brazil
Email: woizumi@inf.puc-rio.br
§PUC-Rio, Brazil
Email: afgarcia@inf.puc-rio.br
¶ISISTAN-CONICET, Argentina
Email: adiaz@exa.unicen.edu.ar
||ISISTAN-CIC, Argentina
Email: cmarcos@exa.unicen.edu.ar

***Abstract*—Architectural problems constantly affect evolving software projects. When not properly addressed, those problems can hinder the longevity of a software system. Some studies revealed that a range of architectural problems are reflected in source code through code smells. However, a software project often contains thousands of code smells and many of them have no relation to architectural problems. Unfortunately, state-of-the-art techniques fall short in assisting developers on the prioritization of architectural problems reified as code smells in the implementation. As a consequence, developers struggle to effectively determine which (groups of) smells are architecturally relevant, i.e., those smells contributing to critical design problems. This work presents and evaluates a suite of criteria for prioritizing groups of code smells as indicators of architectural problems in evolving systems. These criteria are supported by a tool called *JSpIRIT*. We have assessed the prioritization criteria in the context of more than 23 versions of 4 systems, analyzing their effectiveness for detecting symptoms of architectural problems. The results provide evidence that one of the proposed criteria helped to correctly prioritize more than 80 architectural problems in our top-7 rankings, alleviating tedious manual inspections of the source code vis-a-vis with the architecture. This prioritization criteria would have helped developers to discard at least 500 code smells having no relation to architectural problems in the analyzed systems.**

I. Introduction

Software systems usually suffer from architectural problems introduced either during development or along their evolution. Several systems have been restructured with high costs or even discontinued due to the constant occurrence of architectural problems [1], [2], [3], [4]. Many architectural problems occur when one or more components of a system are violating design principles or rules [2]. These violations negatively affect the maintainability and other quality attributes of a system [2], [5]. Typical examples of architectural problems are Fat Interface and Unwanted Dependency between components [6], [1]. The former violates the principle of separation of concerns [2], while the latter violates a dependency rule in the system's architecture [1]. Both of them often impair software performance and maintainability [2].

Unfortunately, the identification of architectural problems is time-consuming and cumbersome for several reasons. The identification generally requires the analysis of both architectural documentation and the realization of architecture decisions in source code. It is hard for a developer to effectively explore these two types of information altogether in order to uncover architectural problems. Architecture documentation is often informal and scarce. Even when architecture information is available, it is often not detailed enough to help developers to detect architectural problems, such as Fat Interfaces and Unwanted Dependencies [2], [7], [5]. Thus, developers need to find hints in the source code that indicate architectural problems. It has been found that well-known anomalies in the source code – popularly known as *code smells* [8] – often provide partial hints of the location of architecture problems in a system [9], [5] (Section II). Classical examples of code smells often related to architectural problems are Long Method, God Class and Feature Envy [10].

A wide range of architectural problems are often realized by a subgroup of code smells scattered in the source code, which makes their detection even more challenging [9], [10], [5]. Even for small systems, developers would need to analyze hundreds of code smells and infer their likelihood of indicating an architectural problem. As those systems evolve, the number of smells tend to grow across system versions, thereby further obscuring the location of architectural problems in a program. In such situations, developers do not know where to focus on, i.e. which code smells may be indicators of architectural problems and thus should be targets for refactorings. A more practical strategy is to prioritize groups of code smells according to their criticality to the system architecture, that is, their ability to point out architectural problems. Unfortunately, existing work (Section II) does not support developers on automatically prioritizing code smells to reveal architectural problems. Even worse, they do not establish any criteria to guide developers on locating architectural problems in their program structure.

In this context, we propose and implement a suite of three scoring criteria for prioritizing code smells (Section IV). The goal is to constrain the search of developers by reducing the amount of candidates of program locations possibly containing architectural problems in their systems. Our criteria are centered on the notion of *agglomerations* of code smells, a concept defined in our previous work [7], [5]. Agglomerations are groups of inter-related code smells (e.g., syntactically-related code smells within a component) that likely indicate together the presence of an architectural problem (Section III). However, our previous work [7], [5] did not address the key challenge of prioritizing smell agglomerations that indicate architectural problems. In order to rank agglomerations according to their harmful impact on the architecture, the criteria proposed in this article consider both the implementation and architectural information that is available, including the versioning history of a system (Section IV). The goal is to assist developers in: (i) encountering agglomerations that likely indicate architectural problems, and (ii) for each architectural problem, identifying its full extent in the source code by inspecting the group of smells comprising a prioritized agglomeration, while discarding irrelevant smells.

We assess how each of the three criteria helps developers to locate symptoms of architectural problems in source code, while keeping aside irrelevant code anomalies. Our study considered more than 23 versions of 4 Java systems (Section V). Furthermore, one of the systems had a very large size (˜1400 classes and ˜1800 code smells) so as to test the scalability of our approach. Our results (Section VI) suggest that the use of one of the criteria can consistently and accurately indicate several architectural problems. They helped to correctly locate more than 80 architectural problems in our top-7 rankings of the 4 systems, alleviating tedious manual inspections of the source code vis-a-vis with the architecture. This prioritization criterion would have also helped developers to discard at least 500 code smells having no relation to architectural problems in the analyzed systems. At the end, we reflect upon these findings and present concluding remarks (Section VII).

II. Related Work

As far as we are aware of, our investigation represents the first effort in supporting the prioritization of architecturally-relevant code smells. Architectural problems have been the focus of various recent studies (e.g. [2], [3], [4]), including a catalog documenting them [2]. However, existing work rarely provides support for locating and prioritizing such problems in the source code. In addition, they tend to assume that a detailed architecture documentation is always available, which is rarely the case. Case studies also mostly focus on reporting the severe impact of architectural problems, such as Fat Interfaces and Unwanted Dependencies, on the longevity of industrial software systems (e.g. [3], [4]). In [11], five types of architectural problems are presented and formalized. These problems can be detected in Design Structure Matrices (DSMs). Two of such problems are based on the analysis of history information, while the other three problems are inferred from the source code structure. The authors show a correlation of these problems with both high frequencies of bugs and major maintenance effort. However, none of these works assists developers in the prioritization of code smells with the goal of identifying and prioritizing architectural problems. We have observed in our study that the use of project history information alone, albeit useful, is of limited applicability (Section VI-B).

Other studies have investigated the impact of *single code smells* throughout system evolution [12], [13]. They analyzed whether the number of smells increased or decreased over time, and how often they resulted in code refactorings intended to improve the system design. In other recent studies [9], [14], [15], the authors report on the relevance of code smells for the identification of architectural problems. As main findings, they observed that tracking of individual code smells without regarding the occurrence of other smells do not suffice to assist developers in revealing architectural problems. Each anomaly only provides a partial realization of an architectural problem. Each architectural problem tended to be realized by seven or more code smells. In addition, a very high proportion of individual smells (i.e. those smells detached from other anomalies in the system) did not impact on the architecture.

Only a few studies have gone beyond and looked at groups of code smells as indicators of architectural problems. The concept of agglomerations was presented in our recent work [5] to capture a group of inter-related code anomalies. The work confirmed that agglomerations are much better indicators of architectural problems than non-agglomerated code smells. However, the results also showed that several agglomerations are not related to any architectural problem. As a result, there is a pressing need for supporting the prioritization of agglomerations that are related to architectural problems. In [16] the authors only documented a few relationships among code smells that may be related to four architecture problems. However, to the best of our knowledge, no work has yet investigated strategies for prioritizing groups of code anomalies. In this way, this is the first work that proposes, implements, and evaluates a criteria for prioritizing agglomerations aimed at locating architectural problems. Existing tools do not provide any support for these tasks [9], [15], [16], [17], [18], [19]. They normally only consider the source code structure, disregarding architectural information. Even worse, the users also cannot use, define or customize their own criteria for prioritizing code-smell agglomerations. We address all these gaps in the study reported in this article.

III. Agglomerations as Pointers to Architectural Problems

In the context of our work, we focus on architectural problems [2] that represent violations of design principles or rules [2], [20]. We mainly target problems affecting the modular decomposition of a system into components and their interfaces, i.e., modifiability-related problems [2]. Based on previous empirical findings (Section II), the premise is that groups of code smells, so-called *agglomerations*, are normally associated with several architectural problems.

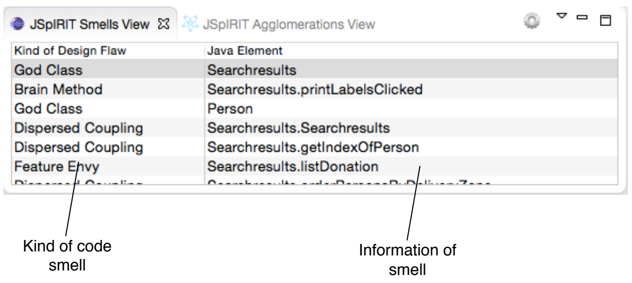
A. Illustrative Example

In order to illustrate the link between architectural problems and agglomerations, let us consider the example of Fig. 1. The left side of the figure shows a fragment of the component structure of the MobileMedia architecture – a system for managing photos, music and videos in mobile devices. Components *Controller* and *UI* are mapped to separate Java packages in the implementation, each one containing several classes (right side). If a static analysis tool is run over the implementation of these components, the developer will receive a list of more than one hundred code anomalies. Then, it may not be clear which code smells should be the focus of her attention as candidates for revealing architectural problems in those components, which prevents her from performing effective maintenance or refactoring activities.

Architectural Problems. This example reveals three architectural problems. First, the *Controller* component is mainly realized by the class hierarchy rooted at class *AbstractController*, which is responsible for handling different commands through the *handleCommand* method. After a broad look at all the anomalous implementations of method *handleCommand* and their callers, the developer realizes that there is an overload of responsibilities, which leads to two architectural problems, called Fat Interface and Ambiguous Interface [2]. These problems mean that *Controller*, as an architectural component, provides several non-cohesive services (Fat Interface) that are not properly exposed in its interface *handleCommand* (Ambiguous Interface). Note that the problem is not the controller itself or its object-oriented materialization in terms of an abstract class with many concrete classes, but rather the decision of having only one single controller (at the architecture level), which can generate ripple effects to other components and their implementations if the controller logic has to be changed. Second, the call from class *PhotoViewController* to class *AlbumListScreen* leads to a usage dependency between packages *Controller* and *UI*, which is not allowed by the component architecture. This violation is indicated in the architecture (left side) by the absence of arrows between the two components.

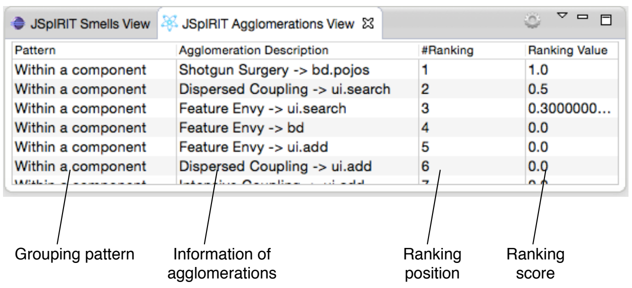
In these examples, a possible way for a developer to identify the architectural problems is by reasoning about the architecture documentation and checking candidate problems in the source code. Unfortunately, developers are usually overwhelmed by these tasks because, even with tool support, it is hard to effectively explore all the available information and all code smells in order to uncover architectural problems. In these cases, the developer needs to turn her attention to the (partial or full) realization of architectural problems in the source code. Along this line, she might discover that the implementations of *handleCommand* in the subclasses of *AbstractController* are simultaneously affected by the code smell called Dispersed Coupling (DC), which is a method that calls various methods of several classes. That is to say that the subclasses of *AbstractController* generate dependencies on many other classes. Since there are several DC anomalies within the *Controller* package, this group of anomalies is considered as an agglomeration. Therefore, this package-level agglomeration is a sign of (potential) architecture decay [2], which in this case affects the *Controller* component.

However, the developer cannot be fully sure about the architectural problem exposed by the agglomeration of DC smells, as it could be a false positive. Other agglomerations can be present nearby, as it is the case of a group of instances of the smell called Feature Envy (FE) in package *UI*, which corresponds to the *UI* component. FE is a smell representing a class that is more interested in accessing data from other classes (instead of using its own data), which often indicates a poor assignment of responsibilities. Things get further complicated for the developer because agglomerations normally vary from a system version to another. These two factors (false positives and variations over time) motivate our interest in the definition of criteria for prioritizing agglomerations.



Kind of Design Flaw	Java Element
God Class	Searchresults
Brain Method	Searchresults.printLabelsClicked
God Class	Person
Dispersed Coupling	Searchresults.Searchresults
Dispersed Coupling	Searchresults.getIndexOfPerson
Feature Envy	Searchresults.listDonation

(a) Code anomalies



Pattern	Agglomeration Description	#Ranking	Ranking Value
Within a component	Shotgun Surgery -> bd.pojos	1	1.0
Within a component	Dispersed Coupling -> ui.search	2	0.5
Within a component	Feature Envy -> ui.search	3	0.3000000...
Within a component	Feature Envy -> bd	4	0.0
Within a component	Feature Envy -> ui.add	5	0.0
Within a component	Dispersed Coupling -> ui.add	6	0.0

(b) Agglomerations

Fig. 2: *JSpIRIT* outputs

B. *Detecting Individual Code Smells*

Existing catalogs of code smells define guidelines to identify single smells and how to provide tool support for their detection [8], [21]. In this work, we use the *JSpIRIT*[1] tool for that purpose. *JSpIRIT* is an Eclipse plugin for detecting code smells of a (Java-based) system and ranking them according to different criteria [19]. Fig. 2a shows the view of *JSpIRIT* that lists the code smells for a system. Currently, *JSpIRIT* supports the identification of 10 single smells (such as Feature Envy, Brain Method, and Disperse Coupling)[2] [19] following the detection strategies presented in Lanza's catalog [21].

C. *Agglomerations as Architectural Problems*

The original version of *JSpIRIT* was extended to support the detection of agglomerations. Fig. 2b shows a list of agglomerations detected on the basis of the smells of Fig. 2a. Since our work focuses on architectural information regarding static code structures, we worked with agglomerations within the scope of architectural components. For our case-studies (Sections V and VI), we assumed a relation (or mapping) between an architectural component and its realization as a Java package in the code. However, developers can flexibly establish other kinds of mappings between components and packages/classes in a program. We are mainly interested in two particular patterns for grouping code anomalies, which are briefly described next.

- **Anomalies within a component.** This grouping pattern identifies code smells that are implemented by the same architectural component. Specifically, we look for one single component with: (i) code smells that

[1]https://sites.google.com/site/santiagoavidal/projects/jspirit

[2]A complete list of the supported code smells can be found at http://eguimaraes15.github.io/

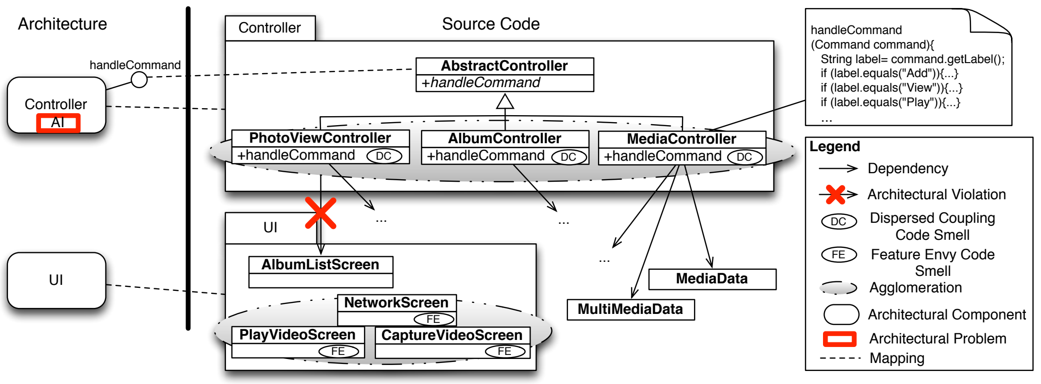

```
handleCommand
(Command command){
  String label= command.getLabel();
  if (label.equals("Add")){...}
  if (label.equals("View")){...}
  if (label.equals("Play")){...}
  ...
```

Fig. 1: Example of a code-smell agglomeration related to architectural problems

are syntactically related, or (ii) code elements infected by the same type of code anomaly. Two classes are syntactically related if at least one of them references the other one. Fig. 1 showed an example of this kind of agglomeration where different classes in package *UI* are affected by the Feature Envy (FE) anomaly.

- **Anomalies in a hierarchy.** This grouping pattern identifies code smells that occur across the same inheritance tree involving one or more components. We only consider hierarchies exhibiting the same type of code smell. The rationale is that a recurring introduction of the same smell in different code elements might represent a bigger problem in the hierarchy. An example of this agglomeration is the *AbstractController* hierarchy in Fig. 1 whose subclasses are affected by Dispersed Coupling (DC) smells.

A more complete description of the above agglomerations can be found in [22]. Certainly, other types of agglomerations are possible, as reported in [5], but they are related to other architectural problems not addressed in this article.

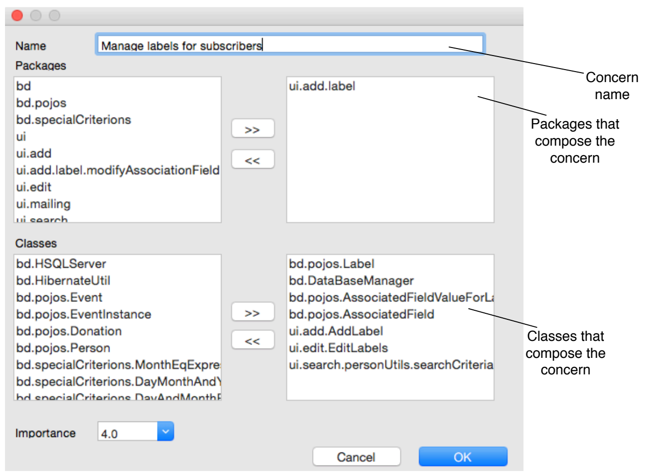
IV. Prioritization Approach

In this section, we present three criteria to prioritize agglomerations by means of scoring criteria. The proposed criteria were implemented in *JSpIRIT*. Our hypothesis is that these criteria are useful for prioritizing those agglomerations with high chances of spotting architectural problems. In this way, a criterion can be seen as a function:

$$criterion_A(agglomeration_B) = score_{A,B}$$

where the score for an agglomeration B given by a criterion A is a value between 0 and 1[3]. The score value indicates how critical the agglomeration is for the system architecture (0=no critical, 1=very critical). In particular, we began working with a criterion based solely on architectural information (namely, architectural concerns). Later, we developed two additional criteria based on the combination of the code versions and architectural information (namely, history of changes and *agglomeration cancer*). In our context, architectural information refers both to the component structure (as used for the detection of the agglomerations) and the architectural concerns.

[3]There can be ties in the scores assigned to different agglomerations.


Name: Manage labels for subscribers

Packages

bd	ui.add.label
bd.pojos	
bd.specialCriterions	
ui	
ui.add	
ui.add.label.modifyAssociationField	
ui.edit	
ui.mailing	
ui.search	

Classes

bd.HSQLServer	bd.pojos.Label
bd.HibernateUtil	bd.DataBaseManager
bd.pojos.Event	bd.pojos.AssociatedFieldValueForL
bd.pojos.EventInstance	bd.pojos.AssociatedField
bd.pojos.Donation	ui.add.AddLabel
bd.pojos.Person	ui.edit.EditLabels
bd.specialCriterions.MonthEqExpre	ui.search.personUtils.searchCriteria
bd.specialCriterions.DayMonthAndY	
bd.specialCriterions.DayAndMonthF	

Importance: 4.0
>>
<<
>>
<<
Cancel
OK
Concern name
Packages that compose the concern
Classes that compose the concern

Fig. 3: Wizard to provide concern mappings in *JSpIRIT*

A. Architectural Concerns

This criterion analyzes the relationship between an agglomeration and an architectural concern. An architectural concern is some important part of the problem (or domain) that developers aim at treating in a modular way [23], such as graphical user interface (GUI), exception handling, or persistence. For example, in Fig. 1, the subclasses of *AbstractController* (along with other system classes) all address a concern called *PhotoLabelManagement*. This criterion was adapted from [14] where it is used to rank single code smells. The rationale behind this criterion is that an agglomeration that realizes several concerns could be an indicator of an architectural problem.

The *JSpIRIT* tool offers a simple interface to specify concerns (Fig. 3). Specifically, the developer must provide a concern name and select the system packages and classes the concern maps to. To compute the ranking score of a given agglomeration, we count the number of concerns involved in that agglomeration. At last, we normalize the values to obtain scores between [0..1]. To do so, the highest number of concerns affecting a single agglomeration is used. For example, given four agglomerations A1, A2, A3, and A4 that involve 0, 1, 2 and 3 concerns respectively, the highest number of concerns per agglomeration is 3. Then, the agglomeration scores will be $0/3 = 0.0$, $1/3 = 0.33$, $2/3 = 0.66$ and $3/3 = 1.0$.

Certainly, the specific mappings of concerns to program elements affect the results of this criterion. Furthermore, as the implementation evolves, the mappings might need to be adjusted. Existing feature-location tools, such as Mallet [24] and XScan [25], can be used here to derive concern mappings automatically and with high accuracy.

B. History of Changes

This criterion analyzes the stability of the classes in which the code smells (of an agglomeration) are located. By looking at the "stability" of the main classes of these smells, we want to check whether the agglomeration is in a component or class hierarchy that is usually modified. Our assumption is that agglomerations appearing in classes that changed often should have a higher score. Note that this notion of stability relies not only on the actual architectural information (e.g. the agglomeration affecting a particular component), but also on information from the history of class changes.

To calculate the score of an agglomeration we use the LENOM metric [12]. This metric identifies the classes that experienced most changes in the last versions of the system. In LENOM, the classes that most frequently changed are identified by weighting the delta in the method count (NOM) of a class between two adjacent versions. More formally:

$$LENOM_{j..k}(C) = \sum_{i=j+1}^{k} \mid NOM_i(C) - NOM_{i-1}(C) \mid * 2^{i-k}$$

where $1 \leq j < k \leq n$ being j the first version of the system analyzed, k the last version analyzed and n the total number of versions of the system.

Once the LENOM values for each main class of the code smells are obtained, we compute the score of the containing agglomeration by averaging the LENOM values. For example, given an agglomeration A1 that is composed by three Brain Method (BM) code smells: Foo.a(), Foo.b(), and Foo2.c(), and knowing that $LENOM(Foo) = 0.8$ and $LENOM(Foo2) = 0.5$, the score of A1 will be $\frac{0.8+0.8+0.5}{3} = 0.7$. A score close to 1.0 means that the classes composing the agglomeration change often during the history of the system. In contrast, a score of 0.0 means that the classes composing the agglomeration did not change since their initial implementation.

C. Agglomeration Cancer

This criterion makes an analogy of the agglomeration with a disease in the system. Our assumption is that a disease that is growing is more critical than a disease that is stable (i.e. it does not change) or that is on a remission state (i.e. it is shrinking). Along this line, we analyze the behavior of the agglomerations across system versions and compute a variation rate in terms of the number of code smells that compose the agglomeration. We can think of this criterion as a variation of the previous one, which concentrates on the "volume" of smells over time. This criterion combines history-based and architectural information.

To calculate the score of a given agglomeration, we consider pairs of adjacent versions and determine the percentage of variation in the number of code smells that constitute the agglomeration. This percentage will be positive or negative, depending on whether the smells increased or decreased. For example, given agglomeration A1 with 3 code smells in version v1, 5 anomalies in v2, and 4 anomalies in v3, the corresponding variation rates are $\frac{5*100}{3} - 100 = 66.6\%$ from v1 to v2, and $\frac{4*100}{5} - 100 = -20\%$ from v2 to v3 (by definition, agglomerations always have at least two smells). Then, all the percentages of variation (for the same agglomeration) are averaged. In our example, this value becomes $\frac{66.6-20}{2} = 23.3\%$. Once averages for all the agglomeration are obtained, we normalize these values to produce scores in the range [0..1].

V. Study Settings

This section describes the research question and hypothesis of our study. We also describe the target applications used in our empirical evaluation, as well as the procedures for data collection and analysis. More details about the evaluation can be found at http://eguimaraes15.github.io/.

A. Research Question and Hypothesis

To investigate the effectiveness of the scoring criteria on the prioritization of architectural problems, we defined the research question to be addressed in this study:

- **RQ**: *Does the use of a scoring criterion assists developers to prioritize smell agglomerations that indicate architectural problems?*

We derived the corresponding hypothesis for this research question: ($H1_0$) *the use of a scoring criterion assists developers to prioritize critical agglomerations*. We will consider that a scoring criterion is effective to assist developers if at least half of the prioritized agglomerations are related to architectural problems. The reasoning is that developers would give up in inspecting the agglomerations if more than 50% of them are not related to architectural problems. If the criterion ranks correctly most of the agglomerations, they can enable developers to analyze and fix the most critical agglomerations.

B. Target Applications

The systems chosen for our study had exhibited several symptoms of architecture degradation, so that we could properly evaluate the effectiveness of the prioritization criteria. The selection of the target systems was performed in two stages. In the first stage, we selected 3 Java applications of reasonable size (from 10 to 54 KLOC). They were also chosen because the original developers were available to validate all the architectural problems and code smells being inspected in our analyses. Due to their availability, we could produce both reliable ground truths and findings. The first application is Mobile Media (MM) [26], a software product line that provides support for manipulation of media on mobile devices. The second application is Health Watcher (HW) [27], a Web-based application that allows citizens to register complaints about health issues in public institutions. Our third application is SubscriberDB (S_{DB}) [19], a subsystem of a publishing house that manages data related to the subscribers of its publications, and also supports different queries on the data.

In the second stage, we selected a very large system, consisting of 182 KLOC. The goal was to check whether our most effective scoring criterion would also be effective to prioritize architectural problems in more complex projects. Given this goal, we end up selecting the fourth application is Apache OODT (OODT) [28], a middleware framework aimed at supporting the management and storage of scientific data. A summary of the application characteristics is given in Table I.

C. Data Collection and Analysis

This section describes each of the main activities of the study, which are graphically summarized in Figure 4.

TABLE I: Characteristics of the Target Applications

Target Application	MM	HW	S_{DB}	OODT
System Type	Software Product Line	Web	Web	Middleware
Programming Language	Java	Java	Java	Java
Architecture Design	MVC	Layers	MVC	Layers
Selected Version	5	8	2.4	10
KLOC	54	49	10	182
#Classes	77	125	151	1424
#Code Anomalies	260	497	82	1816

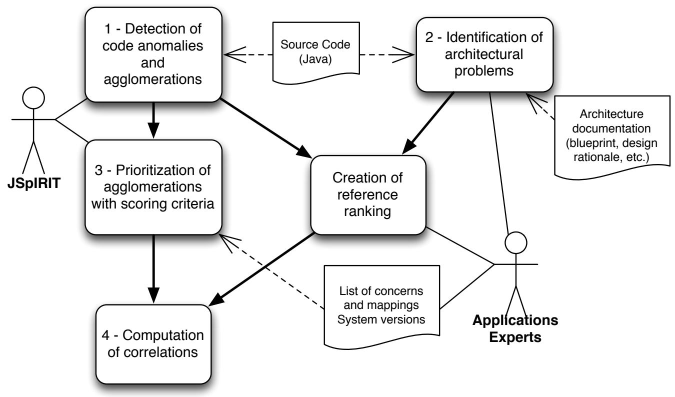

1 - Detection of code anomalies and agglomerations
Source Code (Java)
2 - Identification of architectural problems
JSpIRIT
3 - Prioritization of agglomerations with scoring criteria
Creation of reference ranking
Architecture documentation (blueprint, design rationale, etc.)
List of concerns and mappings System versions
Applications Experts
4 - Computation of correlations

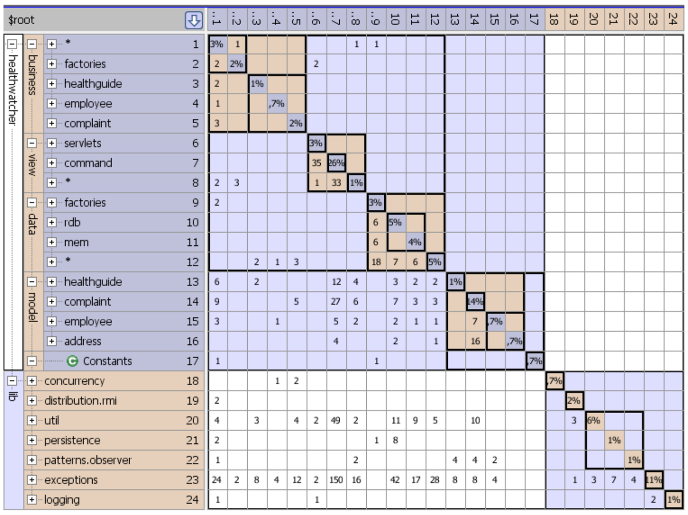
Fig. 4: Procedures for data collection

Detection of code smells and agglomerations. We used *JSpIRIT* to detect both code smells and agglomerations automatically. After detecting all instances of code smells, *JSpIRIT* proceeds to identify the agglomerations based on the grouping patterns described in Section III-C. *JSpIRIT* presents two different outputs: (i) a list of smell instances, and (ii) groups of inter-related code smells, i.e., the agglomerations presented in Section IV, along with their score for a given criterion (Fig. 2). For the criterion of architectural concerns, we relied on a list of concerns provided by the original developers of each system. For each concern, they provided a list of packages/classes realizing the concerns, i.e., the concern mappings. These mappings were further validated by us with the help of Mallet [5], [24]. Mallet is based on the notion of topic modeling in order to infer the list of concerns and the mappings of each concern in the source code. This technique has been successfully used to derive concern mappings with high accuracy [5], [24].

For the assumption of architectural components being represented by Java packages, we looked at the DSMs of each system using Lattix[4]. We applied the component partitioning algorithms of Lattix, and analyzed the differences between the components suggested by Lattix and the package structure. For instance, Fig 5 shows a DSM for HW with 17 components (at the lowest abstraction level) and 20 packages. In all case-studies, there were small differences in this regard.

Identification of architectural problems. For HW, MM and S_{DB}, the application developers identified and reported to us the architectural problems they faced along their projects. Specifically, developers reported the existence of 7 types of architectural problems, namely: Ambiguous Interface, Concern Overload, Connector Envy, Cyclic Dependency, Scattered Functionality, Unused Interface, and Architectural Violations (unwanted dependencies among components) [2], [15]. To

[4]http://lattix.com/



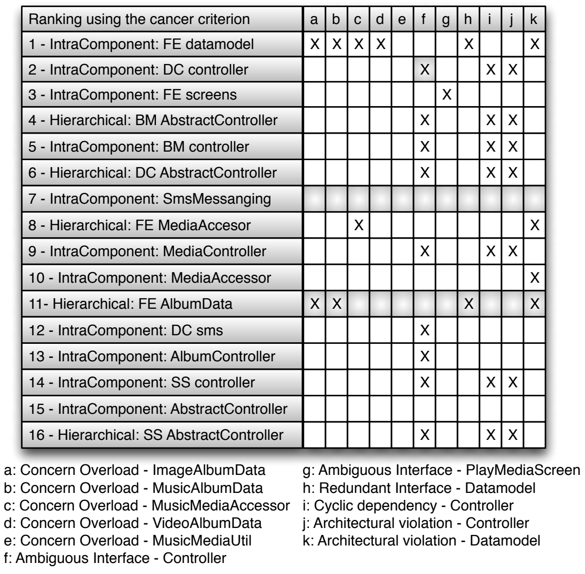
$root				.1	.2	.3	.4	.5	.6	.7	.8	.9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
healthwatcher	business	*	1	3%	1						1	1															
		factories	2	2	2%				2																		
		healthguide	3	2		1%																					
		employee	4	1			,7%																				
		complaint	5	3				2%																			
	view	servlets	6						3%																		
		command	7						35	26%																	
		*	8	2	3				1	33	1%																
	data	factories	9	2								3%															
		rdb	10									6	5%														
		mem	11									6		4%													
		*	12			2	1	3				18	7	6	5%												
	model	healthguide	13	6		2				12	4		3	2	2	1%											
		complaint	14	9				5		27	6		7	3	3		14%										
		employee	15	3			1			5	2		2	1	1		7	,7%									
		address	16							4			2		1		16		,7%								
		Constants	17	1								1								,7%							
lib		concurrency	18				1	2													,7%						
		distribution.rmi	19	2																		2%					
		util	20	4		3		4	2	49	2		11	9	5		10					3	6%				
		persistence	21	2								1	8											1%			
		patterns.observer	22	1							2					4	4	2							1%		
		exceptions	23	24	2	8	4	12	2	150	16		42	17	28	8	8	4				1	3	7	4	11%	
		logging	24	1					1																	2	1%

Fig. 5: DSM of HW after applying the standard partitioning algorithm of Lattix.

confirm the presence of architectural problems, architects first manually inspected the source code and the architecture blueprint of each system. This task was aided with a questionnaire that we provided to them. Based on their experience along the project, they produced a list of the most critical architectural problems for each version of the target applications. As a result, using the list of architectural problems, we produced a reference ranking of the agglomerations detected by *JSpIRIT* that contribute to the most critical architectural problems for each target application.

To determine if an agglomeration X was linked to an architectural problem Y, we check whether problem Y mapped to (some of) the main classes hosting the smells of agglomeration X. That is, we looked at intersections between the program elements realizing the architectural problem and those related to the agglomeration. Coming back to Fig. 1, we can see an example of this intersection for the Ambiguous Interface problem, which is realized by the *Controller* package and some of its classes take also part in an agglomeration. The reference ranking of agglomeration was built in such a way it has in the first positions the agglomerations being related to the highest number of architectural problems. That is to say, the score of the agglomeration is the number of related architectural problems. The agglomerations along with their related architectural problems for each case-study constituted our ground truth. For OODT, we did not produce a ground truth, due to the size and complexity of this application. Our goal with OODT was to evaluate the criteria in a system larger than HWS, MM or S_{DB} and assess the architectural problems for the best-ranked agglomerations. Along this line, we performed a manual analysis considering the top-12 agglomerations as ranked by the cancer criterion (Section IV-C).

Prioritization of agglomerations with scoring criteria (JSpIRIT). We simply asked *JSpIRIT* to apply the scoring strategies from Section IV, one by one, on the agglomerations detected in the previous activity. As a result, the agglomerations were ranked according to their scoring value in a decreasing order. We focused on analyzing the top-7 rankings for each system, as those high-priority agglomerations would represent the focus of the developer's attention.



Ranking using the cancer criterion	a	b	c	d	e	f	g	h	i	j	k
1 - IntraComponent: FE datamodel	X	X	X	X				X			X
2 - IntraComponent: DC controller						X			X	X	
3 - IntraComponent: FE screens							X				
4 - Hierarchical: BM AbstractController						X			X	X	
5 - IntraComponent: BM controller						X			X	X	
6 - Hierarchical: DC AbstractController						X			X	X	
7 - IntraComponent: SmsMessanging											
8 - Hierarchical: FE MediaAccesor			X								X
9 - IntraComponent: MediaController						X			X	X	
10 - IntraComponent: MediaAccessor											X
11- Hierarchical: FE AlbumData	X	X						X			X
12 - IntraComponent: DC sms						X					
13 - IntraComponent: AlbumController						X					
14 - IntraComponent: SS controller						X			X	X	
15 - IntraComponent: AbstractController											
16 - Hierarchical: SS AbstractController						X			X	X	

a: Concern Overload - ImageAlbumData	g: Ambiguous Interface - PlayMediaScreen
b: Concern Overload - MusicAlbumData	h: Redundant Interface - Datamodel
c: Concern Overload - MusicMediaAccessor	i: Cyclic dependency - Controller
d: Concern Overload - VideoAlbumData	j: Architectural violation - Controller
e: Concern Overload - MusicMediaUtil	k: Architectural violation - Datamodel
f: Ambiguous Interface - Controller	

Fig. 6: Matrix of ranked agglomerations for MM versus related architectural problems.

As an example, Fig. 6 shows the ranking of agglomerations for MM as produced by *JSpIRIT* with the cancer criterion (rows), and the associated architectural problems (columns) determined from the ground truth. Note that cell 2f (intra-component agglomeration based on DC for *Controller* intersecting with Ambiguous Interface in *Controller*) corresponds to the situation of Fig. 1. Also note that the intra-component in SmsMessaging (row 7) has no association to architectural problems, even when it is relatively high in the ranking. This is a case of a false positive. which can be due to variations in the number of smells of the agglomerations across system versions, as detected by the cancer criterion. In other cases, like the hierarchical agglomeration based on FE for *AlbumData* (row 11), the agglomeration is ranked low in spite of being related to four architectural problems. This situation can be explained by the fact that the smells of the agglomeration remained almost constant over time.

Computation of correlations: For HW, MM and S_{DB}, once a given scoring strategy was applied on the agglomerations, we measured the correlation between the ranking generated by *JSpIRIT* and the reference ranking (from the ground truth). To do so, we applied the Spearman's correlation coefficient for rankings with ties (p) [29]. This coefficient measures the strength of the association between two rankings. The coefficient can take values between 1 and -1. If p=1, it indicates a perfect association between both rankings. If p=0, it indicates no correlation between the rankings. If p=-1, it indicates a negative association between the rankings. Finally, values between 0.5 and 0.7 are regarded as a good correlation, while values higher than 0.7 are regarded as a strong correlation. As we did not have a ground truth for OODT, we did not use the same correlation strategy. To evaluate OODT, we instead looked at the precision of the criteria for the top-12 ranked agglomerations. With the help of an OODT architect, we analyzed whether each agglomeration (in the top-12 ranking) was related to architectural problems. Table III shows the correlation results computed on the three case-studies, plus the precision value for OODT (7 true positives over 12 cases).

TABLE II: Architectural problems and code-smell agglomerations for the 4 applications

	HW	MM	S_{DB}	OODT
#Architectural problems	61	41	60	n/a
#Agglomerations	11	16	22	431

TABLE III: Correlation results (note that the value for OODT is a precision and not a correlation value)

Applications	Architectural concerns	History of changes	Agglomeration cancer
Health Watcher (HW)	0.01	0.57	0.62
Mobile Media (MM)	0.53	0.34	0.77
SubscriberDB (S_{DB})	0.38	0.71	0.14
SubscriberDB ($S_{DB_{v2}}$)	0.1	0.51	0.6
Apache OODT	n/a	n/a	*0.58*

VI. Empirical Evaluation

In this section, we first report on the results of applying each of the 3 scoring criteria to the 3 target applications. Then, as previously explained (Section V-B), we also discuss the results of applying the most effective criterion to the fourth software project, OODT, which is the largest one. Table II shows the number of architectural problems and agglomerations in each system considered in our study. On one hand, as suggested in recent studies [7], [5], we confirmed that the use of the agglomerations helped to discard hundreds of (non-agglomerated) smells that had no relationship to architectural problems. On the other hand, up to 60% of the agglomerations had no relationship to architectural problems, thereby confirming the need for defining and assessing the effectiveness of alternative prioritization criteria. Therefore, in the following subsections, we carefully analyze the correlation results for each scoring criterion and discuss whether it is effective (or not) to indicate architectural problems. We also derive insights after inspecting all the prioritized agglomerations in order to understand when a criterion has been effective or not.

A. Do Architectural Concerns Help?

The architectural concerns were provided by the system architects. Our goal was to check whether the scoring criterion (Section IV-A) would work with minimal amount of architectural information, which is usually part of either the project documentation or the mindset of architects. The architects spontaneously defined: (i) nine architectural concerns for HW – their mappings encompass around 100 classes in the program, which cover 74% of the total number of classes), (ii) seven architectural concerns for MM – their mappings include ˜65 classes (84% coverage), and (iii) five concerns for S_{DB} – their mappings subsume ˜45 classes (30% coverage).

After applying this criterion, *JSpIRIT* ranked the agglomerations according to their number of concerns. All the agglomerations were related with at least 3 architectural concerns. As shown in Table III, only MM had a moderate correlation with this criterion (correlation of 0.53 with p-value = 0,03471); the correlations for HW and S_{DB} turned out low. The reason for these low correlations is that, albeit agglomerations were often related to architectural problems, this criterion gave the highest scores to agglomerations that were not related with architectural problems. Therefore, the correlations were low because the agglomerations with the largest number of architectural problems were not ranked first. Developers would need to inspect more agglomerations in the ranking in order to find the architectural problems. The use of this criterion would require more effort (than the other criteria) to find problems.

This criterion had the worse results in the HW system. In this system, the first two agglomerations ranked were related with 13 problems. However, the agglomerations ranked third, fourth and fifth were not related with architectural concerns. In the case of the HW system, 11 agglomerations were found, but only 5 of such agglomerations were actually related with problems. Therefore, this result does not necessarily represent a negative result because, on average, the developer would need to approximately inspect two agglomerations for finding at least one agglomeration related to architectural problems. Moreover, we found that certain agglomerations in the ranking tend to concentrate most of the architectural problems. For example, in the case of the HW system: two agglomerations were actually related with 14 problems, two with 13, and one agglomeration with 7 problems.

Concluding, we observed that the successful use of architectural concerns (as a criterion) depends on the completeness and coverage of the list of architectural concerns provided by the developers. In fact, MM was the system that had the mapping with highest coverage (84%) and the highest correlation (0.53). In addition, we observed that this criterion worked well in systems (e.g. MM) where most problems were caused by the poor modularization of architectural concerns.

B. *Does Change History Help?*

In order to compute the rankings using the history criterion (Section IV-B), we loaded in *JSpIRIT* previous versions of the analyzed systems. In particular, we analyzed all the versions available for each application, namely: 10 versions of HW, 8 versions of MM and 15 versions of S_{DB}. In this case, we were able to find a moderate correlation for HW (0.57 with p-value = 0.06713) and a strong correlation for S_{DB} (0.71 with p-value = 0.00021). Also, we obtained a positive correlation for MM (Table III). These results mean that the agglomerations located in the classes that changed often during the history represent sources of architectural problems in the implementation. We observed that the classes realizing agglomerations related with architectural problems experienced more changes during their history than the agglomeration classes that were not affected by those problems. For instance, in the case of HW, after applying this criterion, the agglomeration ranked first by *JSpIRIT* is related to 7 architectural problems, while the agglomerations ranked second and third are related to 14 problems. Regarding the agglomerations related to 13 problems, they were tied in the sixth position. Therefore, we observed that the consideration of history information improves the prioritization of architectural problems as compared to the use of architectural concerns, presented in the previous sub-section.

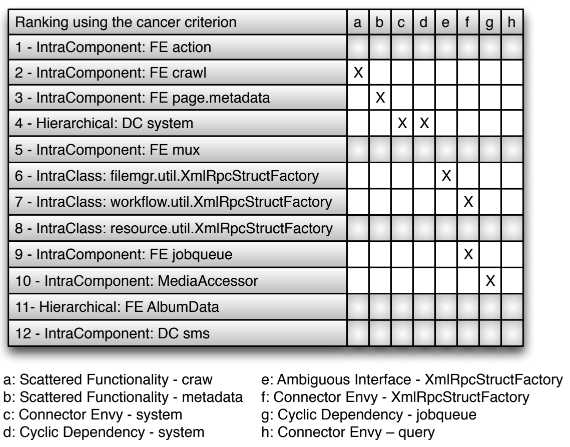
However, the use of the change history criterion was also not effective to prioritize architectural problems in all software projects. Recent studies [3], [4]) have suggested that anomalous source code, whenever it is frequently changed, indicates the presence of major design problems. We found this might be true in certain systems and, therefore, this factor eventually help to identify and prioritize architecturally-relevant code smells. However, this is not always the case, as captured by the low correlation (0.34) in MM. In this system, several architecturally-harmful agglomerations were not often touched by changes. Moreover, the success of the history criterion depends on having several versions to be processed.

C. *Does Agglomeration Cancer Help?*

Overall, the use of agglomeration cancer was, by far, the best-performing criterion in the context of our dataset. As shown in Table III, we obtained strong correlations for HW and MM. However, in principle, we obtained a low correlation in S_{DB}. However, while understanding the reasons for this low correlation, we realized there was an issue to be addressed in the S_{DB} artifacts. When examining the architectural blueprints provided by the system architects, we found out that the blueprint of S_{DB} was inconsistent with the source code [14]. By inconsistent, we mean that the blueprint was an "ideal" design model of the application, but it was not faithfully implemented in the source code. In fact, we computed a consistency metric [14] for HW, MM and S_{DB} . We found that the HW blueprint had a 89.6% of consistency, the MM blueprint had a 67.9%, and the S_{DB} blueprint had just a 54.5%.

For this reason, with the help of an S_{DB} architect, a new, more realistic blueprint called S_{DB_v2} was created, which had a consistency of 77.3%. In this case, the architect found 11 critical architectural problems. Then, we re-computed the reference ranking of this application and ran again the scoring criteria using *JSpIRIT*. Then, we observed a significant improvement in the correlation for the cancer criterion (0.6 with p-value=0.00315), that is, a moderate correlation. As shown in Table III, the correlation values for the remaining criteria decreased in S_{DB_v2}. In the case of the change history criterion, the correlation was still acceptable with the adjusted blueprint. Nonetheless, this was not the case for the criterion of architectural concerns that dropped to 0.1. These results indicate that the correlation values are sensitive to the way in which the blueprints are defined. Therefore, in order to get the best results of this criterion, developers also need to rely on blueprints of the implemented architecture rather than on blueprints of the planned (albeit not implemented) architecture.

As agglomeration cancer was consistently the best-performing criterion in all the three systems, we also applied it to OODT. We checked whether the use of this criterion would scale well to very large systems, such as OODT. In the analysis of the top-12 ranked agglomerations in OODT (Fig. 7), we observed a moderate precision for architectural problems: 7 out of 12 agglomerations were true indicators of architectural problems. Only one of the top-4 agglomerations was not related to any architectural problem. The first position was an agglomeration of Feature Envy (FE) smells, in which the number of FE instances grew over time, but it turned out to be a false positive when judged by the architect. He argued that the component was responsible for parsing command line options, and thus it was expected to depend on several other classes for this task. The ranking also exposed several FE-related agglomerations, because this smell was more prevalent in the OODT versions than other types of smells. Therefore, the results for OODT suggest that the proposed criterion can work well for large software projects in terms of "circumscribing" the search for architectural problems.



Ranking using the cancer criterion	a	b	c	d	e	f	g	h
1 - IntraComponent: FE action								
2 - IntraComponent: FE crawl	X							
3 - IntraComponent: FE page.metadata		X						
4 - Hierarchical: DC system			X	X				
5 - IntraComponent: FE mux								
6 - IntraClass: filemgr.util.XmlRpcStructFactory					X			
7 - IntraClass: workflow.util.XmlRpcStructFactory						X		
8 - IntraClass: resource.util.XmlRpcStructFactory								
9 - IntraComponent: FE jobqueue						X		
10 - IntraComponent: MediaAccessor							X	
11- Hierarchical: FE AlbumData								
12 - IntraComponent: DC sms								

a: Scattered Functionality - craw
b: Scattered Functionality - metadata
c: Connector Envy - system
d: Cyclic Dependency - system
e: Ambiguous Interface - XmlRpcStructFactory
f: Connector Envy - XmlRpcStructFactory
g: Cyclic Dependency - jobqueue
h: Connector Envy – query

Fig. 7: Matrix of (top-12) ranked agglomerations for OODT versus related architectural problems

Overall Conclusion

After analyzing the results of the 3 scoring criteria, we can: (i) reject $H1_0$ for the first two criteria since none of them sufficed to rank correctly at least half of the agglomerations across all the systems, and (ii) accept $H1_0$ for the third criterion, the agglomeration cancer criterion, since it ranked correctly more than half of the agglomerations in all the systems, including OODT. The use of the latter would help developers to find most architectural problems in all the systems with less effort. Developers would still need to inspect each ranked agglomeration and discard the irrelevant ones. However, we found they could discard more than 500 code smells in their analysis. If developers analyze all these individual code smells, they would need to exhaustively and carefully inspect dozens or hundreds of smells in order to eventually find a partial source of a single architectural problem.

Furthermore, even when the detection might lead to some false positives, the automation of the criteria with *JSpIRIT* contributes to significantly reducing mistakes and manual effort of developers. With existing solutions/tools, developers would have to investigate all the architectural information, code smells, and all their relationships, in order to luckily find key architectural problems.

When analyzing why the agglomeration cancer was consistently the best criterion, we observed an interesting phenomenon affecting most of the architectural problems: groups of smells flocking together tend to better indicating the presence of architectural problems, and these groups tend to be increasingly connected with additional new smells when changes are made in the source code over time. This phenomenon is often caused by an ill architectural decision in early versions of the system. This finding can be illustrated by the misuse of Controllers in the MVC architecture of MobileMedia. In principle, the architects decided to rely on the use of a single Controller instead of multiple Controllers (Section **??**). There were only three smells comprising the Controller-affecting agglomeration in version 1. These smells were located in the BaseController class. In the subsequent versions, this agglomeration was being "expanded" to several code elements, including those located in new BaseController subclasses and new BaseController clients. The newly-introduced smells in the existing agglomeration were all directly caused by the harmful constraint of having only a single Controller. Therefore, architectural problems tend to "proliferate" inter-related smells as a "cancer" in the code of evolving software systems.

D. Threats to Validity

In this section, we present potential threats to the validity of our study and how we tried to mitigate them.

Internal and External Validity. An internal threat is related to the quality of the mappings between architectural problems and code elements. We used a consistency metric [14] to make sure that the architectural specification reached a minimum quality. In addition, for each target application, we validated with system experts all the responsibilities and architectural components realized by the code elements in the different system versions. A threat related to the criteria was about the mapping of concerns to code and the selection of the system versions. For the first criterion, we believe that the usage of Mallet mitigated the threat. Also, the usage of LENOM as the main metric for the history criterion can introduce a bias, because some kinds of changes are insensitive to LENOM. The main threat to external validity is that the applications analyzed were relatively small with few instances of code smells and agglomerations. We mitigated this threat by analyzing the cancer criterion in the context of Apache OODT. Unfortunately, performing a complete analysis in larger applications (like OODT) is not always viable because an expert must manually analyze the source code and the blueprints to find the architectural problems.

Construct and Conclusion Validity. As construct threats, we can mention possible errors introduced in the generation of the reference ranking. We partially mitigated this imprecision by involving the original architects and developers in the inspection process. For all target applications, architects with previous experience on the detection of architectural problems and code anomalies, validated and refined the list of problems. The main threat to conclusion validity refers to the number of target applications. We are aware that a higher number of applications is needed for generalizing our findings. However, the information required to conduct this kind of studies can be difficult to obtain. For instance, the activities of identifying and validating architectural problems is highly dependent on having the original personnel available. In order to account for this threat, we selected applications with different sizes, purposes and domains. Moreover, the applications had different architectural styles and involved a different set of architectural problems (with a minor overlapping).

VII. Concluding Remarks

In this article, we proposed a novel approach to prioritize groups of code smells (or agglomerations) that are critical for the architecture of a system. As far as we are aware of, no previous work supports the prioritization of code smells and their agglomerations in order to better assisting developers to focused on a limited set of potential sources of architectural problems. The prioritization is based on three scoring criteria that have the goal of ranking first the agglomerations that likely indicate certain types of architectural problems. Our goal is not to help developers to find all sorts of architectural problems; instead, we aim at helping them to detect architectural problems that manifest as anomalous structures in the source code, while discarding anomalous structures (both agglomerated and non-agglomerated smells) that have no relationship to major design problems. In order to rank agglomerations, the criteria explored different types of information, which are typically available in software projects, including (partial) lists of architectural concerns, (approximate) component structure, and change history. As a proof-of-concept, the scoring criteria were implemented in the *JSpIRIT* tool.

In order to assess and compare the effectiveness of the prioritization criteria, we conducted a study based on the analysis of 4 systems, one of them with a very large size (OODT). In our study, we found out that, although the effectiveness of most criteria depended on the characteristics of each project, the use of the agglomeration cancer criterion tended to be consistently effective across all the projects, including OODT. The other criteria did not present a good correlation in certain projects. For instance, in two projects, the use of architectural concerns alone did not suffice to pinpoint agglomerations related to architectural problems. We observed that the criterion based on architectural concerns is effective only in projects were developers are able to provide a complete coverage of the architectural concerns. In our dataset, this was the case of the MM, where the specification of the architectural concerns covered 84% of the classes in the source code. However, even for this project, it would be useful to also rely on the use of the cancer criterion as: (i) it had a strong correlation with architectural problems in this system, and (ii) it helped to spot a different list of architectural problems, not detected with the criterion of architectural concerns.

We also believe that these findings have practical implications. For instance, the choice amongst concern-based, history-based and cancer-based criteria has tradeoffs [19]. The usage of the criterion of architectural concerns may be preferred in several cases, even at the cost of being an inferior indicator of architectural problems, because problems can be spotted since the first versions when they are usually easier to be dealt with. The use of architectural concerns and agglomeration cancer could be combined in order to get better indicators of architectural problems. In fact, their use in conjunction would lead to the identification of almost 90% of all architectural problems affecting the three first systems: HW, MM and S_{DB}. Therefore, as future work, we plan to further evaluate the combined usage of our criteria in order to get additional insights. We plan to elaborate on particular combinations of scoring criteria and understand which combination tends to be more effective across projects. Furthermore, we would like to experiment with other types of agglomerations (as reported in [5]) and also with other types of architectural problems reported by other authors, such as [11]. As regards history-based information, we envision the usage of metrics other than LENOM as an alternative proxy for maintenance effort.

REFERENCES

[1] P. Clements and R. Kazman, Software Architecture in Practice. Addison-Wesley, 2003.

[2] J. Garcia, D. Popescu, G. Edwards, and N. Medvidovic, “Identifying architectural bad smells.” in CSMR. IEEE, 2009, pp. 255–258.

[3] R. Schwanke, L. Xiao, and Y. Cai, “Measuring architecture quality by structure plus history analysis,” in ICSE, 2013.

[4] S. Wong, Y. Cai, M. Kim, and M. Dalton, “Detecting software modularity violations.” in ICSE, 2011.

[5] W. Oizumi, A. Garcia, L. da Silva Sousa, B. Cafeo, and Y. Zhao, “Code anomalies flock together: Exploring code anomaly agglomerations for locating design problems,” in ICSE’16 – to appear, May 2016 2015.

[6] J. Garcia, D. Popescu, G. Edwards, and N. Medvidovic, “Toward a catalogue of architectural bad smells,” in QoSA, 2009.

[7] W. Oizumi, A. Garcia, T. Colanzi, M. Ferreira, and A. von Staa, “On the relationship of code-anomaly agglomerations and architectural problems,” Journal Soft. Eng. Research and Dev., vol. 3, no. 11, pp. 1–22, 2015.

[8] M. Fowler, Refactoring: improving the design of existing code. Addison-Wesley, 1999.

[9] R. Arcoverde, E. Guimaraes, I. Macia, A. Garcia, and Y. Cai, “Prioritization of code anomalies based on architecture sensitiveness,” in 27th SBES, 2013.

[10] I. Macia, R. Arcoverde, A. Garcia, C. Chavez, and A. von Staa, “On the relevance of code anomalies for identifying architecture degradation symptoms,” in CSMR, 2012.

[11] R. Mo, Y. Cai, R. Kazman, and L. Xiao, “Hotspot patterns: The formal definition and automatic detection of architecture smells,” in WICSA’15, May 2015, pp. 51–60.

[12] T. Gîrba, S. Ducasse, and M. Lanza, “Yesterday’s weather: Guiding early reverse engineering efforts by summarizing the evolution of changes.” in ICSM, 2004.

[13] A. Lozano and M. Wermelinger, “Assessing the effect of clones on changeability,” in ICSM, 2008.

[14] E. Guimaraes, A. Garcia, and Y. Cai, “Exploring blueprints on the prioritization of architecturally relevant code anomalies,” in COMPSAC, 2014.

[15] I. Macia, F. Dantas, A. Garcia, and A. von Staa, “Are code anomaly patterns relevant to architectural problems?” in IEEE Trans. on Soft. Eng., 2014.

[16] N. Moha, Y.-G. Guéhéneuc, L. Duchien, and A.-F. L. Meur, “Decor: A method for the specification and detection of code and design smells.” IEEE Trans. on Soft. Eng., vol. 36, pp. 20–36, 2010.

[17] D. Sjoberg, A. Yamashita, B. Anda, A. Mockus, and T. Dyba, “Quantifying the effect of code smells on maintenance effort,” IEEE Trans. on Soft. Eng., vol. 39, pp. 1144–1156, 2013.

[18] InFusion, “www.intooitus.com/products/infusion.html.”

[19] S. Vidal, C. Marcos, and J. A. Díaz Pace, “An approach to prioritize code smells for refactoring,” Automated Soft. Eng., pp. 1–32, 2014.

[20] D. E. Perry and A. L. Wolf, “Foundations for the study of software architecture,” SIGSOFT Softw. Eng. Notes, vol. 17, pp. 40–52, 1992.

[21] M. Lanza and R. Marinescu, Object-Oriented Metrics in Practices. Springer, 2006.

[22] W. Oizumi, A. Garcia, M. Ferreira, A. von Staa, and T. E. Colanzi, “When code-anomaly agglomerations represent architectural problems?” in SBES, 2014.

[23] C. Sant’Anna, E. Figueiredo, A. Garcia, and C. Lucena, “On the modularity assessment of software architectures: Do my architectural concerns count,” in AOSD, 2007.

[24] A. K. McCallum, “MALLET: A Machine Learning for Language Toolkit,” 2002, http://mallet.cs.umass.edu.

[25] T. T. Nguyen, H. V. Nguyen, H. A. Nguyen, and T. N. Nguyen, “Aspect recommendation for evolving software,” in ICSE’11. New York, NY, USA: ACM, 2011, pp. 361–370.

[26] T. J. Young, “Using aspectj to build a software product line for mobile devices,” Ph.D. dissertation, The University of British Columbia, 2005.

[27] S. Soares, E. Laureano, and P. Borba, “Implementing distribution and persistence aspects with aspectj,” in ACM Sigplan Notices, 2002.

[28] C. A. Mattmann, D. J. Crichton, N. Medvidovic, and S. Hughes, “A software architecture-based framework for highly distributed and data intensive scientific applications,” in ICSE’06, 2006.

[29] F. Ricci, L. Rokach, B. Shapira, and P. Kantor, Eds., Recommender Systems. Springer, 2011.