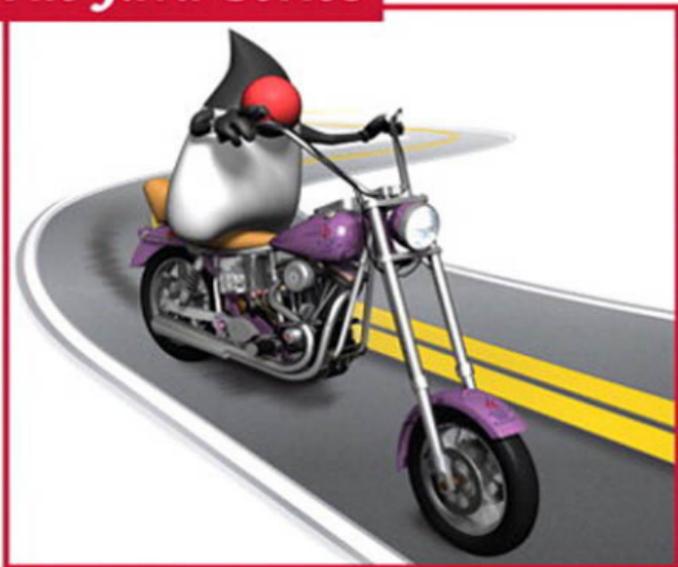


Charlie Hunt · Binu John  
Forewords by James Gosling and Steve Wilson



# Java™ Performance

*The Java Series*



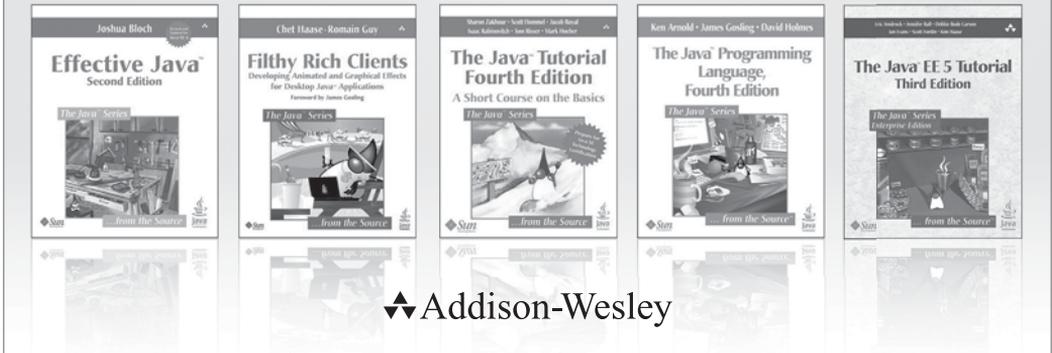
FREE SAMPLE CHAPTER

SHARE WITH OTHERS



# Java™ Performance

# The Java™ Series



Visit [informit.com/thejavaseries](http://informit.com/thejavaseries) for a complete list of available publications.

Publications in **The Java™ Series** are supported, endorsed, and written by the creators of Java at Sun Microsystems, Inc. This series is the official source for expert instruction in Java and provides the complete set of tools you'll need to build effective, robust, and portable applications and applets. **The Java™ Series** is an indispensable resource for anyone looking for definitive information on Java technology.

Visit Sun Microsystems Press at [sun.com/books](http://sun.com/books) to view additional titles for developers, programmers, and system administrators working with Java and other Sun technologies.





# Java™ Performance

---

**Charlie Hunt**  
**Binu John**

◆ Addison-Wesley

Upper Saddle River, NJ • Boston • Indianapolis • San Francisco  
New York • Toronto • Montreal • London • Munich • Paris • Madrid  
Capetown • Sydney • Tokyo • Singapore • Mexico City

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed with initial capital letters or in all capitals.

Oracle and Java are registered trademarks of Oracle and/or its affiliates. Other names may be trademarks of their respective owners.

AMD, Opteron, the AMD logo, and the AMD Opteron logo are trademarks or registered trademarks of Advanced Micro Devices. Intel and Intel Xeon are trademarks or registered trademarks of Intel Corporation. All SPARC trademarks are used under license and are trademarks or registered trademarks of SPARC International, Inc. UNIX is a registered trademark licensed through X/Open Company, Ltd.

The authors and publisher have taken care in the preparation of this book, but make no expressed or implied warranty of any kind and assume no responsibility for errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of the use of the information or programs contained herein.

This document is provided for information purposes only and the contents hereof are subject to change without notice. This document is not warranted to be error-free, nor subject to any other warranties or conditions, whether expressed orally or implied in law, including implied warranties and conditions of merchantability or fitness for a particular purpose. We specifically disclaim any liability with respect to this document and no contractual obligations are formed either directly or indirectly by this document. This document may not be reproduced or transmitted in any form or by any means, electronic or mechanical, for any purpose, without our prior written permission.

The publisher offers excellent discounts on this book when ordered in quantity for bulk purchases or special sales, which may include electronic versions and/or custom covers and content particular to your business, training goals, marketing focus, and branding interests. For more information, please contact

U.S. Corporate and Government Sales  
(800) 382-3419  
corpsales@pearsontechgroup.com

For sales outside the United States, please contact:

International Sales  
international@pearson.com

Visit us on the Web: [informit.com/aw](http://informit.com/aw)

*Library of Congress Cataloging-in-Publication Data*

Hunt, Charlie, 1962-

Java performance / Charlie Hunt, Binu John.  
p. cm.

Includes bibliographical references and index.

ISBN-13: 978-0-13-714252-1

ISBN-10: 0-13-714252-8 (pbk. : alk. paper)

1. Java (Computer program language) 2. Computer programming. I. John, Binu, 1967- II. Title.

QA76.73.J38H845 2012

005.13'3—dc23

2011031889

Copyright © 2012 Oracle America, Inc.

All rights reserved. Printed in the United States of America. This publication is protected by copyright, and permission must be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, One Lake Street, Upper Saddle River, New Jersey 07458, or you may fax your request to (201) 236-3290.

ISBN-13: 978-0-13-714252-1

ISBN-10: 0-13-714252-8

Text printed in the United States on recycled paper at Edwards Brothers Malloy in Ann Arbor, Michigan.  
Third printing, January 2013



To the three B's, Barb, Boyd, and Beau – C.H.

To Rita, Rachael, and Kevin – B.J.

*This page intentionally left blank*



# Contents

---

Foreword by James Gosling	xi
Foreword by Steve Wilson	xiii
Preface	xv
Acknowledgments	xix
About the Authors	xxi
<b>Chapter 1</b> Strategies, Approaches, and Methodologies	1
Forces at Play	2
Two Approaches, Top Down and Bottom Up	5
Choosing the Right Platform and Evaluating a System	8
Bibliography	11
<b>Chapter 2</b> Operating System Performance Monitoring	13
Definitions	14
CPU Utilization	14
CPU Scheduler Run Queue	28
Memory Utilization	32
Network I/O Utilization	41
Disk I/O Utilization	46
	vii

---

	Additional Command Line Tools	49
	Monitoring CPU Utilization on SPARC T-Series Systems	50
	Bibliography	53
<b>Chapter 3</b>	<b>JVM Overview</b>	<b>55</b>
	HotSpot VM High Level Architecture	56
	HotSpot VM Runtime	58
	HotSpot VM Garbage Collectors	80
	HotSpot VM JIT Compilers	92
	HotSpot VM Adaptive Tuning	100
	References	106
<b>Chapter 4</b>	<b>JVM Performance Monitoring</b>	<b>107</b>
	Definitions	108
	Garbage Collection	108
	JIT Compiler	146
	Class Loading	147
	Java Application Monitoring	150
	Bibliography	153
<b>Chapter 5</b>	<b>Java Application Profiling</b>	<b>155</b>
	Terminology	157
	Oracle Solaris Studio Performance Analyzer	159
	NetBeans Profiler	189
	References	209
<b>Chapter 6</b>	<b>Java Application Profiling Tips and Tricks</b>	<b>211</b>
	Performance Opportunities	211
	System or Kernel CPU Usage	212
	Lock Contention	222
	Volatile Usage	234
	Data Structure Resizing	235
	Increasing Parallelism	243
	High CPU Utilization	246
	Other Useful Analyzer Tips	247
	Bibliography	249

---

<b>Chapter 7</b>	<b>Tuning the JVM, Step by Step</b>	<b>251</b>
	Methodology	252
	Application Systemic Requirements	255
	Rank Systemic Requirements	257
	Choose JVM Deployment Model	258
	Choose JVM Runtime	259
	GC Tuning Fundamentals	262
	Determine Memory Footprint	268
	Tune Latency/Responsiveness	278
	Tune Application Throughput	307
	Edge Cases	316
	Additional Performance Command Line Options	316
	Bibliography	321
<b>Chapter 8</b>	<b>Benchmarking Java Applications</b>	<b>323</b>
	Challenges with Benchmarks	324
	Design of Experiments	347
	Use of Statistical Methods	348
	Reference	355
	Bibliography	355
<b>Chapter 9</b>	<b>Benchmarking Multitiered Applications</b>	<b>357</b>
	Benchmarking Challenges	357
	Enterprise Benchmark Considerations	360
	Application Server Monitoring	382
	Profiling Enterprise Applications	399
	Bibliography	401
<b>Chapter 10</b>	<b>Web Application Performance</b>	<b>403</b>
	Benchmarking Web Applications	404
	Web Container Components	405
	Web Container Monitoring and Performance Tunings	408
	Best Practices	427
	Bibliography	450
<b>Chapter 11</b>	<b>Web Services Performance</b>	<b>453</b>
	XML Performance	454

---

Validation	460
Resolving External Entities	462
Partial Processing of XML Documents	465
Selecting the Right API	468
JAX-WS Reference Implementation Stack	471
Web Services Benchmarking	473
Factors That Affect Web Service Performance	477
Performance Best Practices	486
Bibliography	503
<b>Chapter 12</b> Java Persistence and Enterprise Java Beans Performance	505
EJB Programming Model	506
The Java Persistence API and Its Reference Implementation	507
Monitoring and Tuning the EJB Container	511
Transaction Isolation Level	521
Best Practices in Enterprise Java Beans	522
Best Practices in Java Persistence	540
Bibliography	551
<b>Appendix A</b> HotSpot VM Command Line Options of Interest	553
<b>Appendix B</b> Profiling Tips and Tricks Example Source Code	573
Lock Contention First Implementation	573
Lock Contention Second Implementation	583
Lock Contention Third Implementation	593
Lock Contention Fourth Implementation	603
Lock Contention Fifth Implementation	613
First Resizing Variant	624
Second Resizing Variant	636
Increasing Parallelism Single-Threaded Implementation	647
Increasing Parallelism Multithreaded Implementation	657
Index	669



# Foreword

---

Tuning a Java application can be challenging in today's large-scale mission-critical world. There are issues to be aware of in everything from the structure of your algorithms, to their memory allocation patterns, to the way they do disk and file I/O. Almost always, the hardest part is figuring out where the issues are. Even (perhaps especially) seasoned practitioners find that their intuitions are wrong. Performance-killing gremlins hide in the most unlikely places.

As Wikipedia says, “Science (from Latin: *scientia* meaning ‘knowledge’) is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the world.” Performance tuning must be approached as an experimental science: To do it properly, you have to construct experiments, perform them, and from the result construct hypotheses.

Fortunately, the Java universe is awash in performance monitoring tools. From standalone applications to profilers built into development environments to tools provided by the operating system. They all need to be applied in a cohesive way to tease out the truth from a sea of noise.

This book is *the* definitive masterclass in performance tuning Java applications. It readably covers a wide variety of tools to monitor and measure performance on a variety of hardware architectures and operating systems. And it covers how to construct experiments, interpret their results, and act on them. If you love all the gory details, this is the book for you.

—James Gosling

*This page intentionally left blank*



# Foreword

---

Today, Java is used at the heart of the world's largest and most critical computing systems. However, when I joined the Java team in 1997 the platform was young and just gaining popularity. People loved the simplicity of the language, the portability of bytecodes, and the safety of garbage collection (versus traditional malloc/free memory management of other systems). However, there was a trade-off for these great features. Java was slow, and this limited the kinds of environments where you could use it.

Over the next few years, we set about trying to fix this. We believed that just because Java applications were portable and safe they didn't have to be slow. There were two major areas where we focused our attention. The first was to simply make the Java platform faster. Great strides were made in the core VM with advanced Just In Time compilation techniques, parallel garbage collection, and advanced lock management. At the same time the class libraries were tweaked and tuned to make them more efficient. All this led to substantial improvements in the ability to use Java for larger, more critical systems.

The second area of focus for us was to teach people how to write fast software in Java. It turned out that although the syntax of the language looked similar to C, the techniques you needed to write efficient programs were quite different. To that end, Jeff Kesselman and I wrote one of the first books on Java performance, which was published back in 2000. Since then, many books have covered this topic, and experienced developers have learned to avoid some of the most common pitfalls that used to befall Java developers.

After the platform began to get faster, and developers learned some of the tricks of writing faster applications, Java transformed into the enterprise-grade software powerhouse it is today. It began to be used for the largest, most important systems anywhere. However, as this started to happen, people began to realize one part was still missing. This missing piece was *observability*. When these systems get larger and larger, how do you know if you're getting all the performance you can get?

In the early days of Java we had primitive profiling tools. While these were useful, they had a huge impact on the runtime performance of the code. Now, modern JVMs come with built-in observability tools that allow you to understand key elements of your system's performance with almost no performance penalty. This means these tools can be left enabled all the time, and you can check on aspects of your application while it's running. This again changes the way people can approach performance.

The authors of *Java™ Performance* bring all these concepts together and update them to account for all the work that's happened in the last decade since Jeff and I published our book. This book you are now reading is the most ambitious book on the topic of Java performance that has ever been written. Inside are a great many techniques for improving the performance of your Java applications. You'll also come to understand the state of the art in JVM technology from the inside out. Curious about how the latest GC algorithms work? It's in here! You'll also learn how to use the latest and greatest observability tools, including those built into the JDK and other important tools bundled into popular operating systems.

It's exciting to see how all these recent advancements continue to push the platform forward, and I can't wait to see what comes next.

—Steve Wilson

VP Engineering, Oracle Corporation

Founding member of the Java Performance team

Coauthor of *Java™ Platform Performance: Strategies and Tactics*



# Preface

---

Welcome to the definitive reference on Java performance tuning!

This book offers Java performance tuning advice for both Java SE and Java EE applications. More specifically, it offers advice in each of the following areas: performance monitoring, profiling, tuning the Java HotSpot VM (referred to as HotSpot VM hereafter), writing effective benchmarks, and Java EE application performance tuning. Although several Java performance books have been written over the years, few have packed the breadth of information found in this book. For example, the topics covered in this book include items such as an introduction into the inner workings of a modern Java Virtual Machine, garbage collection tuning, tuning Java EE applications, and writing effective benchmarks.

This book can be read from cover to cover to gain an in-depth understanding of many Java performance topics. It can also be used as a task reference where you can pick up the text, go to a specific chapter on a given topic of interest, and find answers.

Readers who are fairly new, or consider themselves a novice in the area of Java performance tuning, will likely benefit the most by reading the first four chapters and then proceeding to the topics or chapters that best address the particular Java performance tuning task they are undertaking. More experienced readers, those who have a fundamental understanding of performance tuning approaches and a basic understanding of the internals of the HotSpot VM along with an understanding of the tools to use for monitoring operating system performance and monitoring JVM performance, will find jumping to the chapters that focus on the performance tuning task at hand to be most useful. However, even those with advanced Java performance skills may find the information in the first four chapters useful.

Reading this book cover to cover is not intended to provide an exact formula to follow, or to provide the full and complete knowledge to turn you into an experienced Java performance tuning expert. Some Java performance issues will require specialized expertise to resolve. Much of performance tuning is an art. The more you work on Java performance issues, the better versed you become. Java performance tuning also continues to evolve. For example, the most common Java performance issues observed five years ago were different from the ones observed today. Modern JVMs continue to evolve by integrating more sophisticated optimizations, runtimes, and garbage collectors. So too do underlying hardware platforms and operating systems evolve. This book provides up-to-date information as of the time of its writing. Reading and understanding the material presented in this book should greatly enhance your Java performance skills. It may also allow you to build a foundation of fundamentals needed to become fluent in the art of Java performance tuning. And once you have a solid foundation of the fundamentals you will be able to evolve your performance tuning skills as hardware platforms, operating systems, and JVMs evolve.

Here's what you can expect to find in each chapter.

Chapter 1, "Strategies, Approaches, and Methodologies," presents various different approaches, strategies, and methodologies often used in Java performance tuning efforts. It also proposes a proactive approach to meeting performance and scalability goals for a software application under development through an enhancement to the traditional software development process.

Chapter 2, "Operating System Performance Monitoring," discusses performance monitoring at the operating system level. It presents which operating system statistics are of interest to monitor along with the tools to use to monitor those statistics. The operating systems of Windows, Linux, and Oracle Solaris are covered in this chapter. The performance statistics to monitor on other Unix-based systems, such as Mac OS X, use similar commands, if not the same commands as Linux or Oracle Solaris.

Chapter 3, "JVM Overview," provides a high level overview of the HotSpot VM. It provides some of the fundamental concepts of the architecture and workings of a modern Java Virtual Machine. It establishes a foundation for many of the chapters that follow in the book. Not all the information presented in this chapter is required to resolve every Java performance tuning task. Nor is it exhaustive in providing all the necessary background to solve any Java performance issue. However, it does provide sufficient background to address a large majority of Java performance issues that may require some of the concepts of the internal workings and capabilities of a modern Java Virtual Machine. The information in this chapter is applicable to understanding how to tune the HotSpot VM along with understanding the subject matter of Chapter 7 and how to write effective benchmarks, the topics covered in Chapters 8 and 9.

Chapter 4, "JVM Performance Monitoring," as the title suggests, covers JVM performance monitoring. It presents which JVM statistics are of interest to monitor

along with showing tools that can be used to monitor those statistics. It concludes with suggesting tools that can be extended to integrate both JVM level monitoring statistics along with Java application statistics of interest within the same monitoring tool.

Chapter 5, “Java Application Profiling,” and Chapter 6, “Java Application Profiling Tips and Tricks,” cover profiling. These two chapters can be seen as complementary material to Chapter 2 and Chapter 4, which cover performance monitoring. Performance monitoring is typically used to identify whether a performance issue exists, or provides clues as to where the performance issue exists, that is, in the operating system, JVM, Java application, and so on. Once a performance issue is identified and further isolated with performance monitoring, a profiling activity usually follows. Chapter 5 presents the basics of Java method profiling and Java heap (memory) profiling. This profiling chapter presents free tools for illustrating the concepts behind these types of profiling. The tools shown in this chapter are not intended to suggest they are the only tools that can be used for profiling. Many profiling tools are available both commercially and for free that offer similar capabilities, and some tools offer capabilities beyond what’s covered in Chapter 5. Chapter 6 offers several tips and tricks to resolving some of the more commonly observed patterns in profiles that tend to be indicative of particular types of performance problems. The tips and tricks identified in this chapter are not necessarily an exhaustive list but are ones that have been observed frequently by the authors over the course of years of Java performance tuning activities. The source code in many of the examples illustrated in this chapter can be found in Appendix B.

Chapter 7, “Tuning the JVM, Step by Step,” covers tuning the HotSpot VM. The topics of tuning the HotSpot VM for startup, memory footprint, response time/latency, and throughput are covered in the chapter. Chapter 7 presents a step-by-step approach to tuning the HotSpot VM covering choices such as which JIT compiler to use, which garbage collector to use, and how to size Java heaps, and also provides an indication when the Java application itself may require some rework to meet the performance goals set forth by application stakeholders. Most readers will likely find Chapter 7 to be the most useful and most referenced chapter in this book.

Chapter 8, “Benchmarking Java Applications,” and Chapter 9, “Benchmarking Multi-tiered Applications,” present information on how to write effective benchmarks. Often benchmarks are used to help qualify the performance of a Java application by implementing a smaller subset of a larger application’s functionality. These two chapters also discuss the art of creating effective Java benchmarks. Chapter 8 covers the more general topics associated with writing effective benchmarks such as exploring some of the optimizations performed by a modern JVM. Chapter 8 also includes information on how to incorporate the use of statistical methods to gain confidence in your benchmarking experiments. Chapter 9 focuses more specifically on writing effective Java EE benchmarks.

For readers who have a specific interest in tuning Java EE applications, Chapter 10, “Web Application Performance,” Chapter 11, “Web Services Performance,” and Chapter 12, “Java Persistence and Enterprise Java Beans Performance,” focus specifically on the areas of Web applications, Web services, persistence, and Enterprise Java Bean performance, respectively. These three chapters present in-depth coverage of the performance issues often observed in Java EE applications and provide suggested advice and/or solutions to common Java EE performance issues.

This book also includes two appendixes. Appendix A, “HotSpot VM Command Line Options of Interest,” lists HotSpot VM command line options that are referenced in the book and additional ones that may be of interest when tuning the HotSpot VM. For each command line option, a description of what the command line option does is given along with suggestions on when it is applicable to use them. Appendix B, “Profiling Tips and Tricks Example Source Code,” contains the source code used in Chapter 6’s examples for reducing lock contention, resizing Java collections, and increasing parallelism.



# Acknowledgments

---

## **Charlie Hunt**

---

Without the help of so many people this book would not have been possible. First I have to thank my coauthor, Binu John, for his many contributions to this book. Binu wrote all the Java EE material in this book. He is a talented Java performance engineer and a great friend. I also want to thank Greg Doech, our editor, for his patience. It took almost three years to go from a first draft of the book's chapter outline until we handed over a manuscript. Thank you to Paul Hohensee and Dave Keenan for their insight, encouragement, support, and thorough reviews. To Tony Printezis and Tom Rodriguez, thanks for your contributions on the details of the inner workings of the Java HotSpot VM garbage collectors and JIT compilers. And thanks to all the engineers on the Java HotSpot VM runtime team for having detailed documentation on how various pieces of the HotSpot VM fit together. To both James Gosling and Steve Wilson, thanks for making time to write a foreword. Thanks to Peter Kessler for his thorough review of Chapter 7, "Tuning the JVM, Step by Step." Thanks to others who contributed to the quality of this book through their insight and reviews: Darryl Gove, Marty Itzkowitz, Geertjan Wielenga, Monica Beckwith, Alejandro Murillo, Jon Masamitsu, Y. Srinivas Ramkakrishna (aka Ramki), Chuck Rasbold, Kirk Pepperdine, Peter Gratzner, Jeanfrancois Arcand, Joe Bologna, Anders Åstrand, Henrik Löf, and Staffan Friberg. Thanks to Paul Ciciora for stating the obvious, "losing the race" (when the CMS garbage collector can't free enough space to keep up with the young generation promotion rate). Also, thanks to Kirill Soshalskiy, Jerry Driscoll,

both of whom I have worked under during the time of writing this book, and to John Pampuch (Director of VM Technologies at Oracle) for their support. A very special thanks to my wife, Barb, and sons, Beau and Boyd, for putting up with a grumpy writer, especially during those times of “writer’s cramp.”

## **Binu John**

---

This book has been possible only because of the vision, determination, and perseverance of my coauthor, Charlie Hunt. Not only did he write the sections relating to Java SE but also completed all the additional work necessary to get it ready for publication. I really enjoyed working with him and learned a great deal along the way. Thank you, Charlie. A special thanks goes to Rahul Biswas for providing content relating to EJB and Java persistence and also for his willingness to review multiple drafts and provide valuable feedback. I would like to thank several people who helped improve the quality of the content. Thank you to Scott Oaks and Kim Lichong for their encouragement and valuable insights into various aspects of Java EE performance; Bharath Mundlapudi, Jitendra Kotamraju, and Rama Pulavarthi for their in-depth knowledge of XML and Web services; Mitesh Meswani, Marina Vatkina, and Mahesh Kannan for their help with EJB and Java persistence; and Jeanfrancois Arcand for his explanations, blogs, and comments relating to Web container. I was fortunate to work for managers who were supportive of this work. Thanks to Madhu Konda, Senior Manager during my days at Sun Microsystems; Sef Kloninger, VP of Engineering, Infrastructure, and Operations; and Sridatta Viswanath, Senior VP of Engineering and Operations at Ning, Inc. A special thank you to my children, Rachael and Kevin, and my wonderful wife, Rita, for their support and encouragement during this process.



# About the Authors

---

**Charlie Hunt** is the JVM Performance Lead Engineer at Oracle. He is responsible for improving the performance of the HotSpot Java Virtual Machine and Java SE class libraries. He has also been involved in improving the performance of both GlassFish Server Open Source Edition and Oracle WebLogic application servers. He wrote his first Java program in 1998 and joined Sun Microsystems, Inc., in 1999 as a Senior Java Architect. He has been working on improving the performance of Java and Java applications ever since. He is a regular speaker on the subject of Java performance at many worldwide conferences including the JavaOne Conference. Charlie holds a Master of Science in Computer Science from the Illinois Institute of Technology and a Bachelor of Science in Computer Science from Iowa State University.

**Binu John** is a Senior Performance Engineer at Ning, Inc., the world's largest platform for creating social web sites. In his current role, he is focused on improving the performance and scalability of the Ning platform to support millions of page views per month. Before joining Ning, Binu spent more than a decade working on Java performance at Sun Microsystems, Inc. As a member of the Enterprise Java Performance team, he worked on several open source projects including the GlassFish Server Open Source Edition application server, the Open Source Enterprise Service Bus (Open ESB), and Open MQ JMS product. He has been an active contributor in the development of the various industry standard benchmarks such as SPECjms2007 and SPECjEnterprise2010, has published several performance white papers and has previously contributed to the XMLTest and WSTest benchmark projects at java.net. Binu holds Master of Science degrees in Biomedical Engineering and Computer Science from The University of Iowa.

*This page intentionally left blank*

# Java Application Profiling Tips and Tricks

---

Chapter 5, “Java Application Profiling,” presented the basic concepts of using a modern Java profiler such as the Oracle Solaris Studio Performance Analyzer and NetBeans Profiler. It did not, however, show any specific tips and tricks in using the tools to identify performance issues and approaches of how to resolve them. This is the purpose of this chapter. Its intention is to show how to use the tools to identify performance issues and take corrective actions to resolve them. This chapter looks at several of the more common types of performance issues the authors have observed through many years of working as Java performance engineers.

## Performance Opportunities

Most Java performance opportunities fall into one or more of the following categories:

- **Using a more efficient algorithm.** The largest gains in the performance of an application come from the use of a more efficient algorithm. The use of a more efficient algorithm allows an application to execute with fewer CPU instructions, also known as a shorter path length. An application that executes with a shorter path length generally executes faster. Many different changes can lead to a shorter path length. At the highest level of the application, using a different data structure or modifying its implementation can lead to a shorter path length. Many applications that suffer application performance issues often use inappropriate data structures. There is no substitute for choosing the

proper data structure and algorithm. As profiles are analyzed, take notice of the data structures and the algorithms used. Optimal performance can be realized when the best data structures and algorithms are utilized.

- **Reduce lock contention.** Contending for access to a shared resource inhibits an application's capability to scale to a large number of software threads and across a large number of CPUs. Changes to an application that allow for less frequent lock contention and less duration of locking allow an application to scale better.
- **Generate more efficient code for a given algorithm.** Clocks per CPU instruction, usually referred to as CPI, for an application is a ratio of the number of CPU clock ticks used per CPU instruction. CPI is a measure of the efficiency of generated code that is produced by a compiler. A change in the application, JVM, or operating system that reduces the CPI for an application will realize an improvement in its performance since it takes advantage of better and more optimized generated code.

There is a subtle difference between path length, which is closely tied to the algorithm choice, and cycles per instruction, CPI, which is the notion of generating more efficient code. In the former, the objective is to produce the shortest sequence of CPU instructions based on the algorithm choice. The latter's objective is to reduce the number of CPU clocks consumed per CPU instruction, that is, produce the most efficient code from a compiler. To illustrate with an example, suppose a CPU instruction results in a CPU cache miss, such as a load instruction. It may take several hundred CPU clock cycles for that load instruction to complete as a result of the CPU cache miss having to fetch data from memory rather than finding it in a CPU cache. However, if a prefetch instruction was inserted upstream in the sequence of instructions generated by a compiler to prefetch from memory the data being loaded by the load instruction, it is likely the number of clock cycles required to load the data will be less with the additional prefetch instruction since the prefetch can be done in parallel with other CPU instructions ahead of the load instruction. When the load instruction occurs, it can then find the data to be loaded in a CPU cache. However, the path length, the number of CPU instructions executed is longer as a result of the additional prefetch instruction. Therefore, it is possible to increase path length, yet make better use of available CPU cycles.

The following sections present several strategies to consider when analyzing a profile and looking for optimization opportunities. Generally, optimization opportunities for most applications fall into one of the general categories just described.

## System or Kernel CPU Usage

Chapter 2, "Operating System Performance Monitoring," suggests one of the statistics to monitor is system or kernel CPU utilization. If CPU clock cycles are spent executing operating system or kernel code, those are CPU clock cycles that cannot

be used to execute your application. Hence, a strategy to improve the performance of an application is to reduce the amount of time it spends consuming system or kernel CPU clock cycles. However, this strategy is not applicable in applications that spend little time executing system or kernel code. Monitoring the operating system for system or kernel CPU utilization provides the data as to whether it makes sense to employ this strategy.

The Oracle Solaris Performance Analyzer collects system or kernel CPU statistics as part of an application profile. This is done by selecting the View > Set Data Presentation menu in Performance Analyzer, choosing the Metrics tab, and setting the options to present system CPU utilization statistics, both inclusive or exclusive. Recall that inclusive metrics include not only the time spent in a given method, but also the time spent in methods it calls. In contrast, exclusive metrics report only the amount of time spent in a given method.

**Tip**

It can be useful to include both inclusive and exclusive metrics when first analyzing a profile. Looking at the inclusive metrics provides a sense of the path the application executes. Looking at the general path an application takes you may identify an opportunity for an alternative algorithm or approach that may offer better performance.

Figure 6-1 shows the Performance Analyzer’s Set Data Presentation form with options selected to present both inclusive and exclusive System CPU metrics. Also notice the options selected report both the raw time value and the percentage of System CPU time.

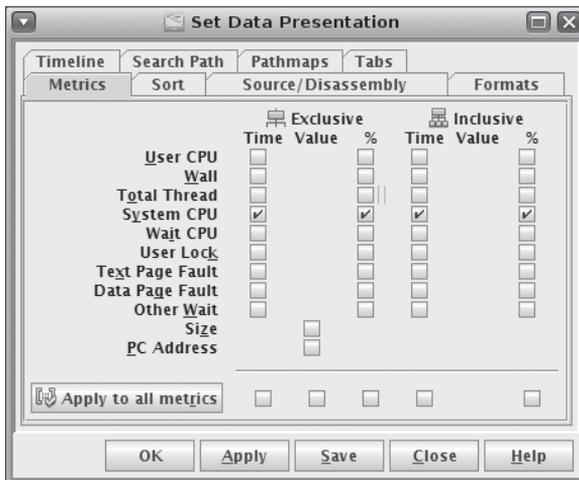


Figure 6-1 Set system CPU data presentation

Functions		Callers-Callees		Call Tree	Source	Disassembly	Timeline	Experiments
Sys. CPU		Sys. CPU		Name				
▼ (sec.)	(%)	(sec.)	(%)					
51.636	100.00	51.636	100.00	<Total>				
33.573	65.02	45.182	87.50	java.io.FileOutputStream.write(int)				
11.648	22.56	11.648	22.56	__write				
2.742	5.31	2.742	5.31	<JVM-System>				
2.172	4.21	2.172	4.21	java.io.FileInputStream.read()				

Figure 6-2 Exclusive system CPU

After clicking on the OK button, the Performance Analyzer displays the profile's System CPU inclusive and exclusive metrics in descending order. The arrow in the metric column header indicates how the data is presented and sorted. In Figure 6-2, the System CPU data is ordered by the exclusive metric (notice the arrow in the exclusive metric header and the icon indicating an exclusive metric).

Figure 6-2 shows a profile from an application that exhibits high system or kernel CPU utilization. You can see this application consumed about 33.5 seconds of System CPU in the `java.io.FileOutputStream.write(int)` method and about 11.6 seconds in a method called `__write()`, or about 65% and 22.5%, respectively. You can also get a sense of how significant the improvement can be realized by reducing the System CPU utilization of this application. The ideal situation for an application is to have 0% System CPU utilization. But for some applications that goal is difficult to achieve, especially if there is I/O involved, since I/O operations require a system call. In applications that require I/O, the goal is to reduce the frequency of making a system call. One approach to reduce the call frequency of an I/O system call is buffer the data so that larger chunks of data are read or written during I/O operations.

In the example shown in Figure 6-2, you can see the file write (output) operations are consuming a large amount of time as illustrated by the `java.io.FileOutputStream.write(int)` and `__write()` entries. To identify whether the write operations are buffered, you can use the Callers-Callees tab to walk up the call stack to see what methods are calling the `FileOutputStream.write(int)` method and the `__write` method. You walk up the call stack by selecting one of the callees from the upper panel and clicking the Set Center button. Figure 6-3 shows the Callers-Callees of the `FileOutputStream.write(int)` method.

The callers of `FileOutputStream.write(int)` are `ExtOutputStream.write(int)` and `OutImpl.outc(int)`. 85.18% of the System CPU attributed to `FileOutputStream.write(int)` comes from its use in `ExtOutputStream.write(int)` and 14.82% of it from `OutImpl.outc(int)`. A look at the implementation of `ExtOutputStream.write(int)` shows:

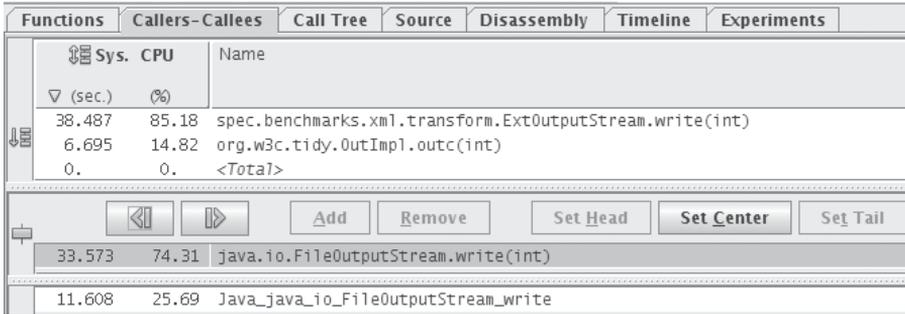


Figure 6-3 FileOutputStream.write(int) callers and callees

```
public void write(int b) throws IOException {
    super.write(b);
    writer.write((byte)b);
}
```

A look at the implementation of `super.write(b)` shows it is not a call to `FileOutputStream.write(int)`:

```
public void write(int b) throws IOException {
    crc = crc * 33 + b;
}
```

But the `writer` field in `ExtOutputStream` is declared as a `FileOutputStream`:

```
private FileOutputStream writer;
```

And it is initialized without any type of buffering:

```
writer = new FileOutputStream(currentFileName);
```

`currentFileName` is a field declared as a `String`:

```
private String currentFileName;
```

Hence, an optimization to be applied here is to buffer the data being written to `FileOutputStream` in `ExtOutputStream` using a `BufferedOutputStream`. This is done rather quickly and easily by chaining or wrapping the `FileOutputStream` in a `BufferedOutputStream` in an `ExtOutputStream`. Here is a quick listing of the changes required:

```
// Change FileOutputStream writer to a BufferedOutputStream
//private FileOutputStream writer;
private BufferedOutputStream writer;
```

Then chain a `BufferedOutputStream` and `FileOutputStream` at initialization time:

```
// Initialize BufferedOutputStream
// writer = new FileOutputStream(currentFileName);
writer = new BufferedOutputStream(
    new FileOutputStream(currentFileName));
```

Writing to the `BufferedOutputStream`, instead of the `FileOutputStream`, in `ExtOutputStream.write(int b)` does not require any update since `BufferOutputStream` has a `write()` method that buffers bytes written to it. This `ExtOutputStream.write(int b)` method is shown here:

```
public void write(int b) throws IOException {
    super.write(b);
    // No update required here,
    // automatically uses BufferedOutputStream.write()
    writer.write((byte)b);
}
```

The other uses of the `writer` field must be inspected to ensure the use of `BufferedOutputStream` operates as expected. In `ExtStreamOutput`, there are two additional uses of the `writer` field, one in a method called `reset()` and another in `checkResult()`. These two methods are as follows:

```
public void reset() {
    super.reset();
    try {
        if (diffOutputStream != null) {
            diffOutputStream.flush();
            diffOutputStream.close();
            diffOutputStream = null;
        }
        if (writer != null) {
            writer.close();
        }
    } catch (IOException e) {
        e.printStackTrace();
    }
}
```

```
    }  
  }  
  public void checkResult(int loopNumber) {  
    try {  
      writer.flush();  
      writer.close();  
    } catch (IOException e) {  
      e.printStackTrace();  
    }  
    check(validationProperties.getProperty(propertyName));  
    outProperties.put(propertyName, "" + getCRC());  
    reset();  
  }  
}
```

The uses of `writer` as a `BufferedOutputStream` works as expected. It should be noted that the API specification for `BufferedOutputStream.close()` indicates it calls the `BufferedOutputStream.flush()` method and then calls the `close()` method of its underlying output stream, in this case the `FileOutputStream.close()` method. As a result, the `FileOutputStream` is not required to be explicitly closed, nor is the `flush()` method in `ExtOutputStream.checkResult(int)` required. A couple of additional enhancements worth consideration are

1. A `BufferedOutputStream` can also be allocated with an optional buffered size. The default buffer size, as of Java 6, is 8192. If the application you are profiling is writing a large number of bytes, you might consider specifying an explicit size larger than 8192. If you specify an explicit size, consider a size that is a multiple of the operating systems page size since operating systems efficiently fetch memory that are multiples of the operating system page size. On Oracle Solaris, the `pagesize` command with no arguments reports the default page size. On Linux, the default page size can be obtained using the `getconf PAGESIZE` command. Windows on x86 and x64 platforms default to a 4K (4096) page size.
2. Change the `ExtOutputStream.writer` field from an explicit `BufferedOutputStream` type to an `OutputStream` type, that is, `OutputStream writer = new BufferedOutputStream()`, instead of `BufferedOutputStream writer = new BufferedOutputStream()`. This allows for additional flexibility in type of `OutputStream`, for example, `ByteArrayOutputStream`, `DataOutputStream`, `FilterOutputStream`, `FileOutputStream`, or `BufferedOutputStream`.

Looking back at Figure 6-3, a second method calls `FileOutputStream.write(int)` called `org.w3c.tidy.OutImpl.outc(int)`, which is a method from a third-party library used in the profiled application. To reduce the amount of system CPU utilization used in a third-party supplied method, the best approach is to file

a bug or enhancement request with the third-party library provider and include the information from the profile. If the source is accessible via an open source license and has acceptable license terms, you may consider further investigating and including additional information in the bug or enhancement request report.

After applying the changes identified in `ExtOutputStream`, using the `BufferedOutputStream` and its default constructor (not including the two additional enhancements just mentioned), and collecting a profile, the amount of system CPU utilization drops substantially. Comparing the profiles in Figure 6-4 to those in Figure 6-2, you can see the amount of inclusive system CPU time spent in `java.io.FileOutputStream.write(int)` has dropped from 45.182 seconds to 6.655 seconds (exclusive system CPU time is the second column).

Executing this application workload outside the profiler in a performance testing environment prior to making the modifications reports it took this application 427 seconds to run to completion. In contrast, the modified version of the application workload that uses the `BufferOutputStream` in the same performance testing environment reports it runs to completion in 383 seconds. In other words, this application realized about a 10% improvement in its run to completion execution.

In addition, looking at the Callers-Callees tab for `java.io.FileOutputStream.write(int)`, only the call to `org.w3c.tidy.OutImpl.outc(int)` remains as a significant consumer of the `FileOutputStream.write(int)` method. The Callers-Callees of `FileOutputStream.write(int)` are shown in Figure 6-5.

Functions		Callers-Callees		Call Tree	Source	Disassembly	Timeline	Experiments
Sys. CPU		Sys. CPU			Name			
▼ (sec.)	(%)	(sec.)	(%)					
13.479	100.00	13.479	100.00		<Total>			
6.655	49.37	6.655	49.37		<code>java.io.FileOutputStream.write(int)</code>			
3.052	22.64	3.052	22.64		<JVM-System>			
2.412	17.89	2.412	17.89		<code>java.io.FileInputStream.read()</code>			
0.240	1.78	0.260	1.93		<code>java.io.FileOutputStream.writeBytes(byte[], int, int)</code>			
0.060	0.45	0.060	0.45		<code>__write</code>			

Figure 6-4 Reduced system CPU utilization

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
Sys. CPU ▼ (sec.)	Name					
6.655	<code>org.w3c.tidy.OutImpl.outc(int)</code>					
<div style="display: flex; justify-content: space-between; align-items: center;"> <span>◀</span> <span>▶</span> <span>Add</span> <span>Remove</span> <span>Set Head</span> <span>Set Center</span> <span>Set Tail</span> </div>						
6.655	<code>java.io.FileOutputStream.write(int)</code>					

Figure 6-5 Callers-Callees after changes

Comparing the Callers-Callees in Figure 6-5, after the changes to ExtStream Output, with the Callers-Callees in Figure 6-3, prior to the changes, you can see the amount of attributable time spent in `org.w3c.tidy.OutImpl.outc(int)` stays close to the same. This should not be a surprise since the changes made to ExtStreamOutput now use `BufferedOutputStream`. But recall that the `BufferedOutputStream` invokes a `FileOutputStream` method when any of the underlying buffer in the `BufferedOutputStream` becomes full, the `BufferedOutputStream.flush()` method is called, or when the `BufferedOutputStream.close()` method is called. If you look back at Figure 6-4 you see a `FileOutputStream.writeBytes(byte[],int,int)` method. This is the method that the `BufferedOutputStream` calls from `ExtStreamOutput`. Figure 6-6 shows the Callers-Callees tab for the `FileOutputStream.writeBytes(byte[],int,int)`.

Selecting `java.io.FileOutputStream.write(byte[],int,int)` method from the upper Callee panel and clicking the Set Center button illustrates that `BufferedOutputStream.flushBuffer()` is its callee; see Figure 6-7.

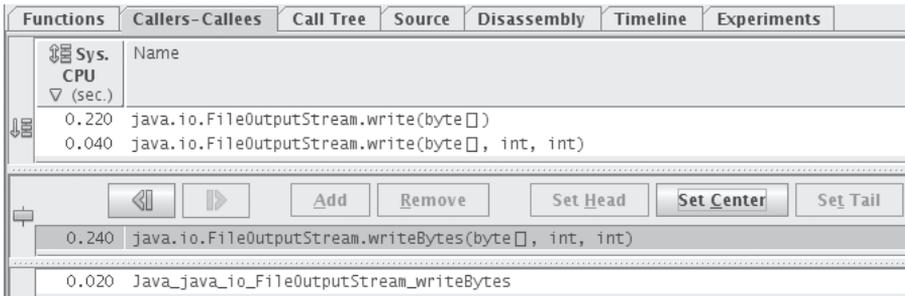


Figure 6-6 Callers-Callees of FileOutputStream.writeBytes(byte[],int,int)

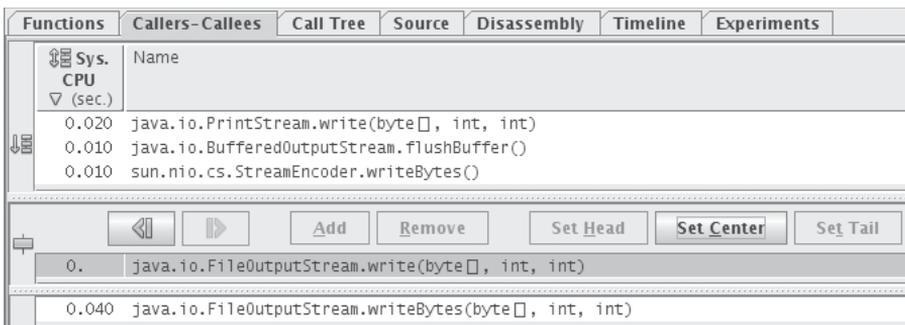


Figure 6-7 Callers-Callees of FileOutputStream.writeBytes(byte[], int, int)

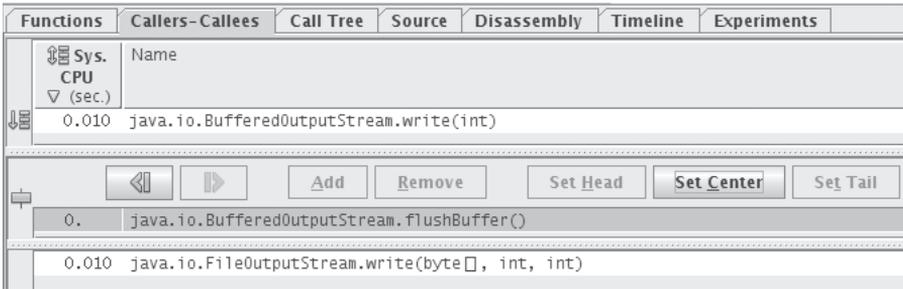


Figure 6-8 Callers-Callees of BufferedOutputStream.flushBuffer()

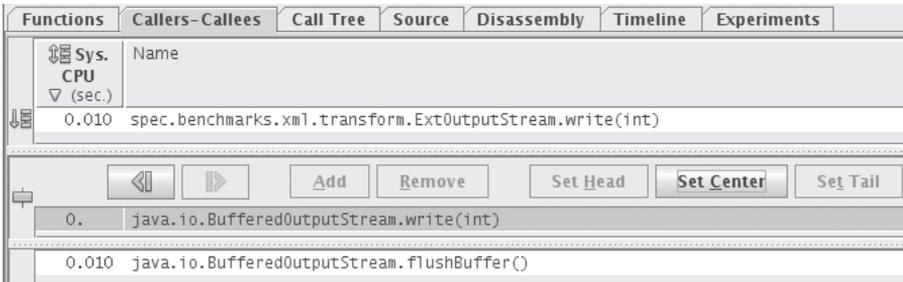


Figure 6-9 Callers-Callees of BufferedOutputStream.write(int)

Selecting the `BufferedOutputStream.flushBuffer()` method in the upper Callee panel and clicking the `Set Center` button shows the callee of `java.io.BufferedOutputStream.flushBuffer()` is `BufferedOutputStream.write(int)`. The Callers-Callees of `BufferedOutputStream.flushBuffer()` are shown in Figure 6-8.

Selecting the `BufferedOutputStream.write(int)` method in the upper Callee panel and clicking the `Set Center` button shows the callee of `java.io.BufferedOutputStream.write(int)` is `ExtOutputStream.write(int)`, the method that has been modified. The Callers-Callees of `BufferedOutputStream.write(int)` are shown in Figure 6-9.

As mentioned earlier, the next step in reducing System CPU utilization for this application requires a modification to a third-party library, a library that holds the implementation of `org.w3c.tidy.OutImpl.outc(int)`. It may be possible for the maintainers of the third-party library to implement a similar modification to `OutImpl.outc(int)` as just described and implemented for `ExtOutputStream.write(int)`. However, the performance improvement realized will likely not be as significant since the profile suggests there is more System CPU utilization attributed

to the call path of `ExtOutputStream.write(int)` than to `OutImpl.outc(int)`; refer to Figure 6-3 for attributable System CPU utilization on callers of `FileInputStream.write(int)`. In addition, looking at the amount of System CPU utilization consumed in `OutImpl.outc(int)`, about 6.6 seconds, compared to the total application runtime of 383 seconds is rather small, about 1.5%. Hence, a modification to reduce the amount of System CPU utilization spent in `OutImpl.outc(int)` would likely not yield more than 1% to 2% improvement.

**Tip**

Applications that perform network I/O can employ a similar, general approach to reduce system CPU utilization as that just described in this section. That is, buffer both the data in the input and output stream used to write and read the data.

An additional strategy to reduce system CPU utilization for applications performing large amounts of network I/O is utilizing Java NIO nonblocking data structures. Java NIO was introduced in Java 1.4.2 with many runtime performance improvements added in Java 5 and Java 6. Java NIO nonblocking data structures allow for the ability to read or write as much data as possible in a single call to a network I/O (read or write) operation. Remember that every network I/O call eventually results in the invocation of an operating system's system call, which consumes system CPU utilization. The challenge with using Java NIO nonblocking data structures is it is more difficult to program than using blocking Java NIO or the older, more traditional Java SE blocking data structures such as `java.net.Socket`. In a Java NIO nonblocking output operation, you can write as many bytes as the operating system allows to be written. But you have to check the return value of the output operation to determine whether all the bytes you asked to be written have indeed been written. In a Java NIO nonblocking input operation, where you read as many bytes as are available, you have to check how many bytes have been read. You also have to implement some complex programming logic to deal with partially read protocol data units, or multiple protocol data units. That is, you may not be able to read enough bytes in a single read operation to construct a meaningful protocol data unit or message. In the case of blocking I/O, you simply wait until you generally read the specified number of bytes that constitute a full protocol data unit or message. Whether to migrate an application to utilize nonblocking network I/O operations should be decided upon by the application's performance needs. If you want to take advantage of the additional performance promised by using nonblocking Java NIO, you should consider using a general Java NIO framework to make the migration easier. Several popular Java NIO frameworks are available such as Project Grizzly (<https://grizzly.dev.java.net>) and Apache MINA (<http://mina.apache.org>).

Another area where high System CPU utilization may show up is in applications experiencing heavy lock contention. Identifying lock contention in a profile and approaches to reduce lock contention are discussed in the next section.

## Lock Contention

In early JVM releases, it was common to delegate Java monitor operations directly to operating system monitors, or mutex primitives. As a result, a Java application experiencing lock contention would exhibit high values of system CPU utilization since operating system mutex primitives involve system calls. In modern JVMs Java monitors are mostly implemented within the JVM in user code rather than immediately delegating them to operating system locking primitives. This means Java applications can exhibit lock contention yet not consume system CPU. Rather, these applications first consume user CPU utilization when attempting to acquire a lock. Only applications that experience severe lock contention may show high system CPU utilization since modern JVMs tend to delegate to operating system locking primitives as a last resort. A Java application running in a modern JVM that experiences lock contention tends to show symptoms of not scaling to a large number of application threads, CPU cores, or a large number of concurrent users. The challenge is finding the source of the lock contention, that is, where are those Java monitors in the source code and what can be done to reduce the lock contention.

Finding and isolating the location of highly contented Java monitors is one of the strengths of the Oracle Solaris Performance Analyzer. Once a profile has been collected with the Performance Analyzer, finding the highly contented locks is easy.

The Performance Analyzer collects Java monitor and lock statistics as part of an application profile. Hence, you can ask the Performance Analyzer to present the Java methods in your application using Java monitors or locks.

### Tip

You can also view locks used within the JVM with the Performance Analyzer, but that requires setting the presentation view mode to Machine Mode.

By selecting the View > Set Data Presentation menu in Performance Analyzer and choosing the Metrics tab, you can ask the Performance Analyzer to present lock statistics, both inclusive or exclusive. Remember that inclusive lock metrics include not only the lock time spent in a given method but also the lock time spent in methods

it calls. In contrast, exclusive metrics report only the amount of lock time spent in a given method.

Figure 6-10 shows the Performance Analyzer’s Set Data Presentation form with options selected to present both inclusive and exclusive lock information. Also notice the options selected report both the time value and the percentage spent locking.

After clicking OK, the Performance Analyzer displays the profile’s lock inclusive and exclusive metrics in descending order. The arrow in the metric column header indicates how the data is presented. In Figure 6-11, the lock data is ordered by the exclusive metric (notice the arrow in the exclusive metric header and note the icon indicating an exclusive metric).

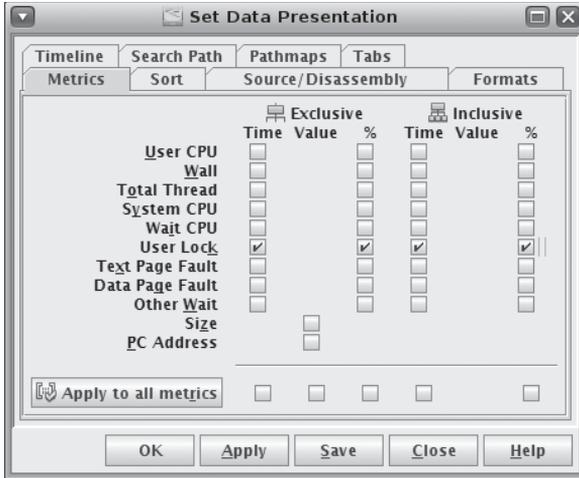


Figure 6-10 Set user lock data presentation

Functions		Callers-Callees		Call Tree	Source	Disassembly	Timeline	Experiments
<input checked="" type="checkbox"/> User Lock ▼ (sec.)    (%)		<input checked="" type="checkbox"/> User Lock (sec.)    (%)		Name				
23 596.316	100.00	23 596.316	100.00	<Total>				
14 151.979	59.98	14 151.999	59.98	java.util.Collections\$SynchronizedMap.get(java.lang.Object)				
9 152.732	38.79	9 152.732	38.79	<JVM-System>				
239.998	1.02	239.998	1.02	sun.misc.Unsafe.park(boolean, long)				
21.195	0.09	21.285	0.09	java.util.Collections\$SynchronizedMap.put(java.lang.Object,				
14.030	0.06	14.120	0.06	java.util.Collections\$SynchronizedMap.remove(java.lang.Object)				

Figure 6-11 Java monitors/locks ordered by exclusive metric

**Tip**

Before blindly looking only at lock metrics in Performance Analyzer, an application should be exhibiting scalability symptoms. The classic scaling symptoms occur when executing an application on a system with a large number of CPUs, CPU cores, or hardware threads does not show an expected scaling in performance throughput relative to a system with a smaller number of CPUs, CPU cores, or hardware threads, or leaves CPU utilization unused. In other words, if an application is not showing scaling issues, then there is no need to investigate an application's locking activity.

The screenshot taken in Figure 6-11 is from a simple example program (complete source code for the remaining examples used in this chapter can be found in Appendix B, “Profiling Tips and Tricks Example Source Code”) that uses a `java.util.HashMap` as a data structure to hold 2 million fictitious tax payer records and performs updates to those records stored in the `HashMap`. Since this example is multithreaded and the operations performed against the `HashMap` include adding a new record, removing a new record, updating an existing record, and retrieving a record, the `HashMap` requires synchronized access, that is, the `HashMap` is allocated as a synchronized `Map` using the `Collections.synchronizedMap()` API. The following list provides more details as to what this example program does:

- Creates 2 million fictitious tax payer records and places them in an in-memory data store, a `java.util.HashMap` using a tax payer id as the `HashMap` key and the tax payer's record as the value.
- Queries the underlying system for the number of available processors using the Java API `Runtime.availableProcessors()` to determine the number of simultaneous Java threads to execute concurrently.
- Uses the number returned from `Runtime.availableProcessors()` and creates that many `java.util.concurrent.Callable` objects to execute concurrently in an allocated `java.util.concurrent.ExecutorService` pool of `Executors`.
- All `Executors` are launched and tax payer records are retrieved, updated, removed, and added concurrently by the `Executor` threads in the `HashMap`. Since there is concurrent access to the `HashMap` through the actions of adding, removing, and updating records, `HashMap` access must be synchronized. The `HashMap` is synchronized using the `Collections.synchronizedMap()` wrapper API at `HashMap` creation time.

From the preceding description, it should be of little surprise this example program experiences lock contention when a large number of threads are trying to concurrently

access the same synchronized `HashMap`. For example, when this program is run on a Sun SPARC Enterprise T5120 Server configured with an UltraSPARC T2 processor, which has 64 virtual processors (the same value as that returned by the Java API `Runtime.availableProcessors()`), the performance throughput reported by the program is about 615,000 operations per second. But only 8% CPU utilization is reported due to heavy lock contention. Oracle Solaris `mpstat` also reports a large number of voluntary thread context switches. In Chapter 2, the “Memory Utilization” section talks about high values of voluntary thread context switches being a potential indicator of high lock contention. In that section, it is said that the act of parking a thread and awaking a thread after being notified both result in an operating system voluntary context switch. Hence, an application experiencing heavy lock contention also exhibits a high number of voluntary context switches. In short, this application is exhibiting symptoms of lock contention.

Capturing a profile of this example program with the Performance Analyzer and viewing its lock statistics, as Figure 6-11 shows, confirms this program is experiencing heavy lock contention. The application is spending about 59% of the total lock time, about 14,000 seconds, performing a synchronized `HashMap.get()` operation. You can also see about 38% of the total lock time is spent in an entry labeled `<JVM-System>`. You can read more about this in the “Understanding JVM-System Locking” sidebar. You can also see the calls to the `put()` and `remove()` records in the synchronized `HashMap` as well.

Figure 6-12 shows the Callers-Callees of the `SynchronizedMap.get()` entry. It is indeed called by the `TaxPayerBailoutDBImpl.get()` method, and the `SynchronizedMap.get()` method calls a `HashMap.get()` method.

## Understanding JVM-System Locking

A JVM-System entry in Performance Analyzer indicates time spent within the JVM internals. In the context of looking at lock contention statistics in Performance Analyzer, this is the amount or percentage of time spent in locks within the internals of the JVM. This may sound alarming when looking at the amount of time spent in the JVM-System in Figure 6-11.

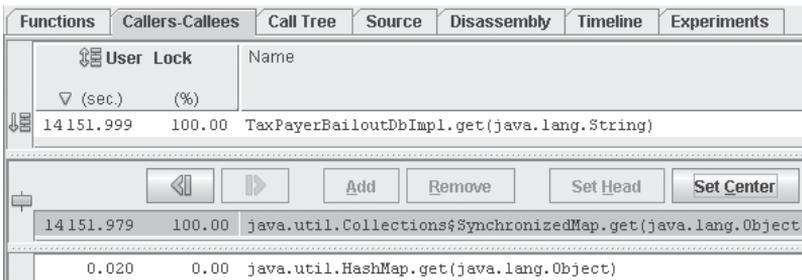


Figure 6-12 Callers-Callees of synchronized `HashMap.get()`

Hence, this requires a little further explanation and clarification. Recall from Chapter 5 that switching from a Data Presentation Format of User mode to either Expert mode or Machine mode shows the internal operations of the JVM and puts them in the JVM-System entry seen in User mode. Also remember that switching to Expert mode or Machine mode also shows highly contended Java monitors as a form of a `__lwp_mutex`, `__lwp_cond_wait`, or `__lwp_park` type of entry and isolates the locking within Java APIs with those found within the JVM. Figure 6-13 shows the same profile but is switched from User mode to Expert mode in the Performance Analyzer.

Comparing Figure 6-11 to Figure 6-13 suggests the JVM-System entry has resolved into `__lwp_condition_wait` and `__lwp_park` operations. The sum of the `__lwp_condition_wait` and `__lwp_park` are close to what is reported for JVM-System in Figure 6-11. Your initial reaction may be the JVM is also experiencing lock contention. However, selecting the `__lwp_cond_wait` entry and selecting the Callers- callees tab and walking up the call stack, the source of the locking activity associated with `__lwp_cond_wait`, in other words the locking activity associated with the JVM-System entry, is shown in Figure 6-14.

All five of the methods shown in Figure 6-14 are internal JVM methods. Notice that over 95% of the attributable lock time is spent in `GCTaskManager::get_task(unsigned)`.

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
User Lock ▾ (sec.) (%)		User Lock (sec.) (%)		Name		
23 596.316	100.00	23 596.316	100.00	<Total>		
14 151.979	59.98	14 151.999	59.98	java.util.Collections\$SynchronizedMap.get(java.lang.Object)		
8 874.037	37.61	8 874.037	37.61	__lwp_cond_wait		
279.726	1.19	279.726	1.19	__lwp_park		

Figure 6-13 Switching from User mode to Expert mode

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
User Lock ▾ (sec.) (%)		Name				
8 401.507	95.54	GCTaskManager::get_task(unsigned)				
278.455	3.17	VMThread::loop()				
112.078	1.27	CompileBroker::compiler_thread_loop()				
1.411	0.02	WaitForBarrierGCTask::wait_for()				
0.010	0.00	SafepointSynchronize::begin()				
<div style="text-align: center;"> </div>						
0.	0.	Monitor::wait(bool, long, bool)				
8 793.461	100.00	Monitor::IWait(Thread*, long)				

Figure 6-14 Traversing up the call stack of callers of `__lwp_cond_wait`

This method is part of the garbage collection subsystem of the Java HotSpot VM. This garbage collection method blocks and waits on a queue for work to do on behalf of the garbage collector subsystem. Each of the method names listed in Figure 6-14 represent areas of the Java HotSpot VM that may block and wait for some work to be placed on their respective work queue. For example, the `VMThread::loop()` method blocks on a queue for work to do on behalf of the Java HotSpot VM. You can think of the `VMThread` as the “kernel thread” of the Java HotSpot VM. The `CompilerBroker::compile_thread_loop()` method blocks and waits for work to do on behalf of the JIT compilation subsystem and so on. As a result, the entries reported as the JVM-System entry in User Mode can be ignored as being hot locks in this profile.

Continuing with the example program, the reaction from many Java developers when he or she observes the use of a synchronized `HashMap` or the use of a `java.util.Hashtable`, the predecessor to the synchronized `HashMap`, is to migrate to using a `java.util.concurrent.ConcurrentHashMap`.<sup>1</sup> Following this practice and executing this program using a `ConcurrentHashMap` instead of a synchronized `HashMap` showed an increase of CPU utilization of 92%. In other words, the previous implementation that used a synchronized `HashMap` had a total CPU utilization of 8% while the `ConcurrentHashMap` implementation had 100% CPU utilization. In addition, the number of voluntary context switches dropped substantially from several thousand to less than 100. The reported number of operations per second performed with the `ConcurrentHashMap` implementation increased by a little over 2x to 1,315,000, up from 615,000 with the synchronized `HashMap`. However, seeing only a 2x performance improvement while utilizing 100% CPU utilization compared to just 8% CPU utilization is not quite what was expected.

### Tip

When performance testing, observing an unexpected result or observing a result that looks suspicious is a strong indication to investigate performance results and revisit testing methodology.

Capturing a profile and viewing the results with the Performance Analyzer is in order to investigate what happened. Figure 6-15 shows the hot methods as `java.util.Random.next(int)` and `java.util.concurrent.atomic.AtomicLong.compareAndSet(long, long)`.

Using the Callers-Callees tab to observe the callers of the `java.util.concurrent.atomic.AtomicLong.compareAndSet(long, log)` method shows `java.util.Random.next(int)` as the most frequent callee. Hence, the two hottest methods in the profile are in the same call stack; see Figure 6-16.

---

1. `java.util.concurrent.ConcurrentHashMap` was introduced in the Java 5 SE class libraries and is available in Java 5 and later Java JDKs/JREs.

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
<div style="display: flex; justify-content: space-between;"> <span>🔍 User CPU</span> <span>Name</span> </div> <div style="display: flex; justify-content: space-between;"> <span>▼ (sec.) (%)</span> </div>						
<Total>						
13 768.531	100.00					
5 253.455	38.16		java.util.concurrent.atomic.AtomicLong.compareAndSet(long, long)			
5 137.324	37.31		java.util.Random.next(int)			
837.496	6.08		java.util.concurrent.ConcurrentHashMap\$Segment.get(java.lang.Obj			

Figure 6-15 Hot methods in the ConcurrentHashMap implementation of the program

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
<div style="display: flex; justify-content: space-between;"> <span>🔍 User CPU</span> <span>Name</span> </div> <div style="display: flex; justify-content: space-between;"> <span>▼ (sec.) (%)</span> </div>						
4 880.624	92.90		java.util.Random.next(int)			
372.841	7.10		java.util.concurrent.atomic.AtomicLong.addAndGet(long)			
<div style="display: flex; justify-content: space-between; align-items: center;"> <span>⏪</span> <span>⏩</span> <span>Add</span> <span>Remove</span> <span>Set Head</span> <span>Set Center</span> <span>Set Tail</span> </div>						
5 253.455	100.00		java.util.concurrent.atomic.AtomicLong.compareAndSet(long, long)			
0.010	0.00		sun.misc.Unsafe.compareAndSwapLong(java.lang.Object, long, long, long)			

Figure 6-16 Callers of AtomicLong.compareAndSet

Functions	Callers-Callees	Call Tree	Source	Disassembly	Timeline	Experiments
<div style="display: flex; justify-content: space-between;"> <span>🔍 User CPU</span> <span>Name</span> </div> <div style="display: flex; justify-content: space-between;"> <span>▼ (sec.) (%)</span> </div>						
9 304.999	92.20		TaxCallable.updateTaxPayer(long, TaxPayerRecord)			
218.853	2.17		BailoutMain.getRandomAddress()			
182.518	1.81		BailoutMain.getRandomTaxPayerId()			
180.056	1.78		BailoutMain.getRandomName()			
104.963	1.04		BailoutMain.getRandomSSN()			
90.563	0.90		BailoutMain.getRandomCity()			
10.707	0.11		BailoutMain.getRandomState()			
<div style="display: flex; justify-content: space-between; align-items: center;"> <span>⏪</span> <span>⏩</span> <span>Add</span> <span>Remove</span> <span>Set Head</span> <span>Set Center</span> <span>Set Tail</span> </div>						
74.712	0.74		java.util.Random.nextInt(int)			
10 017.948	99.26		java.util.Random.next(int)			

Figure 6-17 Callers and callees of Random.nextInt(int)

Figure 6-17 shows the result of traversing further up the call stack of the callers of Random.next (int). Traversing upwards shows Random.next (int) is called by Random.nextInt (int), which is called by a TaxCallable.updateTaxPayer(long, TaxPayerRecord) method and six methods from

the `BailoutMain` class with the bulk of the attributable time spent in the `TaxCallable.updateTaxPayer(long, TaxPayerRecord)` method.

The implementation of `TaxCallable.updateTaxPayer(long, TaxPayerRecord)` is shown here:

```
final private static Random generator = BailoutMain.random;
// these class fields initialized in TaxCallable constructor
final private TaxPayerBailoutDB db;
private String taxPayerId;
private long nullCounter;
private TaxPayerRecord updateTaxPayer(long iterations,
                                      TaxPayerRecord tpr) {
    if (iterations % 1001 == 0) {
        tpr = db.get(taxPayerId);
    } else {
        // update a TaxPayer's DB record
        tpr = db.get(taxPayerId);
        if (tpr != null) {
            long tax = generator.nextInt(10) + 15;
            tpr.taxPaid(tax);
        }
    }
    if (tpr == null) {
        nullCounter++;
    }
    return tpr;
}
```

The purpose of `TaxCallable.updateTaxPayer(long, TaxPayerRecord)` is to update a tax payer's record in a tax payer's database with a tax paid. The amount of tax paid is randomly generated between 15 and 25. This randomly generated tax is implemented with the line of code, `long tax = generator.nextInt(10) + 15`. `generator` is a class instance `static Random` that is assigned the value of `BailoutMain.random` which is declared in the `BailoutMain` class as `final public static Random random = new Random(Thread.currentThread().getId())`. In other words, the `BailoutMain.random` class instance field is shared across all instances and uses of `BailoutMain` and `TaxCallable`. The `BailoutMain.random` serves several purposes in this application. It generates random fictitious tax payer ids, names, addresses, social security numbers, city names and states which are populated in a tax payer database, a `TaxPayerBailoutDB` which uses a `ConcurrentHashMap` in this implementation variant as its storage container. `BailoutMain.random` is also used, as described earlier, to generate a random tax for a given tax payer.

Since there are multiple instances of `TaxCallable` executing simultaneously in this application, the static `TaxCallable.generator` field is shared across all `TaxCallable` instances. Each of the `TaxCallable` instances execute in different threads, each sharing the same `TaxCallable.generator` field and updating the same tax payer database.

This means all threads executing `TaxCallable.updateTaxPayer(long, TaxPayerRecord)` trying to update the tax payer database must access the same `Random` object instance concurrently. Since the Java HotSpot JDK distributes the Java SE class library source code in a file called `src.zip`, it is possible to view the implementation of `java.util.Random`. A `src.zip` file is found in the JDK root installation directory. Within the `src.zip` file, you can find the `java.util.Random.java` source code. The implementation of the `Random.next(int)` method follows (remember from the Figure 6-17 that `Random.next(int)` is the method that calls the hot method `java.util.concurrent.atomic.AtomicLong.compareAndSet(int, int)`).

```
private final AtomicLong seed;
private final static long multiplier = 0x5DEECE66DL;
private final static long addend = 0xBL;
private final static long mask = (1L << 48) - 1;
protected int next(int bits) {
    long oldseed, nextseed;
    AtomicLong seed = this.seed;
    do {
        oldseed = seed.get();
        nextseed = (oldseed * multiplier + addend) & mask;
    } while (!seed.compareAndSet(oldseed, nextseed));
    return (int)(nextseed >>> (48 - bits));
}
```

In `Random.next(int)`, there is a `do/while` loop that performs an `AtomicLong.compareAndSet(int, int)` on the old seed and the new seed (this statement is highlighted in the preceding code example in bold). `AtomicLong` is an atomic concurrent data structure. Atomic and concurrent data structures were two of the features added to Java 5. Atomic and concurrent data structures typically rely on some form of a “compare and set” or “compare and swap” type of operation, also commonly referred to as a CAS, pronounced “kazz”.

CAS operations are typically supported through one or more specialized CPU instructions. A CAS operation uses three operands: a memory location, an old value, and a new value. Here is a brief description of how a typical CAS operation works. A CPU atomically updates a memory location (an atomic variable) if the value at that location matches an expected old value. If that property fails to hold, no changes are made. To be more explicit, if the value at that memory location prior to the

CAS operation matches a supplied expected old value, then the memory location is updated with the new value. Some CAS operations return a boolean value indicating whether the memory location was updated with the new value, which means the old value matched the contents of what was found in the memory location. If the old value does not match the contents of the memory location, the memory location is not updated and false is returned.

It is this latter boolean form the `AtomicLong.compareAndSet(int, int)` method uses. Looking at the preceding implementation of the `Random.next(int)` method, the condition in the do/while loop does not exit until the `AtomicLong` CAS operation atomically and successfully sets the `AtomicLong` value to the nextseed value. This only occurs if the current value at the `AtomicLong`'s memory location has a value of the `oldseed`. If a large number of threads happen to be executing on the same `Random` object instance and calling `Random.next(int)`, there is a high probability the `AtomicLong.compareAndSet(int, int)` CAS operation will return false since many threads will observe a different `oldseed` value at the `AtomicLong`'s value memory location. As a result, many CPU cycles may be spent spinning in the do/while loop found in `Random.next(int)`. This is what the Performance Analyzer profile suggests is the case.

A solution to this problem is to have each thread have its own `Random` object instance so that each thread is no longer trying to update the same `AtomicLong`'s memory location at the same time. For this program, its functionality does not change with each thread having its own thread local `Random` object instance. This change can be accomplished rather easily by using a `java.lang.ThreadLocal`. For example, in `BailoutMain`, instead of using a static `Random` object, a static `ThreadLocal<Random>` could be used as follows:

```
// Old implementation using a static Random
//final public static Random random =
//    new Random(Thread.currentThread().getId());

// Replaced with a new ThreadLocal<Random>
final public static ThreadLocal<Random> threadLocalRandom =
    new ThreadLocal<Random>() {
        @Override
        protected Random initialValue() {
            return new Random(Thread.currentThread().getId());
        }
    };
```

Then any reference to or use of `BailoutMain.random` should be replaced with `threadLocalRandom.get()`. A `threadLocalRandom.get()` retrieves a unique `Random` object instance for each thread executing code that used to use `BailoutMain.random`. Making this change allows the `AtomicLong`'s CAS operation

in `Random.next(int)` to succeed quickly since no other thread is sharing the same `Random` object instance. In short, the `do/while` in `Random.next(int)` completes on its first loop iteration execution.

After replacing the `java.util.Random` in `BailoutMain` with a `ThreadLocal<Random>` and re-running the program, there is a remarkable improvement performance. When using the static `Random`, the program reported about 1,315,000 operations per second being executed. With the static `ThreadLocal<Random>` the program reports a little over 32,000,000 operations per second being executed. 32,000,000 operations per second is almost 25x more operations per second higher than the version using the static `Random` object instance. And it is more than 50x faster than the synchronized `HashMap` implementation, which reported 615,000 operations per second.

A question that may be worthy of asking is whether the program that used the synchronized `HashMap`, the initial implementation, could realize a performance improvement by applying the `ThreadLocal<Random>` change. After applying this change, the version of the program that used a synchronized `HashMap` showed little performance improvement, nor did its CPU utilization improve. Its performance improved slightly from 615,000 operations per second to about 620,000 operations per second. This should not be too much of a surprise. Looking back at the profile, the method having the hot lock in the initial version, the one that used a synchronized `HashMap`, and shown in Figure 6-11 and Figure 6-12, reveals the hot lock is on the `synchronized HashMap.get()` method. In other words, the `synchronized HashMap.get()` lock is masking the `Random.next(int)` CAS issue uncovered in the first implementation that used `ConcurrentHashMap`.

One of the lessons to be learned here is that atomic and concurrent data structures may not be the holy grail. Atomic and concurrent data structures rely on a CAS operation, which in general employs a form of synchronization. Situations of high contention around an atomic variable can lead to poor performance or scalability even though a concurrent or lock-free data structure is being used.

Many atomic and concurrent data structures are available in Java SE. They are good choices to use when the need for them exists. But when such a data structure is not available, an alternative is to identify a way to design the application such that the frequency at which multiple threads access the same data and the scope of the data that is accessed is minimized. In other words, try to design the application to minimize the span, size, or amount of data to be synchronized. To illustrate with an example, suppose there was no known implementation of a `ConcurrentHashMap` available in Java, that is, only the `synchronized HashMap` data structure was available. The alternative approach just described suggests the idea to divide the tax payer database into multiple `HashMaps` to lessen the amount or scope of data that needs to be locked. One approach might be to consider a `HashMap` for tax payers in each state. In such an approach, there would be two levels of `Maps`. The first

level Map would find one of the 50 state Maps. Since the first level Map will always contain a mapping of the 50 states, no elements need to be added to it or removed from it. Hence, the first level Map requires no synchronization. However, the second level state maps require synchronized access per state Map since tax payer records can be added, removed, and updated. In other words, the tax payer database would look something like the following:

```
public class TaxPayerBailoutDbImpl implements TaxPayerBailoutDB {
    private final Map<String, Map<String, TaxPayerRecord>> db;
    public TaxPayerBailoutDbImpl(int dbSize, int states) {
        db = new HashMap<String, Map<String, TaxPayerRecord>>(states);
        for (int i = 0; i < states; i++) {
            Map<String, TaxPayerRecord> map =
                Collections.synchronizedMap(
                    new HashMap<String, TaxPayerRecord>(dbSize/states));
            db.put(BailoutMain.states[i], map);
        }
    }
    ...
}
```

In the preceding source code listing you can see the first level Map is allocated as a HashMap in the line `db = new HashMap<String, Map<String, TaxPayerRecord>>(dbSize)` and the second level Map, one for each of the 50 states is allocated as a synchronized HashMap in the for loop:

```
for (int i = 0; i < states; i++) {
    Map<String, TaxPayerRecord> map =
        Collections.synchronizedMap(
            new HashMap<String, TaxPayerRecord>(dbSize/states));
    db.put(BailoutMain.states[i], map);
}
```

Modifying this example program with the partitioning approach described here shows about 12,000,000 operations per second being performed and a CPU utilization of about 50%. The number of operations per second is not nearly as good as the 32,000,000 observed with a `ConcurrentHashMap`. But it is a rather large improvement over the single large synchronized HashMap, which yielded about 620,000 operations per second. Given there is unused CPU utilization, it is likely further partitioning could improve the operations per second in this partitioning approach. In general, with the partitioning approach, you trade-off additional CPU cycles for additional path length, that is, more CPU instructions, to reduce the scope of the data that is being locked where CPU cycles are lost blocking and waiting to acquire a lock.

## Volatile Usage

JSR-133, which was introduced in Java 5, addressed many issues in the Java Memory Model. This is well documented at <http://jcp.org/jsr/detail?id=133> by the JSR-133 Expert Group with further material at <http://www.cs.umd.edu/~pugh/java/memoryModel/> maintained by Dr. Bill Pugh. One of the issues addressed with JSR-133 is the use of the Java keyword `volatile`. Fields in Java objects that are declared as `volatile` are usually used to communicate state information among threads. The inclusion of JSR-133 into Java 5 and later Java revisions, ensures that a thread that reads a `volatile` field in an object is guaranteed to have the value that was last written to that `volatile` field, regardless of the thread that is doing read or write, or the location of where those two threads are executing, that is, different CPU sockets, or CPU cores. The use of a `volatile` field does limit optimizations a modern JVM's JIT compiler can perform on such a field. For example, a `volatile` field must adhere to certain instruction ordering. In short, a `volatile` field's value must be kept in sync across all application threads and CPU caches. For instance, when a `volatile` field's value is changed by one thread, whose field might be sitting in a CPU cache, any other thread that might have a copy of that `volatile` field in its CPU cache, a different CPU cache than the other thread that performed the change, must have its CPU cache updated before its thread reads that `volatile` field found in its local CPU cache, or it must be instructed to retrieve the updated `volatile` field's value from memory. To ensure CPU caches are updated, that is, kept in sync, in the presence of `volatile` fields, a CPU instruction, a memory barrier, often called a *membar* or *fence*, is emitted to update CPU caches with a change in a `volatile` field's value.

In a highly performance sensitive application having multiple CPU caches, frequent updates to `volatile` fields can be a performance issue. However, in practice, few Java applications rely on frequent updates to `volatile` fields. But there are always exceptions to the rule. If you keep in mind that frequent updates, changes, or writes to a `volatile` field have the potential to be a performance issue (i.e., reads of a `volatile` field are okay, not a cause for performance concern), you will likely not experience performance issues when using `volatile` fields.

A profiler, such as the Performance Analyzer, that has the capability to gather CPU cache misses and associate them to Java object field access can help isolate whether the use of a `volatile` field is a performance issue. If you observe a high number of CPU cache misses on a `volatile` field and the source code suggests frequent writes to that `volatile` field, you have an application that is experiencing performance issues as a result of its usage of `volatile`. The solution to such a situation is to identify ways in which less frequent writes are performed to the `volatile` field, or refactor the application in a way to avoid the use of the `volatile` field. Never remove the use of a `volatile` field if it breaks program correctness or introduces a potential race condition. It is much better to have an underperforming application than it is to have an incorrect implementation, or one that has the potential for a race condition.

## Data Structure Resizing

Java applications tend to make high use of Java SE's `StringBuilder` or `StringBuffer` for assembling `Strings` and also make high use of Java objects that act as containers of data such as the Java SE Collections classes. Both `StringBuilder` and `StringBuffer` use an underlying `char []` for their data storage. As elements are added to a `StringBuilder` or `StringBuffer`, the underlying `char []` data storage, may be subject to resizing. As a result of resizing, a new larger `char []` array is allocated, the `char` elements in the old `char []` are copied into the new larger `char []` array, and the old `char []` discarded, that is, available for garbage collection. Similar resizing can also occur in Java SE Collections classes that use an array for their underlying data store.

This section explores ways to identify data structure resizing, in particular `StringBuilder`, `StringBuffer`, and Java SE Collections classes resizing.

### StringBuilder/StringBuffer Resizing

When a `StringBuilder` or `StringBuffer` becomes large enough to exceed the underlying data storage capacity, a new `char` array of a larger size, 2x larger in the OpenJDK `StringBuilder` and `StringBuffer` implementation (used by Java HotSpot Java 6 JDK/JRE), is allocated, the old `char` array elements are copied into the new `char` array, and the old `char` array is discarded. A version of the implementation used by `StringBuilder` and `StringBuffer` follows:

```
char[] value;
int count;

public AbstractStringBuilder append(String str) {
    if (str == null) str = "null";
    int len = str.length();
    if (len == 0) return this;
    int newCount = count + len;
    if (newCount > value.length)
        expandCapacity(newCount);
    str.getChars(0, len, value, count);
    count = newCount;
    return this;
}

void expandCapacity(int minimumCapacity) {
    int newCapacity = (value.length + 1) * 2;
    if (newCapacity < 0) {
        newCapacity = Integer.MAX_VALUE;
    } else if (minimumCapacity > newCapacity) {
        newCapacity = minimumCapacity;
    }
    value = Arrays.copyOf(value, newCapacity);
}
```

Continuing with the fictitious tax payer program example from the previous section (full listing of the source code used in this section can be found in Appendix B in the section “First Resizing Variant”), `StringBuilder` objects are used to assemble random Strings representing tax payer names, addresses, cities, states, social security numbers, and a tax payer id. It also uses the no argument `StringBuilder` constructor. Hence, the program is likely to be subject to `StringBuilder`’s underlying `char []` being resized. A capture of a memory or heap profile with a profiler such as NetBeans Profiler confirms that is the case. Figure 6-18 shows a heap profile from NetBeans Profiler.

In Figure 6-18, you can see that `char []`, `StringBuilder`, and `String` are the most highly allocated objects and also have the largest amount of live objects. In the NetBeans Profiler, selecting and right-clicking on the `char []` class name in the far left column as shown in Figure 6-19 shows the allocation stack traces for all `char []` objects.

In the `char []` stack allocation traces, shown in Figure 6-20, you can see an entry for `java.lang.AbstractStringBuilder.expandCapacity(int)`, which is

Class Name - Live Allocated Objects	Live Bytes ▾	Live Bytes	Live Objects	Allocated Objects
<b>char[]</b>		118,792,912 B (63.6%)	2,460,612 (44.9%)	2,926,057
java.lang.String		30,427,464 B (16.3%)	1,267,811 (23.1%)	1,267,815
java.lang.StringBuilder		14,524,080 B (7.8%)	907,755 (16.6%)	1,266,550
<b>TaxPayerRecord</b>		8,453,440 B (4.5%)	211,336 (3.9%)	211,336
java.util.HashMap\$Entry		5,067,552 B (2.7%)	211,148 (3.9%)	211,148
java.util.concurrent.atomic.AtomicLong		3,380,416 B (1.8%)	211,276 (3.9%)	211,276
<b>StateAndId</b>		3,378,960 B (1.8%)	211,185 (3.9%)	211,185
java.util.HashMap\$Entry[]		2,868,112 B (1.5%)	37 (0%)	67
byte[]		11,416 B (0%)	6 (0%)	8

Figure 6-18 Heap profile

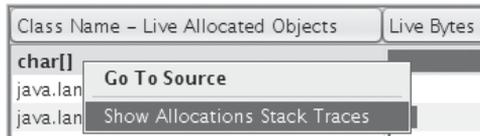


Figure 6-19 Showing allocation stack traces

Method Name - Allocation Call Tree	Live Bytes...	Live Objects ▾	Allocated Objects
char[]		2,460,612 (100%)	2,926,048
java.util.Arrays.copyOfRange(char[], int, int)		1,268,072 (51.5%)	1,268,073
java.lang.AbstractStringBuilder.<init>(int)		911,056 (37%)	1,266,982
java.util.Arrays.copyOf(char[], int)		281,480 (11.4%)	390,988
<b>java.lang.AbstractStringBuilder.expandCapacity(int)</b>		281,480 (11.4%)	390,988
java.lang.AbstractStringBuilder.append(char)		281,476 (11.4%)	390,984
java.lang.AbstractStringBuilder.append(String)		4 (0%)	4

Figure 6-20 char[] allocations from expanding StringBuilders

called from `AbstractStringBuilder.append(char)` and `AbstractStringBuilder.append(String)` methods. The `expandCapacity(int)` method calls `java.util.Arrays.copyOf(char[], int)`. Looking back at the previous source code listing, you can see where `AbstractStringBuilder.append(String str)` calls `expandCapacity(int)` and calls `Arrays.copyOf(char[] int)`.

You can also see from Figure 6-20, over 11% of the current live `char[]` objects are from resized `StringBuilder char[]`. In addition, there are a total of 2,926,048 `char[]` objects that have been allocated, and of those, 390,988 `char[]` allocations occurred as a result of `StringBuilder char[]` resizing. In other words, about 13% (390,988/2,926,048) of all `char[]` allocations are coming from resized `StringBuilder char[]`s. Eliminating these `char[]` allocations from resizing improves the performance of this program by saving the CPU instructions needed to perform the new `char[]` allocation, copying the characters from the old `char[]` into the new `char[]`, and the CPU instructions required to garbage collect the old discarded `char[]`.

In the Java HotSpot JDK/JRE distributions, both the `StringBuilder` and `StringBuffer` offer no argument constructors that use a default size of 16 for their underlying `char` array data storage. These no argument constructors are being used in this program. This can be seen in the profile by expanding the `java.lang.AbstractStringBuilder.<init>(int)` entry seen in Figure 6-20. The expansion of the `java.lang.AbstractStringBuilder.<init>(int)` entry, shown in Figure 6-21, shows it is called by a no argument `StringBuilder` constructor.

In practice, few `StringBuilder` or `StringBuffer` object instances result in having consumed 16 or fewer `char` array elements; 16 is the default size used with the no argument `StringBuilder` or `StringBuffer` constructor. To avoid `StringBuilder` and `StringBuffer` resizing, use the explicit size `StringBuilder` or `StringBuffer` constructor.

A modification to the example program follows, which now uses explicit sizes for constructing `StringBuilder` objects. A full listing of the modified version can be found in Appendix B in the section “Second Resizing Variant.”

Recent optimizations in Java 6 update releases of the Java HotSpot VM analyze the usage of `StringBuilder` and `StringBuffer` and attempt to determine the

Method Name – Allocation Call Tree	Live Bytes...	Live Objects ▼	Allocated Objects
char[]		2,460,612 (100%)	2,926,048
▶ java.util.Arrays.copyOfRange(char[], int, int)		1,268,072 (51.5%)	1,268,073
▼ java.lang.AbstractStringBuilder.<init>(int)		911,056 (37%)	1,266,982
▶ java.lang.StringBuilder.<init>()		911,055 (37%)	1,266,981
▶ java.lang.StringBuffer.<init>(int)		1 (0%)	1
▼ java.util.Arrays.copyOf(char[], int)		281,480 (11.4%)	390,988
▼ java.lang.AbstractStringBuilder.expandCapacity(int)		281,480 (11.4%)	390,988
▶ java.lang.AbstractStringBuilder.append(char)		281,476 (11.4%)	390,984
▶ java.lang.AbstractStringBuilder.append(String)		4 (0%)	4

Figure 6-21 Uses of `StringBuilder` default constructor

```
public static String getRandomTaxPayerId() {
    StringBuilder sb = new StringBuilder(20);
    for (int i = 0; i < 20; i++) {
        int index =
            threadLocalRandom.get().nextInt(alphabet.length);
        sb.append(alphabet[index]);
    }
    return sb.toString();
}

public static String getRandomAddress() {
    StringBuilder sb = new StringBuilder(24);
    int size = threadLocalRandom.get().nextInt(14) + 10;
    for (int i = 0; i < size; i++) {
        if (i < 5) {
            int x = threadLocalRandom.get().nextInt(8);
            sb.append(x + 1);
        }
        int index =
            threadLocalRandom.get().nextInt(alphabet.length);
        char c = alphabet[index];
        if (i == 5) {
            c = Character.toUpperCase(c);
        }
        sb.append(c);
    }
    return sb.toString();
}
```

optimal char array size to use for a given `StringBuilder` or `StringBuffer` object allocation as means to reduce unnecessary `char []` object allocations resulting from `StringBuilder` or `StringBuffer` expansion.

Measuring the performance impact after addressing `StringBuilder` and `StringBuffer` resizing will be done in combination with addressing any Java Collection classes resizing, the topic of the next section.

## Java Collections Resizing

The addition of the Java Collections to Java SE offered an enormous boost to developer productivity by providing containers with interfaces allowing the ability to easily switch between alternative concrete implementations. For example, the `List` interface offers an `ArrayList` and `LinkedList` concrete implementation.

---

### Java Collections Definition

As of Java 6, there were 14 interfaces in the Java SE Collections:

`Collection`, `Set`, `List`, `SortedSet`, `NavigableSet`, `Queue`, `Deque`, `BlockingQueue`, `BlockingDeque`, `Map`, `SortedMap`, `NavigableMap`, `ConcurrentMap`, and `ConcurrentNavigableMap`

The following is a listing of the most common concrete implementations of the Java SE Collections:

HashMap, HashSet, TreeSet, LinkedHashSet, ArrayList, ArrayDeque, LinkedList, PriorityQueue, TreeMap, LinkedHashMap, Vector, Hashtable, ConcurrentLinkedQueue, LinkedBlockingQueue, ArrayBlockingQueue, PriorityBlockingQueue, DelayQueue, SynchronousQueue, LinkedBlockingDeque, ConcurrentHashMap, ConcurrentSkipListSet, ConcurrentSkipListMap, WeakHashMap, IdentityHashMap, CopyOnWriteArrayList, CopyOnWriteArraySet, EnumSet, and EnumMap

Some of the Collections' concrete implementations are subject to potential expensive resizing as the number of elements added to the Collection grows such as `ArrayList`, `Vector`, `HashMap`, and `ConcurrentHashMap` since their underlying data store is an array. Other Collections such as `LinkedList` or `TreeMap` often use one or more object references between the elements stored to chain together the elements managed by the Collection. The former of these, those that use an array for the Collection's underlying data store, can be subject to performance issues when the underlying data store is resized due to the Collection growing in the number of elements it holds. Although these Collections classes have constructors that take an optional size argument, these constructors are often not used, or the size provided in an application program is not optimal for the Collection's use.

### Tip

It is possible that there exists concrete implementations of Java Collections classes, such as `LinkedList` and `TreeMap`, that use arrays as underlying data storage. Those concrete implementations may also be subject to resizing. Collecting a heap profile and looking at collection resizing will show which Java Collections classes are resizing.

As is the case with `StringBuilder` or `StringBuffer`, resizing of a Java Collections class that uses an array as its data storage requires additional CPU cycles to allocate a new array, copy the old elements from the old array, and at some point in the future garbage collect the old array. In addition, the resizing can also impact Collection's field access time, the time it takes to dereference a field, because a new underlying data store, again typically an array, for the Collection's underlying data store may be allocated in a location in the JVM heap away from the object references stored within the data store and the other fields of the Collection. After a Collection resize occurs, it is possible an access to its resized field can result in CPU cache misses due to the way a modern JVM allocates objects in memory, in particular how those objects are laid out in memory. The way objects and their fields are laid out in memory can vary between JVM implementations. Generally, however, since

an object and its fields tend to be referenced frequently together, an object and its fields laid out in memory within close proximity generally reduce CPU cache misses. Hence, the impact of Collections resizing (this also applies to `StringBuffer` and `StringBuilder` resizing) may extend beyond the additional CPU instructions spent to do the resizing and the additional overhead put on the JVM's memory manager to having a lingering higher field access time due to a change in the layout of the Collection's fields in memory relative the Collection object instance.

The approach to identifying Java Collections resizing is similar to what was described earlier for identifying `StringBuilder` and `StringBuffer` resizing, collecting heap or memory profile with a profiler such as NetBeans Profiler. Looking at the source code for the Java Collection classes helps identify the method names that perform the resizing.

Continuing with the fictitious tax payer program, the program variant in which tax payer records were populated into multiple `HashMap`s using a tax payer's state of residence as a key into a second `HashMap` where a tax payer's id is used as an index is a good example of where Collections resizing can occur. A full source code listing from this variant can be found in Appendix B in the section "First Resizing Variant." The source code, found in `TaxPayerBailoutDbImpl.java`, that allocates the `HashMap`s follows:

```
private final Map<String, Map<String, TaxPayerRecord>> db;

public TaxPayerBailoutDbImpl(int numberOfStates) {
    db = new HashMap<String, Map<String, TaxPayerRecord>>();
    for (int i = 0; i < numberOfStates; i++) {
        Map<String, TaxPayerRecord> map =
            Collections.synchronizedMap(
                new HashMap<String, TaxPayerRecord>());
        db.put(BailoutMain.states[i], map);
    }
}
```

Here you can see the `HashMap`s are using a `HashMap` constructor that takes no arguments. As a result, the `HashMap` relies on a default size for its underlying mapping array. The following is a portion of OpenJDK's `HashMap.java` source code that shows the default size chosen for a `HashMap`'s underlying data storage.

```
static final int DEFAULT_INITIAL_CAPACITY = 16;
static final float DEFAULT_LOAD_FACTOR = 0.75f;

public HashMap() {
    this.loadFactor = DEFAULT_LOAD_FACTOR;
    threshold =
        (int)(DEFAULT_INITIAL_CAPACITY * DEFAULT_LOAD_FACTOR);
    table = new Entry[DEFAULT_INITIAL_CAPACITY];
    init();
}
void init() {
}
```

Two factors decide when the data storage for a `HashMap` is resized: the capacity of the data storage and the load factor. The capacity is the size of the underlying data storage. That's the `HashMap.Entry[]`'s size. And the load factor is a measure of how full the `HashMap` is allowed to reach before the `HashMap`'s data storage, the `Entry[]`, is resized. A `HashMap` resize results in a new `Entry[]` being allocated, twice as large as the previous `Entry[]`, the entries in the `Entry[]` are rehashed and put in the `Entry[]`. The CPU instructions required to resize a `HashMap` are greater than what is required by `StringBuilder` or `StringBuffer` resizing due to the rehashing of the `Entry[]` elements.

In Figure 6-18, you can see a row for `java.util.HashMap$Entry[]`. For this entry you can see there are 67 allocated objects, and 37 of them are live at the time of the profile snapshot. This suggests that 37/67, about 55%, are still live. That also suggests 45% of those `Entry[]` objects that had been allocated have been garbage collected. In other words, the `HashMap`s are experiencing resizing. Notice that the total bytes consumed by `HashMap.Entry[]` objects is much less than those consumed by `char[]` objects. This suggests the impact of eliding the `HashMap` resizing is likely to be less than the impact realized from eliding the `StringBuilder` resizing.

Figure 6-22 shows the allocation stack traces for `HashMap.Entry[]`. Here you can see some of those `HashMap.Entry[]` allocations result from a `HashMap.resize(int)` method call. In addition, you can see the no argument `HashMap` constructor is being used, which also allocates a `HashMap.Entry[]`.

Since this example program populates 50 different `HashMap`s with a total of 2,000,000 fictitious records, each of those 50 `HashMap`s hold about  $2,000,000 / 50 = 40,000$  records. Obviously, 40,000 is much greater than the default size of 16 used by the no argument `HashMap` constructor. Using the default load factor of .75, and the fact that each of the 50 `HashMap` holds 40,000 records, you can determine a size for the `HashMap`s so they will not resize ( $40,000 / .75 = \sim 53,334$ ). Or simply passing the total number of records to store divided by the number of states, divided by the default load factor, i.e.,  $(2,000,000 / 50) / .75$ , to the `HashMap` constructor that holds the records. Following is the modified source code for `TaxPayerBailoutDbImpl.java` that elides `HashMap` resizing:

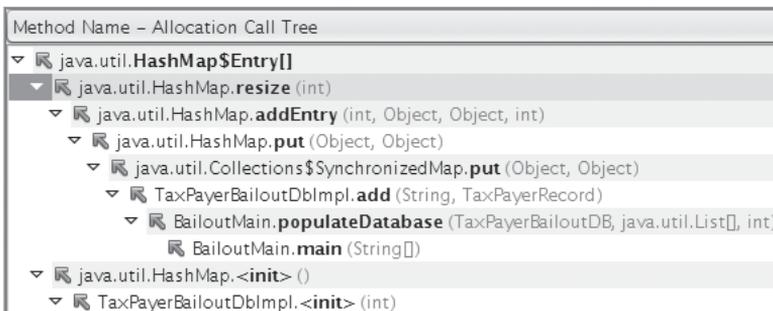


Figure 6-22 `HashMap.Entry[]` allocation stack traces

```

private final Map<String, Map<String,TaxPayerRecord>> db;
private final int dbSize = 2000000;

public TaxPayerBailoutDbImpl(int dbSize, int numberOfStates) {
    final int outerMapSize = (int) Math.ceil(numberOfStates / .75);
    final int innerMapSize =
        (int) (Math.ceil((dbSize / numberOfStates) / .75));
    db =
        new HashMap<String,Map<String,TaxPayerRecord>>(outerMapSize);
    for (int i = 0; i < numberOfStates; i++) {
        Map<String,TaxPayerRecord> map =
            Collections.synchronizedMap(
                new HashMap<String,TaxPayerRecord>(innerMapSize));
        db.put(BailoutMain.states[i], map);
    }
}

```

In this example program, both `StringBuilder` and `HashMap` resizing occur during the initialization phase of the program, the phase of the program that populates a `Map` of `Maps` with fictitious, randomly generated tax payer records. Hence, to measure the performance impact of eliding the `StringBuilder` and `HashMap` resizing, the initialization phase of this program has been instrumented with a time stamp at the beginning of the program and after the `Map` of `Maps` has been populated. A modified version of this example program, one that uses the no argument `HashMap` constructor, calculates and reports the time it takes to populate the `HashMaps` with 2,000,000 records, can be found in Appendix B in the section “First Resizing Variant.”

When this variant of the program is run on a Sun SPARC Enterprise T5120 Server configured with 64 virtual processors (the same value as that returned by the `Java API Runtime.availableProcessors()`), the amount of time it takes to complete the initialization phase is 48.286 seconds.

### Tip

Since the populating of records is single threaded and the Sun SPARC Enterprise T5120 Server has a 1.2GHz clock rate, a processor with a smaller number of cores with a higher clock rate will likely report a shorter duration time needed to populate the 2,000,000 records in the `HashMaps`.

Updating this program variant with the changes described in this section to address both `StringBuilder` and `HashMap` resizing and running on the same Ultra-SPARC T5120 system with the same JVM command line options reports it takes 46.019 seconds to complete its initialization phase. That’s about a 5% improvement in elapsed time. The source code for this variant can be found in Appendix B in the section “Second Resizing Variant.”

Applying the data resizing strategy reduces the application's path length, the total number of CPU instructions required to execute the program, and potentially more efficient use of CPU cycles due to fewer possibilities of CPU cache misses as a result of frequently accessed data structure fields being laid out in memory next to each other.

You may have noticed that the initialization phase in this program is single threaded. But the system it is being executed on has a CPU that is multicore and multithreaded per core. The Sun SPARC Enterprise T5120 Server this program is executing on has 8 cores, and 8 hardware threads per core. It is a chip multithreading type of CPU chip, CMT for short. In other words, 8 cores and 8 hardware threads per core means it has 64 virtual processors. That also means the Java API, `System.availableProcessors()`, returns a value of 64. A next step to improve the performance of the initialization phase of this program is to refactor it to utilize all of those 64 virtual processors. This is the topic of the next section.

## Increasing Parallelism

Modern CPU architectures have brought multiple cores and multiple hardware execution threads to developer desktops. This means there are more CPU resources available to do additional work. However, to take advantage of those additional CPU resources, programs executed on them must be able to do work in parallel. In other words, those programs need to be constructed or designed in a multithreaded manner to take advantage of the additional hardware threads.

Java applications that are single threaded cannot take advantage of additional hardware threads on modern CPU architectures. Those applications must be refactored to be multithreaded to do their work in parallel. In addition, many Java applications have single-threaded phases, or operations, especially initialization or startup phases. Therefore, many Java applications can improve initialization or startup performance by doing tasks in parallel, that is, making use of multiple threads at the same time.

The example program used in the previous sections “Lock Contention” and “Data Structure Resizing” has a single-threaded initialization phase where random fictitious tax payer records are created and added to a Java `Map`. This single-threaded initialization phase could be refactored to being multithreaded. The single-threaded form, as it was run in the “Lock Contention” and “Data Structure Resizing” sections, when run on the same Sun SPARC Enterprise T5120 Server, reports it takes about 45 to 48 seconds for the initialization phase to complete. Since there are 64 virtual processors on an a Sun SPARC Enterprise T5120 Server, 63 of those 64 virtual processors are idle doing little or no work during the initialization phase. Therefore, if the initialization phase could be refactored to utilize those additional 63 virtual processors, the elapsed time it takes to execute the initialization phase should be significantly less.

The key to being able to refactor single-threaded phases of a program to be multi-threaded is constrained by the program's logic. If there is a loop of execution involved, and much of the work performed within that loop is independent of what happens within each loop iteration, it may be a good candidate to be refactored into a multithreaded version. In the case of the fictitious tax payer program, Map records are added to a ConcurrentMap. Since a ConcurrentMap can handle multiple threads adding records to it and the records can be created independently of each other, the work performed in the single-threaded loop can be broken up and spread among multiple threads. With a Sun SPARC Enterprise T5120 Server that has 64 virtual processors, the work that is being done in the single-threaded loop could be spread across those 64 virtual processors.

Here is the core part of the single-threaded loop logic (full implementation can be found in Appendix B in the section “Increasing Parallelism Single-Threaded Implementation”):

```
// allocate the database
TaxPayerBailoutDB db = new TaxPayerBailoutDBImpl(dbSize);
// allocate list to hold tax payer names
List<String>[] taxPayerList = new ArrayList<String>[numberOfThreads];
for (int i = 0; i < numberOfThreads; i++) {
    taxPayerList[i] = new ArrayList<String>(taxPayerListSize);
}
// populate the database and tax payer list with random records
populateDatabase(db, taxPayerList, dbSize);

...

private static void populateDatabase(TaxPayerBailoutDB db,
                                    List<String>[] taxPayerIdList,
                                    int dbSize) {
    for (int i = 0; i < dbSize; i++) {
        // make random tax payer id and record
        String key = getRandomTaxPayerId();
        TaxPayerRecord tpr = makeTaxPayerRecord();
        // add tax payer id & record to database
        db.add(key, tpr);
        // add tax payer id to to tax payer list
        int index = i % taxPayerIdList.length;
        taxPayerIdList[index].add(key);
    }
}
```

The core part of refactoring the for/loop to be multithreaded results in creating a Runnable, or Callable, along with an ExecutorService to execute the Runnables or Callables in addition to ensuring the implementation of a TaxPayerBailoutDB and taxPayerIdList are thread safe. That is, the data they hold will not be corrupted as a result of having multiple threads writing data to them simultaneously. Following are segments of source code that contain the most relevant parts to the multithreaded refactoring (full implementation can be found in Appendix B in the section “Increasing Parallelism Multithreaded Implementation”):

```

// allocate the database
TaxPayerBailoutDB db = new TaxPayerBailoutDbImpl(dbSize);
List<String>[] taxPayerList = new List[numberOfThreads];
for (int i = 0; i < numberOfThreads; i++) {
    taxPayerList[i] =
        Collections.synchronizedList(
            new ArrayList<String>(taxPayerListSize));
}

// create a pool of executors to execute some Callables
int numberOfThreads = System.availableProcessors();
ExecutorService pool =
    Executors.newFixedThreadPool(numberOfThreads);
Callable<DbInitializerFuture>[] dbCallables =
    new DbInitializer[numberOfThreads];
for (int i = 0; i < dbCallables.length; i++) {
    dbCallables[i] =
        new DbInitializer(db, taxPayerList, dbSize/numberOfThreads);
}

// start all db initializer threads running
Set<Future<DbInitializerFuture>> dbSet =
    new HashSet<Future<DbInitializerFuture>>();
for (int i = 0; i < dbCallables.length; i++) {
    Callable<DbInitializerFuture> callable = dbCallables[i];
    Future<DbInitializerFuture> future = pool.submit(callable);
    dbSet.add(future);
}

// A Callable that will execute multi-threaded db initialization
public class DbInitializer implements Callable<DbInitializerFuture> {
    private TaxPayerBailoutDB db;
    private List<String>[] taxPayerList;
    private int recordsToCreate;

    public DbInitializer(TaxPayerBailoutDB db,
                        List<String>[] taxPayerList,
                        int recordsToCreate) {
        this.db = db;
        this.taxPayerList = taxPayerList;
        this.recordsToCreate = recordsToCreate;
    }

    @Override
    public DbInitializerFuture call() throws Exception {
        return BailoutMain.populateDatabase(db, taxPayerList,
            recordsToCreate);
    }
}

static DbInitializerFuture populateDatabase(TaxPayerBailoutDB db,
                                           List<String>[] taxPayerIdList,
                                           int dbSize) {
    for (int i = 0; i < dbSize; i++) {
        String key = getRandomTaxPayerId();
        TaxPayerRecord tpr = makeTaxPayerRecord();
        db.add(key, tpr);
    }
}

```

```
        int index = i % taxpayerIdList.length;
        taxpayerIdList[index].add(key);
    }
    DbInitializerFuture future = new DbInitializerFuture();
    future.addToRecordsCreated(dbSize);
    return future;
}
```

After applying the refactoring to make the initialization phase multithreaded by dividing up the number of records to be added to the Map to run in 64 threads rather than 1 thread, the time it takes to perform the initialization phase drops from about 45 seconds to about 3 seconds on the Sun SPARC Enterprise T5120 Server. A higher clock rate dual or quad core desktop system may not observe as much of an improvement. For example, the author's dual core desktop system realized about a 4 second improvement, 16 seconds down to about 12. The larger the number of virtual processors that additional parallel work can be spread among, the greater the potential performance improvement.

This simple example illustrates the potential benefit of being able to take advantage of additional virtual processors on a system that may be idle for some phase of an application by making that phase multithreaded.

## High CPU Utilization

Sometimes an application simply cannot meet service level performance or scalability agreements even though performance efforts have reduced system CPU utilization, have addressed lock contention, and other optimization opportunities have been addressed. In such cases, doing an analysis of the program logic and the algorithms used is the direction to take. Method profilers such as the Performance Analyzer or NetBeans Profilers do a good job at collecting information about where in general an application spends most of its time.

The Performance Analyzer's Call Tree tab is good at providing an application's hottest use case by showing the call stack trees. This information can be leveraged to answer questions in a more abstract way, such as how long does it take the application to perform a unit of work, or perform a transaction, use case, and so on so long as the person looking at the profile has sufficient understanding of the implementation to be able to map a method entry point as the beginning of a unit of work, beginning of a transaction, use case, and so on. Being able to analyze the profile in this way provides the opportunity to step back, look at a higher level, and ask questions such as whether the algorithms and data structures being used are the most optimal or are there any alternative algorithms or data structures that might yield better performance or scalability. Often the tendency when analyzing profiles is to focus primarily on the methods that consume the most time in an exclusive metric kind of way, that is, focusing only on the contents of a method rather than at a higher level unit of work, transaction, use case, and so on.

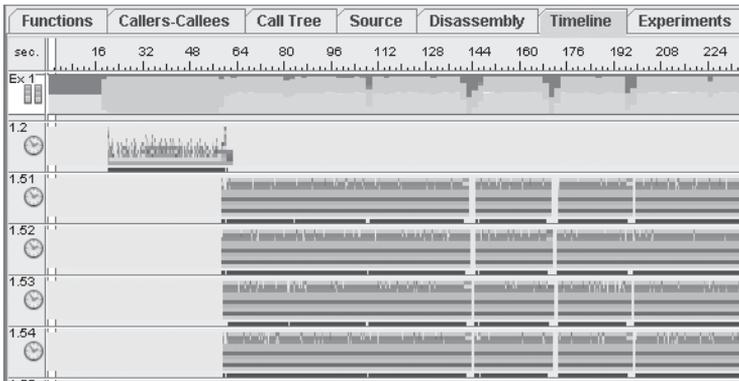


Figure 6-23 Performance analyzer timeline view

## Other Useful Analyzer Tips

Another useful strategy to employ when using the Performance Analyzer is to look at the Timeline view in the Performance Analyzer GUI (see Figure 6-23).

The Timeline view provides a listing of all threads, one in each row of the listing, that executed during the time when the profile was collected. At the top of the Timeline view is a timeline of seconds that have passed since the initiation of the collection of the profile. If the recording of the profiling data is enabled at Java application launch time, then the timeline contains data since the launching of the Java application. For each horizontal row, a thread within the application, a unique color is used to distinguish the method the application was executing in at the time of the sample. Selecting a thread, one of the rows within a colored area shows the call stack, their method names in the Call Stack for Selected Event panel, executing at the time the sample was taken. Figure 6-24 is a screenshot of the Call Stack for Selected Event panel for the selected thread, thread 1.2 in Figure 6-23.

Hence, by looking at the timeline, you can determine which threads are executing in the program at any particular point in time. This can be useful when looking for opportunities to multithread single-threaded phases or operations in an application. Figure 6-23, shows the single-threaded program variant presented in the “Increasing Parallelism” section earlier in the chapter. In Figure 6-23, you can see from the timeline, from about 16 seconds to a little past 64 seconds, the thread labeled as Thread 1.2, is the only thread that appears to be executing. The timeline

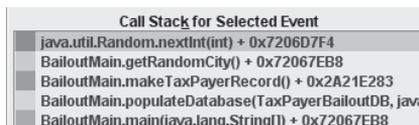


Figure 6-24 Performance analyzer’s call stack for selected event panel

in Figure 6-23, suggests the program may be executing its initialization or beginning phase as a single threaded. Figure 6-24 shows a Call Stack for the Selected Event after clicking in the region of Thread 1.2 between the timeline of 16 seconds and 64 seconds. Figure 6-24 shows the call stack that’s being executed during the selected thread and selected timeline sample. As you can see in Figure 6-24, a method by the name `BailoutMain.populateDatabase()` is being called. This is the method identified in the “Increasing Parallelism” section earlier in the chapter as one that could be multithreaded. Hence, this illustrates how you can use the Performance Analyzer to identify areas or phases of an application that could benefit from parallelism.

Another useful tip when using the Timeline view is make note of the range of seconds for some time period of interest that has caught your attention in the timeline. Then use the filtering capability to narrow the profile data loaded by the Analyzer GUI. After applying the filter, the Functions and Callers-Callees views show data only for the filtered range. In other words, filtering allows you to focus exclusively on the profile data collected within the period of interest. To illustrate with an example, in Figure 6-23, Thread 1.2 between 16 and 64 seconds is the only thread executing. To narrow the focus of the collected profile data to that particular time range, the Analyzer can be configured to load only the profile data between 16 and 64 seconds using the `View > Filter Data` menu and specifying 16-64 samples in the Filter Data form’s Samples field as shown in Figure 6-25.

Filtering allows for the ability to eliminate data collected outside an area of interest, which leads to more accurate analysis since only the data of interest is being presented.

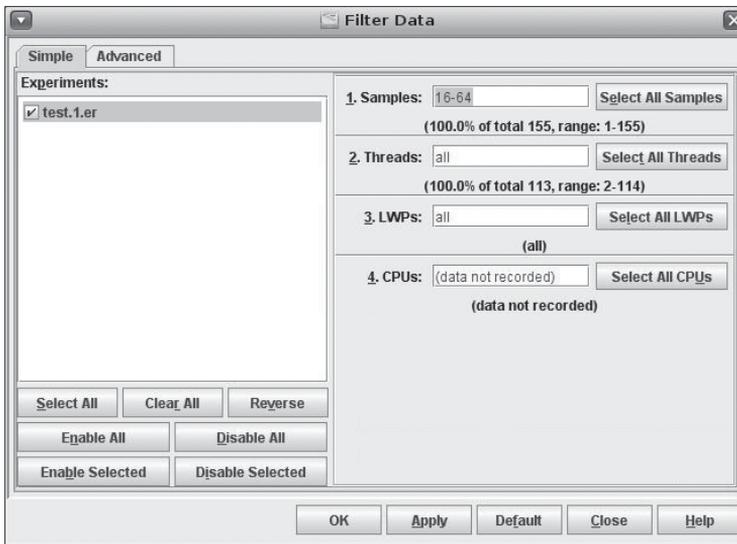


Figure 6-25 Filtering the range of samples to view in performance analyzer

There are many additional features of the Performance Analyzer, but this chapter presents those likely to be the most useful when profiling and analyzing Java applications. Additional details on using Performance Analyzer for profiling Java applications, including the Java EE application, can be found at the Performance Analyzer product Web site: <http://www.oracle.com/technetwork/server-storage/solarisstudio/overview/index.html>.

## Bibliography

---

Keegan, Patrick, et al., *NetBeans IDE field guide: developing desktop, web, enterprise, and mobile applications*, 2nd Edition. Sun Microsystems, Inc., Santa Clara, CA, 2006.

Oracle Solaris Studio 12.2: Performance Analyzer. Oracle Corporation. <http://dlc.sun.com/pdf/821-1379/821-1379.pdf>.

JSR-133: Java Memory Model and Thread Specification. JSR-133 Expert Group. <http://jcp.org/en/jsr/summary?id=133>.

The Java Memory Model. Dr. Bill Pugh. <http://www.cs.umd.edu/~pugh/java/memoryModel/>.

*This page intentionally left blank*



# Index

---

- : (colon), keyword delimiter, 182
- \* (asterisk), wildcard character, 44
- \ (backslash), line termination character, 181
- (dash) option, 181
- ! (exclamation point) keyword, 182
- % (percent sign) keyword, 182
- + (plus sign) keyword, 182
- . (period) keyword, 182
- 32-bit runtime environment *vs.* 64-bit, 260–261

## A

- $\alpha$  (alpha), 351–353
- A keyword, 182
- A option, `collect` tool, 163
- Acceptor threads, monitoring and tuning, 414–417
  - `acceptor-thread` property, 415
- Access logging, best practices, 446–450
- Accessing XML documents, 455, 458–459
- Adaptive heap sizing
  - description, 104–105
  - disabling, 105, 309–311
  - enabling/disabling, 558
  - HotSpot VM, 104–105, 558
  - policy, printing, 563
  - throughput, tuning, 309–311
- Adaptive tuning. *See* HotSpot VM adaptive tuning.
- Administration console, monitoring server applications, 383–384
- Aggressive optimization, 568–569
- Aging statistics, 145–146

- Algorithms, increasing efficiency, 211–212
- Allocated objects, profiling, 205
- Allocation, HotSpot VM garbage collectors, 91
- Allocations tracked, specifying, 204
- Alpha ( $\alpha$ ), 351–353
- Analyzer, definition, 158
- APIs. *See also* JPA (Java Persistence API).
  - DOM, 459–460
  - JAXB (Java API for XML Binding), 454, 469–470
  - JAXP (Java API for XML Processing), 454, 457 showing/hiding, 168
  - `System.currentTimeMillis` API, 328–329
  - `System.nanoTime` API, 328–329
  - for XML documents, selecting, 468–471
- Application performance
  - ideal CPU utilization, 15
  - improving with network I/O utilization, 45
- Application server monitoring
  - disk I/O, 395–398
  - external systems, 392–395
  - with GlassFish
    - administration console, 383–384
    - `asadmin` CLI, 386–388
    - JConsole, 384–386
    - overview, 382
    - VisualVM, 384–386
  - monitoring resource pools, 398–399
  - overview, 382
  - subsystems
    - JVM, 388–389
    - network I/O, 390–392

- Application server monitoring (*continued*)
    - thread dumps, 389–390
    - tuning resource pools, 398–399
  - Application threads, isolating, 25, 27
  - Applications. *See also* Benchmarking multitiered applications; Benchmarking Web applications; Java applications.
    - concurrent run time, printing, 564
    - developing. *See* Software development.
    - JMX, configuring, 135–137
    - startup time, decreasing, 68
    - stop time, printing, 563
  - Archiving artifacts, 163
  - asadmin CLI, monitoring server applications, 386–388
  - Asterisk (\*), wildcard character, 44
  - Asynchronous benchmarks, 381
  - Asynchronous requests, benchmarking, 360
  - Attach Mode, specifying, 193–194
  - Attributed time, definition, 158
  - Availability
    - performance metrics, calculating, 365–366
    - service, benchmarking, 359
    - tuning the JVM, 255–256
  - Average age, profiling, 206
  - Averages, calculating, 349
- B**
- Backedge counters, 95–96
  - Backslash (\), line termination character, 181
  - Bandwidth, monitoring, 44
  - Barriers, memory, 234
  - Bean caches, monitoring and tuning, 514–520
  - Bean pools, monitoring and tuning, 514–520
  - Benchmarking. *See also* Experiments; Statistics.
    - compilation activity, eliminating, 333–334
    - deoptimization, 340–345
    - EJB best practices, 522
    - elapsed time, calculating, 328–329
    - garbage collection pauses, 327–328
    - inlining methods, 335–339
    - micro-benchmarks, creating, 345–346
    - optimizing away dead code, 329–335
    - warm-ups, 324–327, 333–334
    - Web services, 473–476
  - Benchmarking multitiered applications. *See also* Applications.
    - challenges
      - asynchronous requests, 360
      - external dependencies, 360
      - firewalls, 360
      - nature of enterprise applications, 358
      - payload sizes, 359
      - secure interactions, 359
      - service availability, 359
      - session maintenance, 359
      - user scaling, 358
    - variety of client types, 359
    - vertical and horizontal scaling, 358, 377
  - enterprise considerations
    - availability metrics, calculating, 365–366
    - cycle time, 365
    - injection rate, 365
    - Markov chains, 362–366
    - micro-benchmarks, developing, 361–362
    - system boundaries, defining, 360–361
    - think time, 364
    - user interaction modeling, 362–366
  - Little’s Law verification, 372–374
  - maximum number of concurrent clients, 372–374
  - performance metrics, calculating
    - availability, 365–366
    - page view, 366–367
    - requests, 366
    - response time, 368–369
    - round-trip time, 366
    - think time, 366
    - throughput, 369–370
    - user transactions, 366, 367–368
  - running the benchmark
    - asynchronously, 381
    - isolating the SUT, 378–379
    - ramp down time, 380
    - ramp up time, 380
    - repeatability, 380–381
    - resource monitoring, 379–380
    - statistical methods, 381–382
    - steady state time, 380
  - scalability
    - analysis, 377–378
    - hybrid, 377
    - user scaling, 358
    - vertical and horizontal scaling, 358, 377
  - scalability analysis, 377–378
  - scaling the benchmark, 370–372
  - SUT (System Under Test), isolating, 360–361, 378–379
  - think time
    - benchmarking, 374–377
    - calculating, 366
    - definition, 366
    - enterprise considerations, 364
  - Benchmarking Web applications
    - See also* Applications, 446–450
    - best practices
      - access logging, 446–450
      - accessing JavaBean components, 434–436
      - bean, locating or instantiating, 432–434
      - compression, 440–443
      - content caching, 439–443
      - context listeners, 427–429
      - distributed caches, 439–443
      - EL (expression language), 434–436
      - HTTP compression, 436–438

- HTTP Server File Cache, 445–450
- JSP, 427–438
- JSP include mechanism, 429–430
- log file aggregation, 450
- object size *vs.* cost, 444
- overview, 427
- serialization, 440–443
- servlets, 427–438
- session persistence, 443–445
- trimming whitespaces, 430–431
- tuning the file cache, 446
- overview, 404–405
- Web container components, GlassFish
  - Coyote connector, 407
  - GlassFish, 406–407
  - Grizzly connector, 406–407
  - HTTP connector, 406–407
  - overview, 405–406
  - servlet engines, 407–408
- Web container monitoring and tuning
  - configuration settings, 408–409
  - development mode, 408–409
  - garbage collection, 411
  - HTTP service, 412
  - JIT compiler tuning, 410
  - JVM tuning, 410–412
  - overview, 408
  - page freshness, checking, 409
  - production mode, 408–409
  - security manager, 409–410
- Web container monitoring and tuning, HTTP listener
  - acceptor threads, 414–417
  - connection queues, 414–417
  - elements to be monitored, 412
  - individual applications, 420–427
  - keep alive, 414–417
  - request processing, 418–420
  - request response codes, 419
  - thread pools, 412–414
- Best practices
  - benchmarking Web applications
    - access logging, 446–450
    - accessing JavaBean components, 434–436
    - bean, locating or instantiating, 432–434
    - compression, 440–443
    - content caching, 439–443
    - context listeners, 427–429
    - distributed caches, 439–443
    - EL (expression language), 434–436
    - HTTP compression, 436–438
    - HTTP Server File Cache, 445–450
    - JSP, 427–438
    - JSP include mechanism, 429–430
    - log file aggregation, 450
    - object size *vs.* cost, 444
    - overview, 427
    - serialization, 440–443
    - servlets, 427–438
    - session persistence, 443–445
    - trimming whitespaces, 430–431
    - tuning the file cache, 446
  - JPA (Java Persistence API)
    - bulk updates, 548–549
    - connection pooling, 546–548
    - database locking strategies, 549
    - data-fetching strategy, 544–546
    - dynamic queries, 541
    - inheritance, 550
    - JPA Query Language queries, 540–543
    - named native queries, 541
    - named queries, 541
    - native queries, 542
    - query results cache, 543–544
    - reads without transactions, 550
  - Web service performance
    - binary payload, 486–495
    - catalog file locations, 502–503
    - client performance, 502–503
    - Fast Infoset, 499–501
    - HTTP compression, 501–502
    - MTOM (Message Transmission Optimization Mechanism), 487–495
    - overview, 486
    - Provider interface, 495–498
    - SOAP messages, 499–501
    - XML documents, 492
    - XML documents as attachments, 492–495
- Best practices, EJB (Enterprise JavaBeans)
  - beans, locating or instantiating, 432–434
  - benchmarking, 522
  - EJB 2.1
    - cache static resource references, 524–526
    - coarse-grained access, 529–530
    - control serialization, 523–524
    - database locking strategies, 532–533
    - EJB Query Language, 533–535
    - lazy loading, 530–532
    - local *vs.* remote interfaces, 526–528
    - optimistic locking, 532–533
    - pessimistic locking, 532–533
    - prefetching, 530–532
    - read-only entity beans, 535–536
    - Session Façade pattern, 529–530
    - transaction attributes, choosing, 523
    - transactions, container managed *vs.* bean managed, 522–523
  - EJB 3.0
    - business method interceptors, 537–540
    - compatibility with EJB 2.1, 536–537
- Biased locking, enabling, 569
- Binary heap dumps, 140
- Binary XML payload, Web service performance
  - best practices, 486–495
- Blocked thread state, 74
- Blocking *vs.* nonblocking sockets, 45

- Bootstrap class loader, 65
  - Bottom up software development, 7–8
  - buffer-size-bytes property, 415
  - Bulk updates, JPA best practices, 548–549
  - Bump-the-pointer technique, 85
  - Business interface, 506–507
  - Business method interceptors, 537–540
  - Bytecode analysis, JIT compilers, 96–97
  - Bytecode verification, 66–67
- C**
- C++ heap management, 76–77
  - Cache static resource references, 524–526
  - calibrate.sh script, 196–197
  - Call stack trees, displaying, 246
  - Call stacks, attributed time, 174–175
  - Call Tree tab, 169–171, 246
  - Call trees, 157–158, 170–171
  - Caller-callee relationships, 158, 172–174
  - Callers-callees, monitoring System CPU usage, 218–221
  - callers-callees command, 184
  - Callers-Callees tab, 169–170, 172–174
  - Callers-Callees tables, printing, 184–185
  - Card tables, 82–83
  - Catalog file locations, Web service performance best practices, 502–503
  - Catalog resolvers, 463–464
  - Catching exceptions, 70–71
  - checkInterval property, 409
  - Chrome, Developer Tools for, 363
  - Class data sharing, 65, 67–68
  - Class Hierarchy Analysis, 94–95
  - Class level interceptor methods, 538–539
  - Class loader. *See also* HotSpot VM Runtime, class loading.
    - delegation, 65
    - time, monitoring, 144
  - Class metadata, 66
  - Classes. *See also specific classes.*
    - uninitialized, 98
    - unloaded, 98
  - Client JIT, 97
  - Client performance, Web service performance best practices, 502–503
  - Client runtime environment *vs.* server, 260
  - Client types, benchmarking, 359
  - Clock cycles. *See* CPU, cycles.
  - Clock cycles per CPU instruction (CPI), 15, 211–212
  - cmetrics command, 186
  - CMS (Concurrent Mark-Sweep GC)
    - collection cycle, initiating, 298–303
    - concurrent collection, enabling, 561
    - incremental mode, 561
    - incremental pacing, 562
    - overview, 88–90
    - pause time tuning, 305–306
    - remarks, scavenging before, 560
    - sample output, 113–114
    - throughput, tuning, 307–308
    - tuning latency/responsiveness, 287–289, 298–303
  - Coarse-grained access, EJB best practices, 529–530
  - collect tool, 158, 162–164
  - Colon (:), keyword delimiter, 182
  - Command line flags, printing, 571
  - Command line names, printing, 572
  - command option, 181
  - Common subexpression elimination, 93
  - Compilation
    - activity, eliminating, 333–334
    - JIT compilers, 93
    - policy, JIT compilers, 95–96
  - Compile time, monitoring, 144
  - Compiler structure, JIT compilers, 93
  - compressableMimeType property, 438
  - Compressed oops, 57, 554
  - Compression
    - best practices, 440–443
    - GlassFish server, 436–438
    - HTTP, 436–438
  - Compression property, 438
  - compressionMinSize property, 438
  - Concurrent collection, enabling, 560
  - Concurrent garbage collection, sample output, 115–117
  - Concurrent marking phase, 88
  - Concurrent Mark-Sweep GC (CMS). *See* CMS (Concurrent Mark-Sweep GC).
  - Concurrent mode failure, 117
  - Concurrent permanent generation garbage collection, 304–305
  - Concurrent sweeping phase, 89
  - CONDVAR\_WAIT statement, 74
  - Confidence intervals, calculating, 350–351
  - Configuring remote systems for profiling, 196–197
  - Connection pooling, JPA best practices, 546–548
  - Connection queues, monitoring and tuning, 414–417
  - Constant folding, 93
  - Contented operations, 71–72
  - Content caching, best practices, 439–443
  - Context listeners, best practices, 427–429
  - Context switching, monitoring, 37
  - Control flow representation, JIT compilers, 98–100
  - Control serialization, EJB best practices, 523–524
  - Copying collectors, 85
  - corestat tool
    - aggregating instruction counts, 52
    - downloading, 52
    - monitoring CPU utilization, SPARC T-series, 52
  - count5xx-count attribute, 419
  - count200-count attribute, 419

- count302-count attribute, 419
  - count304-count attribute, 419
  - count404-count attribute, 419
  - countconnections-count attribute, 417
  - counthits-count attribute, 417
  - countoverflows-count attribute, 416
  - countqueued-count attribute, 416
  - countqueued\*minuteaverage-count attribute, 416
  - countrefusals-count attribute, 417
  - countrequests-count attribute, 419
  - counttimeouts-count attribute, 417
  - Coyote connector, 407
  - CPI (clock cycles per CPU instruction), 15, 211–212
  - CPU
    - architecture, choosing, 9–10. *See also specific architectures.*
    - cache efficiency, 57
    - counters, collecting, 163–164
    - cycles
      - CPI (clock cycles per CPU instruction), 15
      - IPC (CPU instructions per clock cycle), 15
      - monitoring, 14–16. *See also* Monitoring CPU utilization.
      - monitoring context switching, 39
      - stalls, 15
      - waiting for data, 15
    - performance counters
      - listing, 50
      - monitoring, 49–50
    - scheduler's run queue, monitoring
      - Linux, 31–32
      - overview, 28–29
      - Solaris, 31
      - Windows, 29–31
    - utilization. *See also* Monitoring CPU utilization.
      - application performance, ideal situation for, 15
      - definition, 15
      - high, identifying, 246
      - scalability, ideal situation for, 15
      - system CPU, 15
      - user CPU, 15
  - CPU instructions per clock cycle (IPC), 15
  - cpubar tool. *See also* iobar tool.
    - monitoring CPU utilization, 21–24
    - monitoring memory utilization, 34–35
    - monitoring run queue depth, 31
  - cpustat tool
    - listing CPU performance counters, 50
    - monitoring CPU performance counters, 49–50
    - monitoring CPU utilization, SPARC T-series, 52
    - monitoring instructions per hardware thread, 52
  - cputrack tool
    - listing CPU performance counters, 50
    - monitoring CPU performance counters, 49–50
  - Criteria for performance, 2–3. *See also* Metrics.
  - csingle command, 185–186
  - currentthreadsbusy-count attribute, 414
- ## D
- d option, collect tool, 163
  - d64 option, 554
  - Dash (-) option, 181
  - Data structure resizing
    - identifying, 235
    - Java collections, 238
    - overview, 235
    - StringBuffer, 235–238
    - StringBuilder, 235–238
  - Database locking strategies
    - EJB best practices, 532–533
    - JPA best practices, 549
  - Data-fetching strategy, JPA best practices, 544–546
  - Date and time stamps
    - monitoring garbage collection, 117–119
    - printing, 266, 562
  - dateTime schema, effects on Web service performance, 481–482
  - Dead code, optimizing away, 329–335
  - Deadlocks, 80
  - Debug VM, 69
  - Debugging
    - alternative interface, enabling, 568
    - log files, dumping, 79
    - threads, 74–75
    - VMError class, 79
    - XX:OnError, 79
  - Default interceptor methods, 538
  - DefaultServlet servlet engine, 408
  - DefNew garbage collector, 111, 264
  - Degrees of freedom, 351–353
  - Deoptimization, 95, 96–97, 340–345
  - Deployment model, choosing
    - multiple JVM deployment, 258–259
    - overview, 259
    - single JVM deployment, 258
  - Destroying threads, 73–74
  - DestroyJavaVM method, 62–63
  - DetachCurrentThread method, 60
  - Development mode, Web containers, 408–409
  - Disassembly tab, 169–170
  - Disk I/O utilization. *See* Monitoring disk I/O.
  - Disks, formatting, 49
  - Distributed caches, best practices, 439–443
  - DocumentBuilder class, creating, 455–456
  - DocumentBuilderFactory class, 456
  - DOM APIs
    - modifying XML documents, 459–460
    - XML document performance, 469–470
  - DTD (document type definition), external subsets, 462–464
  - Dynamic queries, JPA best practices, 541

- E**
- e keyword, 182
  - EclipseLink session cache, monitoring and tuning, 519–520
  - Eden space
    - description, 83–85
    - size, compared to survivor space, 290–291, 556
    - utilization, monitoring, 143, 144
  - Edge cases, tuning, 316
  - EJB (Enterprise JavaBeans). *See also* NetBeans.
    - Business interface, 506–507
    - components, 505–506
    - Home interface, 506–507
    - message driven beans, 505–506
    - optimistic locking, 521
    - persistent entities, 505–506
    - programming model, 506–507
    - session beans, 505–506
    - stateful session beans, 506
    - stateless session beans, 506
    - transaction isolation levels, 521–522
  - EJB (Enterprise JavaBeans), best practices
    - beans, locating or instantiating, 432–434
    - benchmarking, 522
    - EJB 2.1
      - cache static resource references, 524–526
      - coarse-grained access, 529–530
      - control serialization, 523–524
      - database locking strategies, 532–533
      - EJB Query Language, 533–535
      - lazy loading, 530–532
      - local *vs.* remote interfaces, 526–528
      - optimistic locking, 532–533
      - pessimistic locking, 532–533
      - prefetching, 530–532
      - read-only entity beans, 535–536
      - Session Façade pattern, 529–530
      - transaction attributes, choosing, 523
      - transactions, container managed *vs.* bean managed, 522–523
    - EJB 3.0
      - business method interceptors, 537–540
      - compatibility with EJB 2.1, 536–537
  - EJB container, monitoring and tuning
    - bean caches, 514–520
    - bean pools, 514–520
    - EclipseLink session cache, 519–520
    - entity bean caches, 516
    - invocation patterns, 512
    - overview, 511
    - Ready Cache, 516–517
    - stateful session bean caches, 516
    - thread pool, 512–514
    - Transactional Cache, 516–517
  - EJB Query Language, best practices, 533–535
  - EL (expression language), best practices, 434–436
  - Elapsed time
    - calculating, 328–329
    - monitoring garbage collection, 114
  - Endpoint implementation, effects on Web service performance, 483–484
  - Entering a Java monitor, 71–72
  - Enterprise applications, profiling, 399–400
  - Entity bean caches, monitoring and tuning, 516
  - Entity resolvers, 462–464
  - Ergonomics
    - defaults, printing, 102–103
    - definition, 100
    - Java 1.4.2 defaults, 101
    - Java 5 defaults, 101–103
    - Java 6 Update 18 defaults, 103–104
    - server-class machines, 101–103
  - er\_print tool. *See also* Printing, experiment profiles.
    - : (colon), keyword delimiter, 182
    - \ (backslash), line termination character, 181
    - (dash) option, 181
    - ! (exclamation point) keyword, 182
    - % (percent sign) keyword, 182
    - + (plus sign) keyword, 182
    - . (period) keyword, 182
    - A keyword, 182
    - abbreviations, 181
    - callers-callees command, 184
    - cmetrics command, 186
    - command option, 181
    - csingle command, 185–186
    - definition, 158
    - e keyword, 182
    - er\_print\_metric\_list command, 183
    - filters command, 186–187
    - i keyword, 182
    - limit command, 183–184
    - lock keyword, 182
    - metric keywords, 182–184
    - outfile command, 187
    - script option, 181
    - scripting, 180, 187–189
    - sort command, 183
    - splitting commands, 181
    - syntax, 180–181
    - system keyword, 182
    - user keyword, 182
    - v option, 181
    - viewmode command, 187
  - er\_print\_metric\_list command, 183
  - Error checking, XML documents, 460
  - Error handling, 568
  - Escape analysis, enabling, 569
  - Even Faster Web Sites*, 404
  - Event tab, 168–169
  - Exception handling, 70–71
  - Exclamation point (!) keyword, 182
  - Exclusive time
    - definition, 158, 160
    - displaying, 176
  - Exiting a Java monitor, 71–72

- Experiment files
    - creating, 163
    - opening, 168
    - specifying a directory for, 163
  - Experiments. *See also* Benchmarking; Monitoring; Performance Analyzer, experiments; Profiles; Profiling; Tuning.
    - definition, 158
    - designing, 347–348
  - Experiments tab, 170
  - Expert mode, 178
  - Explicit garbage collection
    - monitoring, 121
    - tuning latency/responsiveness, 303–304
  - Expression language (EL), best practices, 434–436
  - External dependencies, benchmarking, 360
- F**
- Factory lookup, 456–457
  - Factory objects, reusing, 457
  - Fast allocation, HotSpot VM garbage collectors, 85
  - Fast Infoset Web service performance best practices, 499–501
  - Fast-path code, synchronization, 72
  - Fatal error handling, 78–80
- FetchType, 544–546
- File cache tuning, best practices, 446
  - Filtering data
    - data presentation, 168, 179–180, 248–249
    - printing experiment profiles, 186–187
  - Filters, definition, 158
  - filters command, 186–187
  - Firebug plug-in, 363
  - Firewalls, benchmarking, 360
  - Footprint. *See* Memory footprint.
  - format command, 49
  - Fragmentation issues, garbage collection, 90
  - Full garbage collection. *See also* Major garbage collection.
    - definition, 85
    - monitoring, 109–110, 112–113
    - sample output, 112
    - scavenging young generation space, 110, 561
    - tuning latency/responsiveness, 286
  - Full Identity Map option, 509
  - Functions tab, 169–170, 171–174
- G**
- G1 GC, 90–91
  - Garbage collection. *See also* HotSpot VM garbage collectors.
    - definition, 159
    - GlassFish server, 411–412
    - logging results, 562
    - monitoring. *See* Monitoring garbage collection.
    - old generation, enabling, 558
    - pauses, benchmarking, 327–328
    - pausing for swapping, 32
    - stop-the-world, 76, 558
    - tuning latency/responsiveness, activities affecting, 278–279
    - Web containers, 411
  - Garbage collection reports
    - adaptive size policy, 563
    - application concurrent run time, 564
    - application stop time, 563
    - date and time stamps, printing, 562
    - detailed, enabling, 562
    - enabling, 562
    - safepoint statistics, 564
    - tenuring statistics, 563
  - Garbage collection threads, 75
  - Garbage collectors. *See also* HotSpot VM garbage collectors.
    - tuning
      - choosing, 261–262
      - command line options, 263–267
      - date stamp, printing, 266
      - directing output to a file, 264
      - latency, 262
      - logging, 263–267
      - memory footprint, 262
      - OutOfMemoryError, 273–274
      - performance attributes, 262–263
      - principles of, 263
      - safepoint pauses, 267
      - statistics, printing, 264
      - throughput, 262, 308–311
      - time stamp, printing, 264, 266
  - Garbage-First GC, 90–91
  - GC time, monitoring, 144
  - GCHisto tool, 121–125
  - Generational garbage collection. *See* HotSpot VM garbage collectors, generational.
  - Generations, NetBeans Profiler, 206–207
  - getElementsByTagName method, 459
  - getElementsByTagNameNS method, 459
  - GlassFish server
    - access logging, 447
    - application server monitoring
      - administration console, 383–384
      - asadmin CLI, 386–388
      - JConsole, 384–386
      - overview, 382
      - VisualVM, 384–386
    - benchmarking Web container components
      - Coyote connector, 407
      - GlassFish, 406–407
      - Grizzly connector, 406–407
      - HTTP connector, 406–407
      - servlet engines, 407–408
    - compression, 436–438
    - dynamic JSP modification, 408
    - garbage collection, 411–412

- GlassFish server (*continued*)
    - maximum connections, 407
    - monitoring Java applications, 150–151
    - monitoring server applications
      - administration console, 383–384
      - asadmin CLI, 386–388
      - JConsole, 384–386
      - overview, 382
      - VisualVM, 384–386
  - RMI server, 411–412
  - security manager, 410
  - Web container components
    - Coyote connector, 407
    - GlassFish, 406–407
    - Grizzly connector, 406–407
    - HTTP connector, 406–407
    - overview, 405–406
    - servlet engines, 407–408
  - Web containers
    - Coyote connector, 407
    - development mode, 408–409
    - GlassFish, 406–407
    - Grizzly connector, 406–407
    - HTTP connector, 406–407
    - production mode, 408–409
    - servlet engines, 407–408
  - GlassFish Server Open Source Edition. *See* GlassFish server.
  - GlassFish Web container
    - development mode, 408–409
    - production mode, 408–409
  - GMT, adjusting to local time, 118–119
  - GNOME System Monitor, monitoring CPU utilization, 20–21
  - gnome-system-monitor command, 20–21
  - Graph coloring, 94
  - Graphs panel, 144–145
  - Grizzly connector, 406–407
- H**
- h option, collect tool, 163–164
  - Handler performance, effects on Web service performance, 484–486
  - Hard Cache Weak Identity Map option, 510
  - Hardware threads, SPARC T-series processor, 9–10
  - hasAttributes method, 459
  - Heap
    - aggressive options, 569
    - definition, 159
    - initial size, configuring, 275–277
    - in JConsole. *See* Memory pools.
    - layout, 268–272
    - live data size, calculating, 274–275
    - management, C++, 76–77
    - memory, JConsole, 129
    - profiling. *See* Memory profiles.
    - size, specifying, 554–555
    - size, starting point, 272–274
    - space, on NUMA systems, 571
    - space limitation, 57
    - splitting for garbage collection, 81
    - utilization, monitoring, 111–113, 114
  - Heap dumps
    - analyzing with NetBeans Profiler, 209
    - directory path, specifying, 567–568
    - enabling on OutOfMemoryError, 567
    - on OutOfMemoryError, 567
    - specifying a location for, 80
  - Heap sizing, adaptive
    - description, 104–105
    - disabling, 105, 309–311
    - enabling/disabling, 558
    - HotSpot VM, 104–105, 558
    - policy, printing, 563
    - throughput, tuning, 309–311
  - High Performance Web Sites*, 404
  - Histogram panel, 145–146
  - Home interface, 506–507
  - Horizontal scaling, 358, 377. *See also* Scaling.
  - Hot locks, isolating, 39–40
  - HotSpot VM. *See also* JVM (Java Virtual Machine), tuning.
    - 64-bit version, loading, 554
    - architectural overview
      - 32-bit vs. 64-bit versions, 57
      - compressed oops, 57
      - CPU cache efficiency, 57
      - garbage collectors, 57
      - high level architecture, 56–58
      - Java heap space limitation, 57
      - memory address limitation, 57
      - platforms supporting, 58
      - register spilling, 58
    - debug VM, 69, 337
    - launching, 60–62
    - lock optimization, 37
    - shutting down, 62–63
  - HotSpot VM, optimization
    - aggressive, 568–569
    - for client applications, 553
    - for server applications, 553
  - HotSpot VM adaptive tuning
    - adaptive heap sizing
      - enabling/disabling, 558
      - overview, 104–105
    - ergonomics
      - defaults, printing, 102–103
      - definition, 100
      - Java 1.4.2 defaults, 101
      - Java 5 defaults, 101–103
      - Java 6 Update 18 defaults, 103–104
      - server-class machines, 101–103
    - heap sizing, disabling, 105
    - overview, 100
  - HotSpot VM garbage collectors
    - allocation, 91
    - bump-the-pointer technique, 85

- creating work for, 91
- fast allocation, 85
- history of, 92
- live data size, 91
- monitoring. *See* Monitoring garbage collection.
- overhead, reducing, 91–92
- overview, 80–81
- reference updates in old generation, 91
- TLABs (Thread-Local Allocation Buffers), 85
- HotSpot VM garbage collectors, generational
  - card tables, 82–83
  - copying collectors, 85
  - full garbage collection, 85. *See also* Major garbage collection.
  - generational, 81–83
  - major garbage collection, 81. *See also* Full garbage collection; Old generation garbage collection.
  - minor collection. *See also* Young generation garbage collection.
    - definition, 81
    - process flow, 84–85
    - reducing runtime, 82–83
  - old generation space, 81
  - permanent generation, 81
  - premature promotion, 85
  - promotion, 81
  - promotion failure, 85
  - splitting the heap, 81
  - tenure, 81
  - weak generational hypothesis, 81
  - write barriers, 83
  - young generation collection
    - definition, 81
    - eden space, 83–85
    - layout, 83–85
    - survivor spaces, 84–85
- HotSpot VM garbage collectors, types of. *See also specific types.*
  - CMS (Concurrent Mark-Sweep GC), 88–90
  - comparison chart, 91
  - G1 GC, 90–91
  - Garbage-First GC, 90–91
  - mark-compact, 86–87
  - Mostly-Concurrent GC
    - concurrent marking phase, 88
    - concurrent sweeping phase, 89
    - definition, 88
    - disadvantages of, 89–90
    - enabling, 559
    - fragmentation issues, 90
    - initial mark, 88
    - phases of, 88–89
    - pre-cleaning phase, 89
    - remark pause, 88–89
  - Parallel GC, 87–88
  - Parallel Old GC, 87–88
  - Serial GC, 86–87, 92
  - sliding compacting mark-sweep, 86–87
  - Throughput GC. *See* Parallel GC.
  - Train GC, 92
- HotSpot VM JIT compilers. *See* JIT compilers.
- HotSpot VM Runtime
  - application startup time, decreasing, 68
  - bytecode verification, 66–67
  - C++ heap management, 76–77
  - class data sharing, 67–68
  - class loading
    - bootstrap class loader, 65
    - class data sharing, 65
    - class loader delegation, 65
    - class metadata, 66
    - definition, 63
    - initialization phase, 64
    - internal data, 66
    - link phase, 64
    - load class phase, 64
    - monitoring, 147–150
    - phases, 64–65
    - reasons for, 64
    - safepoints, 66
    - type safety, 65–66
  - command line options, 58–59
  - developer command line options, 59
  - exception handling, 70–71
  - fatal error handling, 78–80
  - interpreter, 69–70
  - JNI (Java Native Interface), 77–78
  - memory footprint cost, reducing, 68
  - nonstandard command line options, 59
  - overview, 58
  - standard command line options, 59
  - synchronization
    - biased state, 72
    - concurrency, 71
    - contended operations, 71–72
    - entering a Java monitor, 71–72
    - exiting a Java monitor, 71–72
    - fast-path code, 72
    - inflated state, 72
    - Java monitors, 71–72
    - mark word, 72
    - mutual exclusion, 71
    - neutral state, 72
    - owning Java monitors, 71–72
    - races, avoiding, 71–72
    - slow-path code, 72
    - stack-loaded state, 72
    - states, 72
    - synchronized blocks, 71
    - uncontended operations, 71
- thread management
  - blocked thread state, 74
  - CONDVAR\_WAIT statement, 74
  - creating threads, 73–74
  - deadlocks, 80
  - debugging, 74–75
  - destroying threads, 73–74

- HotSpot VM Runtime (*continued*)
    - garbage collection threads, 75
    - internal VM threads, 75
    - JIT compiler threads, 75
    - MONITOR\_WAIT statement, 74
    - new thread state, 74
    - OBJECT\_WAIT statement, 75
    - overview, 72
    - periodic task threads, 75
    - safepoints, 75–76
    - signal dispatcher thread, 75
    - thread in Java state, 74
    - thread in Java vm state, 74
    - thread states, 74–75
    - threading model, 72–73
    - VM operations, 75–76
    - VM threads, 75
    - type inference, 67
    - type verification, 67
    - VM life cycle, 59–61
  - HTTP compression
    - best practices, 436–438
    - Web service performance, best practices, 501–502
  - HTTP connector, 406–407
  - HTTP listener, monitoring and tuning
    - acceptor threads, 414–417
    - connection queues, 414–417
    - elements to be monitored, 412
    - individual applications, 420–427
    - keep alive, 414–417
    - request processing, 418–420
    - request response codes, 419
    - thread pools, 412–414
  - HTTP Server File Cache, best practices, 445–450
  - HTTP service, Web containers, 412
  - Hybrid scalability, 377
  - Hypothesis tests, 351–354
- I**
- i keyword, 182
  - Identity transformation, 93
  - include file directive, 429
  - Inclusive time
    - definition, 158, 160
    - displaying, 160
  - Inflated state, synchronization, 72
  - Inheritance, JPA best practices, 550
  - init method, 427–429
  - Initial mark, 88
  - Initialization phase, 64
  - Injection rate, benchmarking, 365
  - Inlined methods
    - benchmarking, 335–339
    - maximum bytecode size, 567
    - printing, 566–567
  - Inlined of functions, 93
  - Instrumentation, definition, 159
  - Intermediate representation (IR), 93
  - Internal class loader data, 66
  - Internal VM threads, 75
  - Interpreter
    - adaptive optimization, 70
    - overview, 69
    - vs. switch statements, 69
  - Invocation counters, 95
  - Involuntary context switching, monitoring, 40–41
  - I/O, monitoring System CPU usage, 214–218, 221–222
  - iobar tool, Solaris, 46–47. *See also* cpubar tool.
  - iosnoop. d script, 47–48
  - iostat tool, 46–47
  - iostat tool, 46–47. *See also* prstat tool; top tool.
  - IPC (CPU instructions per clock cycle), 15
  - IR (intermediate representation), 93
  - Iteration splitting, 99–100
- J**
- Java API for XML Binding (JAXB), 454, 469–470
  - Java API for XML Processing (JAXP), 454, 457
  - Java applications. *See also* Applications.
    - listing, 134
    - monitoring
      - GlassFish server, 150–151
      - jstack output, example, 151–153
      - overview, 150–151
      - quick lock contention, 151–153
  - Java collections
    - overview, 238–243
    - resizing, 238
  - Java heap. *See* Heap.
  - Java HotSpot VM. *See* HotSpot VM.
  - Java monitors, synchronization, 71–72
  - Java Native Interface (JNI), 77–78
  - Java Persistence API (JPA). *See* JPA (Java Persistence API).
  - Java Virtual Machine (JVM). *See* JVM (Java Virtual Machine), tuning.
  - JavaBean components, accessing with best practices, 434–436
  - java.util.Random, lock contention
    - hottest methods, displaying, 228–229
    - replacing with ThreadLocal<Random>, 232
    - sample code, 593–603, 603–613, 613–624, 624–635
    - source code, 230
  - javaw command, 60
  - javaws command, 60
  - JAXB (Java API for XML Binding), 454, 469–470
  - JAXP (Java API for XML Processing), 454, 457
  - JAX-WS RI (JAX-WS Reference Implementation)
    - stack, 471–473
  - JConsole. *See also* VisualGC; VisualVM.
    - heap memory, 129
    - local monitoring, 127

- memory, monitoring, 128–130
- memory metrics, 129–130
- memory pools, mapping to HotSpot VM spaces, 129
- monitoring server applications, 384–386
- overview, 125–127
- remote monitoring, 127–128
- tabs, 128–130
- JIT compiler reports
  - inlined methods, 566–567
  - optimization decisions, 567
  - optimized methods, 565–566
- JIT compilers
  - backedge counters, 95–96
  - batch, 564–565
  - bytecode analysis, 96–97
  - class files, 93
  - Class Hierarchy Analysis, 94–95
  - Client JIT, 97
  - common subexpression elimination, 93
  - compilation, 93
  - compilation policy, 95–96
  - compiler structure, 93
  - constant folding, 93
  - control flow representation, 98–100
  - defaults for server-class machines, 101–102
  - deoptimization, 95, 96–97
  - future enhancements, 100
  - graph coloring, 94
  - in HotSpot VM, 70
  - identity transformation, 93
  - inline methods, maximum bytecode size, 567
  - inlining of functions, 93
  - invocation counters, 95
  - IR (intermediate representation), 93
  - linear scan register allocation, 94
  - loop optimization, 99–100
  - machine representation, 93–94
  - metadata for compiled code, 96–97
  - method counters, 95
  - Method Liveness, 96–97
  - methodDataOop object, 98
  - monitoring, 146–147
  - OopMaps tables, 97
  - optimizations, 93–94
  - OSRs (On Stack Replacements), 95
  - overridden methods, detecting, 94–95
  - overview, 92–94
  - program dependence graphs, 98–100
  - register allocation, 94
  - register tables, 97
  - running in background, 564–565
  - Server JIT, 97–98
  - SSA (single static assignment), 93, 98–100
  - stack location tables, 97
  - superword, 99–100
  - threads, 75
  - tiered compilation, 565
  - tuning Web containers, 410
  - uncommon traps, 96–97, 98–100
  - uninitialized classes, 98
  - unloaded classes, 98
  - JMeter tool, 363
  - JMX applications, configuring, 135–137
  - JNI (Java Native Interface), 77–78
  - JNI\_CreateJavaVM method, 61–62
  - JOINED inheritance, 550
  - JPA (Java Persistence API)
    - best practices
      - bulk updates, 548–549
      - connection pooling, 546–548
      - database locking strategies, 549
      - data-fetching strategy, 544–546
      - dynamic queries, 541
      - inheritance, 550
      - JPA Query Language queries, 540–543
      - named native queries, 541
      - named queries, 541
      - native queries, 542
      - query results cache, 543–544
      - reads without transactions, 550
    - L2 (level two) cache
      - configuring, 509–511
      - default type, 511
      - Full Identity Map option, 509
      - Hard Cache Weak Identity Map option, 510
      - No Identity Map option, 510
      - options, 509–511
      - overview, 508
      - size, *vs.* performance, 508
      - Soft Cache Weak Identity Map option, 510
      - Soft Identity Map option, 509
      - Weak Identity Map option, 509
    - overview, 507
    - JPA Query Language queries, best practices, 540–543
  - JSP best practices, 427–438
  - jsp:include page action, 429
  - jspInit method, 428–429
  - JspServlet servlet engine, 408
  - jsp:useBean action, 432–434
  - JSR-133, 234
  - jstack command
    - monitoring CPU utilization, 27–28
    - monitoring thread dumps, 390
    - output, example, 151–153
  - jstat command, 389
  - jstatd daemon, 133–134
  - jvisualvm program, 191
  - JVM (Java Virtual Machine), tuning. *See also* HotSpot VM.
    - application systemic requirements
      - availability, 255–256
      - latency, 256
      - manageability, 256
      - memory footprint, 256–257
      - overview, 255
      - responsiveness, 256

JVM (Java Virtual Machine), tuning. *See also* HotSpot VM. (*continued*)

- startup time, 256–257
- throughput, 256
- application throughput
  - adaptive sizing, disabling, 309–311
  - CMS, 307–308
  - deploying on NUMA systems, 315
  - garbage collectors, 308–311
  - overview, 307
  - parallel GC threads, 314–315
  - survivor spaces, 311–314
- assumptions, 254
- command line options, latest optimizations, 317
- deployment model, choosing
  - multiple JVM deployment, 258–259
  - overview, 259
  - single JVM deployment, 258
- edge cases, 316
- garbage collectors
  - choosing, 261–262
  - command line options, 263–267
  - date stamp, printing, 266
  - directing output to a file, 264
  - latency, 262
  - logging, 263–267
  - memory footprint, 262
  - OutOfMemoryError, 273–274
  - performance attributes, 262–263
  - principles of, 263
  - safepoint pauses, 267
  - statistics, printing, 264
  - throughput, 262
  - time stamp, printing, 264, 266
- latency/responsiveness
  - CMS (Concurrent Mark-Sweep GC), 287–289
  - CMS collection cycle, initiating, 298–303
  - CMS pause time tuning, 305–306
  - concurrent permanent generation garbage collection, 304–305
  - explicit garbage collection, 303–304
  - full garbage collections, 286
  - garbage collection activities affecting, 278–279
  - inputs, 279–280
  - old generation size, refining, 283–287
  - overview, 278–279
  - promotion, 291–293
  - survivor spaces, 289–291
  - survivor spaces, occupancy, 298
  - survivor spaces, sizing, 294–303
  - tenuring threshold, 291–294
  - young generation size, refining, 280–283
- overview, 252–255
- ranking systemic requirements, 257–258
- runtime environment, choosing
  - 32-bit *vs.* 64-bit, 260–261
  - client *vs.* server, 260
  - tiered, 260

testing infrastructure requirements, 255

Web containers, 410–412

## K

- Keep alive, monitoring and tuning, 414–417
- Kernel CPU. *See* System CPU.
- Kernel statistics, 49
- Kernel thread queue depths, monitoring, 21–24
- Kesselman, Jeff, 2–5
- kstat tool, 49

## L

- L2 (level two) cache
  - configuring, 509–511
  - default type, 511
  - Full Identity Map option, 509
  - Hard Cache Weak Identity Map option, 510
  - No Identity Map option, 510
  - options, 509–511
  - overview, 508
  - size, *vs.* performance, 508
  - Soft Cache Weak Identity Map option, 510
  - Soft Identity Map option, 509
  - Weak Identity Map option, 509
- Latency/responsiveness
  - tuning garbage collectors, 262
  - tuning the JVM
    - CMS (Concurrent Mark-Sweep GC), 287–289
    - CMS collection cycle, initiating, 298–303
    - CMS pause time tuning, 305–306
    - concurrent permanent generation garbage collection, 304–305
    - description, 256
    - explicit garbage collection, 303–304
    - full garbage collections, 286
    - garbage collection activities affecting, 278–279
    - inputs, 279–280
    - old generation size, refining, 283–287
    - overview, 278–279
    - promotion, 291–293
    - survivor spaces, 289–291
    - survivor spaces, occupancy, 298
    - survivor spaces, sizing, 294–303
    - tenuring threshold, 291–294
    - young generation size, refining, 280–283
- Lazy loading, EJB best practices, 530–532
- limit command, 183–184
- Linear scan register allocation, 94
- Link phase, 64
- Little's Law verification, 372–374
- Live bytes, profiling, 205
- Live data size, HotSpot VM garbage collectors, 91
- Live HTTP Headers, 363
- Live objects, profiling, 205

- Live Results control, 199
  - Load class phase, 64
  - Local vs. remote interfaces, EJB best practices, 526–528
  - Lock contention
    - finding, 222–225
    - isolating, 222–225
    - overview, 222–225
    - reducing, 212
    - scaling symptoms, 224
    - User Lock metric, 176–177
  - Lock contention, monitoring
    - hot locks, isolating, 39–40
    - HotSpot VM, 37
    - Linux, 38–39
    - Solaris, 36–38
    - Windows, 39
  - Lock contention, sample code
    - ConcurrentHashMap, 583–593
    - java.util.Random, 593–603, 603–613, 613–624, 624–635
    - parallelism
      - multithreaded, 657–668
      - single-threaded, 647–657
    - partitioned database, 624–635
    - resizing variant, 624–635, 636–647
    - synchronized HashMap, 573–583, 603–613
  - lock keyword, 182
  - Locking, JVM-System
    - ConcurrentHashMap, 227–233
    - overview, 225–233
    - synchronized HashMap, 225–233
  - Log files
    - aggregation, best practices, 450
    - dumping, 79
    - garbage collection, specifying, 119
    - loading multiple, 124–125
  - Logging
    - best practices, 396
    - garbage collection results, 562
    - garbage collectors, 263–267
    - GlassFish server, 447
  - Long latency CPU events, SPARC T-series processor, 11
  - Loops
    - iteration splitting, 99–100
    - optimizing, 99–100
    - range check elimination, 99–100
    - superword, 99–100
    - unrolling, 99–100
    - unswitching, 99–100
- M**
- Machine mode, 178
  - Machine representation of code, 93–94
  - Major garbage collection, 81, 109–110. *See also* Full garbage collection; Old generation garbage collection.
  - Manageability, tuning the JVM, 256
  - Mark word, 72
  - Mark-compact garbage collectors, 86–87
  - Markov chains, benchmarking, 362–366
  - Marshal XML documents. *See* Parse/unmarshall; Serialize/marshall.
  - max-connections-count property, 415–416
  - Maximum number of concurrent clients, benchmarking, 372–374
  - maxthreads-count attribute, 414
  - Members, memory, 234
  - Memory
    - address limitations, 57
    - barriers, 234
    - fences, 234
    - footprint cost, reducing, 68
    - members, 234
    - metrics, 129–130
    - OutOfMemoryError, 78–80
    - scan rate, monitoring, 21–24
    - volatile usage, 234
  - Memory footprint
    - garbage collectors, 262
    - tuning the JVM, 256–257
  - Memory footprint, determining
    - application total memory, determining, 277
    - constraints, 268
    - heap
      - initial size, configuring, 275–277
      - layout, 268–272
      - live data size, calculating, 274–275
      - size, starting point, 272–274
    - old generation space, 269–272
    - overview, 268
    - permanent generation space, 269–272
    - young generation space, 269–272
  - Memory leaks
    - definition, 159
    - NetBeans Profiler, 206–207, 208
  - Memory pages
    - large, enabling, 570
    - touching, enabling, 570–571
  - Memory paging, monitoring, 21–24
  - Memory pools, mapping to HotSpot VM spaces, 129
  - Memory profiles, NetBeans Profiler, 202–205
  - Memory utilization. *See also* Monitoring memory utilization.
    - freeing memory. *See* Garbage collection.
    - monitoring, 23–24
    - swap space, 32. *See also* Swapping memory.
  - Message driven beans, 505–506
  - Message size, effects on Web service performance, 477–479
  - Message Transmission Optimization Mechanism (MTOM), best practices, 487–495
  - Metadata for compiled code, 96–97
  - Method counters, 95
  - Method level interceptor methods, 539

- Method Liveness, 96–97
- Method profiles. *See* NetBeans Profiler, method profiles.
- methodDataOop object, 98
- Methods
  - overridden, detecting, 94–95
  - showing/hiding, 168
- Metric keywords, 182–184
- Metrics, profiling, 175–176. *See also* Criteria for performance; Performance Analyzer, metrics.
- Micro-benchmarks. *See also* Benchmarking.
  - creating, 345–346
  - developing, 361–362
- Minor garbage collection. *See also* Young generation garbage collection.
  - definition, 81
  - monitoring, 109–110
  - process flow, 84–85
  - reducing runtime, 82–83
  - sample output, 113–114
- Modes, experiment data
  - Expert, 178
  - Machine, 178
  - User, 177–178
- Modify Profiling control, 199
- Modifying XML documents
  - attributes, checking for and retrieving, 459
  - definition, 455
  - description, 459–460
  - DOM APIs, 459–460
  - error checking, 460
  - node expansion, deferring, 460
  - nodes, creating, renaming and moving, 459
- Monitor contention, 177
- Monitoring. *See also* Experiments; Profiling; Tuning.
  - application servers. *See* Application server monitoring.
  - definition, 14, 108
  - JIT compilers, 146–147
  - JVM, 388–389
  - local applications, 127
  - memory, 128–130
  - network I/O, 390–392
  - remote applications, 127–128, 133–137
  - resource pools, 398–399
  - thread dumps, 389–390
- Monitoring CPU scheduler's run queue
  - Linux, 31–32
  - overview, 28–29
  - Solaris, 31
  - Windows, 29–31
- Monitoring CPU utilization. *See also* CPU, utilization.
  - Linux
    - application threads, isolating, 25, 27
    - memory utilization, 26–27
    - printing statistics, 26–27
    - reporting intervals, setting, 24–26
  - Linux tools
    - command line tools, 24–28
    - GNOME System Monitor, 20–21
    - mpstat tool, 25–26
    - top tool, 26
    - vmstat tool, 24–25
    - xosview tool, 21
  - overview, 14–16
  - Solaris
    - application threads, isolating, 25, 27
    - kernel thread queue depths, 21–24
    - memory paging, 21–24
    - memory scan rate, 21–24
    - memory utilization, 23–24
    - printing statistics, 26–27
    - process thread stack dumps, 27
    - reporting intervals, setting, 24–26
    - thread ids, converting to hexadecimal, 27–28
  - Solaris tools
    - command line tools, 24–28
    - cpubar, 21–24
    - GNOME System Monitor, 21
    - jstack, 27–28
    - mpstat, 25–26
    - prstat, 26–27
    - pstack, 27
    - vmstat, 24–25
  - SPARC T-series systems
    - overview, 50
    - stalls, 50–51
  - Windows
    - Performance Manager, 16–19
    - Task Manager, 16–19
    - typeperf tool, 19–20
- Monitoring disk I/O
  - benchmarking, 395–398
  - disk cache, enabling, 48–49
  - Linux, 46
  - patterns, 48
  - process ids, 47–48
  - seek times, 48
  - service times, 48
  - servicing I/O events, 48
  - Solaris, 46
  - user ids, 47–48
  - Windows, 46
- Monitoring EJB containers
  - bean caches, 514–520
  - bean pools, 514–520
  - EclipseLink session cache, 519–520
  - entity bean caches, 516
  - invocation patterns, 512
  - overview, 511
  - Ready Cache, 516–517
  - stateful session bean caches, 516
  - thread pool, 512–514
  - Transactional Cache, 516–517

## Monitoring garbage collection

- CPU usage, 114–115
- data of interest, 109
- enabling/disabling, 110
- full collections, 109–110
- GCHisto tool, 121–125
- graphical tools, 125. *See also specific tools.*
- major collections, 109–110
- minor collections, 109–110
- offline analysis, 121–125
- overhead, 122–123
- overview, 108–109
- pause times, 122–124
- stop-the-world pauses, 122
- types of collections, 109–110
- young generation collections, 109–110

## Monitoring garbage collection, reporting

- concurrent mode failure, 117
- CPU usage, 114–115
- date and time stamps, 117–119
- elapsed time, 114
- explicit collection, 121
- full garbage collection, 112–113
- Java heap utilization, 111–113, 114
- log files, specifying, 119
- offline analysis, 119
- old generation space
  - calculating, 112–113, 114
  - reducing, 116–117
- permanent generation space, 113
- premature promotion, 117
- recommended command line options, 121
- runtime between safepoint operations, 119–120
- sample output
  - call to `System.gc`, 121
  - CMS (Concurrent Mark-Sweep GC), 113–114
  - concurrent garbage collection, 115–117
  - full garbage collection, 112
  - minor garbage collection, 113–114
  - runtime between safepoint operations, 119–120
  - from `-XX:+PrintGCApplicationConcurrentTime option`, 120
  - from `-XX:+PrintGCApplicationStoppageTime option`, 120
  - from `-XX:+PrintGCDetails option`, 110–111
  - from `-XX:+PrintGCTimeStamps option`, 118–119
- tenuring distribution, 117
- `-verbose` option, 110

## Monitoring HTTP listener

- acceptor threads, 414–417
- connection queues, 414–417
- elements to be monitored, 412
- individual applications, 420–427
- keep alive, 414–417

request processing, 418–420

request response codes, 419

thread pools, 412–414

## Monitoring Java applications

- GlassFish server, 150–151
- `jstack` output, example, 151–153
- overview, 150–151
- quick lock contention, 151–153

Monitoring memory utilization. *See also* Memory utilization.

involuntary context switching, 40–41

Linux, 35–36

lock contention

hot locks, isolating, 39–40

HotSpot VM, 37

Linux, 38–39

Solaris, 36–38

Windows, 39

Solaris, 34–35

Windows, 33–34

Monitoring network I/O. *See also* Network I/O utilization.

Linux, 43

Solaris, 42–43

Windows, 44–45

## Monitoring Web containers

configuration settings, 408–409

development mode, 408–409

garbage collection, 411

HTTP service, 412

JIT compiler tuning, 410

JVM tuning, 410–412

overview, 408

page freshness, checking, 409

production mode, 408–409

security manager, 409–410

MONITOR\_WAIT statement, 74

## Mostly-Concurrent GC

concurrent marking phase, 88

concurrent sweeping phase, 89

definition, 88

disadvantages of, 89–90

fragmentation issues, 90

initial mark, 88

phases of, 88–89

pre-cleaning phase, 89

remark pause, 88–89

`mpstat` tool, Linux

lock contention, 37–38

monitoring CPU utilization, 25–26

`mpstat` tool, Solaris

monitoring context switching, 37–38

monitoring CPU utilization, 25–26

monitoring involuntary context switching, 40–41

monitoring lock contention, 37–38

monitoring thread migrations, 41

reporting CPU utilization for SPARC T-series, 51–52

MTOM (Message Transmission Optimization Mechanism), best practices, 487–495  
 Multithreaded reference processing, enabling, 561  
 Multithreaded young generation garbage collection, 111, 559

## N

Named native queries, JPA best practices, 541  
 Named queries, JPA best practices, 541  
 Native queries, JPA best practices, 542  
 NetBeans Profiler  
   allocations tracked, specifying, 204  
   downloading, 190–191  
   features, 190  
   generations, 206–207  
   heap dumps, analyzing, 209  
   installing, 190–191  
   memory leaks, 206–207, 208  
   memory profiles, 202–205  
   overview, 189–190  
   results  
     allocated objects, 205  
     average age, 206  
     discarding, 199  
     displaying, 199  
     generations, 206  
     live bytes, 205  
     live objects, 205  
     taking snapshots, 199, 207–208  
   supported platforms, 190  
   terminology, 159  
   *vs.* VisualVM, 189  
 NetBeans Profiler, method profiles. *See also* Profilers.  
   Attach Mode, specifying, 193–194  
   calibrating the target JVM, 196–197  
   configuring the remote system, 196–197  
   controls, 198–199  
   local *vs.* remote, specifying, 193–195  
   remote profiling pack, generating, 194, 196  
   results  
     displaying, 201  
     taking a snapshot, 201–202  
   sample rate, reducing, 193  
   starting a session, 191–198  
   status, 198–199  
   telemetry, 200–201  
   views, 200  
 Network I/O  
   monitoring, 390–392  
   System CPU usage, monitoring, 221–222  
 Network I/O utilization. *See also* Monitoring network I/O.  
   bandwidth, 44  
   blocking *vs.* nonblocking sockets, 45  
   improving application performance, 45  
   overview, 41–42

Neutral state, synchronization, 72  
 nicstat tool, 42–43  
 NIO nonblocking data structures, 221–222  
 No Identity Map option, 510  
 Nodes, XML documents  
   creating, 459  
   expansion, deferring, 460  
   moving, 459  
   renaming, 459  
 Nonstandard command line options, 59  
 Null hypothesis, 351–353  
 NUMA (Non-Uniform Memory Architecture) systems  
   deploying applications on, 315  
   heap space, 571  
 numberOfavailablethreads-count attribute, 513–514  
 numberofworkitemsinqueue-current attribute, 513–514

## O

-o option, collect tool, 163  
 Object size *vs.* cost, best practices, 444  
 OBJECT\_WAIT statement, 75  
 Offline analysis, garbage collection, 119, 121–125  
 Old generation garbage collection, enabling, 558  
 Old generation space  
   calculating, 112–113, 114  
   definition, 81  
   memory footprint, 269–272  
   size, refining, 283–287  
   triggering CMS garbage collection, 559–560  
   utilization, monitoring, 144–145  
 On Stack Replacements (OSRs), 95  
 oops (ordinary object pointers), 57, 554  
 Optimistic locking, 521, 532–533  
 Optimization decisions, printing, 567  
 Optimizations, JIT compilers, 93–94  
 Optimized methods, printing, 565–566  
 Optimizing away dead code, 329–335  
 Optimizing loops, 99–100  
 Oracle Solaris. *See* Solaris.  
 Oracle Solaris Studio Performance Analyzer. *See* Performance Analyzer.  
 Ordinary object pointers (oops), 57, 554  
 OSRs (On Stack Replacements), 95  
 outfile command, 187  
 OutOfMemoryError  
   error handling, 78–80  
   heap dumps, enabling, 567  
   running commands on error, 568  
   tuning garbage collectors, 273–274  
 Overhead  
   definition, 157  
   reducing, 91–92  
 Owning Java monitors, 71–72

**P**

- p option, collect tool, 163
- Page view, performance metrics, 366–367
- Parallel GC
  - defaults for server-class machines, 101–102
  - overview, 87–88
  - threads, throughput tuning, 314–315
- Parallel Old GC, 87–88
- Parallelism, increasing
  - multithreaded applications, 243–246
  - overview, 243–246
  - sample code
    - multithreaded, 657–668
    - single-threaded, 647–657
  - single-threaded applications, 243–246
- ParNew garbage collector
  - description, 111
  - enabling, 292, 559
- Parse/unmarshall XML documents
  - definition, 455
  - description, 455–458
  - DocumentBuilder, creating, 455–456
  - factory lookup, 456–457
  - Factory objects, reusing, 457
  - parser, creating, 455–456
  - SAXParser, creating, 455–456
  - thread safety, 457
  - XMLStreamReader, creating, 455–456
- Parsing XML documents, performance
  - comparisons, 469–470
- Path length
  - vs. CPI, 211–212
  - definition, 7
- Patterns, garbage collection time line, 124
- Pause times, garbage collection, 122–124
- Payload sizes, benchmarking, 359
- Percent sign (%) keyword, 182
- perform. *See* Performance Manager.
- Performance
  - attributes of, 262–263
  - monitoring. *See* Monitoring.
  - principles of, 263
  - profiling. *See* Profiling.
  - statistics, plotting, 144–145
  - tuning. *See* Tuning.
- Performance Analyzer. *See also* Profilers.
  - analyzers, definition, 158
  - attributed time, 158
  - caller-callee relationships
    - attributed metrics, 172–174
    - definition, 158
    - displaying, 158
  - Callers-Callees tables, printing, 184–185
  - closing, 168
  - collect tool
    - definition, 158
    - options, 162–164
  - downloading, 161–162
  - er\_print tool, 158, 180–189
  - exiting, 168
  - experiment files
    - creating, 163
    - opening, 168
    - specifying a directory for, 163
  - filters, definition, 158
  - installing, 161–162
  - modes
    - Expert, 178
    - Machine, 178
    - User, 177–178
  - new windows, creating, 168
  - overview, 156–157
  - printing data, 168
  - product Web page, 159
  - supported platforms, 160–161
  - System CPU time, printing, 182
  - tabs
    - Call Tree, 169–171, 246
    - Callers-Callee, 172–174
    - Callers-Callees, 169–170
    - Disassembly, 169–170
    - Event, 168–169
    - Experiments, 170
    - Functions, 169–170, 171–174
    - Source, 169–170
    - Summary, 168–169
    - Timeline, 170, 246–248
  - terminology, 158
  - toolbar, 168
  - User CPU time, printing, 182
  - viewing mode, switching, 168
- Performance Analyzer, experiments. *See also* Experiments.
  - archiving artifacts, 163
  - call stacks, attributed time, 174–175
  - collecting data, 162–166, 168
  - combining, 168
  - CPU counters, collecting, 163–164
  - data presentation
    - APIs, showing/hiding, 168
    - filtering data, 168, 179–180, 248–249
    - by function name, 178
    - lock contention, 176–177
    - by method name, 177–178
    - methods, showing/hiding, 168
    - metrics, 175–176
    - monitor contention, 177
  - definition, 158
  - dropping results from, 168
  - metrics of interest, 176
  - printing, 180–189
  - printing experiment profiles. *See also* er\_print tool.
    - Callers-Callees tables, 184–185
    - directory output to a file, 187
    - filtering, 186–187
    - limiting methods printed, 183–184

- Performance Analyzer, experiments. *See also* Experiments. (*continued*)
    - metrics, specifying, 182–184
    - scripting, 180, 187–189
    - sorting, 183
    - splitting commands, 181
    - System CPU time, 182
    - User CPU time, 182
    - view mode, specifying, 187
  - profiling interval, specifying, 163
  - toggleing data collection on/off, 163
  - viewing, 166–175
  - Performance Analyzer, metrics
    - adding/removing, 175
    - exclusive time
      - definition, 158, 160
      - displaying, 176
    - inclusive time
      - definition, 158, 160
      - displaying, 160
    - System CPU, 158, 176
    - User CPU, 158, 176
    - User Lock, 176
  - Performance counters, CPU, 49–50
  - Performance Manager, monitoring
    - CPU utilization, 16–19
    - lock contention, 39
    - memory utilization, 33–34
    - run queue depth, 29–31
  - Period (.) keyword, 182
  - Periodic task threads, 75
  - Permanent generation garbage collection, 560
  - Permanent generation space
    - definition, 81
    - memory footprint, 269–272
    - monitoring, 113
    - size
      - specifying, 556
      - triggering CMS garbage collection, 560
    - utilization, monitoring, 145
  - Persistent entities, 505–506
  - Pessimistic locking, EJB best practices, 532–533
  - pidstat tool, Linux
    - monitoring involuntary context switching, 41
    - monitoring lock contention, 38–39
  - ping utility, 390–391
  - Platforms, choosing, 9–10
  - Plus sign (+) keyword, 182
  - Pre-cleaning phase, 89
  - Prefetching, EJB best practices, 530–532
  - Premature promotion, garbage collection, 85
  - Printing
    - Callers-Callees tables, 184–185
    - CPU utilization statistics, 26–27
    - data, 168
    - experiment profiles. *See also* er\_print tool.
      - Callers-Callees tables, 184–185
      - directory output to a file, 187
      - filtering, 186–187
      - limiting methods printed, 183–184
      - metrics, specifying, 182–184
      - scripting, 180, 187–189
      - sorting, 183
      - splitting commands, 181
      - System CPU time, 182
      - User CPU time, 182
      - view mode, specifying, 187
    - optimized methods, 325, 565–566
  - Process thread stack dumps, monitoring, 27
  - Product Web page, 159
  - Production mode, Web containers, 408–409
  - Profilers, 157. *See also* NetBeans Profiler; Performance Analyzer.
  - Profiles, 157. *See also* Experiments.
  - Profiling. *See also* Experiments; Monitoring; Tuning.
    - definition, 14, 108
    - enterprise applications, 399–400
    - memory, 156
    - method, 156
    - with VisualVM
      - capabilities, 131, 138
      - pausing, 138–139
      - remote, 138–139
  - Program dependence graphs, 98–100
  - Programs, developing. *See* Software development.
  - Promotion
    - garbage collection
      - definition, 81
      - failure, 85
      - premature, 117
      - tuning latency/responsiveness, 291–293
  - Provider interface, 495–498
  - prstat tool, Solaris. *See also* iotop tool.
    - involuntary context switching, 40–41
    - monitoring CPU utilization, 26–27
  - pstack tool, 27
  - p-value, 353
- ## Q
- Query results cache, JPA best practices, 543–544
  - Quick lock contention, monitoring, 151–153
- ## R
- Races, avoiding, 71–72. *See also* Synchronization.
  - Ramp down time, 380
  - Ramp up time, 380
  - Range check elimination, 99–100
  - READ\_COMMITTED isolation level, 521
  - Read-only entity beans, EJB best practices, 535–536
  - Reads without transactions, 550
  - READ\_UNCOMMITTED isolation level, 521
  - Ready Cache, 516–517
  - Reference updates in old generation, 91

- Register allocation, 94
  - Register tables, 97
  - Rejecting a true null hypothesis, 353
  - Remark pause, 88–89
  - Remote profiling pack, generating, 194, 196
  - Repeatability, benchmarking, 380–381
  - REPEATABLE\_READ isolation level, 521
  - Reporting intervals, setting, 24–26
  - Request processing, monitoring and tuning, 418–420
  - Request response codes, monitoring and tuning, 419
  - Requests, calculating performance metrics, 366
  - ReRun Last Profiling control, 199
  - Reset Collected Results control, 199
  - Resource monitoring, benchmarking, 379–380
  - Resource pools, monitoring and tuning, 398–399
  - Response time
    - calculating performance metrics, 368–369
    - Web services metric, 476
  - Responsiveness, tuning the JVM, 256. *See also* Latency/responsiveness.
  - Results of profiling
    - displaying, 201
    - method profiles, 201–202
    - NetBeans Profiler
      - allocated objects, 205
      - average age, 206
      - discarding, 199
      - displaying, 199
      - generations, 206
      - live bytes, 205
      - live objects, 205
      - taking snapshots, 199, 201–202, 207–208
  - RMI server, 411–412
  - Root method, definition, 159
  - Round-trip time, calculating performance metrics, 366
  - Run GC control, 199
  - Run queue. *See* CPU, scheduler's run queue.
  - Runtime. *See* HotSpot VM Runtime.
  - Runtime environment, choosing, 260–261
- S**
- Safepoints
    - class loaders, 66
    - HotSpot VM Runtime
      - class loading, 66
      - initiating, 76
      - thread management, 75–76
    - operations, monitoring runtime between, 119–120
    - pauses, tuning garbage collectors, 267
    - statistics, printing, 564
    - VM operations, 75–76
  - Sample rate, reducing, 193
  - sar tool, 49
  - SAX performance, XML documents, 469–470
  - SAXParser, creating, 455–456
  - SAXParserFactory class, 456
  - Scalability
    - analysis, 377–378
    - ideal CPU utilization, 15
  - Scaling
    - benchmarks, 370–372
    - user, 358
    - vertical and horizontal, 358, 377
  - Scavenging young generation space, 110, 306, 561
  - Schema caching, 461–462
  - Schema types, effects on Web service performance, 479–483
  - script option, 181
  - Scripting, `er_print` tools, 180, 187–189
  - Secure interactions, benchmarking, 359
  - Security manager, 409–410
  - Security policies, VisualVM, 133
  - Self time, 159
  - Serial GC, 86–87, 92
  - SERIALIZABLE isolation level, 521
  - Serialization, best practices, 440–443
  - Serialize/marshall XML documents. *See also* Parse/unmarshall XML documents.
    - definition, 455
    - description, 460
  - Server JIT, 97–98
  - server option, 553
  - Server runtime environment *vs.* client, 260
  - Server-class machines, JIT defaults for, 101–102
  - Servers, monitoring. *See* Application server monitoring.
  - Service availability, benchmarking, 359
  - Service Oriented Architecture (SOA). *See* Web services; XML documents.
  - Servlet engines, 407–408
  - Servlets, best practices, 427–438
  - Session beans, 505–506
  - Session Façade pattern, 529–530
  - Session maintenance, benchmarking, 359
  - Session persistence, best practices, 443–445
  - `setStrictErrorChecking` attribute, 460
  - Single static assignment (SSA), 93, 98–100
  - SINGLE\_TABLE inheritance, 550
  - Single-threaded young generation garbage collection, 111
  - SJSXP performance, 469–470
  - Sliding compacting mark-sweep garbage collection, 86–87
  - Slow-path code, synchronization, 72
  - Snapshots. *See also* Thread dumps.
    - NetBeans Profiler, 199, 201–202, 207–208
    - NetBeans Profiler results, 199, 207–208
    - Take Snapshot control, 199
    - VisualVM applications, 132, 139–140
  - Snapshots of applications
    - saving, 139–140
    - taking, 132
    - viewing, 139–140

- SOA (Service Oriented Architecture). *See* Web services; XML documents.
- SOAP messages, Web service performance best practices, 499–501
- Soft Cache Weak Identity Map option, 510
- Soft Identity Map option, 509
- Software development
  - bottom up approach, 7–8
  - phases of, 2–5. *See also specific phases.*
  - process overview, 3
  - top down approach, 6–7
- Solaris Performance Analyzer. *See* Performance Analyzer.
- Solaris Performance Tools CD 3.0, 47
- Solaris Studio Performance Analyzer. *See* Performance Analyzer.
- sort command, 183
- Source tab, 169–170
- Space utilization, monitoring, 142–143
- Spaces panel, 142–143
- SPARC T-series processor
  - evaluating performance, 10–11
  - hardware threads, 9–10
  - long latency CPU events, 11
  - monitoring CPU utilization, 52
  - multiprocessing, 9–10
  - multithreading, 9–10
  - Solaris Internals wiki, 51
  - thread context switches, 9–10
- SSA (single static assignment), 93, 98–100
- Stack-loaded state. synchronization, 72
- Stalls
  - CPU cycles, 15
  - SPARC T-series systems, 50–51
- Standard command line options, 59
- Standard deviations, calculating, 349
- Startup time, tuning the JVM, 256–257
- Stateful session bean caches, monitoring and tuning, 516
- Stateful session beans, 506
- Stateless session beans, 506
- States, synchronization, 72
- Statistics. *See also* Benchmarking; Experiments.
  - $\alpha$  (alpha), 351–353
  - aging, 145–146
  - averages, calculating, 349
  - benchmarking, 381–382
  - confidence intervals, calculating, 350–351
  - degrees of freedom, 351–353
  - guidelines for using, 354–355
  - hypothesis tests, 351–354
  - kstat tool, 49
  - null hypothesis, 351–353
  - performance, collecting, 49
  - plotting performance, 144–145
  - printing
    - CPU utilization, 26–27
    - monitoring CPU utilization, 26–27
    - safepoint, 564
    - tuning garbage collectors, 264
  - p-value, 353
  - rejecting a true null hypothesis, 353
  - safepoint, garbage collection reports, 564
  - sar tool, 49
  - standard deviations, calculating, 349
  - tenuring, garbage collection reports, 563
  - t-statistics, 351–353
  - Type I Errors, 353
- Steady state time, benchmarking, 380
- Stop control, 199
- Stop-the-world garbage collection, 76, 558
- Stop-the-world pauses, monitoring, 122
- StringBuffer, resizing, 235–238
- StringBuilder, resizing, 235–238
- Studio Performance Analyzer. *See* Performance Analyzer.
- Summary tab, 168–169
- Sun Microsystems. *See* Solaris; SPARC T-series processor.
- Superword, 99–100
- Supported platforms, 160–161
- Survivor spaces
  - description, 84–85
  - occupancy, 298
  - overflows, 145
  - size
    - after garbage collection, 557–558
    - changing, 294–303
    - compared to eden space, 290–291, 556
    - initial ratio, specifying, 557
  - sizing, 294–303
  - throughput, tuning, 311–314
  - tuning latency/responsiveness, 289–291
  - utilization, monitoring, 143, 144
- SUT (System Under Test), isolating, 360–361, 378–379
- Swapping memory, 32–36
- Sweeping, enabling, 560
- Synchronization
  - biased state, 72
  - concurrency, 71
  - contended operations, 71–72
  - entering a Java monitor, 71–72
  - exiting a Java monitor, 71–72
  - fast-path code, 72
  - inflated state, 72
  - Java monitors, 71–72
  - mark word, 72
  - mutual exclusion, 71
  - neutral state, 72
  - owning Java monitors, 71–72
  - paces, avoiding, 71–72
  - slow-path code, 72
  - stack-loaded state, 72
  - states, 72
  - synchronized blocks, 71
  - uncontended operations, 71
- Synchronized blocks, 71

- Synchronized HashMap
    - lock contention, sample code, 573–583, 603–613
    - locking, JVM-System, 225–233
  - System boundaries, defining for benchmarking, 360–361
  - System CPU. *See also* CPU, utilization.
    - definition, 15
    - profiling, 158, 176
    - time, printing, 182
    - usage, monitoring
      - callers-callees, 218–221
      - I/O, 214–218
      - network I/O, 221–222
      - NIO nonblocking data structures, 221–222
      - overview, 212–222
  - system keyword, 182
  - System Under Test (SUT), isolating, 360–361, 378–379
  - System.currentTimeMillis API, 328–329
  - System.gc
    - full garbage collection, disabling, 110, 561
    - invoking CMS cycle *vs.* stop-the-world, 561
    - sample output, 121
    - unloading classes, 561
  - System.nanoTime API, 328–329
- T**
- Take Snapshot control, 199
  - Task Manager
    - monitoring CPU utilization, 16–19
    - monitoring involuntary context switching, 41
  - Telemetry, 200–201
  - TemplateTable data structure, 69
  - Tenure, 81
  - Tenuring
    - distribution, monitoring, 117
    - maximum threshold, setting, 559
    - monitoring, 145–146
    - statistics, printing, 563
    - threshold, 291–294
  - Terminology, 158
  - Thick clients, Web services, 474–476
  - Thin clients, Web services, 475–476
  - Think time
    - benchmarking, 364, 374–377
    - calculating, 366
    - definition, 366
    - enterprise considerations, 364
    - performance metrics, calculating, 366
  - 32-bit runtime environment *vs.* 64-bit, 260–261
  - Thread dump analysis, unanticipated file interactions, 397
  - Thread dumps. *See also* Snapshots.
    - monitoring, 389–390
    - VisualVM, 138
  - Thread ids, converting to hexadecimal, 27–28
  - Thread in Java state, 74
  - Thread in vm state, 74
  - Thread management
    - blocked thread state, 74
    - CONDVAR\_WAIT statement, 74
    - creating threads, 73–74
    - deadlocks, 80
    - debugging, 74–75
    - destroying threads, 73–74
    - garbage collection threads, 75
    - internal VM threads, 75
    - JIT compiler threads, 75
    - MONITOR\_WAIT statement, 74
    - new thread state, 74
    - OBJECT\_WAIT statement, 75
    - overview, 72
    - periodic task threads, 75
    - safepoints, 75–76
    - signal dispatcher thread, 75
    - thread in Java state, 74
    - thread in Java vm state, 74
    - thread states, 74–75
    - threading model, 72–73
    - VM operations, 75–76
    - VM threads, 75
  - Thread pools, monitoring and tuning, 412–414, 512–514
  - Thread safety, parsing/unmarshalling XML documents, 457
  - Thread states, 74–75
  - Threading model, 72–73
  - Threads control, 200
  - Throughput
    - metric, Web services, 476
    - performance metrics, calculating, 369–370
    - tuning
      - adaptive sizing, disabling, 309–311
      - CMS, 307–308
      - deploying on NUMA systems, 315
      - garbage collectors, 262, 308–311
      - JVM, 256
      - overview, 307
      - parallel GC threads, 314–315
      - survivor spaces, 311–314
  - Throughput GC. *See* Parallel GC.
  - Throwing exceptions, 70–71
  - Tiered runtime environment, 260
  - Time and date stamp, printing, 264, 266
  - Time stamps. *See* Date and time stamps.
  - Timeline tab, 170, 246–248
  - TLABs (Thread-Local Allocation Buffers), 85
  - Toolbar, 168
  - Top down software development, 6–7
  - top tool, 26. *See also* iotop tool.
  - Train GC, 92
  - Transactional Cache, 516–517
  - Transactions
    - attributes, choosing, 523
    - container managed *vs.* bean managed, 522–523
    - isolation levels, 521–522

- Trimming whitespaces, best practices, 430–431
- t-statistics, 351–353
- Tuning. *See also* Experiments.
  - definition, 14, 108. *See also* Monitoring; Profiling.
  - the file cache, best practices, 446
  - resource pools, 398–399
- Tuning EJB container
  - bean caches, 514–520
  - bean pools, 514–520
  - EclipseLink session cache, 519–520
  - entity bean caches, 516
  - invocation patterns, 512
  - overview, 511
  - Ready Cache, 516–517
  - stateful session bean caches, 516
  - thread pool, 512–514
  - Transactional Cache, 516–517
- Tuning HTTP listener
  - acceptor threads, 414–417
  - connection queues, 414–417
  - elements to be monitored, 412
  - individual applications, 420–427
  - keep alive, 414–417
  - request processing, 418–420
  - request response codes, 419
  - thread pools, 412–414
- Tuning the JVM
  - application systemic requirements
    - availability, 255–256
    - latency, 256
    - manageability, 256
    - memory footprint, 256–257
    - overview, 255
    - responsiveness, 256
    - startup time, 256–257
    - throughput, 256
  - application throughput
    - adaptive sizing, disabling, 309–311
    - CMS, 307–308
    - deploying on NUMA systems, 315
    - garbage collectors, 308–311
    - overview, 307
    - parallel GC threads, 314–315
    - survivor spaces, 311–314
  - assumptions, 254
  - deployment model, choosing
    - multiple JVM deployment, 258–259
    - overview, 259
    - single JVM deployment, 258
  - edge cases, 316
  - garbage collectors
    - choosing, 261–262
    - command line options, 263–267
    - date stamp, printing, 266
    - directing output to a file, 264
    - latency, 262
    - logging, 263–267
    - memory footprint, 262
    - OutOfMemoryError, 273–274
    - performance attributes, 262–263
    - principles of, 263
    - safepoint pauses, 267
    - statistics, printing, 264
    - throughput, 262
    - time stamp, printing, 264, 266
  - latency/responsiveness
    - CMS (Concurrent Mark-Sweep GC), 287–289
    - CMS collection cycle, initiating, 298–303
    - CMS pause time tuning, 305–306
    - concurrent permanent generation garbage collection, 304–305
    - explicit garbage collection, 303–304
    - full garbage collections, 286
    - garbage collection activities affecting, 278–279
    - inputs, 279–280
    - old generation size, refining, 283–287
    - overview, 278–279
    - promotion, 291–293
    - survivor spaces, 289–291
    - survivor spaces, occupancy, 298
    - survivor spaces, sizing, 294–303
    - tenuring threshold, 291–294
    - young generation size, refining, 280–283
  - overview, 252–255
  - ranking systemic requirements, 257–258
  - runtime environment, choosing
    - 32-bit *vs.* 64-bit, 260–261
    - client *vs.* server, 260
    - tiered, 260
  - testing infrastructure requirements, 255
  - work flow, 253
- Tuning the JVM, command line options
  - biased locking, 318–319
  - escape analysis, 317–318
  - garbage collection read/write barriers, eliminating, 318
  - large pages
    - Linux, 320–321
    - Solaris, 319–320
    - window, 321
  - object explosion, 317
  - scalar replacement, 318
  - synchronization, eliminating, 318
  - thread stack allocation, 318
- Tuning the JVM, determining memory footprint
  - application total memory, determining, 277
  - constraints, 268
  - heap
    - initial size, configuring, 275–277
    - layout, 268–272
    - live data size, calculating, 274–275
    - size, starting point, 272–274
  - old generation space, 269–272
  - overview, 268
  - permanent generation space, 269–272

- young generation space, 269–272
- Tuning Web containers
  - configuration settings, 408–409
  - development mode, 408–409
  - garbage collection, 411
  - HTTP service, 412
  - JIT compiler tuning, 410
  - JVM tuning, 410–412
  - overview, 408
  - page freshness, checking, 409
  - production mode, 408–409
  - security manager, 409–410
- Type I Errors, 353
- Type safety, class loaders, 65–66
- `typeperf` tool, monitoring
  - CPU utilization, 19–20
  - lock contention, 39
  - memory utilization, 33–34
  - run queue depth, 29–31

## U

- Uncommon traps, 96–97, 98–100
- Uncontended operations, 71
- Uninitialized classes, 98
- Unloaded classes, 98
- Unloading classes, `System.gc`, 561
- Unrolling loops, 99–100
- Unswitching loops, 99–100
- User CPU. *See also* CPU, utilization.
  - description, 15
  - profiling, 158, 176
  - time, printing, 182
- User interaction modeling, benchmarking, 362–366
- `user` keyword, 182
- User Lock, 176
- User mode, 177–178
- User scaling, 358. *See also* Scaling.
- User transactions, calculating performance metrics, 366, 367–368

## V

- `-v` option, 181
- Validating XML documents, 460–462
- `-verbose` option, 110, 389
- `-verbose:gc`, 562
- Vertical scaling, 358, 377. *See also* Scaling.
- Viewing mode, switching, 168
- `viewmode` command, 187
- Virtual processors, monitoring CPU utilization, 51
- VisualGC. *See also* JConsole; VisualVM.
  - aging statistics, 145–146
  - class loader time, 144
  - compile time, 144
  - downloading, 141
  - eden space utilization, 143, 144

- GC time, 144
- Graphs panel, 144–145
- Histogram panel, 145–146
- old generation space utilization, 144–145
- overview, 141
- performance statistics, plotting, 144–145
- permanent generation space utilization, 145
- space utilization, 142–143
- Spaces panel, 142–143
- survivor space overflows, 145
- survivor space utilization, 143, 144
- tenuring, 145–146
- VisualVM. *See also* JConsole; VisualGC.
  - application snapshots
    - saving, 139–140
    - taking, 132
    - viewing, 139–140
  - binary heap dumps, 140
  - JMX applications, configuring, 135–137
  - `jstatd` daemon, 133–134
  - `jvisualvm` program, 191
  - launching, 131
  - listing Java applications, 134
  - monitoring remote applications, 133–137
  - monitoring server applications, 384–386
  - vs.* NetBeans Profiler, 189
  - obtaining, 191
  - overview, 130–131
  - profiling
    - capabilities, 131, 138
    - pausing, 138–139
    - remote, 138–139
  - security policy, 133
  - table of features, 131
  - thread dumps, 138
- VM life cycle, 59–61
- VM operations, threads, 75–76
- VM Telemetry control, 199, 200
- VM threads, 75
- `vmstat` tool
  - Linux
    - monitoring CPU utilization, 24–25
    - monitoring memory utilization, 35–36
    - monitoring run queue depth, 31–32
  - monitoring CPU utilization, 24–25
  - Solaris
    - monitoring CPU utilization, 24–25
    - monitoring memory utilization, 34–35
    - monitoring run queue depth, 31
    - reporting CPU utilization for SPARC T-series, 51–52
- `volatile` keyword, 234
- Volatile memory usage, 234

## W

- Waiting for data. *See* Stalls.
- Warm-ups, benchmarking, 324–327, 333–334
- Weak generational hypothesis, 81

Weak Identity Map option, 509

Web containers

components, GlassFish

Coyote connector, 407

GlassFish, 406–407

Grizzly connector, 406–407

HTTP connector, 406–407

servlet engines, 407–408

monitoring and tuning

configuration settings, 408–409

development mode, 408–409

garbage collection, 411

HTTP service, 412

JIT compiler tuning, 410

JVM tuning, 410–412

overview, 408

page freshness, checking, 409

production mode, 408–409

security manager, 409–410

monitoring and tuning HTTP listener

acceptor threads, 414–417

connection queues, 414–417

elements to be monitored, 412

individual applications, 420–427

keep alive, 414–417

request processing, 418–420

request response codes, 419

thread pools, 412–414

Web pages, checking freshness, 409

Web service performance

best practices

binary payload, 486–495

catalog file locations, 502–503

client performance, 502–503

Fast Infoset, 499–501

HTTP compression, 501–502

MTOM (Message Transmission

Optimization Mechanism), 487–495

overview, 486

Provider interface, 495–498

SOAP messages, 499–501

XML documents, 492

XML documents as attachments, 492–495

factors affecting

dateTime schema, 481–482

endpoint implementation, 483–484

handler performance, 484–486

message size, 477–479

schema types, 479–483

Web services. *See also* XML documents.

benchmark metrics, 476

benchmarking, 473–476

response time metric, 476

thick clients, 474–476

thin clients, 475–476

throughput metric, 476

Whitespaces, trimming, 430–431

Woodstox performance, 469–470

Write barriers, 83

## X

-Xbatch, 564–565

-Xcheck:jni, 568

-Xcheck:jni method, 78

-Xloggc, 264, 267, 562

-Xloggc option, 119

XML documents. *See also* Web services.

APIs, selecting, 468–471

catalog resolvers, 463–464

DOM performance, 469–470

encoding in binary format, 499–501

entity resolvers, 462–464

external DTD subsets, 462–464

JAXB (Java API for XML Binding), 454,  
469–470

JAXP (Java API for XML Processing), 454, 457

JAX-WS RI (JAX-WS Reference

Implementation) stack, 471–473

parsing performance, comparisons, 469–470

partial processing, 465–468

resolving external entities, 462–464

SAX performance, 469–470

schema caching, 461–462

sending as attachments, 492–495

SJSXP performance, 469–470

validation, 460–462

Web service performance, best practices,  
492–495

Woodstox performance, 469–470

XML documents, processing life cycle

access

definition, 455

description, 458–459

modify

attributes, checking for and retrieving, 459

definition, 455

description, 459–460

DOM APIs, 459–460

error checking, 460

node expansion, deferring, 460

nodes, creating, renaming and moving, 459

overview, 454–455

parse/unmarshall

definition, 455

description, 455–458

DocumentBuilder, creating, 455–456

factory lookup, 456–457

Factory objects, reusing, 457

parser, creating, 455–456

SAXParser, creating, 455–456

thread safety, 457

XMLStreamReader, creating, 455–456

serialize/marshall

definition, 455

description, 460

XMLInputFactory class, 456

XMLStreamReader, creating, 455–456

-Xmn, 270, 555

- Xms, 269, 276, 554
  - Xmx, 269, 276, 554
  - xosview tool, 21
  - XX:+PrintCommandLineFlags, 102–103
  - XX:+PrintGCDateStamps, 264
  - XX:+PrintGCDetails, 264
  - XX:+PrintGCTimeStamps, 264
  - XX:-ScavengeBeforeFullGC, 110
  - XX:-UseAdaptiveSizePolicy, 309–311, 558
  - XX:+AggressiveHeap, 569
  - XX:+AggressiveOpts, 317, 568
  - XX:+AlwaysPreTouch, 570–571
  - XX:+BackgroundCompilation, 564
  - XX:+CMSClassUnloadingEnabled, 560
  - XX:+CMSIncrementalMode, 561
  - XX:+CMSIncrementalPacing, 562
  - XX:+CMSInitiatingOccupancyFraction, 299–300, 559–560
  - XX:+CMSInitiatingPermOccupancyFraction, 305, 560
  - XX:+CMSPermGenSweepingEnabled, 560
  - XX:+CMSScavengeBeforeRemark, 306, 560
  - XX:+DisableExplicitGC, 412, 561
  - XX:+DoEscapeAnalysis, 317–318, 569
  - XX:ErrorFile, 79
  - XX:+ExplicitGCInvokesConcurrent, 561
  - XX:+ExplicitGCInvokesConcurrentAndUnloadsClasses, 561
  - XX:+HeapDumpOnOutOfMemoryError, 567
  - XX:HeapDumpPath, 567
  - XX:InitialHeapSize, 272
  - XX:InitialSurvivorRatio, 557
  - XX:LargePageSizeInBytes, 570
  - XX:MaxHeapSize, 272
  - XX:MaxInlineSize, 567
  - XX:MaxNewSize, 270, 555
  - XX:MaxPermSize, 270–271, 276, 556
  - XX:MaxTenuringThreshold, 292–293, 559
  - XX:NewRatio, 555
  - XX:NewSize, 269–270, 555
  - XX:OnError, 79, 568
  - XX:OnOutOfMemoryError, 568
  - XX:ParallelGCThreads, 305–306, 559
  - XX:+ParallelRefProcEnabled, 561
  - XX:PermSize, 270, 276, 556
  - XX:+PrintAdaptiveSizePolicy, 310, 563
  - XX:+PrintCommandLineFlags, 272, 571
  - XX:+PrintCompilation, 325, 565–566
  - XX:+PrintFlagsFinal, 572
  - XX:+PrintGC, 562
  - XX:+PrintGCApplicationConcurrentTime, 120, 267, 564
  - XX:+PrintGCApplicationStoppedTime, 267, 563
  - XX:PrintGCDateStamps, 267
  - XX:+PrintGCDateStamps, 562
  - XX:+PrintGCDetails, 110–111, 267, 389, 562
  - XX:+PrintGCTimeStamps
    - date and time stamps, 118–119
    - description, 562
    - garbage collection logging, 267
    - garbage collection reporting, 117–119
    - monitoring the JVM, 389
  - XX:+PrintInlining, 566–567
  - XX:+PrintOptoAssembly, 567
  - XX:+PrintSafepointStatistics, 267, 564
  - XX:+PrintTenuringDistribution, 293–294, 563
  - XX:+ScavengeBeforeFullGC, 561
  - XX:+ShowMessageBoxOnError, 568
  - XX:SurvivorRatio, 290–291, 556
  - XX:TargetSurvivorRatio, 298, 557–558
  - XX:+TieredCompilation, 565
  - XX:+UseBiasedLocking, 318–319, 569
  - XX:+UseCMSInitiatingOccupancyOnly, 300, 560
  - XX:+UseCompressedOops, 554
  - XX:+UseConcMarkSweepGC, 559
  - XX:+UseLargePages, 319–321, 570
  - XX:+UseNUMA, 571
  - XX:+UseParallelGC, 272, 558
  - XX:+UseParallelOldGC, 272, 558
  - XX:+UseParNewGC, 292, 559
  - XX:+UseSerialGC, 558
- ## Y
- y option, collect tool, 163
  - Young generation garbage collection. *See also* Minor garbage collection.
    - definition, 81
    - DefNew collector, 111
    - eden space, 83–85
    - layout, 83–85
    - monitoring, 109–110
    - multithreaded, 111
    - ParNew collector, 111, 559
    - single-threaded, 111
    - survivor spaces, 84–85
  - Young generation space
    - memory footprint, 269–272
    - size
      - compared to old generation space, 555
      - refining, 280–283
      - specifying, 555