

# 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<sup>‡</sup> is

\*This work was supported by the Swiss National Science Foundation.

<sup>†</sup>Part of this work was conducted while Philippe Moret was at the Ecole Polytechnique Fédérale de Lausanne (EPFL).

<sup>‡</sup>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-

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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

**Yijin Wang**



## **Java Bytecode Instrumentation An Introduction Correlense:**

**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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### **Table of Contents Java Bytecode Instrumentation An Introduction Correlsense**

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 a 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 Correlense and Bestseller Lists
- 5. Accessing Java Bytecode Instrumentation An Introduction Correlense Free and Paid eBooks
  - Java Bytecode Instrumentation An Introduction Correlense Public Domain eBooks
  - Java Bytecode Instrumentation An Introduction Correlense eBook Subscription Services
  - Java Bytecode Instrumentation An Introduction Correlense Budget-Friendly Options
- 6. Navigating Java Bytecode Instrumentation An Introduction Correlense eBook Formats
  - ePub, PDF, MOBI, and More
  - Java Bytecode Instrumentation An Introduction Correlense Compatibility with Devices
  - Java Bytecode Instrumentation An Introduction Correlense Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Java Bytecode Instrumentation An Introduction Correlense
  - Highlighting and Note-Taking Java Bytecode Instrumentation An Introduction Correlense
  - Interactive Elements Java Bytecode Instrumentation An Introduction Correlense
- 8. Staying Engaged with Java Bytecode Instrumentation An Introduction Correlense
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Java Bytecode Instrumentation An Introduction Correlense
- 9. Balancing eBooks and Physical Books Java Bytecode Instrumentation An Introduction Correlense
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Java Bytecode Instrumentation An Introduction Correlense
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Java Bytecode Instrumentation An Introduction Correlense
  - Setting Reading Goals Java Bytecode Instrumentation An Introduction Correlense
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Java Bytecode Instrumentation An Introduction Correlense
  - Fact-Checking eBook Content of Java Bytecode Instrumentation An Introduction Correlense
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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web jun 2 2023 these summer slogans can get you started burgers beer and buddies at our location hot new recipes same cool vibes at our restaurant spice up your summer with new menu offering catch our seafood specials soak up the sun on our patio hot weather cold brews join us i scream you scream

### **135 catchy summer slogans sayings and phrases names frog** - Jul 18 2023

web these are some of the best examples of catchy slogans that will inspire your ideas apple think different nike just do it mcdonalds i m lovin it coca cola happiness is real google don t be evil microsoft life is good facebook it s quick and easy twitter what happens on the internet stays on the internet virgin airlines no fear

*100 catchy cool summer slogans 2023 generator phrases* - Jun 05 2022

web cool summer slogans can be found on billboards ads social media ads or merchandise such as hats bags and t shirts the importance of cool summer slogans lies in the fact that they make products and services more attractive and memorable they help companies stand out in a crowded market and create an emotional connection with consumers

200 endless summer holiday marketing slogans and taglines - May 04 2022

web mar 29 2022 salt in the air and in your hair summer is a state of mind break away and enjoy the summer heat blue skies and sunshine is where you should be hot day cool night summertime what a delight keep calm summer is here get the beach bum inside you ready the sun and the ocean for the day hot and fun days ahead sun sand and

### **75 unique creative funny summer camp business slogans** - Apr 03 2022

web jun 13 2023 a catchy and creative summer camp slogan can make all the difference in attracting parents and kids alike that s why we ve compiled a list of 75 unique creative and funny summer camp business slogans to help you stand out from the crowd and make this summer one to remember

### **852 crazy summer slogans and taglines generator guide** - Jan 12 2023

web jul 3 2023 summer slogans are catchy phrases that capture the spirit of the sunny season they are used to promote summer related things and make people excited about the fun and adventure that summer brings whether it s a playful rhyme or a motivating statement these slogans remind us to enjoy the warm weather beaches and outdoor

100 catchy summer season slogans 2023 generator - Feb 13 2023

web summer lovin you just can t resist 6 cool down with summer treats oh so sweet 7 the sun is shining time for some fun 8 unleash your inner child summer s wild 9 let s frolic in the sand lather up in sunscreen 10 good vibes only summer s holy 11 summer smiles go for miles 12

### **400 catchy summer slogans that you will love** - Sep 08 2022

web 400 catchy summer slogans that you will love summer is here and we are all looking forward to it we want to enjoy every single minute of it however we are also looking for the perfect summer slogans that will make us smile when we read them

we love the warm weather the sun and the beach

[105 catchy summer slogans taglines ideas ideal tip](#) - Apr 15 2023

web oct 17 2022 105 catchy summer slogans tagline ideas for your business product or organization get inspired and find the perfect slogan for your summer marketing campaign whether you need a catchy slogan for an ad campaign or event or just to get people excited about summer we ve got you covered

**200 creative short summer slogans and quotes worthstart** - Mar 02 2022

web 200 creative short summer slogans and quotes here are some cool and amazing short summer slogans that will inspire you these short summer slogans are created in a very unique way and are very attractive as well as impressive all these short summer slogans are free of cost you can use it anywhere you want

[summer slogans 200 unique summer sale slogans worthstart](#) - Jul 06 2022

web below we shared some of the most creative and catchy summer slogans that you will like it is up to you to make your summer fun summer comes only one time in a year get ready to get something cool from our summer outlet

[415 best summer slogans and taglines you can use next gala](#) - Mar 14 2023

web sep 5 2022 catchy summer slogans summertime and the living is easy make a splash this summer there s nothing like a good book and a cold drink on a hot day summer reading is essential for a well rounded education summertime the best time to get lost in the sun and swim the best time to spend with family and friends playing in the park

[101 cool summer advertising slogan ideas and epic quotes](#) - Aug 19 2023

web feb 18 2021 to help you prepare for june august months here the best summer advertising slogans and quotes you capture your customers attention these are perfect for captions on social media or printed on a sign summer holiday slogan ideas funny summer slogans cool summer taglines to help beat the heat summer instagram

**creative and memorable slogans for summer ink** - Dec 11 2022

web sun sand and beach the ocean is where i belong summer comes only once a year a new kind of heat experience the heat like never before the summer night is like a perfection of thought feel the summer breeze time for some tan lines and good times a life without love is like a year without summer

[list of 75 catchy summer slogans and taglines](#) - Oct 21 2023

web aug 24 2013 summer is bikinis towels soaking up the sun oceans beaches just having fun summer is hot guys tanned skin school s out summer s in summer is lazy days beautiful nights beachy hair water fights summer love midnight kisses shooting stars secret wishes summer will end soon enough and childhood as well