Advanced Java Bytecode Instrumentation*

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ABSTRACT

Bytecode instrumentation is a valuable technique for transparently enhancing virtual execution environments for purposes such as monitoring or profiling. Current approaches to bytecode instrumentation either exclude some methods from instrumentation, severely restrict the ways certain methods may be instrumented, or require the use of native code. In this paper we compare different approaches to bytecode instrumentation in Java and come up with a novel instrumentation framework that goes beyond the aforementioned limitations. We evaluate our approach with an instrumentation for profiling which generates calling context trees of various platform-independent dynamic metrics.

Categories and Subject Descriptors

D.1.2 [**Programming Techniques**]: Automatic Programming; D.2.8 [**Software Engineering**]: Metrics—*Performance measures*

General Terms

Algorithms, Languages, Measurement

Keywords

Java, JVM, dynamic bytecode instrumentation, program transformations, dynamic metrics, profiling

1. INTRODUCTION

Altering Java semantics via bytecode instrumentation[1] is a well-known technique [16] and has been used for many purposes that can be generally characterized as adding reflection or aspect-orientedness to programs. When working at the bytecode level, the program source code is not needed. In previous work, we applied bytecode instrumentation in order to monitor and control resource consumption in standard Java Virtual Machines (JVMs) [4], and to generate calling-context-sensitive profiles for performance analysis [2, 3].

A common goal when applying bytecode instrumentation is full coverage of every bytecode that is being executed in the JVM. I.e., no method should 'escape' bytecode instrumentation, because incomplete instrumentation would result in incompleteness of the data collected by instrumentation-code. However, currently many applications of bytecode instrumentation suffer from one or both of the following two limitations: (1) Certain core classes of the JDK are excluded from instrumentation. Consequently, the bytecode executed by the methods in these classes is not tracked by instrumentation-code. (2) Instrumentation is performed only statically; the whole application (including libraries) has to be instrumented prior to execution. Hence, dynamically generated or downloaded code is not instrumented.

In this paper we present a generic framework for dynamic bytecode instrumentation in *pure Java* called FERRARI (Framework for Efficient Rewriting and Reification by Advanced Runtime Instrumentation), which enables the instrumentation of the *whole JDK* including all core classes, as well as the instrumentation of dynamically loaded classes *at runtime*. FERRARI has been designed to take an arbitrary user-defined instrumentation-process (conforming to the simple FERRARI API, which will be explained later in this paper) and to enhance it with support for full JDK instrumentation and dynamic instrumentation.

FERRARI uses a combination of static and dynamic instrumentation to achieve its goals. Only core classes of the JDK are instrumented statically, whereas all other classes are instrumented at runtime. Instrumenting core classes of the JDK requires special caution, since instrumentation-code must not disrupt the bootstrapping of the JVM. We solved this problem by ensuring that instrumentation-code is not executed before the bootstrapping phase is completed.

Dynamic instrumentation can perturbate measurements, particularly because any Java-based bytecode engineering library relies on classes of the JDK which themselves have been instrumented. Hence, we had to provide a mecha-

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[1]In this paper, the term *instrumentation-process* refers to the code that performs an instrumentation, whereas the expression *instrumentation-code* denotes the extra code inserted by an instrumentation-process. *Instrumented-code* describes the code resulting from an instrumentation-process, i.e., including the original code as well as the inserted instrumentation-code.

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Java Bytecode Instrumentation An Introduction Correlsense

Michael Brown

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Exectracer ArunKumar ShanmugaVelayutham,2019 Abstract The amount of coding in Java Applications has increased over the years which necessitates the understanding of the behavior of Java Applications at runtime to evaluate performance Because of this growth in coding within Java Applications computer scientists have been increasingly interested in correlating execution data and performance Collection of execution data about a running Java Application is referred to as Tracing Tracing the Java code execution is most effectively done by source code instrumentation and bytecode instrumentation This project illustrates the use of ExecTracer as a bytecode instrumentation tool to trace Java code execution ExecTracer uses the ASM bytecode manipulation framework to manipulate bytecode and Java Agent is used to perform on the fly bytecode manipulation otherwise known as Dynamic Instrumentation Java Agent utilizes the Instrumentation Application Program Interface API that provides alteration for the existing bytecode loaded in the Java Virtual Machine JVM ExecTracer performs Instrumentation on the running Java Application and logs execution trace information Trace results from ExecTracer on several Java Applications shows excellent accuracy about instructions executed execution frequency and percentage coverage The execution trace information provided by ExecTracer can be used for code coverage analysis during testing phase or for monitoring the performance of the Java Application after deployment thereby aiding in selecting better code refactoring techniques and reduce code complexity **Information Flow Analysis and Enforcement in Java Bytecode** Deepak Chandra,2006 Information flow analysis policies are more flexible and powerful than currently prevalent discretionary access control DAC policies Current information flow systems are either purely dynamic or static Pure dynamic systems are overly conservative as they suffer from label creep due to lack of information about other paths On the other hand pure static systems are conservative about runtime values require source code and programmer annotations We propose hybrid information flow analysis which is more flexible and precise than either pure static or dynamic techniques individually It leverages the strengths of the two approaches while mitigating their weaknesses It statically gathers information and makes it available to the runtime so that the runtime mechanism can safely contain the label creep while precisely tacking information in current path of execution The proposed analysis works on Java bytecode does not require source code or programmer annotations

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