Comprehending Object-Oriented Software Frameworks API Through Dynamic Analysis

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Abstract

A common practice followed by many application developers is to use existing framework applications as a guide to understand how to implement a framework-provided concept of interest. Unfortunately, finding the code that implements the concept of interest might be very difficult since the code might be scattered across and tangled with code implementing other concepts. To address this issue, this report presents an approach called *FUDA* (*Framework API Understanding through Dynamic Analysis*). The main idea of this approach is to extract implementation recipes of a given concept from runtime information collected when that concept is invoked in a number of different sample applications. For this purpose, we introduce a novel dynamic slicing approach named *concept trace slicing* and combine it with clustering and data mining techniques. The experimental evaluation of FUDA suggests that this approach is effective in producing useful implementation recipes for a given concept with few false positives and false negatives.

Contents

1 Introduction

Object-oriented frameworks allow the reuse of both designs and code and are one of the most effective reuse technologies available today. Unfortunately, many existing frameworks are difficult to use because of their large and complex Application Programming Interfaces (APIs) and often incomplete user documentation. To cope with this problem, application developers frequently apply the *Monkey See/Monkey Do* rule [5]: "Use existing framework applications as a guide to develop new applications".

While following the Monkey See/Monkey Do rule can be an effective application development strategy, it requires the ability to quickly locate relevant coding examples. As an illustration of this problem, consider the task of implementing Drag&Drop in a view of the *Eclipse* environment. Even though the concept of selecting an object, dragging it to another location and dropping it is intuitive and succinct at the graphical user interface, the implementation code consisting of event listeners and registration calls to the appropriate framework services involves multiple classes and is scattered across and tangled with the code implementing other concepts. Consequently, despite the fact that Drag&Drop is present in many Eclipse plug-ins, finding the relevant instructions among potentially many thousands lines of source code is a challenge.

Several tools have been proposed to address this challenge. Examples include code searchers (e.g., [12, 6]) and static code miners (e.g., [11, 15]). These tools apply static analysis to the source code of existing applications and allow retrieving code fragments or usage rules for a particular API element. While these tools can be very helpful in situations where the developer at least knows the name of the API element of interest, they are less helpful if the developer has only a high-level idea of the concept that needs to be implemented. In the latter case, a concept location tool based on dynamic analysis (e.g., [4]) can be used to locate the code implementing the concept of interest. However, the existing concept-location tools do not focus on framework API usage and, thus, the code identified using these tools will still include many application-specific instructions that are irrelevant from the viewpoint of framework usage.

To address the above challenges, we introduce a new approach for framework comprehension called *FUDA* (*Framework API Understanding through Dynamic Analysis*). The key idea of FUDA is to execute a number of example applications that implement the desired framework-provided concept and collect all runtime interactions between the applications and the framework API. The collected interactions are then sliced with respect to the invocations of the concept of interest and the resulting dynamic information is processed using clustering and data mining techniques to extract concept implementation recipes. A recipe specifies the API calls and callbacks that are commonly involved in the implementation of a concept. The main focus of FUDA is to obtain useful implementation recipes from only *few* executions of sample applications in order to make the approach attractive in practice.

This report offers the following three contributions. First, we introduce *concept trace slicing*, a novel dynamic slicing technique that operates on traces representing the interaction between a framework API and an application. Concept trace slicing can be used to identify the API instructions that create and destroy the objects used in the concept invocation. These instructions are often executed well before or after the concept is invoked. Second, we combine concept trace slicing with clustering and data mining techniques into a novel approach for framework comprehension. A distinctive feature of this approach is that it employs *API event abstraction*, which eliminates application-specific characteristics of API events in order to produce useful results with only a few traces from different applications. Third, we empirically evaluate the comprehension approach and show that it is possible to extract the implementation recipes for a desired concept with few false positives and false negatives by using only a small number of example applications. To the best of our knowledge, FUDA is the first approach for mining framework API usage based on dynamic analysis.

The remainder of the report is organized as follows. In Section 2 we describe the FUDA approach in detail. An empirical evaluation of FUDA is presented in Section 3. Section 4 provides a discussion on several aspects of FUDA and in Section 5 we present related work. Finally, Section 6 concludes the report and gives some directions for future work.

2 The FUDA Approach

Before delving into details of the FUDA approach, we shall clarify the nature of the problem with an example, which will be used throughout the report, and also provide an overview of FUDA's process, describing the purpose of and the relationships between its constituting phases.

Consider the case of a developer creating a plug-in in the Eclipse environment. During development, the developer notices that many plug-ins already present in the *workbench* that implement a *context menu*. Interested in creating something similar, the developer has basically two possibilities. One is to search for help on documentation, mailing lists and newsgroups. Another option is to look at the code of the plug-ins that implement the menu and search for the parts relevant to its implementation. However, the implementation of such a simple framework-provided concept often requires that certain specific steps be employed in conjunction, not necessarily in a single code location. Moreover, such steps are frequently not well documented by framework developers and waiting for answers in mailing lists and newsgroups can become a frustrating, time-consuming task.

In order to tackle this problem, we propose the FUDA approach for framework comprehension. The key idea is to take advantage of the information contained in sample applications and utilize dynamic analysis to help determining the portions that are relevant to the implementation of the concept. The goal is to be able to extract recipes with simple instructions that indicate the steps necessary to implement the concept, using as few sample applications as possible. To do so, FUDA defines a process composed of 4 phases. Initially, the developer must identify exactly what the concept of interest is, and select a number of sample applications implementing it. This phase is called the *preparation*. The following phase is the *data collection*, when each sample application is executed and a profiler tool collects a full trace of the interactions between the application and the framework API. For the purpose of pinpointing the location of the concept execution in the trace, the developer informs the profiler tool of the moments right before and after the invocation of the concept, a process we call *marking*.

In the subsequent *automated analysis* phase the developer uses an analyzer tool to dissect the collected traces and extract the recipes. The analysis starts with the application of our novel concept trace slicing technique, which determines the trace interactions that are potentially relevant to the concept. Next, the traces go through a process of removing application specific content from the interactions. Clustering is then applied to group traces that correspond to concept implementation variants. Finally, a data mining technique is employed on each cluster, generating a set of recipes containing implementation instructions.

The last phase is named *results inspection*. Having a set of recipes, the developer can understand *i)* which are the mandatory steps for implementing the concept *ii)* what were the variants in the sample applications, and *iii)* where the concept is located in the sample application's code, which can be used to learn more implementation details.

We elaborate on each phase in the following subsections.

2.1 Preparation

The goal of this phase is to precisely define the framework-provided concept of interest and select sample applications that implement the concept. This is an essential step that developers must take in order to understand if FUDA is the appropriate approach to be taken and to maximize the quality of the results.

2.1.1 Determining the Framework-Provided Concept

In FUDA, a *framework-provided concept* is defined as a feature accessible through the framework's API and implemented in applications by writing *framework completion code*, *i.e.*, the framework provides a certain functionality and prescribes steps for its reification and configuration in applications. Typical framework completion code consists of API method invocations, class extensions, interface implementations and so on.

FUDA imposes two requirements around the concepts it can successfully analyze. First, the developer must have a minimal knowledge about the framework that provides the concept. FUDA requires as input the name of the framework's package, so that the profiler tool can understand the framework's boundary and concentrate only on the interactions that cross this boundary. Without this delimitation, the analysis would be flooded with irrelevant information. In our example, the developer must know that those context menus are provided by JFace, and that JFace's package is named *org.eclipse.jface*.

Second, it must be possible to demarcate the limits of the concept's invocation in sample applications. This is necessary because the developer must mark these limits with the profiler tool, so that it distinguishes the framework interactions that occur while the concept is being executed from the remainder of the trace. The concept can itself be a graphical interface concept, such as the context menu, but it can also be any other concept whose invocation can be demarcated.

2.1.2 Selection of Sample Applications

It is necessary that developers have access to some applications implementing the concept. As we will see in Section 3, usually 3 or 4 samples is enough for the retrieval of quality recipes. It is not required that developers know the packages of the sample applications. However, this knowledge makes the data collection process more efficient and, because it helps to narrow down the number of interactions in the traces, it potentially generates better results.

2.2 Data Collection

In FUDA we are interested in the interactions between the sample applications and the framework API. In this phase, the developer executes the sample applications assisted by a profiler tool and invokes the concept of interest, demarcating this invocation with the tool. An atomic interaction collected by the tool is called a *framework API interaction event*, which is a runtime event corresponding to either a method invocation, a constructor invocation, a field assignment or a field read access, where:

- it is an *outgoing event*, if the invocation, assignment or access is made from within the application's code and the target is at least declared in the framework's code.
- it is an *incoming event*, if the invocation, assignment or access is made from within the framework's code and the target is implemented in the application's code.

We consider both static and instance variants of methods and fields. This definition reflects the direction of the interaction with respect to the application and distinguishes events that cross the application-framework boundaries from internal events. For instance, an outgoing event is triggered by the application, but is prescribed by the framework (at least declared). This definition includes both targets fully implemented by the framework, such as a constructor or method, and targets prescribed by the framework and implemented in the application, such as an interface method implementation or an overridden method, provided that the framework declared it. An incoming event occurs when the framework is the driver and the implementation is in the application. This direction is usually implemented by method callbacks, but also includes reflective usage of application objects by the framework.

We describe events collected by the profiler using the notation $D : O : n(\{P\}) : R_v$. D represents the direction of the event, O is the target object's id (or is missing if the target is static), n represents the fully qualified name of the target method, constructor or field, $\{P\}$ is the set of ids of parameter objects of method and constructor invocations, and of field assignments, and R_v is the object id of the return value of invocations and field accesses.

The events collected during the execution of an application form the *framework API interaction trace*, which is defined as the sequence of framework API interaction events, as chronologically determined by the entry of the event. The trace is therefore a flattened version of the runtime picture, since nested events and events from different threads are linearized based on their entry points. By joining the events from different threads, FUDA is capable of analyzing multi-threaded systems. For example, in the case where two threads cooperate to the execution of a concept, such as an implementation of the Worker Pattern[9], all interactions are merged and analyzed in conjunction. This is possible because FUDA recipes do not preserve order.

The framework API interaction trace contains a *marked region*, which is the subsequence of events that were marked in the process by the developer, *i.e.*, the ones that started during the concept execution. For example, when collecting data on the context menu, we could get a trace with the following events, among others, where ⊛ indicates a marked event:

```
Outgoing:155:
    org.eclipse.jface.action.MenuManager.addMenuListener({2456}):
⊛ Outgoing:155:
    org.eclipse.jface.action.MenuManager.createContextMenu({}):62412
```

2.3 Automated Analysis

In this phase, the interaction traces are dissected by an analyzer tool and implementation recipes are extracted. This process involves the following 4 stages:

2.3.1 Concept Trace Slicing

We have seen that the interaction events that occurred during the concept execution are marked by the developer. The marked region therefore contains the events that were explicitly involved in running the concept, potentially among other irrelevant events. However, the necessary setup for the concept execution frequently happens well before the execution itself. Likewise, the marked region may miss cleanup events, such as service deregistration.

In order to address this problem we present a novel concept trace slicing technique. The key idea is to introduce the notion of *dependency* between events and compute the transitive closure of the events in the marked region. The resulting set of events is defined as the *concept slice* of the trace.

Two events are said to be dependent if they involve at least one object in common. Objects can take part in events as targets, parameters or return values. Hence, we can specify fine grained versions of dependencies, based on how the common object is used in the events. Since events are ordered in the trace, we can say that events e_i and e_j have a $target-parameter$ dependency if e_i precedes e_j in the trace and the same object used as a target in event e_i is subsequently used as a parameter in e_j. The concept trace slicing technique can be configured to account for all types of dependencies or for just a subset, depending on the nature of the concept. In order to maximize the reach of the concept trace slicing, in our experiments we have used all types of dependencies in conjunction.

The concept trace slicing technique assumes that all initial events are relevant for the concept. For the purposes of FUDA we may safely assume that events in the marked region are relevant, because any irrelevant event is very likely going to be removed by the subsequent stages of the analysis.

The result of this process is a concept slice of the trace, where events that do not by any means depend on an event of the marked region are declared irrelevant and removed from the trace. Within the concept slice, events have a *minimal distance to the marked region.* If we create a graph where events represent the vertices and dependencies are the edges, the distance between events is defined as the shortest path between their corresponding vertices. In the concept slice, this is a measure of how far an event is from the marked region and can be used to order events in the implementation recipes.

Looking at the example events from Section 2.2 it can be noticed that both use the same target object. Hence, it constitutes a $target - target$ dependency and both events would remain in the resulting trace. Because the second event is in the marked region, its distance is 0. The first event is reachable in one step, thus, it has a distance 1.

2.3.2 Event Abstraction

At this point of the analysis, the sliced traces still contain application specific information. Since the next steps will attempt to find similarities between traces, it is necessary to abstract any application specific elements from the events. FUDA translates events into *abstract events* in 3 steps. First, since object ids are just relevant to determine dependencies in the concept trace slicing, they are removed from events. Second, parameters of method and constructor invocations are also ignored. The reason is that two methods with the same name but different number or types of parameters are very likely conceptually equivalent, *i.e.*, they probably serve the same purpose and just differ in the input data they are working with. Similarly, constructors with different parameters have the same purpose of creating an object and we can assume that they are equivalent.

The third step deals with the fully qualified name of the event's target. Independently if the target is a method, a constructor or a field, the fully qualified name of the enclosing class is always present. In this step we perform a simple static analysis on the type hierarchy of the target's enclosing class to find the so called *root types* of the event and generate an abstract event for each root type. Thus, a single event may potentially result in many abstract events. In the following we discuss the abstraction rules for each type of target. In order to illustrate the possible cases, we use the example displayed in Figure 1. The class diagram is taken from the context menu implementation in JFace, but was extended to assist the explanation.

Static methods, static fields and instance fields. Fields and static methods cannot be polymorphically called. However, it is possible to hide the member if a sub-class declares a method or field with the same name as the super-class. For example, in Figure 1 both `ContributionManager` and `MenuManager` declare the field `overrides`. Depending on which class is used statically, a different field is really being used. Therefore, in order to find the exact member in use we search the type hierarchy of the target bottom-up and we assume the first type that declares the member as the root type.

Constructors. A constructor invocation means that an object of a certain class is going to be created. However, the class can represent many types, both coming from its class inheritance hierarchy and from the possible implemented interfaces. Looking bottom-up from the target type, the type hierarchy is a

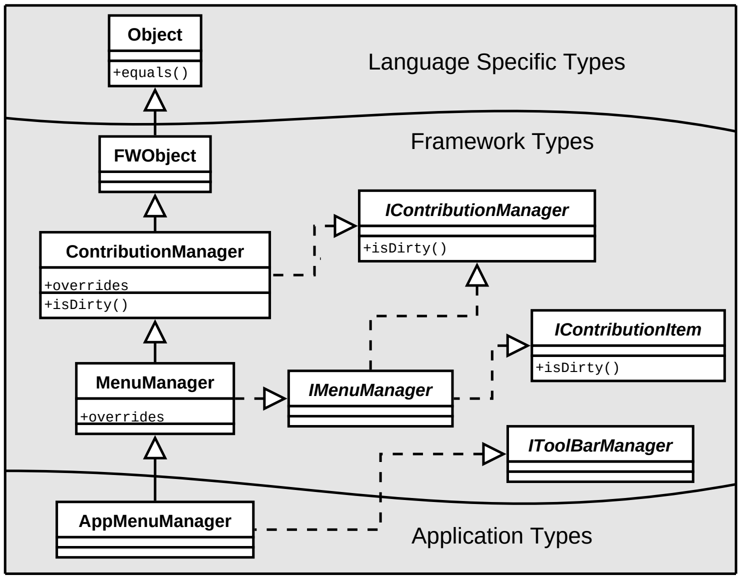

Figure 1: An example of inheritance hierarchy and the boundaries between application, framework, and language specific types.

directed acyclic graph (DAG), as can be seen in Figure 1 for the class `MenuManager`. For constructor invocations, a meaningful abstraction is to generate one root type for each type at the bottom borderline of the framework of the target type's inheritance DAG. The rationale is that, both for incoming and outgoing events, the construction of objects with application types is irrelevant, hence we look for the most specific framework type. The analysis traverses the DAG bottom-up and generates a root type for the first framework-declared type for each branch. For example, if `AppMenuManager` is the target, it generates `MenuManager` and `IToolBarManager` as root types; if `MenuManager` is the target, the only root type will be `MenuManager` itself. Note that another approach could be to generate a root type for each topmost framework type. While this approach would help agglomerate more events, we would loose the information of framework variants in use. To exemplify the problem, consider the hierarchy in the figure, where the framework defines a root class called `FWObject`. By using this approach, all construction invocations would generate an `FWObject` root type.

Instance Methods. When abstracting instance methods, two factors influence our approach. First, since we are trying to maximize the generalization, we search for the topmost type that declares the method. This also reflects the fact that the type declaring a method is its conceptual host. For example, the `equals` method in Java is declared by the `Object` class. Although there might be many implementation of `equals`, it conceptually belongs to `Object`, and it makes sense to aggregate events in this type. Second, since the same method might have multiple topmost types, one root type is generated for the topmost type of each branch. For instance, a method invocation to `MenuManager.isDirty` would generate roots for `IContributionManager` and `IContributionItem`, because both interfaces declare the method.

The example events described in Section 2.2 are both outgoing method invocations. The `createContextMenu` invocation is just declared by `MenuManager`. But `addMenuListener` is in fact declared by `IMenuManager`. Therefore, those events would yield the following abstract events:

```
Outgoing:
    org.eclipse.jface.action.IMenuManager.addMenuListener()
Outgoing:
    org.eclipse.jface.action.MenuManager.createContextMenu()
```

2.3.3 Traces Clustering

It is often possible for applications to implement framework-provided concepts in different ways. For example, there are many different ways of implementing a figure in an Eclipse Graphical Editing Framework (GEF[1]) editor: simple figures are easily handled by pre-defined framework classes, while more complex figures require more interaction with the API. In order to account for this situation, FUDA employs a clustering technique that groups traces based on a degree of similarity. Applying clustering brings 2 main benefits. First, the existence of different clusters of recipes in the result indicates to the developer that there are various ways of implementing the concept.

Second, clustering helps removing outliers from the sample. For example, it may happen that the developer incorrectly supposes that an application implements a certain concept. For instance, the concept of *Action* in Eclipse can be analyzed by FUDA because actions are triggered by buttons in the graphical user interface. If the developer analyzes an application using a button that does not utilize an action, then the trace will not contain the concept. By using clustering, this trace would belong to a separate cluster and the developer will be able to identify the mistake.

FUDA's process is agnostic with respect to the clustering algorithms it can utilize. In general, clustering is the process of partitioning a set of data items into groups (clusters) such that items within a cluster are more similar to each other than they are similar to items in other clusters. The degree of similarity between two items or two clusters is called their distance. There is a variety of algorithms to cluster the data items and a multitude of distance measures. It is not in the scope of this report to go into their details and the reader is directed to [7] for a thorough discussion. Currently, FUDA utilizes *hierarchical clustering* [7], which is appropriate when the number of clusters is determined dynamically.

2.3.4 Recipes Mining

The mining stage takes the traces of abstract events of a cluster and extracts implementation recipes. To this end, FUDA uses *mining frequent closed itemsets* [16] to find abstract events that are common between traces. Broadly speaking, this technique is used to look at a set of *transactions* (traces) containing *items*

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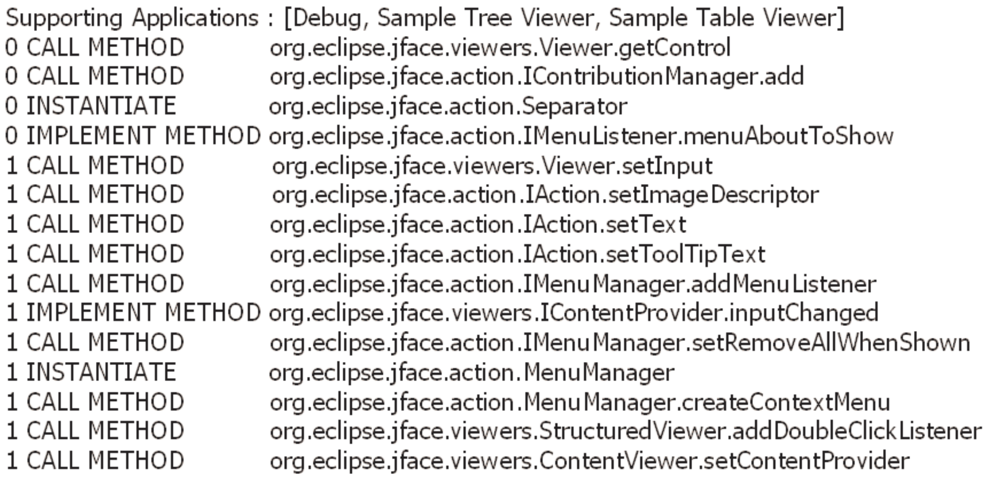
[1] `http://www.eclipse.org/gef/`



```
Supporting Applications : [Debug, Sample Tree Viewer, Sample Table Viewer]
0 CALL METHOD          org.eclipse.jface.viewers.Viewer.getControl
0 CALL METHOD          org.eclipse.jface.action.IContributionManager.add
0 INSTANTIATE          org.eclipse.jface.action.Separator
0 IMPLEMENT METHOD org.eclipse.jface.action.IMenuListener.menuAboutToShow
1 CALL METHOD          org.eclipse.jface.viewers.Viewer.setInput
1 CALL METHOD          org.eclipse.jface.action.IAction.setImageDescriptor
1 CALL METHOD          org.eclipse.jface.action.IAction.setText
1 CALL METHOD          org.eclipse.jface.action.IAction.setToolTipText
1 CALL METHOD          org.eclipse.jface.action.IMenuManager.addMenuListener
1 IMPLEMENT METHOD org.eclipse.jface.viewers.IContentProvider.inputChanged
1 CALL METHOD          org.eclipse.jface.action.IMenuManager.setRemoveAllWhenShown
1 INSTANTIATE          org.eclipse.jface.action.MenuManager
1 CALL METHOD          org.eclipse.jface.action.MenuManager.createContextMenu
1 CALL METHOD          org.eclipse.jface.viewers.StructuredViewer.addDoubleClickListener
1 CALL METHOD          org.eclipse.jface.viewers.ContentViewer.setContentProvider
```

Figure 2: An example implementation recipe generated by FUDA for the concept Context Menu by using three sample applications.

(abstract events), and determine the largest sets (recipes) of items that are commonly found in these transactions. In this context, *largest set* means that the technique ignores frequent subsets, since they are part of another frequent set.

When creating the recipe, an abstract event is transformed into an *instruction*. Because the distance to the marked region of the abstract event can be different on each trace, only the minimal distance is taken by the instruction. For example, suppose that the `createContextMenu` invocation is also found in another trace, but with distance 2. The generated instruction would have the same format of the abstract event, but with distance 1, which is their minimum.

The *support* of an instruction is the percentage of traces that contained its corresponding abstract event and the support of a recipe is the minimum support between its instructions. The *supporting applications* of a recipe are those applications that generated all instructions contained in the recipe. The result of this phase is a sequence of recipes in descending order of their support. Besides an indication of its support, a recipe also contains a list of supporting applications and a list of instructions in ascending order of their distance to the marked region. For instance, Figure 2 illustrates an example implementation recipe generated by FUDA for the concept Context Menu when three sample applications are used.

2.4 Results Inspection

The last phase deals with making right use of the recipes. The existence of different clusters of recipes indicates that there are main variants in the implementation of the concept, or eventually that some outliers were detected. Within a cluster, the developer can locate the best recipe and check its instructions. In general, they indicate the mandatory steps to implement the concept. The distance to the marked region roughly indicates the steps that separate the instruction from the actual execution of the concept. For example, the `addMenuListener` invocation is one step away from the marked region, which means that, although not directly involved in the execution of the concept, this instruction is directly related to an object used in the execution. Furthermore, in order to get more details, the developer is handed with a list of the applications where these instructions were detected.

3 Empirical Evaluation

The main objectives of the FUDA approach can be formalized in the following hypothesis:

Hypothesis. FUDA can determine *useful* implementation recipes with *few* false positives and false negatives by using only a *small number* of example applications.

In order to verify this hypothesis, we have designed an empirical experiment that provides the following evidence: *i)* a quantitative analysis of how the number of sample applications impacts the size and the number of false positives and false negatives on the resulting recipes, and *ii)* a qualitative analysis of the usefulness of the extracted recipes.

Moreover, we have engineered the experiment so that we can also quantitatively analyze the influence of marking, concept trace slicing and clustering on the results. In the following we describe the tool implementations and the experiment.

3.1 Tool Support

As described earlier, FUDA prescribes the use of a profiler and an analyzer tool. The former is responsible for assisting the developer in collecting and marking traces during data collection, and the latter implements the automated analysis phase. We have implemented a profiler tool that instruments applications using aspects written in *AspectJ*[2]. Developers must only define the framework and application packages, and execute the instrumented application. The tool also contains a GUI that helps developers to demarcate the begin and end of a concept's execution. To instrument code inside the Eclipse platform, the profiler tool can be used together with an *AJEER*[3] plug-in.

We have also implemented an analyzer tool in Java. The tool receives application traces stored in files by the profiler tool, applies the whole process of the automated analysis phase and outputs the implementation recipes. To conduct mining frequent closed itemsets in clusters of traces of abstract events, we use *LCM ver. 3.0* (*Linear time Closed itemset Miner*) [13] that outperforms many of the existing algorithms.

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[2] `http://www.aspectj.org/`

[3] `http://ajeer.sourceforge.net/`

3.2 Setup of the Experiment

The empirical experiment was designed to provide evidence that corroborates the aforementioned hypothesis. The experiment was executed in the two following steps.

3.2.1 Data Collection

The first task was to select input data for the experiment, *i.e.*, the frameworks, concepts and applications to be analyzed. Table 1 describes the selected concepts, their corresponding framework and their origins. Concepts marked with a *** represent the ones we selected from newsgroups. We focused on Eclipse based frameworks, because they provide a variety of concepts and many open source example applications. The selected concepts came either from developer questions posted on the frameworks' newsgroups or came from simply looking at the Eclipse workbench and asking how to implement some functionalities present in its plug-ins. The concepts were categorized in two types. Concepts of *Type I* are questions related only to the concept's execution, without worrying about setups and cleanups, in which case it is not necessary to employ concept trace slicing to augment the marked region. Concepts of *Type II* are those which require complete information regarding the concept implementation and concept trace slicing is necessary.

For each concept we randomly selected a number of applications of different domains and having different sizes. The applications came from default Eclipse plug-ins and from the *Eclipse Plug-ins Repository*[4]. Each application was instrumented by our profiler tool and executed separately. The invocation of the concept was demarcated with the assistance of the tool. The result of this step was a number of framework API interaction traces of the complete execution and containing the marked region for the concepts. For each concept at least 6 application traces were collected.

3.2.2 Data Analysis

The collected data was then processed by our analyzer tool to generate implementation recipes. The first part of the analysis concerns the evaluation of the impact of the number of applications on the resulting recipes. To this end, for each concept we randomly selected a single trace and processed it alone. Then we subsequently added more randomly selected traces to the analysis and generated the corresponding recipes. The second part was related to the impact of marking, concept trace slicing and clustering on the results. In this regard, for each concept we processed 4 random traces considering *i)* that the complete trace would be the marked region (simulating if marking was not possible), *ii)* only the marked region (without concept trace slicing), *iii)* the traditional process with concept trace slicing, and *iv)* forced the analysis to use just a single cluster for the concept. In both parts we have just analyzed the first resulting recipe of each cluster.

In order to evaluate the content of the resulting recipes, we must introduce the notion of *mandatory* and *optional* instructions. An instruction is mandatory for a concept if the realization of the concept cannot be completed without the instruction. For example, the instructions corresponding to the abstract

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[4] `http://www.eclipse-plugins.info`

Table 1: Concepts selected for the experiment.

	Concept	Framework	Description
CONCEPT TYPE I	Select*	GEF	What events happen when a user clicks on a figure in a GEF editor?
	Double Click*	GEF	What events happen when a user double clicks inside a GEF editor?
	Hover*	GEF	What events happen when a user hovers a figure in a GEF editor?
	Focus*	JFace	What events happen when a user clicks on the title-bar of an Eclipse view?
CONCEPT TYPE II	Table Viewer	Eclipse	How to create a typical table viewer in the Eclipse environment?
	Tree Viewer	Eclipse	How to create a typical tree viewer in the Eclipse environment?
	Navigation	Eclipse	How to create the set of *Go Home*, *Go Back* and *Go Into* actions in the Eclipse tree viewer's toolbar for navigating trees?
	ContextMenu	JFace	How to create a context menu in an Eclipse view?
	Action	JFace	How to create an action in the toolbar of an Eclipse view?
	Figure*	GEF	How to implement drawing a figure in a GEF editor?
	Connection	GEF	How to implement drawing a connection between two figures in a GEF editor?
	Drag-N-Drop*	GEF	How to implement drag and drop into a GEF editor from its palette?
	ContentAssist	JFace	How to implement the content assistant feature in the Eclipse text editors?

events of Section 2.3.2 are mandatory for the implementation of a context menu because without these instructions a context menu does not work. However, a context menu can optionally contain a *separator* and, thus, the corresponding instruction is optional.

Besides mandatory and optional instructions, a recipe may also contain instructions that are not relevant to the implementation of the concept. Such instructions are called the *false positives* of a recipe. The instructions that are mandatory for a concept but that are not included in a recipe are called the recipe's *false negatives*.

The determination of the set of mandatory instructions for the realization of a concept, as well as of which instructions can be declared optional, requires a reference. For some concepts the available documentation served as a guide. Independently of documentation availability, the authors manually inspected sample applications code to come up with the set of mandatory instructions. Also, an instruction was declared optional based on the authors understanding of the concept. This knowledge acquired while studying the extracted recipes, the available documentation and the sample application's code was the input for the last step, the qualitative analysis.

3.3 Results

3.3.1 Quantitative Analysis

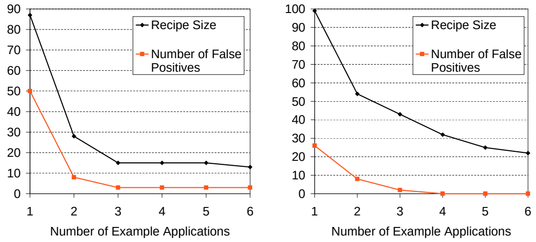
Figure 3 presents the results of the first part of the quantitative analysis. It displays the impact of the number of sample applications on the recipe. For brevity and because we have collected very similar results for all concepts in the experiment, we just present the results for 4 concepts here.

The diagrams display only the number of false positives and the size of the resulting recipes. The number of false negatives is omitted because in all cases it was 0, *i.e.*, it was always possible to detect all mandatory instructions, even when increasing the number of applications. Still, as can be seen in the diagrams, by slightly increasing the number of applications the recipes become smaller and with fewer false positives. After the number of applications is increased to 3 or 4, the quality of the recipe tends to stabilize, with the number of false positives approaching 0. This shows that by using only a few applications it is possible to obtain recipes that get closer to the set of mandatory instructions.

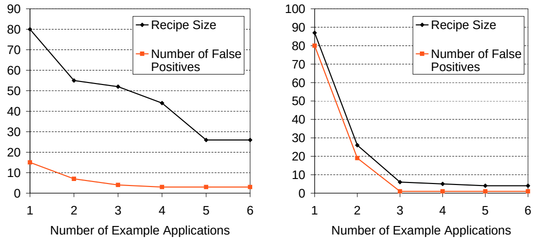
The results of the second part are presented in Table 2. In this Table, *Complete Trace* shows the simulation of not having marking, when the whole trace in considered the marked region; *Just Marked Region* represents the processing of just the marked region, without slicing; and *With Concept Trace Slicing* displays the results when the concept trace slicing technique is in use. Furthermore, S, P, and N are the size, number of false positives and negatives, respectively. The column S displays not only the size, but also the number of mandatory and optional instructions found in the recipe, in this order. The concepts whose recipes ended up in different clusters have one row for each cluster. Concepts marked with a * represent the ones without available documentation, in which case the set of mandatory instructions is determined only by code inspection. All results correspond to the use of 4 random applications to extract the recipe.

Table 2: Quality of recipe extracted with 4 sample applications for the concepts introduced in Table 1.

Concept	Complete Trace			Just Marked Region			With Concept Trace Slicing		
	S	*P*	*N*	*S*	*P*	*N*	*S*	*P*	*N*
Select*	54 (3)(4)	47	0	3 (3)(0)	0	0	-	-	-
Double Click*	62 (2)(3)	57	0	2 (2)(0)	0	0	-	-	-
Hover*	52 (0)(0)	52	4	4 (4)(0)	0	0	-	-	-
	52 (0)(0)	52	1	1 (1)(0)	0	0	-	-	-
Focus	20 (1)(0)	19	0	1 (1)(0)	0	0	-	-	-
Table Viewer	27 (13)(14)	0	0	27 (13)(14)	0	0	27 (13)(14)	0	0
Tree Viewer	31 (13)(18)	0	0	31 (13)(18)	0	0	31 (13)(18)	0	0
Navigation*	23 (9)(7)	7	0	7 (3)(4)	0	6	19 (9)(7)	3	0
ContextMenu	15 (6)(6)	3	0	3 (2)(1)	0	4	15 (6)(6)	3	0
Action	15 (2)(2)	11	0	1 (1)(0)	0	1	5 (2)(2)	1	0
Figure	63 (16)(33)	14	0	23 (12)(11)	0	4	56 (16)(33)	7	0
	68 (16)(34)	18	0	24 (12)(12)	0	4	55 (16)(32)	7	0
Connection	57 (23)(19)	15	0	22 (14)(8)	0	9	44 (23)(18)	3	0
Drag-N-Drop	53 (20)(20)	13	0	18 (12)(6)	0	8	40 (20)(19)	1	0
ContentAssist	18 (2)(11)	5	0	1 (0)(0)	1	2	16 (2)(11)	3	0



(a) Context Menu (b) Tree Viewer



(c) Connection (d) Action

Figure 3: Impact of the number of sample applications on the recipe size and number of false positives.

The results for the *Complete Trace* column indicate that using the whole application trace is insufficient for getting quality recipes, because, although those recipes contain few false negatives, they are very large and present many false positives. We can understand the impact of marking at runtime by comparing the results of this column with *Just Marked Region.* For all concepts, the size of the recipes and the number of false positives are drastically reduced. For concepts of *Type I*, whose target is solely the concept execution, the recipes are perfect, in the sense that they contain all mandatory instructions and no optionals. However, because the marked region can miss setup and cleanup interactions, using only the marked region events to retrieve complete recipes yields many false negatives for concepts of *Type II.*

The impact of the concept trace slicing technique is observable by comparing column *With Concept Trace Slicing* with the previous results. Because the technique selectively augments the marked region, it is able to reach all relevant events without bringing many irrelevant ones. In this way, it extracts recipes without false negatives and that are in general much smaller and with fewer false positives if compared with the complete trace. The only exception is the Context Menu, where the results were very similar to the complete trace. By analyzing this case closely, we realized that the selected sample applications have only this concept in common, a situation that eliminated false positives from the analysis of the complete trace. Note that concepts of *Type I* don't require concept slicing and are left outside this analysis.

The impact of clustering can be measured by forcing the analysis to use just a single cluster for each concept. The only concepts affected are those that presented clusters in the first place, Hover and Figure. The results of forcing a single cluster in their analysis is presented in Table 3. For Hover, using the

Table 3: Impact of not performing clustering on the quantitative results.

Concept	Complete Trace			Just Marked Region			With Concept Trace Slicing		
	S	*P*	*N*	*S*	*P*	*N*	*S*	*P*	*N*
Hover	52 (0)(0)	52	4 1	4 (4)(0)	0	0	-	-	-
Figure	51 (16)(22)	13	0	20 (12)(8)	0	4	39 (16)(20)	3	0

complete trace generates a recipe that only contains false positives. The reason is because the sample applications have many instructions in common that are not implementing the concept. The two rows of false negatives indicates the situation for each of the recipes generated with clusters. If just the marked region is used, then the process extracts a complete and useful recipe. However, it represents only one of the two possible variants discovered with clustering. This result is similar to the ones obtained for Figure. For this concept, the resulting recipes had quality relatively comparable to the ones obtained with clustering. Yet, one implementation variant was missing.

3.3.2 Qualitative Analysis

To perform the qualitative analysis of the recipes generated by the FUDA, they were compared against the documentation of the frameworks, actual example application' source code and their enclosing comments, and the responses to the questions in the developers newsgroups. Using this analysis, we were able to validate our evaluation hypothesis that it is possible to determine useful implementation recipes by using a few example applications. In particular, we were able to answer some questions to which there were no answer in the newsgroups; find some errors in some of the responses; or find recipes which are more complete than what is provided in the documentation of the frameworks under the study.

For the concept Select, the response in the newsgroup is: "it looks like `handleMousePressed` is called". Nevertheless, when we searched all the example plug-ins in the GEF package and example plug-ins from the Internet, none of them had this method in their source code. However, by applying the FUDA technique on just the marked regions of traces, it was easily possible to understand that those example applications call method `createDeleteCommand` when a figure is selected in a GEF editor. For the concept Double Click, when just marked regions of traces were used, the recipe found by FUDA was exactly the same as the response in the GEF developers newsgroup. For the concepts Hover, Focus, and Drag-N-Drop there were no answers to those questions in the forum. However, with the help of the FUDA technique, we were able to find the answers to those questions. Then, we checked our recipes against the source code of example applications and existing documentation and confirmed that the generated recipes are true. In particular, for the concept Drag-N-Drop, we found that `Outgoing EditPartViewer.addDragSourceListener` and

`Outgoing EditPartViewer.addDropTargetListener` are relevant instructions to the concept Drag-N-Drop which are not discussed in the GEF Programmer's Guide in the Eclipse environment. For this concept, the only false positive in the recipe when concept trace slicing is performed was `Outgoing EditPartViewer.setContextMenu` which is easily identifiable by the software engineer.

For the concepts Context Menu and Action, the false positives were those that manipulate the Eclipse view itself such as `Outgoing ContentViewer.setContentProvider`. The reason is that a context menu is invoked or an action is run inside an Eclipse view, and therefore the false positive instructions that manipulate the Eclipse view show themselves in the recipes.

For the concepts Figure and Connection, all the false positives when concept trace slicing is performed are those instructions that manipulate the palette of the GEF editor. The reason is that in order to draw a figure or create a connection in a GEF editor, we had to select them from the its palette in all of our example applications and therefore the instructions that were related to the implementation of palette were included in the recipes. If the software engineer is interested in those instructions as well, then they can be removed from the set of false positives.

When complete traces are used for the concepts in GEF, many of the false positives are those that initialize the GEF editor itself such as creating the action bar and creating the palette and its entries.

3.3.3 Tool Performance

All experiments were executed on a Pentium IV 1.60GHz machine with 1.00 GB of RAM. The required time for processing the framework API interaction traces and extracting the implementation recipes varied between 2 and 3 seconds. However, the time for collecting the traces depended on the size and usual performance of the example applications and frameworks, and on the target concept. In our experiments, recording each framework API interaction trace took up to 5 minutes.

3.4 Threats to Validity

This section discusses the threats to validity of the evaluation results presented in the preceding sections. We distinguish between *internal validity* in which potential threats in executing the steps of the experimental study are discussed, from *external validity* which relates to what extent the results can be generalized [8].

Internal Validity. The main threat to internal validity is related to manually counting the number of false positives and false negatives. Manual inspection is typically subject to errors. However, to compute the number of false positives, it was easily possible to identify the relevance of a given instruction using documentation and/or program source code. Furthermore, since the size of the recipes were often succinct, it was easily possible for the authors to check the correctness of number of false positives in several iterations to minimize this threat.

Regarding the number of false negatives, it is difficult to guarantee their correctness because of some sort of context dependency in the definition of a concept, i.e., it depends on users' point of view of a concept;

particularly when a concept includes variable elements. To minimize this threat, in our experiments, we focused only on well-defined concepts in frameworks documentation or newsgroups. Moreover, the authors put great care while defining the set of mandatory instructions for a target concept.

Another threat to internal validity relates to the incompleteness of frameworks documentation we used to compute the number of false positives and false negatives. To minimize this threat, we not only used the documentation provided by the frameworks developers, but also we used a number of articles available over the Internet. Furthermore, we used example applications source code as the complement of those documentation.

Finally, there might be some problems in the prototype implementation of FUDA that can lead to wrong conclusions. To minimize this threat, the authors of this report independently debugged the profiler and analyzer tools. However, there might be still some issues with the instrumentation of applications and frameworks. For instance, AspectJ which we used for the purpose of instrumentation can not instrument static strings since they are in-lined with the code. Nevertheless, there are a number of predefined static strings in the GEF framework to which different requests from the applications to the framework are compared. Using our prototype implementation of FUDA, we were not able to capture those strings.

External Validity. Our experimental evaluation involves three inputs: frameworks, concepts, and example applications. The way in which instances were selected for these variables directly affects the external validity of the results.

Frameworks. One threat to external validity is that all the frameworks in our experimental study are GUI frameworks in the Eclipse environment. Therefore, the experimented frameworks are not representative of different types of frameworks in practise. In particular, frameworks that use reflection such as *Struts*[5] and *Spring*[6] are quite common nowadays. Nevertheless, we did not perform experimental study with these frameworks and left it for our future work.

Concepts. One major threat to external validity is that the experimented concepts are all GUI concepts, self-contained, and very easy to delineate during invocation. This threat was minimized by selecting the most common concepts in the experimented frameworks, and referring to newsgroups to answer real programming issues. Nonetheless, another threat to external validity is that the selected questions from the forums are not representative. To minimize this threat, we randomly selected the questions from the pool of questions we extracted from newsgroups.

Example Applications. The selection of example applications for each concept and the order of processing them directly affects the results since the number of false positives and false negatives are highly dependent on how the desired concept is implemented in those applications. To reduce the risk of this threat and obtain results that can be generalized, we not only used example applications that were provided by the framework developers, but also we used example applications available in open source software repositories in the Internet. Furthermore, for each concept, at each step of the experiment, we randomly selected the example applications from the pool of sample applications.

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[5] `http://struts.apache.org/`

[6] `http://www.springframework.org/`

4 Discussion

4.1 Strengths and Weaknesses

The empirical evaluation results indicate that FUDA can retrieve useful recipes from only few sample applications. Furthermore, the approach is highly automated and scalable. The processing of the traces is fully automatic and the instrumentation does not impose significant overhead on the application execution since only the API interaction rather than full traces are recorded. Given a set of applications and scenarios, the amount of time needed to retrieve recipes is mainly determined by the amount it takes to execute the scenarios on the applications. Furthermore, dynamic analysis will detect what API elements are actually being invoked. This is important since frameworks typically use polymorphism and reflection and the presence of these languages renders static analysis less applicable. Finally, using the current implementation of FUDA, it is possible to profile closed source Java applications as well. This property makes FUDA applicable even if the sources of the sample applications are not available.

Nevertheless, the approach has some potential drawbacks. Most importantly, the quality of the results may depend on the selection of the applications. Thus, creating the scenarios might require some careful design to isolate the API instructions of interest in the context of composite concepts. We comment on this issue in the next subsection. Second, all dynamic approaches are dependent on the input data and generalizing from this data might not be safe. In that sense, FUDA will retrieve the set of API instructions that are invoked in each execution, but may fail to retrieve optional API instructions. Finally, dynamic approaches require the setup of the runtime environment, which might not be easy in some situations. Therefore, being able to retrieve useful recipes from only few application executions is particularly important.

4.2 Scenario Design Considerations

The nature of the concept and the ways in which it is implemented by the applications can influence the results. Ideally, the concept is self-contained, its invocation is easily delimitable, and the sample applications have only this concept in common. If this is the case, FUDA will bring most benefits. In general, concepts are composites of other concepts, the invocation of a concept might not be easily demarcated, and the sample applications have many concepts in common. For example, most plugins implementing context menus also implement *actions*, *views* and other Eclipse concepts. In this case, it is even more crucial that developers can demarcate the boundaries of the concept execution. Furthermore, some concepts usually come always associated with other concepts and, as it turns out, it is very difficult to separate them. For example, in order to open a popup menu in an Eclipse view, something must be selected. It is therefore hard to describe the concept of popup menu without the concept of selection.

4.3 Concept Trace Slicing

It is worth noting that the dynamic concept trace slicing presented in Section 2.3.1 is quite different from traditional dynamic program slicing [2]. First, while program slicing is defined in terms of data and control dependencies, concept trace slicing is defined in terms of relevance relationships between API invocations that incurred by the use of common objects as targets, parameters, or return values. Furthermore, while traditional dynamic slicing is defined with respect to a trace containing all program instructions that were executed, dynamic concept mining operates on API interaction traces.

The dependency relationship is motivated by common API usage patterns. For example, two method invocations sharing the same target objects could be related by the fact that one invocation initializes the target for the second invocation, or the second invocation cleans up the object that was used in the first one. Similarly, an invocation that returns an object that is later used as a target or parameter in a subsequent invocation may be an invocation to a factory method. Clearly, our relevance relationship may lead both to false positives and false negatives. For example, false positives commonly occur if the same object is used in two invocations for unrelated uses. False negatives can happen if invocations are related by side effects, such as accessing some objects in some framework registry. Nevertheless, as shown in the empirical evaluations, many of the false positives would be sorted out of the recipes in the data mining stage, and situations leading to false negatives are uncommon in the first place.

As the final point, one may question why the dependencies between two events in a framework API interaction trace are defined using the objects that are involved in those events instead of the actual data dependencies between the events, similarly to traditional slicing techniques. To answer this question, we defined the relevancy between two events using their data dependencies and performed the empirical evaluations for a number of concepts in Table 1. In all the experiments, it turned out that the complete framework API interaction traces were automatically marked since the API events were densely connected by data dependencies. As a result, many false positives were present in the resulting recipes, and we decided to use the object dependencies approach.

5 Related Work

Framework Usage Comprehension. Several tools for mining framework usage patterns from sample applications exist. Examples include *XSnippet* [12], *Strathcona* [6], *Prospector* [10], *MAPO* [15], *CodeWeb* [11], and *FrUiT* [3]. Both XSnippet and Strathcona are context-sensitive code assistant tools that allow developers to query a repository of code snippets that are relevant to the programming task at hand. Prospector is a tool that accepts queries in the form of a pair (τ_{in}, τ_{out}) where τ_{in} and τ_{out} are class types. A query returns code snippets that instantiate an object of type τ_{out} from a given input object type τ_{in}. MAPO is a tool that searches open source repositories by using a query that characterizes an API by a method, class, or package. Then, it applies data mining techniques to mine closed sequential patterns from method call sequences extracted from the source files. *CodeWeb* [11] applies data mining on the source code of programming libraries or frameworks to discover reuse patterns in existing applications. *FrUiT* uses the association rules mining technique to extract common framework usage patterns from existing framework applications and keep them in a database. Then, application developers can automatically query those patterns that are relevant in the context of their current task.

A recent work done by Acharya et al. [1] uses a frequent partial order mining tool to mine partial orders in program traces that are statically generated for APIs of interest by using a model checker tool. All these tools mentioned before use static analysis and are mainly code assistants in the context of a programming task at hand, such as how to call a specific framework method or how to instantiate a particular framework class. Therefore, these tools are mostly helpful when the developer at least knows the API element of interest and they are less helpful if the developer has only a high level idea of the concept that needs to be implemented. In contrast, FUDA uses primarily dynamic analysis in order to allow the developer to identify the concept of interest by invoking it explicitly. As a result, the developer does not need any knowledge of the framework API other than the names of the packages in which it resides.

Concept Location. Understanding how a certain concept or functionality is implemented in the source code of an application is an important program comprehension problem that is often referred to as the *concept location* or *feature location*. The concept location techniques can be mainly classified into *static*, such as *SNIAFL* [17], *dynamic*, such as *Software Reconnaissance* [14], and *hybrid* ones, such as the approach based on *concept analysis* [4], which combine static and dynamic analysis. To the best of our knowledge, none of these techniques explicitly address the issue of concept location in the context of framework comprehension. Nevertheless, the approach based on concept analysis is worth discussing in more detail as it is highly related to FUDA. The key idea of the approach is to execute a set of scenarios—each exhibiting one or more features—to obtain execution traces and then to use concept analysis to locate the relevant units in the application code. In essence, the approach locates the features by computing all intersections and unions of the traces. The located units become starting points for user-assisted static analysis to locate additional feature-relevant units, e.g., object creation and clean-up instructions. There are several significant differences between this approach and FUDA. (i) Most importantly, the approach is not focused on API usage and the resulting feature slices will contain many application-specific instructions that are irrelevant from the viewpoint of framework usage. FUDA avoids this problem by focusing on API interaction traces. (ii) Furthermore, the approach works with traces from a single application, while FUDA enables the use of different applications through API event abstraction. The use of different applications affords more diversity in the traces and can lead to better results with fewer traces. In some cases, using different applications may even be the only way to obtain any useful results. For example, obtaining traces that use an Eclipse tree view in different ways from one application may not be possible. (iii) Another difference is that concept invocations are marked in FUDA. This marking avoids the need for a non-invoking trace to mask irrelevant events in the concept invoking trace. (iv) Finally, FUDA uses dynamic concept trace slicing instead of user-assisted static analysis. Static analysis for object-oriented programs is often highly imprecise due to polymorphism and reflection.

6 Conclusion and Future Work

The API of many modern object-oriented software frameworks is large and complex. Hence, novice application developers often require a great amount of time and effort to learn how to use it. This report presented FUDA, a new approach that combines a novel dynamic slicing approach with clustering and data mining techniques to comprehend the implementation recipes of a framework-provided concept. A recipe specifies the API instructions that are commonly involved in the implementation of a concept. Our experimental results show that FUDA can generate the implementation recipes for a given framework-provided concept with just few false positives and false negatives by using only a few different sample applications implementing that concept.

Suggestions for future work include augmenting the recipes with additional information extracted from the traces, such as call nesting, partial ordering of calls, and object passing patterns. Furthermore, a simple postprocessing of the recipes could provide more detail about the instructions, such as listing whether a call back was provided by implementing an interface or overriding framework-provided class. User studies are necessary to determine which of these extensions should be provided first and how the information should be presented.

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