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Feature Location in a Collection of Product Variants: Combining Information Retrieval and Hierarchical Clustering

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Abstract

Locating source code elements relevant to a given feature is an important step in the process of re-engineering software variants, developed by an ad-hoc reuse technique, into a Software Product Line (SPL) for systematic reuse. Existing works on using Information Retrieval (IR) techniques do not consider the abstraction gap between feature and source code levels. In our recent work, we have improved the effectiveness of IR-based feature location by introducing an intermediate level between feature and source code levels, called “code-topics”. We used Formal Concept Analysis (FCA) to identify such “code-topics”. In this paper, we investigate the results of using Agglomerative Hierarchical Clustering (AHC) algorithm to identify code-topics. In our experimental evaluation, we show that AHC significantly increases the recall of feature location with a minor decrease of precision compared to FCA.

Keywords: Software product line, product variants, feature location, FCA, AHC, IR.

1 Introduction

Software product variants are a set of similar software products developed by ad-hoc copying with adaptations to meet new demands of customers [1]. They share some features, called mandatory features, and also support different, customer-specific features, called optional features. A feature is “a prominent or distinctive user-visible aspect, quality or characteristic of a software system” [2]. As numbers of variants and features grow, maintaining such software variants and developing new variants becomes more difficult and expensive over time. Therefore, a transition to a systematic reuse approach, such as Software Product Line Engineering (SPLE) becomes necessary.

SPLE is a engineering discipline providing methods to promote systematic software reuse for developing short time-to-market and quality products in a cost-efficient way [3]. These products are known as SPL. SPL is rarely developed from scratch. It is often built by exploiting artifacts of pre-existing software product variants. To re-engineer software variants into a SPL, it is important to locate source code elements (e.g., classes) that implement each feature [4]. Feature location is needed to understand the source code of software variants and support product derivation from SPL core assets[3]. Manually locating feature implementations is an error-prone and time consuming task. This is because maintainers must understand several software artifacts to decide which feature is implemented by which source code elements.

Information Retrieval (IR) techniques have been widely used for feature location [5][6]. In our recent work [4], we have improved the effectiveness of IR-based feature location in a collection of product variants by bridging the abstraction gap between feature and source code levels. This bridging is performed by introducing an intermediate level, called code-topic. A code-topic is a cluster of similar classes that reveal source code intention. A code-topic can be a functionality implemented by the source code and provided by a feature. In our recent work [4], we have combined a technique called Formal Concept Analysis (FCA) and IR to identify such code-topics. In this paper, we propose to investigate the results of using Agglomerative Hierarchical Clustering (AHC) to identify “code-topics”.

The rest of this paper is organized as follows. Section 2 presents necessary background to understand our proposal. Then, Section 3 shows how AHC can be used to identify code-topics. In sections 4 and 5, we present experimental evaluation and discuss related work, respectively. Finally, Section 6 concludes the paper.

2 Background

2.1 IR-based Feature Location

IR-based feature location methods exploit source code information (identifier and comments) to locate a feature’s implementation. These methods works by conducting lexical matching between source code information and feature information (i.e., feature description). Different IR techniques, such as Vector Space Model (VSM) and Latent Semantic Indexing (LSI), have been proposed in the context of locating features in the source code. These techniques
share four steps: corpus creation, preprocessing, indexing and querying. For more details, the reader can refers to [7]. In both LSI and VSM, the textual similarity between source code documents (corpus) and features documents (queries) is measured by the cosine of the angle between their corresponding vectors. Both LSI and VSM return a ranked list of source code documents against each feature document.

The effectiveness of IR techniques is measured by their recall, precision and F-Measure [7]. For a given query, recall is the percentage of retrieved documents that are relevant to the total number of relevant documents, while precision is the percentage of retrieved documents that are relevant to the total number of retrieved documents. F-Measure defines a tradeoff between precision and recall so that it gives a high value only in case where both recall and precision are high. All measures have values in [0,1].

2.2 IR-based Feature Location in a Collection of Product Variants: An Overview

In this section, we give an overview of our recent work [4], in order to more easily understand our proposal.

2.2.1 Basic Assumptions

We focus on functional features that express the behavior or the way users may interact with a product. We restrict ourselves to object-oriented systems. A functional feature can be implemented by a set of packages, classes, methods and attributes. A class represents a main building unit in all object-oriented programming where it encapsulates functionality and data. Moreover, developers typically think of a class as a set of responsibilities that simulate a concept or functionality from the application domain. Consequently, we assume that a functional feature is implemented by a set of classes.

The functional feature’s implementation spans multiple classes. We assumed that classes that contribute to implement a feature have shared terms and called near to each other. By grouping these classes into a cohesive unit based on their natural language content, we can get more relevant information describing features implemented by these classes. Therefore, we proposed the code-topic, as a coherent cluster of similar classes that are grouped based on their textual contents to implement a functionality. The code-topic constitutes an intermediate level that bridges the abstraction gap between feature and source code levels. Consequently, the functional feature (i.e., its description) can be textually matched to a set of code-topics (i.e., their source code information) representing its functionalities. This allows us to easily map a feature to a set of classes that are similar and grouped as a code-topic instead of mapping each feature to each class individually.

3 Code-Topics Identification based on Hierarchical Clustering

Clustering, in general, is the division of objects into groups of similar objects. Each group, called a cluster, consists of objects that are similar amongst themselves and dissimilar to objects of other groups [8]. Clustering approaches are classified into hierarchical or non-hierarchical. Hierarchical clustering methods are further categorized into agglomerative (AHC for short) and divisive. Below, we present how AHC is used to identify code-topics.
3.1 Code-Topic Identification as a Partitioning Problem

According to our definition of the code-topic, the content of a code-topic matches a set of classes. Therefore, in order to determine a set of classes that can belong to a code-topic, it is important to formulate the code-topic identification as a partitioning problem. The input is a set of classes \( C \). This set could be classes of the common partition or classes of any minimal disjoint set (see Figure 1). The output is a set of code-topics \( T \) of \( C \): \( C = \{c_1, c_2, ..., c_n\} \) and \( T(C) = \{T_1, T_2, ..., T_k\} \) where: (1) \( c_i \) is a class belonging to \( C \); (2) \( T_i \) is a subset of \( C \); (3) \( k \) is the number of identified code-topics; (4) \( T(C) \) does not contain empty elements: \( \forall T_i \in T(C), T_i \neq \Phi \); (5) The union of all \( T(C) \) elements is equal to \( C \): \( \bigcup_{i=1}^{k} T_i = C \).

For a given set of classes, we cluster them based on the strength of the relationship between the classes. In our case, this relationship refers to textual similarity. We use VSM to compute this similarity. We create a document for each class containing a list of terms extracted from all the identifiers of its corresponding class. VSM computes the text similarity between two class documents by using cosine similarity between their corresponding vectors. One of these documents is treated as a query. The cosine similarity equation (refer to equation 1) represents a fitness function to decide which class documents belong to a cluster.

\[
F(d_j, q) = \frac{\sum_{i=0}^{n} w_{i,j} w_{i,q}}{\sqrt{\sum_{i=0}^{n} w_{i,j}^2} \sqrt{\sum_{i=0}^{n} w_{i,q}^2}} \tag{1}
\]

Where \( F \) is the fitness function with value in the range \([0,1]\). \( d_j \) and \( q \) are class and query vector documents respectively while \( w \) is a term weight. In our case, we try to maximize the fitness value for each cluster where similar classes use similar vocabulary.

3.2 Building a Hierarchy of Clusters

AHC groups similar classes that use similar vocabulary together and aggregate them into clusters. The basis for clustering classes is the strength of the relationship between them. The previously defined fitness function is used to measure this strength. AHC relies on a series of successive binary mergers, initially of individual class documents and later of clusters formed during the previous stages. We obtain from these binary mergers a single cluster dendrogram (dendgr) that contains a set of nested clusters. Figure 2 shows an example of dendrogram tree. At the lowest level, each class is in its own unique cluster. At the highest level, all classes belong to the same cluster. The internal nodes represent new clusters formed by merging the clusters that appear as their children in the tree.

3.3 Selection Candidate Code-Topics

Breaking the dendrogram tree based on predefined criteria allows to group classes into clusters. Each cluster can be a candidate code-topic. Therefore, we must select the breaking point to obtain code-topics. This selection is performed by an algorithm based on a depth-first search (refer to algorithm 1). This algorithm takes as input the dendrogram tree and returns a set of clusters. We interpret these clusters as code-topics. For each node in the dendrogram (starting from the root), we compare the fitness value of the focused node and its sons ( \( d_j \) and \( q \) in equation 1 become cluster nodes). If the fitness value of the focused node is less than the average of the fitness values of its two sons, then the algorithm continues on to the next son nodes. Otherwise, the focused node is identified as a code-topic, added to the code-topics(\( T \)) and the algorithm computes the next node in the stack. In this way, the most relevant code-topics will be identified as the traversal continues.

![Figure 2. An example of dendrogram tree.](image)

Algorithm 1: CodeTopicDendrogramTraversal

| Input: Dendrogram(dendgr) |
| Output: Code-Topics(\( T \)) |
| stack traversedClusters |
| push(traversedClusters, dendgr) |
| while (|traversedClusters| > 0) do |
| parent ← pop(traversedClusters) |
| son1 ← getSon1Cluster(parent, dendgr) |
| son2 ← getSon2Cluster(parent, dendgr) |
| avg ← average(\( F(son1), F(son2) \)) |
| if (\( F(parent) > (avg) \)) then |
| add(parent, \( T \)) |
| else |
| push(son1, traversedClusters) |
| push(son2, traversedClusters) |
| end |
| end |
| return \( T \) |
3.4 Code-Topics for Locating Feature Implementations

After identifying code-topics, we apply LSI (as shown in Figure 1) to link mandatory features and their possible corresponding code-topics, as well as to link each minimal disjoint set of optional features and their possible corresponding code-topics. LSI is applied by following the steps described in section 2.1, but we build LSI’s corpus and queries as follows. LSI’s corpus consists of code-topic documents, which each one corresponds to a code-topic. Each document consists of terms extracted from identifiers of corresponding code-topic’s classes. LSI takes code-topic and feature documents as input. Then, LSI measures the similarity between the code-topics and features using the cosine similarity. This returns a list of code-topics, ordered by their cosine similarity values against each feature. The retrieved code-topics should have a cosine similarity value greater than or equal to 0.70, where this value represents the most widely used threshold for the cosine similarity [5].

After linking each feature with all its corresponding code-topics, we can easily link each feature with its classes by decomposing each code-topic to its classes. For instance, if the feature \( f_1 \) is linked to two code-topics: \( topic1 = c_1, c_4 \) and \( topic2 = c_7, c_6 \), by decomposing these topics into their classes; we can find that \( f_1 \) is implemented by five classes \( c_1, c_4, c_7, c_6 \).

4 Experimental Evaluation

4.1 Case Studies and Experiments Setting

To validate our approach, we have applied it to a collection of seven variants of a large-scale system, ArgoUML-SPL\(^1\) modeling tool, and five variants of a small-scale system, MobileMedia\(^2\).

The ArgoUML-SPL is a Java open-source which supports all standard UML 1.4 diagrams. The ArgoUML-SPL’s products are generated from the same framework so that products that share the same features also share the same code. The selected products differ in terms of provided features but they support all UML diagram features. These features are implemented by source code classes. To establish ground truth links between features and their classes while AHC computes the similarity not only among clusters. Therefore, the number of code-topics obtained by FCA is higher than AHC (423, 17 respectively). Identifying a small number of code-topics means that each code-topic document contain more rele-

Table 1. Precision, recall and F-measure of AHC against FCA for ArgoUML-SPL and MobileMedia.

<table>
<thead>
<tr>
<th></th>
<th>Precision</th>
<th>Recall</th>
<th>F-measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArgoUML-SPL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>AHC</td>
<td>FCA</td>
<td>AHC</td>
</tr>
<tr>
<td>0.1</td>
<td>52%</td>
<td>70%</td>
<td>40%</td>
</tr>
<tr>
<td>0.2</td>
<td>52%</td>
<td>57%</td>
<td>9%</td>
</tr>
<tr>
<td>0.3</td>
<td>52%</td>
<td>57%</td>
<td>9%</td>
</tr>
<tr>
<td>0.4</td>
<td>52%</td>
<td>57%</td>
<td>9%</td>
</tr>
<tr>
<td>0.5</td>
<td>52%</td>
<td>57%</td>
<td>9%</td>
</tr>
</tbody>
</table>

| MobileMedia    |           |        |           |
| K              | AHC       | FCA    | AHC       | FCA       |
| 0.1            | 5%        | 8%     | 3%        | 5%        |
| 0.2            | 5%        | 8%     | 3%        | 5%        |
| 0.3            | 5%        | 9%     | 9%        | 9%        |
| 0.4            | 5%        | 9%     | 9%        | 9%        |
| 0.5            | 9%        | 9%     | 9%        | 9%        |

1Available at http://argouml-spl.tigris.org/
2Available at http://www.ic.unicamp.br/tizzei/mobilemedia/
vant source code information. This is allow to do better
textual matching with feature descriptions, and hence the
recall. Regarding the minor decreasing in the precision, this
is due to the fact that AHC depends a lot on VSM compared
with FCA. AHC uses VSM to compute similarity between
classes and clusters while FCA uses VSM to compute simi-
arity only between classes. This means that the number of
false-positive links in the case of AHC is higher than
FCA because VSM retrieve false-positive links which leads
to impression. F-measure results refer to AHC achieve a
better compromise between precision and recall than FCA.

On a small system (MobileMedia), it is observed that
AHC and FCA produce the same precision, recall and F-
measure results for the following reasons. Firstly, most
minimal disjoint sets of optional features consist of only one feature, and hence their corresponding minimal disjoint sets of classes contain only the implementation of that feature, no more and no less). Thus, in this case we do not require LSI and code-topics. Secondly, MobileMedia’s features are implemented by a small number of classes, sometimes by only two classes. These classes have little information that hinders building code-topics.

5 Related Work

The approach was proposed by Kuhn et al. [6] is the
closest to ours. They proposed an approach to identify lin-
guistic topics from object-oriented source code. Their ap-
proach relied on LSI to compute similarity among given set
of methods, classes or packages. Then, AHC was used to
cluster similar elements together as linguistic topics. The
clusters retrieved by their approach are not necessarily do-
main concepts (i.e., features), but rather code-oriented top-
ics. In our approach, we identify feature-oriented topics
where these topics are identified from a set of classes that
implement features.

Maskeri et al. [9] identify business topics from source
code by using Latent Dirichlet Allocation (LDA). Their in-
terpretation for a topic is a set of semantically related lin-
guistic terms identified from identifiers names and com-
ments. Kawaguchi et al. [10] proposed an automatic catego-
rization method for a large collection of software systems.
They use linguistic information in source code for identifying
categories (topics) from open source repositories (e.g., SourceForge). A category is a cluster of related identifiers. Our approach differs from the works of Maskeri et al. and Kawaguchi et al. in two ways. Firstly, topics in their ap-
proaches are clusters of terms while code-topics in our ap-
approach are clusters of software artifacts (classes). Secondly,
topics retrieved by their approach are code-oriented topics
while we identify feature-oriented topics, as they are identi-
fied from source code classes that implement features (and
only features).

6 Conclusion

In this paper, we have proposed to combine IR and AHC
to improve the effectiveness of IR-based feature location in
a collection of product variants. This improvement involves
reducing the abstraction gap between feature and source
code levels by introducing the concept of code-topic as an
intermediate level. We have compared between two algo-

rithms to identify code-topics: AHC and FCA. In our ex-
perimental evaluation using two different case studies, we
showed that AHC significantly increases the recall of IR-
based feature location with a minor decrease of precision
compared to FCA.

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