

Reverse Engineering an iPhone Applications using Dynamic Analysis

Philippe Dugerdil and Roland Sako

Geneva School of Business Administration, Univ. of Applied Sciences Western Switzerland (HESSO),

7 route de Drize, CH-1227 Geneva, Switzerland

Keywords: Reverse Engineering, Mobile Application, Dynamic Analysis.

Abstract: Mobile applications are becoming very complex since business applications increasingly move to the mobile. Hence the same problem of code maintenance and comprehension of poorly documented apps, as in the desktop world, happen to the mobile today. One technique to help with code comprehension is to reverse engineer the application. Specifically, we are interested in the functional structure of the app i.e. how the classes that implement the use cases interact. Then we adapted, to the iPhone, the code analysis technique we developed for the desktop applications. In this paper we present the reverse engineering process and tool we used to reverse engineer the code of an iPhone app and show, in a case study, how these tools are used.

1 INTRODUCTION

According to several surveys, mobile business applications are the trend of the day, although not all surveys agree on the strength of the trend (Appcelerator/IDC, 2013); (IDC, 2013); (Zend, 2013) (Wasserman, 2011). With the growing interest in B2B and B2E mobile apps (IDC, 2013) mobile development becomes mainstream (IBM, 2014) (Hammond, 2013). Then the very same problems of application maintenance and understanding arise as in desktop applications. There are no reasons to believe that mobile apps will be any easier to maintain than desktop ones. In particular the lack of documentation could even be higher, on average, than on traditional desktop platform since these applications are notoriously developed using agile approaches such as Scrum which leaves a lot of freedom to the developer as to what documentation to produce. Then we decided to develop a mobile version of our methodology for the reverse engineering of applications. This is a complete set of techniques and tools to analyze the functional structure of an application (Dugerdil and Niculescu, 2014) to improve its understanding hence its maintenance. Indeed it is known for a long time that to “understand” a large software system, the structural aspects of the system are more important than any single algorithmic component (Tilley et al., 1996). Since there are several views of software architecture (Clements et al., 2002), each targeting a

particular purpose, we developed a new one specifically targeted at software understanding. The latter is what we call the functional structure of the system (Dugerdil and Niculescu, 2014) i.e. the structure of the components of the system that implement the high level business function of the software, together with their relationships. Our approach rests on dynamic analysis techniques i.e. the analysis of the execution trace of the program corresponding to some scenario (use-case) relevant to the business. One key problem in dynamic analysis is to cope with the amount of data to process. In fact, the execution trace file can contain several hundreds of thousands of events. To cope with this data volume, we developed a trace segmentation technique (Dugerdil, 2007) that has showed to be very efficient at analyzing the interactions between the components of the system. In this paper we first present our reverse engineering framework for software system (Section 2). Then we show the tools we developed specifically to adapt our framework to the reverse engineering of Objective-C applications on the iPhone (Section 3). Next, in Section 4, we present a case study. Section 5 presents the related work and Section 6 concludes the paper.

2 REVERSE ENGINEERING

The goal of our reverse engineering process is to

recover the functional structure of the program ((Dugerdil and Niculescu, 2014) i.e. to analyze what classes or components support the high level function of the application. The process starts with the recovery of the use-cases of the system, if they are not readily available from the documentation of the app (which is generally the case), by watching the users interacting with the system. We simply ask the user to go through all the business-relevant scenario and we take note of all the actions he does with the app. (In the case of legacy desktop applications we even video-record the actions of the user. But this is not required here because the use-cases for mobile apps are usually much simpler). Starting from the use cases allows us to concentrate on scenarios of business value. Next we instrument the source code of the program to be able to generate the execution traces (i.e. the sequence of method calls in a given run of the system). Code instrumentation consists of inserting extra statements in the source code to record events when the methods are executed. An event is generated when the method is entered and exited. Next the system is run according to the use-cases and the corresponding execution trace is recorded. Finally, an off-line analysis of the execution trace is performed to recover the functional structure of the system using many views. Figure 1 illustrates a simplified version of the reverse engineering process with only the key tasks.

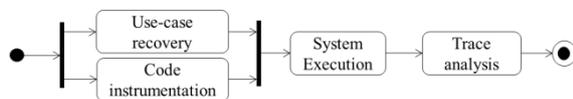


Figure 1: Reverse Engineering process.

This process has been implemented using a set of tools that are presented in Figure 2. To instrument the source code, many variants exist among which:

- developing an instrumentor for the programming language of the system;
- leveraging an AOP environment to inject the “instrumentation aspects” into the code.

Depending on the programming language considered, the second option may not be available. For Objective-C it is indeed the case and we developed our own code instrumentor that will be detailed in the next section. Once the code has been instrumented it is compiled and shipped onto the iPhone. Then the app is run according to the use-cases and the execution trace is recorded in a file on the device. Next, the file is downloaded from the device and uploaded into a trace database using a trace loader which performs a few integrity checks.

Finally, the trace is analyzed using our trace analysis tools. The latter is able to present the information from the trace using several views. Since Objective-C does not have any *package* construct, the identification of the events uses only the class name. There are two formats for the events to be recorded in the execution trace. The first is for method *entry* and the second for method *exit*. By recording these two kinds of events, we can reconstruct the call graph with the call hierarchy.

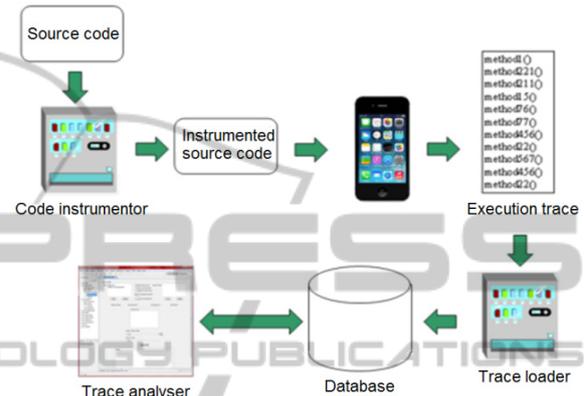


Figure 2: Tools workflow.

The syntax of the events is the following:

[SCI] [DCI] '[' [TN] ']' [Sign] 'AS' [Type] '[' [TS] ']' [Param]
 Or
 'END' [SCI] [DCI] '[' [TN] ']' [Sign] 'AS' [Type] '[' [TS] ']'

With :

- [SCI] : Static class identifier : the class in which the executed method is implemented.
- [DCI] : Dynamic class identifier : the class of the instance that executed the method.
- [TN] : Thread number.
- [Sign] : Method signature.
- [Type] : Type of the element returned by the method.
- [TS] : Time stamp of the event
- [Param]: List of the comma-separated values for the primitive-typed parameters of the method. Non primitive-typed values are replaced by ‘_’.

The first event represents the *entry* into a method and the second, headed by the keyword ‘END’, indicates the *exit* from the method. The thread number allows us to gather all the events that belong to the same thread for further analysis.

3 APP INSTRUMENTATION

Dynamic analysis as opposed to static analysis aims at observing the application's behavior while it is running. Although many techniques can be used (Hamou-Lhadj and Lethbridge, 2004) we decided to use code instrumentation because, on the mobile device, there are not many alternatives. Indeed one cannot install any profiling or debugging environment without deeply impacting the behavior of the code. The least intrusive technique is simply to add lightweight tracing statements in the application source code to write the events in a flat file. Each of the recorded events must contain the signature of the method called. As for the class identifier we record the name of the class and, in case of the languages using module or package declarations, the package or module in which the class is defined. Once the trace file is generated (that could contain millions of events), it is loaded into a database for further processing. Many of the existing dynamic techniques focus on the monitoring of the low level instructions of the program, in particular when the purpose is to analyze an app for which only the compiled code is available. Since we wish to reverse engineer the functional structure of the app, access to the source code is a must.

The first step to build our own instrumentor for Objective-C is to be able to parse the source code. To build such a parser, several possibilities exist. Tools like JavaCC (JavaCC, 2014) YaCC (YaCC, 2014) or ANTLR (ANTLR, 2014) are capable of generating a parser given the syntax definition of the programming language in the EBNF format. Such parser is completed by adding some extra parsing instructions in the target language. The main difference between these tools is the language in which the parser is generated. Our choice was JavaCC which generates a parser in Java. This is because JavaCC -encoded grammars are available for several programming languages, including Objective-C, and also because we had some previous successful experience with it. However we do not only need to parse the code, we also need to build an abstract syntax tree (AST) of the code in memory so that we could add the extra trace event generation code to some of the nodes in the AST. We used the Java Tree Builder (JTB, 2014) to produce the AST. Some Visitor (Gamma et al., 1995) classes are generated by the same tool to visit each node of the AST. We use the "Visitor" classes to add the instrumentation instructions at the proper locations in the code: as the first statement of each method and right before each of the methods' exit

statements. The output of the parser generation process is represented by two packages named `syntaxtree` and `visitor` which respectively contain the AST elements and their associated "visitors". Because every single abstract syntax tree element comes with its own "Visitor" class, we focused on the ones responsible for the handling of methods. The added instructions in the source code must satisfy two conditions:

- 1 Do not produce any changes to the application semantics;
- 2 Limit as much as possible the impact on the application processing time.

The first constraint is self-evident. The second condition aims at avoiding any impact on the scheduling of multi-threaded applications. To be able to record the events during the execution of the app, we need to build a little runtime program, called HEGTrace, to write the events to a flat file. Then the instructions we insert into the source code of the methods are simple calls to the function of HEGTrace. The latter contains:

- A class with two methods to write an event at the *entry* and at the *exit* of the instrumented method.
- A class responsible for converting the primitive-typed values of the parameters into NSString, to write these values in the trace event (see the [Param] element of the trace event grammar).

Every iOS application has its own set of directories in which it can read and write files. An application's private file system is called a Sandbox (Apple iOS, 2014) and it is specific to the application. Inside a sandbox, there are three predefined directories: `Documents`, `Library` and `tmp`. To store a trace file, the HEGTrace program can write in either the `Library` or `Documents` directory. But we should avoid `tmp`, since its content may be cleared away by the system when the application stops running. Because these folders generally contain user-generated content and other resources used by the application's logic, we need to make sure the trace files we write will not interfere with the existing files. To do so, we create the trace files in a custom folder inside the `Library` folder:

```
<Application_Home>/Library/HEG_TRACE/trace_[timestamp].
```

This will not only ensure that our tool does not hamper the application's behavior but also allows the running of our use-cases in sequence to get several trace files all at once. Next, to upload the trace file into the desktop machine for further

analysis we pull it out of the iPhone using iExplorer (iExplorer, 2014) which gives access to the part of the device’s file system where the applications reside. A technique to shortcut the creation of the trace file could have been to embed a socket communication module in our HEGTrace program to “pipe” all the data in real time to a listening socket. However this would require a permanent connection to server and this would not respect our second constraint to have as little an impact on the processing time as possible. Another alternative technique to trace file writing could have been to monitor the application execution using an embarked version of a debugger such as GDB (GDB, 2014). Unlike C++ or Java, the runtime of Objective-C (Objective C, 2014) uses a specific syntax to do message sending. A message sending is a statement like `[object1 foo:@"arg"]` meaning that `object1` is sent a message whose “selector” is `foo:` and whose argument is “arg”. This syntax is converted to

```
objc_msgSend(object1, foo("arg"))
```

by the Objective-C runtime. Then, using the debugger, we would set a break on every `objc_msgSend` to monitor the execution. As the iOS devices use the ARM processor, fetching the right registers could give access to all the methods’ execution context. But this technique would delay the program execution at each message sending and then would exaggeratedly slow down the whole application, therefore not respecting the second constraint. The chosen instrumentation technique using our own instrumentor has the extra advantage to be applicable to any programming language provided that a LALR-analyzable grammar is available. Hence the technique presented in this paper can be extended to the Android platform (Parada and de Brisolará, 2012) since it uses Java as the programming language.

4 CASE STUDY

We chose to reverse engineer an app that is used to search and display the acts and articles of the Swiss Law recorded in the device. With our reverse engineering technique we can quickly identify what classes are involved in the delivery of a given functionality and what are the dynamic caller-callee relationships for the use-case. As an example, here is the analysis of the classes involved in the use-case “Read a judgment of the Swiss Federal Court”. In Figure 3 the trace analyzer tool displays the classes involved in the use-case and specifically what class

calls what other class. As we can see in the display, the class `RootViewController` is called by 3 other classes:

- `CPCAppDelegate` 12 times
- `homeViewController` only once
- `RootViewController` 170 times.

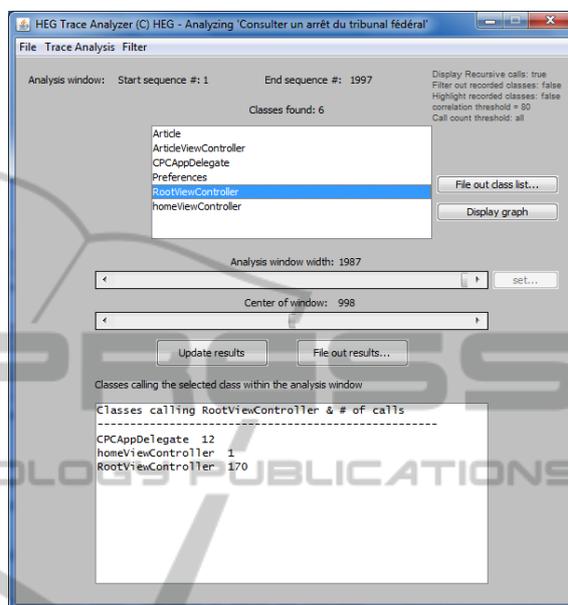


Figure 3: Trace analyzer.

Figure 4 displays the call graph with all the involved classes. In this figure we can see that four classes are coupled bi-directionally which, on the point of view of program quality, could be something to investigate further. But this is neither the case of the `ArticleViewController` nor the `Preferences` classes. The call graph is generated by our tool using the Graphviz open source library (Graphviz, 2015). Now we are interested to know when, in the course of the execution, the classes are involved. Then our trace analysis tool could display a “time series” graph of the classes’ presence in the trace. But the problem is that the trace is quite huge. Then the display of each and every method in the trace would lead to a very dense graph. To overcome the problem we introduce a little bit of statistical processing: we segment the trace in contiguous segments of a predefined size and, for each segment, we count the number of times a given class is called. Therefore the size of the horizontal display is now given by the number of segments in the trace which is user-defined.

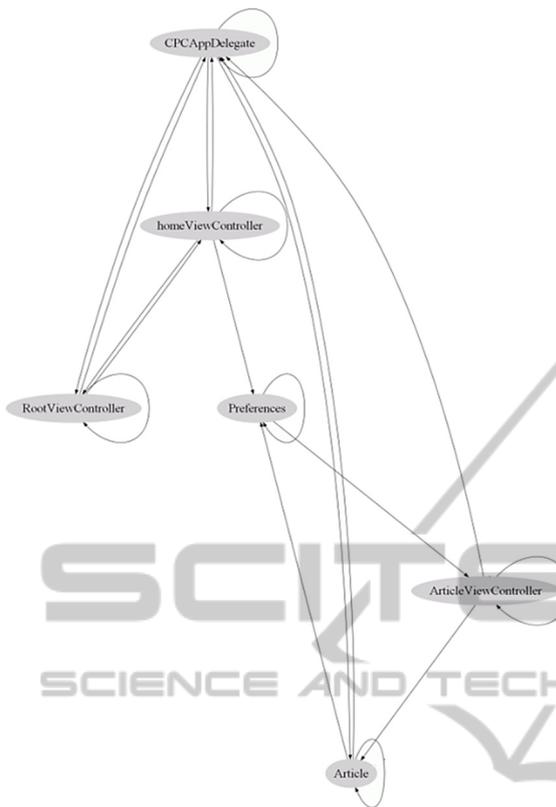


Figure 4: caller-callee graph.

Figure 5 presents such a time series graph for the Preference class.

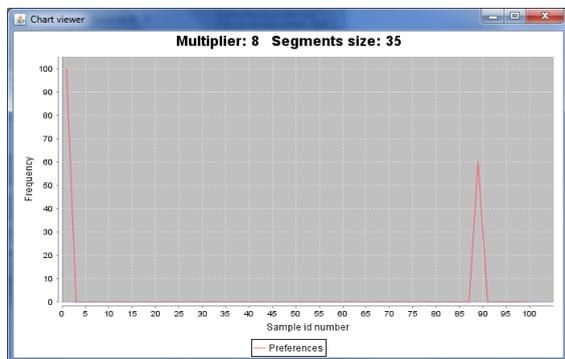


Figure 5: Preference class time series.

As we can see, the class is used at the beginning of the processing and close to the end. Figure 6 displays the methods that are called in the Preferences class. We observe that very few calls are made in this class. Indeed this class holds the application’s preferences parameters. All the behavior, showed by Figure 5 and 6, rightfully represents what we could expect from a class which holds preferences information. Next, we could compare the time series of two classes.

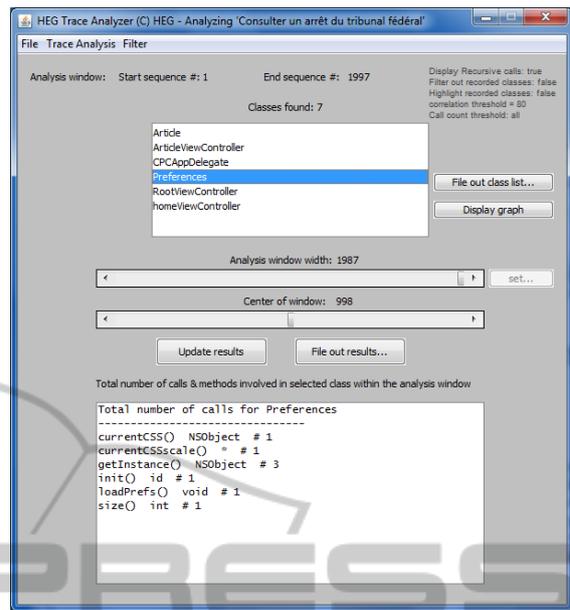


Figure 6: Methods called in Preference class.

Figure 7 shows the joint time series for the classes RootViewController and Article.

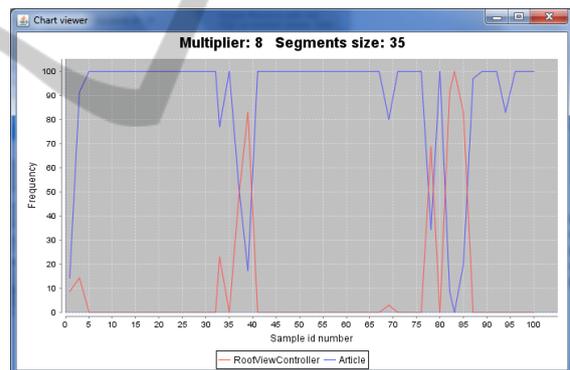


Figure 7: Joint time series for 2 classes.

Interestingly, the involvement of these two classes seems opposite. In the few segment where the Article class is much less involved then the RootViewController class is heavily involved. A further source code investigation revealed that the hundreds of Article objects (i.e. articles of the law) to be loaded in memory from a file are loaded all at once. Because this process is not in a dedicated thread, it blocks everything else until it is finished. The RootViewController contains a UITableView and implements its delegate and datasource protocols (Apple UITableView, 2014). Because the structure of the law acts and articles is hierarchical, a RootViewController is reclusively created every time the user browses a

subcategory of the law acts and articles. Then the relevant Article objects are accessed in memory, inserted into the UITableView cells and the RootViewController is quit. This explains the sudden “bursts” of activity of the RootViewController following the activity on Article objects. With this information we can now reconstruct the *dynamic UML class diagram* corresponding to the executed use case (Figure 8). This diagram represents the implementation classes of the *functional structure of the system* in relation to the use-case. It contains the classes, methods and dynamic associations involved in the execution of the use-case. In some sense this represents a “projection” of the use-case to the whole system.

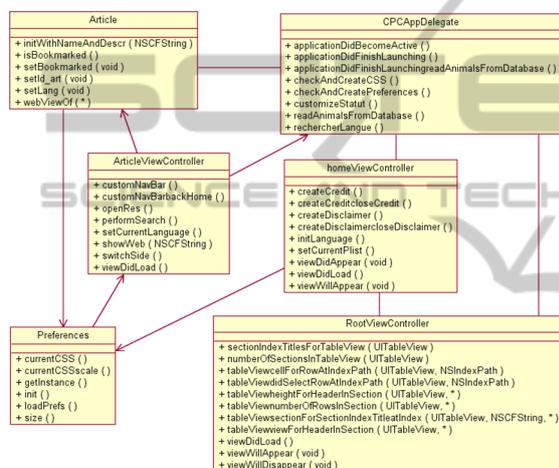


Figure 8: Class diagram of the functional structure.

Today, this UML class diagram is built by hand from the output of the tool. We intend however to integrate our tool with the software modeling environment we use (IBM’s Rational Software Architect) so that this class diagram could be created automatically.

5 RELATED WORK

Dynamic analysis of iOS applications has been a subject of interest for a few years. For example, it has been used to check the security of the app when its source code is unavailable and specifically to do black-box penetration testing. However, when the source code of the app is available, the tester generally turns to static code review and white box testing. Gianchandani (Gianchandani, 2014) uses snoop-it (Snoop-it, 2014) to hook into a chosen application’s process and to monitor network and

file system activities. He also uses Introspy (Introspy, 2014) which is composed of a tracer module and an analyzer module. After having selected the API to trace, the tracer will log the corresponding calls to a database. Next, the analyzer will produce a human readable report in HTML. However the tool does not target all the custom application classes but focuses on the specific ones related, but not limited to cryptography, data storage and networking. Szydowski M. et al (Szydowski et al., 2011) proposed a technique to perform automatic dynamic analysis of iOS applications by hooking to the application’s delegate and triggering all of the UI controls on every view. The result is a state model of the application. However, most of the dynamic analysis methods operate on the low level instructions. Hence, hooking to the running process is needed. But Apple does not include any default debugger on the device and installing one requires to jailbreak the iPhone. An alternative consists of running the application on the iOS Simulator (iOS Simulator, 2014) that comes with XCode then monitoring its process using GDB (GDB, 2014) or LLDB (LLDB, 2014). But the dynamic analysis of a simulated application using a debugger does not provide as much information as is available when writing the trace events to a file and analyzing the file off-line. Indeed the latter method let us perform statistical analysis which is difficult when using a debugger. Moreover, working on a simulated device, the technique does not allow analyzing apps that involve sensors such as accelerometer, compass or camera as they cannot be reproduced in the iOS Simulator.

6 CONCLUSIONS

The contribution of this paper is to present a reverse-engineering process and the associated tools to reverse-engineer iPhone applications. Of course, the technique is not limited to iPhone apps since the core of the technique is to generate a trace file by instrumenting the source code of the app. Then it is applicable to whatever environment, provided that we can build a source code instrumentor for the associated programming language. In particular, since we already developed an instrumentor for Java, we are ready to analyze any Android application. The trace analyzer we developed provides a rich set of view through which the maintenance engineer can study the running of the code. In our simple case study, we observed that the “time series” technique can visually present the

mutual behavior of the classes in a convenient format. It provides some useful clues as to how classes interact when running the use-cases. The *dynamic UML class diagram* of the functional structure of the use-case conveniently summarizes all the programming elements involved in the execution of the use-cases.

The drawback of our reverse-engineering technique is that we are unsure to go through the all the alternative paths in each of the scenarios since the latter are recovered from the observation of the users. For example, in the case of legacy desktop applications, we investigated a semi-automated technique to recover the use case from the legacy code (Dugerdil, Sennhauser, 2013) with moderate success however, due to the complexity of the task. Indeed, use-case recovery from source code is still an open problem. As future work we will integrate our tool with IBM's RSA to be able to generate the *dynamic UML class diagram* automatically. We also intend to develop new views to represent the dynamic business-level application semantics. Indeed we are building domain concept ontologies whose concepts will be dynamically identified in the executed code. This technique will help to close the semantic gap between the high level business domain concepts and the code level.

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