

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[‡] is

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[‡]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-*

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-

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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1. Understanding the eBook Java Bytecode Instrumentation An Introduction Correlsense
 - The Rise of Digital Reading Java Bytecode Instrumentation An Introduction Correlsense
 - Advantages of eBooks Over Traditional Books
2. Identifying Java Bytecode Instrumentation An Introduction Correlsense
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Java Bytecode Instrumentation An Introduction Correlsense
 - User-Friendly Interface
4. Exploring eBook Recommendations from Java Bytecode Instrumentation An Introduction Correlsense
 - Personalized Recommendations
 - Java Bytecode Instrumentation An Introduction Correlsense User Reviews and Ratings
 - Java Bytecode Instrumentation An Introduction Correlsense and Bestseller Lists

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 - Java Bytecode Instrumentation An Introduction Correlsense Budget-Friendly Options
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 - Java Bytecode Instrumentation An Introduction Correlsense Compatibility with Devices
 - Java Bytecode Instrumentation An Introduction Correlsense Enhanced eBook Features
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 - Highlighting and Note-Taking Java Bytecode Instrumentation An Introduction Correlsense
 - Interactive Elements Java Bytecode Instrumentation An Introduction Correlsense
8. Staying Engaged with Java Bytecode Instrumentation An Introduction Correlsense
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Java Bytecode Instrumentation An Introduction Correlsense
9. Balancing eBooks and Physical Books Java Bytecode Instrumentation An Introduction Correlsense
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Java Bytecode Instrumentation An Introduction Correlsense
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Java Bytecode Instrumentation An Introduction Correlsense
 - Setting Reading Goals Java Bytecode Instrumentation An Introduction Correlsense
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Java Bytecode Instrumentation An Introduction Correlsense
 - Fact-Checking eBook Content of Java Bytecode Instrumentation An Introduction Correlsense
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
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