

On Evaluating the Renaissance Benchmarking Suite: Variety, Performance, and Complexity

Aleksandar Prokopec

Oracle Labs
Switzerland

aleksandar.prokopec@oracle.com

Gilles Duboscq

Oracle Labs
Switzerland

gilles.m.duboscq@oracle.com

Lubomír Bulej

Charles University
Czech Republic

bulej@d3s.mff.cuni.cz

Doug Simon

Oracle Labs
Switzerland

doug.simon@oracle.com

Andrea Rosà

Università della Svizzera italiana
Switzerland

andrea.rosa@usi.ch

Petr Tůma

Charles University
Czech Republic

petr.tuma@d3s.mff.cuni.cz

Yudi Zheng

Oracle Labs
Switzerland

yudi.zheng@oracle.com

Thomas Wuerthinger

Oracle Labs
Switzerland

thomas.wuerthinger@oracle.com

David Leopoldseder

Johannes Kepler Universität Linz
Austria

david.leopoldseder@jku.at

Martin Studener

Johannes Kepler Universität Linz
Austria

martinstudener@gmail.com

Alex Villazón

Universidad Privada Boliviana
Bolivia

avillazon@upb.edu

Walter Binder

Università della Svizzera italiana
Switzerland

walter.binder@usi.ch

Abstract

The recently proposed *Renaissance* suite is composed of modern, real-world, concurrent, and object-oriented workloads that exercise various concurrency primitives of the JVM. *Renaissance* was used to compare performance of two state-of-the-art, production-quality JIT compilers (HotSpot C2 and Graal), and to show that the performance differences are more significant than on existing suites such as DaCapo and SPECjvm2008.

In this technical report, we give an overview of the experimental setup that we used to assess the variety and complexity of the *Renaissance* suite, as well as its amenability to new compiler optimizations. We then present the obtained measurements in detail.

CCS Concepts • Software and its engineering → General programming languages; • Social and professional topics → History of programming languages;

Keywords benchmarks, JIT compilation, parallelism

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1 Introduction

The *Renaissance* suite /citepldi-prokopec-19 has proposed a set of new benchmarks for the JVM, shown in Table 1, which are focused on modern functional, concurrent and parallel applications and frameworks. In related work, we evaluated *Renaissance* by determining a set of runtime metrics, presented in Table 2, which focus on traditional complexity indicators, such as dynamic dispatch and object allocation rate, as well as concurrency-focused behavior of the program. Using a PCA analysis on these metrics, we showed that the benchmarks in the *Renaissance* suite behave considerably different than other benchmark suites with respect to these metrics. Furthermore, we have shown that some benchmarks in the new suite indicate the need for new compiler optimizations. Figure 1 shows the impact of each of the seven optimizations that we studied, across all the benchmarks from *Renaissance*, as well as the existing DaCapo, Scalabench and SPECjvm2008 suites. At the same time, we showed that *Renaissance* is comparable to these existing suites in terms of its code complexity.

In this report, we give a more detail account of our experimental setup and our measurements. We first explain the technical details of our experimental setup, and we then present our experimental results, in terms of the metrics used in our PCA analysis, performance comparison and the Chidamber & Kemerer software complexity metrics. We conclude the report by presenting some basic information about the impact of the new optimizations on the warmup time of JIT-compiled code.

Table 1. Summary of benchmarks included in Renaissance.

Benchmark	Description	Focus
akka-uct	Unbalanced Cobwebbed Tree computation using Akka [2].	actors, message-passing
als	Alternating Least Squares algorithm using Spark.	data-parallel, compute-bound
chi-square	Computes a Chi-Square Test in parallel using Spark ML [39].	data-parallel, machine learning
db-shootout	Parallel shootout test on Java in-memory databases.	query-processing, data structures
dec-tree	Classification decision tree algorithm using Spark ML [39].	data-parallel, machine learning
dotty	Compiles a Scala codebase using the Dotty compiler for Scala.	data-structures, synchronization
finagle-chirper	Simulates a microblogging service using Twitter Finagle [8].	network stack, futures, atomics
finagle-http	Simulates a high server load with Twitter Finagle [8] and Netty [7].	network stack, message-passing
fj-kmeans	K-means algorithm using the Fork/Join framework [33].	task-parallel, concurrent data structures
future-genetic	Genetic algorithm function optimization using Jenetics [5].	task-parallel, contention
log-regression	Performs the logistic regression algorithm on a large dataset.	data-parallel, machine learning
movie-lens	Recommender for the MovieLens dataset using Spark ML [39].	data-parallel, compute-bound
naive-bayes	Multinomial Naive Bayes algorithm using Spark ML [39].	data-parallel, machine learning
neo4j-analytics	Analytical queries and transactions on the Neo4J database [6].	query processing, transactions
page-rank	PageRank using the Apache Spark framework [78].	data-parallel, atomics
philosophers	Dining philosophers using the ScalaSTM framework [14].	STM, atomics, guarded blocks
reactors	A set of message-passing workloads encoded in the Reactors framework [64].	actors, message-passing, critical sections
rx-scrabble	Solves the Scrabble puzzle [44] using the RxJava framework.	streaming
scrabble	Solves the Scrabble puzzle [44] using Java 8 Streams.	data-parallel, memory-bound
stm-bench7	STMBench7 workload [27] using the ScalaSTM framework [14].	STM, atomics
streams-mnemonics	Computes phone mnemonics [41] using Java 8 Streams.	data-parallel, memory-bound

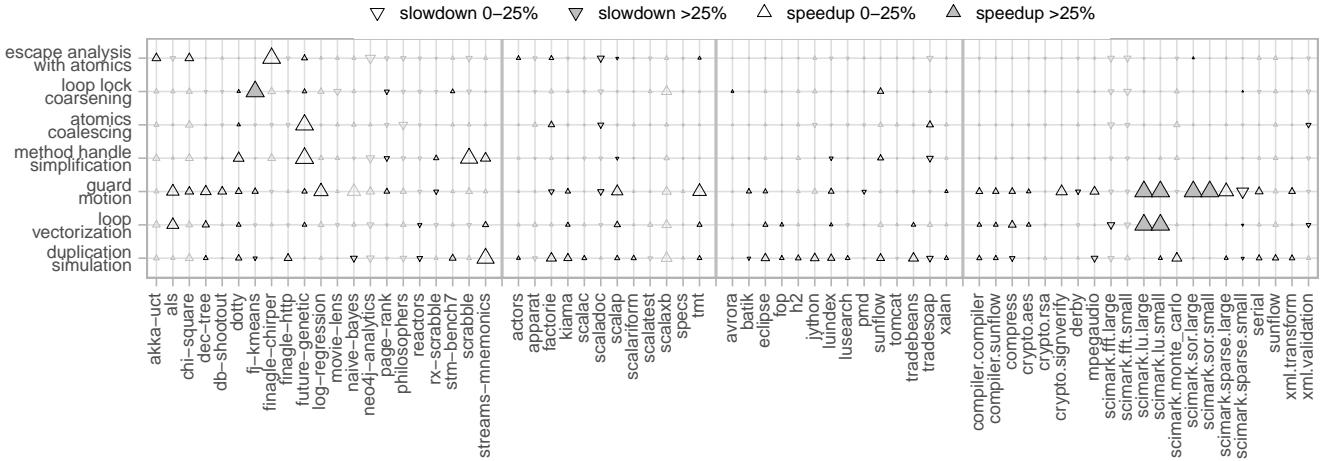


Figure 1. Optimization impact on individual benchmarks. Results with black outline significant at $\alpha = 0.01$.

2 Analyzed Benchmarks

Table 3 lists the benchmarks from the DaCapo, ScalaBench and SPECjvm2008 suites that were considered in the main paper, along with the used input size (expressed as number of operations executed in SPECjvm2008).

3 Experimental Setup for Metric Profiling and Principal Component Analysis

Here, we detail the experimental setup for the collection of metrics described in Table 2 and analyzed in Section 4 and 5 of the main paper.

The metrics are profiled during a single steady-state benchmark execution. Before collecting the metrics, we let the

Table 2. Metrics considered during benchmark selection.

Name	Description
synch	synchronized methods and blocks executed.
wait	Invocations of <code>Object.wait()</code> .
notify	Invocations of <code>Object.notify()</code> and <code>Object.notifyAll()</code> .
atomic	Atomic operations executed.
park	Park operations.
cpu	Average CPU utilization (user and kernel).
cachemiss	Cache misses, including L1 cache (instruction and data), last-layer cache (LLC), and translation lookaside buffer (TLB; instruction and data).
object	Objects allocated.
array	Arrays allocated.
method	Methods invoked with <code>invokevirtual</code> , <code>invokeinterface</code> or <code>invokedynamic</code> bytecodes.
idynamic	<code>invokedynamic</code> bytecodes executed.

Table 3. Benchmarks considered in the paper, including input size and number of operations executed (# ops).

Benchmark DaCapo [13]	Input size	Benchmark ScalaBench [72]	Input size
<i>avro</i>	large	<i>actors</i>	huge
<i>batik</i>	large	<i>apparatus</i>	<i>gargantuan</i>
<i>eclipse</i>	large	<i>factories</i>	<i>gargantuan</i>
<i>fop</i>	default	<i>kiama</i>	default
<i>h2</i>	huge	<i>scalac</i>	large
<i>jython</i>	large	<i>scaladoc</i>	large
<i>luindex</i>	default	<i>scalap</i>	large
<i>lusearch-fix</i>	large	<i>scalariform</i>	huge
<i>pmd</i>	large	<i>scalatest</i>	default
<i>sunflow</i>	large	<i>scalaxb</i>	huge
<i>tomcat</i>	huge	<i>specs</i>	large
<i>tradebeans</i>	huge	<i>tmt</i>	huge
<i>tradesoap</i>	huge		
<i>xalan</i>	large		

Benchmark SPECjvm2008 [1]	# ops	Benchmark	# ops
<i>compiler.compiler</i>	20	<i>scimark.lu.small</i>	125
<i>compiler.sunflow</i>	20	<i>scimark.monte_carlo</i>	900
<i>compress</i>	50	<i>scimark.sor.large</i>	15
<i>crypto.aes</i>	20	<i>scimark.sor.small</i>	75
<i>crypto.rsa</i>	150	<i>scimark.sparse.large</i>	10
<i>crypto.signverify</i>	125	<i>scimark.sparse.small</i>	25
<i>derby</i>	30	<i>serial</i>	25
<i>mpegaudio</i>	50	<i>sunflow</i>	30
<i>scimark.fft.large</i>	10	<i>xml.transform</i>	7
<i>scimark.fft.small</i>	100	<i>xml.validation</i>	40
<i>scimark.lu.large</i>	4		

benchmarks warp-up until dynamic compilation and GC ergonomics are stabilized, following the methodology of Lengauer et al. [35]. We could not collect metrics for benchmarks *tradebeans*, *actors* and *scimark.monte_carlo* either because bytecode instrumentation causes a premature workload termination with a `TimeoutException` (*tradebeans*, *actors*) or because profiling takes an excessive amount of time,

exceeding 7 days (*scimark.monte_carlo*). Therefore we excluded such benchmarks from the PCA analysis (Section 4 of the main paper).

We collect the metrics on a machine with two NUMA nodes, each containing an Intel Xeon E5-2680 (2.7 GHz) processor with 8 physical cores and 64 GB of RAM, running under Ubuntu 16.04.03 LTS (kernel GNU/Linux 4.4.0-112-generic x86_64). We configure top to sample CPU utilization only for the NUMA node where the benchmark is executing, to increase the accuracy of the collected measurements (as the computational resources used by perf and top are not accounted). We disable Turbo Boost [32] and Hyper-Threading [31]. We use Java OpenJDK 1.8.0_161-b12.

We collect the metrics in two runs, profiling OS- and hardware-layer metrics (cpu and cachemiss) in the first run on the original program, and the other metrics in the second run (using DiSL instrumentation). This way, we obtain more precise metrics at the OS- and hardware-layer, which do not account for the execution of instrumentation code. During metric collection, no other CPU-, memory-, or IO-intensive application is executing on the system to reduce measurement perturbations. In addition, we pin the execution to an exclusive NUMA node, to reduce performance interference caused by other running processes.

4 Experimental Setup for Performance Evaluation

Here, we describe the experimental setup for the performance evaluation described in Section 6 of the main paper.

The performance measurement experiments are conducted on 8-core Intel servers, equipped with an Intel Xeon E5-2620v4 CPU (2.1 GHz, 8 cores, 20 MB cache, Hyper Threading disabled), 64 GB RAM, running Fedora Linux 27 (kernel 4.15.6). For stable measurement, power management features are disabled and the processor is run at the nominal frequency. Prior to each benchmark execution, the physical memory pool is randomized. We use Oracle JDK 8u172 with Graal 1.0.0-rc9 as virtual machine. The heap size is fixed at 12 GB with the G1 collector, and except for the selection of individual compiler optimizations used to produce Figure 1, no other option is used.

For each benchmark and each optimization configuration, we execute the measurements in a new JVM 15 times. Each execution consists of a warm-up period of 5 minutes, followed by 60 seconds of steady-state execution, rounded up to the next complete benchmark iteration. The duration of the warm-up period is chosen so that major performance fluctuations due to compilation happen before actual measurement (verified manually). To provide for meaningful comparison across benchmarks, we always collect the execution times of the main benchmark operation (we have modified the

SPECjvm2008 benchmark harness to achieve this, the benchmark would normally report aggregated throughput). Winsorized filtering is used to remove outliers from Figure 1.

5 Collected Metrics

Table 4 reports the metrics (listed in Table 2) collected on all analyzed benchmarks, before being normalized by reference cycles. The experimental setup used for metric collection is detailed in Section 3 of the main paper.

6 Principal Component Analysis

In Figure 2, we report a larger version of the scatter plots shown in Figure 1 and discussed in Section 4 of the main paper.

7 Additional Data for the Software Complexity Metrics

In Tables 5 to 8, we present additional data for the Chidamber & Kemerer metrics (Section 7.1 in the main paper), across all four suites. Tables 5 and 6 contain the sum for each metric across all benchmarks of a suite, while in Tables 7 and 8 we present the arithmetic mean for each metric across all benchmarks of a suite.

8 Additional Data for the Optimization Impact Measurements

In Tables 9 to 12, we provide numerical data for the optimization impact overview from Figure 1. The seven columns – AC, DS, EAWA, GM, LV, LLC and MHS – stand for the seven optimizations considered, namely Atomic-Operation Coalescing, Dominance-Based Duplication Simulation, Escape Analysis with Atomic Operations, Speculative Guard Motion, Loop Vectorization, Loop-Wide Lock Coarsening, and Method-Handle Simplification. In each column, the first number gives the change in benchmark execution times observed when the relevant optimization is turned off, relative to a baseline with all optimizations turned on (positive numbers mean optimization speeds up execution, negative numbers mean optimization slows down execution). The second number gives the p-value as computed by the Welch’s t-test.

Table 13 provides estimate on the compilation overhead associated with each of the seven optimizations considered. In each row, the value gives the relative reduction in compiler thread execution time when the particular optimization is disabled, measured over the entire warm up period. The values are aggregated across all benchmarks.

9 Related Work

Since its introduction in 2006, the DaCapo suite [13] has been a de facto standard for JVM benchmarking. While much of

the original motivation for the DaCapo suite was to understand object and memory behavior in complex Java applications, this suite is still actively used to evaluate not only JVM components such as JIT compilers [24, 36, 57, 59, 73] and garbage collectors [10, 40], but also tools such as profilers [17, 70], data-race detectors [12, 77], memory monitors and contention analyzers [30, 76], static analyzers [26, 74], and debuggers [37].

The subsequently proposed ScalaBench suite [71, 72] identified a range of typical Scala programs, and argued that Scala and Java programs have considerably different distributions of instructions, polymorphic calls, object allocations, and method sizes. This observation that benchmark suites tend to over-represent certain programming styles was also noticed in other languages, (e.g., JavaScript [69]). On the other hand, the SPECjvm2008 benchmark suite [1] focused more on the core Java functionality. Most of the SPECjvm2008 benchmarks are considerably smaller than the DaCapo and ScalaBench benchmarks, and do not use a lot of object-oriented abstractions – SPECjvm2008 exercises classic JIT compiler optimizations, such as instruction scheduling and loop optimizations [21].

The tuning of compilers such as C2 [43] and Graal [3, 22] was heavily influenced by the DaCapo, ScalaBench, and SPECjvm2008 suites. Given that these existing benchmark suites do not exercise many frameworks and language extensions that gained popularity in the recent years, we looked for workloads exercising frameworks such as Java Streams [23] and Parallel Collections [55, 66, 67], Reactive Extensions [9], Akka [2], Scala actors [28] and Reactors [46, 49, 58, 64], coroutines [4, 60, 61], Apache Spark [78], futures and promises [29], Netty [7], Twitter Finagle [8], and Neo4J [6]. Most of these frameworks either assist in structuring concurrent programs, or enable programmers to declaratively specify data-parallel processing tasks. In both cases, they achieve these goals by providing a higher level of abstraction – for example, Finagle supports functional-style composition of future values, while Apache Spark exposes data-processing combinators for distributed datasets. By inspecting the IR of the open-source Graal compiler (c.f. Section 5), we found that many of the benchmarks exercise the interaction between different types of JIT compiler optimizations: optimizations, such as inlining, duplication [36], and partial escape analysis [73], typically start by reducing the level of abstraction in these frameworks, and then trigger more low-level optimizations such as guard motion [21], vectorization, or atomic-operation coalescing. Aside from a challenge in dealing with high-level abstractions, the new concurrency primitives in modern benchmarks pose new optimization opportunities, such as contention elimination [38], application-specific work-stealing [63], NUMA-aware node replication [18], speculative spinning [47], access path caching [48, 50–52], or other

Benchmark	synch	wait	notify	atomic	park	cpu	cachemiss	object	array	method	idynamic
Renaissance											
akka-uct	4.27E+05	1.00E+00	2.00E+00	1.18E+07	1.75E+05	94.45	6.24E+08	1.16E+08	6.00E+05	1.96E+09	0.00E+00
als	3.01E+06	1.15E+02	1.31E+04	1.81E+06	2.39E+03	58.90	9.63E+08	1.10E+08	2.38E+07	2.91E+09	0.00E+00
chi-square	1.52E+06	8.70E+01	4.30E+01	1.58E+05	7.20E+01	26.19	4.97E+08	1.73E+08	2.40E+07	2.39E+09	0.00E+00
db-shootout	7.28E+06	3.20E+01	0.00E+00	2.72E+07	4.01E+05	45.53	2.91E+09	2.16E+08	1.92E+08	1.11E+10	1.00E+06
dec-tree	5.83E+05	8.80E+01	1.37E+03	5.45E+05	5.35E+02	27.23	7.54E+08	2.50E+08	2.84E+07	2.96E+09	0.00E+00
dotty	5.63E+06	4.00E+00	2.56E+04	4.33E+04	0.00E+00	15.68	7.59E+08	4.92E+08	1.42E+07	1.26E+09	7.22E+06
finagle-chirper	1.29E+07	1.72E+03	1.74E+03	1.02E+08	1.72E+04	69.82	2.52E+09	1.43E+08	1.01E+07	4.44E+09	2.36E+03
finagle-http	2.72E+04	2.00E+01	0.00E+00	5.20E+04	6.66E+02	14.72	4.14E+08	2.81E+08	6.40E+04	3.09E+09	5.80E+02
fj-kmeans	1.01E+08	6.57E+02	6.62E+02	1.89E+04	1.19E+03	69.59	4.23E+08	1.35E+08	2.45E+03	7.08E+08	0.00E+00
future-genetic	6.72E+05	2.37E+04	2.40E+04	5.00E+07	1.59E+05	55.85	7.04E+08	2.11E+08	2.64E+05	1.58E+09	2.34E+06
log-regression	2.09E+05	1.09E+02	9.81E+02	4.77E+05	6.62E+02	24.83	6.58E+08	5.39E+09	1.68E+07	1.86E+09	0.00E+00
movie-lens	1.24E+07	5.78E+02	2.22E+05	3.11E+07	3.98E+04	44.17	3.37E+09	2.00E+08	2.58E+07	7.32E+09	2.16E+02
naive-bayes	2.33E+05	3.50E+01	1.09E+02	1.81E+04	1.32E+02	76.90	1.04E+09	3.60E+08	8.21E+07	3.65E+09	0.00E+00
neo4j-analytics	1.37E+07	4.23E+02	1.54E+05	2.05E+06	2.02E+02	59.74	1.05E+18	1.42E+09	3.29E+07	2.22E+10	2.49E+07
page-rank	2.63E+06	9.10E+01	1.26E+02	9.25E+06	1.38E+02	56.14	1.23E+09	2.01E+08	2.94E+06	5.15E+09	0.00E+00
philosophers	2.21E+06	1.52E+04	8.15E+04	1.18E+08	2.52E+04	99.21	1.16E+09	1.80E+08	4.81E+07	6.28E+09	0.00E+00
reactors	2.59E+08	0.00E+00	0.00E+00	1.76E+08	5.52E+06	56.62	4.22E+09	2.71E+08	1.86E+07	1.24E+10	0.00E+00
rx-scrabble	7.55E+06	0.00E+00	0.00E+00	7.49E+05	8.90E+01	25.10	8.11E+07	1.07E+07	0.00E+00	1.02E+08	1.71E+06
scrabble	2.00E+00	1.00E+00	1.00E+00	3.00E+01	1.00E+00	66.70	2.81E+08	5.65E+07	3.44E+06	4.99E+08	2.73E+07
stm-bench7	3.56E+03	1.00E+01	3.00E+00	2.92E+06	0.00E+00	49.44	3.48E+08	3.03E+07	2.96E+06	8.15E+08	0.00E+00
streams-mnemonics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	19.24	7.99E+08	2.04E+08	2.09E+08	1.15E+09	2.15E+07
DaCapo											
avrora	7.22E+06	1.75E+06	1.68E+05	0.00E+00	0.00E+00	20.28	7.11E+17	7.22E+06	2.05E+06	2.78E+09	0.00E+00
batik	1.67E+06	6.00E+00	0.00E+00	7.00E+00	0.00E+00	24.54	1.96E+08	8.77E+05	2.03E+05	3.46E+07	0.00E+00
eclipse	6.80E+07	1.88E+04	3.60E+05	1.27E+05	0.00E+00	13.91	4.66E+09	9.06E+07	9.89E+07	2.41E+09	0.00E+00
fop	2.45E+06	0.00E+00	0.00E+00	1.60E+01	0.00E+00	6.25	5.10E+07	1.63E+06	7.12E+05	3.50E+07	0.00E+00
h2	7.76E+08	4.65E+03	0.00E+00	2.82E+07	0.00E+00	17.78	2.14E+10	2.91E+08	1.23E+08	2.62E+10	0.00E+00
jython	1.06E+08	0.00E+00	0.00E+00	1.72E+07	0.00E+00	11.41	8.86E+08	1.38E+08	2.80E+07	4.14E+09	0.00E+00
luindex	2.77E+05	1.00E+00	1.25E+03	1.00E+01	0.00E+00	5.57	3.74E+07	1.85E+05	8.48E+04	7.81E+07	0.00E+00
lusearch-fix	6.32E+06	1.38E+02	9.05E+02	5.12E+02	0.00E+00	85.00	6.60E+08	1.04E+07	4.64E+06	6.28E+08	0.00E+00
pmd	3.05E+06	0.00E+00	3.34E+03	4.62E+03	3.00E+00	22.26	4.06E+08	1.04E+07	2.86E+06	1.73E+08	0.00E+00
sunflow	1.53E+03	5.00E+00	0.00E+00	0.00E+00	79.55	1.13E+09	1.71E+08	4.34E+06	4.19E+09	0.00E+00	0.00E+00
tomcat	2.28E+08	6.04E+02	2.18E+05	7.84E+06	1.93E+05	27.51	1.61E+18	1.07E+08	7.61E+07	4.44E+09	0.00E+00
tradesoap	7.31E+08	2.12E+02	1.29E+06	2.39E+06	1.30E+05	64.92	2.96E+10	6.64E+08	2.44E+08	1.50E+10	1.40E+02
xalan	2.12E+08	3.48E+02	1.01E+05	0.00E+00	97.89	5.11E+09	6.12E+07	4.00E+07	3.84E+09	0.00E+00	0.00E+00
ScalaBench											
apparatus	1.35E+07	5.64E+03	5.16E+05	1.19E+06	4.54E+04	15.80	2.69E+10	3.22E+08	2.55E+07	1.00E+11	0.00E+00
factories	3.10E+07	3.00E+00	0.00E+00	9.81E+07	0.00E+00	12.04	1.43E+10	7.43E+09	1.16E+08	6.00E+10	0.00E+00
kiama	6.47E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.12	6.28E+07	9.67E+06	2.10E+06	9.10E+07	0.00E+00
scalac	2.52E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	15.45	6.36E+08	4.69E+07	6.45E+06	1.27E+09	0.00E+00
scaladoc	1.90E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11	3.74E+08	3.92E+07	7.62E+06	9.76E+08	0.00E+00
scalap	7.83E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32	2.05E+07	3.39E+06	3.40E+05	7.73E+07	0.00E+00
scalariform	1.90E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	15.65	3.12E+08	5.70E+07	4.17E+06	5.78E+08	0.00E+00
scalatest	7.83E+05	6.45E+02	1.93E+04	6.53E+04	3.30E+01	20.00	2.56E+08	2.61E+06	7.83E+05	3.51E+07	0.00E+00
scalaxb	1.76E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	12.42	9.55E+09	1.22E+08	4.08E+06	1.14E+10	0.00E+00
specs	1.14E+06	4.10E+01	1.38E+04	9.48E+04	5.10E+01	10.53	3.08E+08	1.33E+07	1.93E+06	1.12E+08	0.00E+00
tint	1.35E+08	5.56E+03	8.70E+01	5.13E+04	5.00E+03	36.54	1.26E+19	3.47E+09	1.75E+07	7.19E+10	0.00E+00
SPECjvm2008											
compiler.compiler	4.50E+06	5.00E+00	1.00E+00	2.60E+01	0.00E+00	98.30	1.31E+10	4.17E+08	4.78E+07	1.01E+10	0.00E+00
compiler.sunflow	3.31E+07	1.52E+02	1.00E+00	3.00E+01	0.00E+00	97.85	2.38E+10	1.02E+09	1.72E+08	2.98E+10	0.00E+00
compress	6.18E+05	4.00E+00	1.00E+00	5.50E+01	0.00E+00	98.56	7.06E+10	2.15E+05	1.43E+05	1.56E+11	0.00E+00
crypto.aes	2.94E+07	5.00E+00	1.00E+00	7.70E+01	0.00E+00	97.63	8.29E+09	2.80E+05	3.83E+05	2.91E+09	0.00E+00
crypto.rsa	4.10E+07	4.00E+00	1.00E+00	9.74E+02	0.00E+00	97.33	4.17E+09	1.47E+08	1.83E+08	1.92E+09	1.00E+00
crypto.signverify	2.68E+09	4.00E+00	1.00E+00	7.30E+01	0.00E+00	97.65	1.71E+10	1.51E+07	2.48E+07	2.55E+10	0.00E+00
derby	4.39E+08	1.50E+04	2.60E+07	1.97E+06	1.50E+01	97.92	2.05E+10	1.59E+09	4.25E+08	1.43E+10	0.00E+00
mpegaudio	9.38E+06	8.50E+01	3.00E+00	3.19E+03	0.00E+00	98.29	2.86E+10	1.50E+05	4.81E+06	1.73E+10	1.00E+00
scimark.fft.large	3.36E+08	6.00E+00	1.00E+00	3.70E+01	0.00E+00	95.31	5.94E+10	4.01E+03	2.84E+03	3.36E+08	0.00E+00
scimark.fft.small	3.36E+09	4.00E+00	1.00E+00	3.60E+01	0.00E+00	98.14	3.27E+11	4.90E+05	5.29E+05	3.36E+09	0.00E+00
scimark.lu.large	1.34E+08	4.00E+00	1.00E+00	3.20E+01	0.00E+00	92.28	1.01E+11	1.80E+03	1.39E+03	1.34E+08	0.00E+00
scimark.lu.small	4.02E+09	4.00E+00	1.00E+00	3.30E+01	0.00E+00	97.83	2.95E+11	6.12E+05	9.16E+05	4.02E+09	0.00E+00
scimark.sor.large	5.03E+08	5.00E+00	1.00E+00	3.90E+01	0.00E+00	92.38	1.78E+11	5.34E+03	3.35E+03	5.03E+08	0.00E+00
scimark.sor.small	6.00E+08	5.00E+00	1.00E+00	3.90E+01	0.00E+00	98.22	7.24E+10	7.00E+04	5.13E+04	6.01E+08	0.00E+00
scimark.sparse.large	3.36E+08	4.00E+00	1.00E+00	3.20E+01	0.00E+00	87.15	1.96E+11	3.64E+03	2.71E+03	3.36E+08	0.00E+00
scimark.sparse.small	2.40E+08	5.00E+00	1.00E+00	3.20E+01	0.00E+00	96.42	5.16E+10	2.36E+04	3.33E+04	2.40E+08	0.00E+00
serial	2.25E+09	2.20E+02	7.50E+01	8.35E+02	0.00E+00	98.09	3.89E+10	1.78E+08	1.05E+09	3.70E+10	1.00E+00
sunflow	1.03E+05	4.49E+02	1.00E+00	5.14E+02	0.00E+00	96.95	1.34E+10	2.54E+09	6.26E+07	6.23E+10	0.00E+00
xml.transform	4.76E+08	7.00E+00	1.00E+00	2.40E+01	0.00E+00	97.82	5.80E+09	1.75E+08	7.74E+07	7.73E+09	0.00E+00
xml.validation	8.99E+08	5.00E+00	1.00E+00	1.22E+02	0.00E+00	98.80	2.05E+10	5.49E+08	2.11E+08	2.41E+10	0.00E+00

Table 4. Unnormalized metrics collected on all analyzed benchmarks.

traditional compiler optimizations applied to concurrent programs [75]. Many of these newer optimizations may be applicable to domains such as concurrent data structures, which

have been extensively studied on the JVM [11, 15, 19, 34, 42, 45, 53, 54, 56, 62, 65].

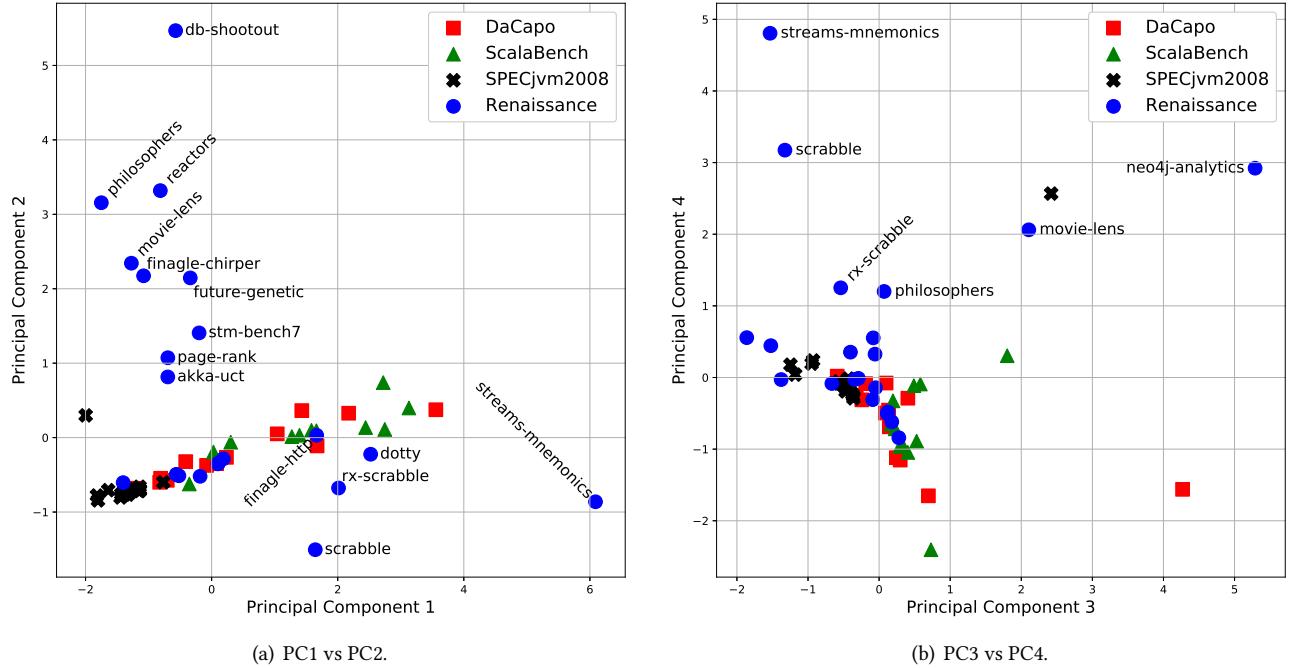


Figure 2. Scatter plots of benchmark scores over the first four principal components (PCs) - Larger version.

Benchmark	WMC	DIT	CBO	NOC	RFC	LCOM
Renaissance						
akka-uct	34607	4938	35384	2718	66665	674747
als	96524	13465	95480	7488	184730	5049619
chi-square	116483	13963	108544	8110	232191	3465588
db-shootout	57652	7393	51499	4285	99878	1874929
dec-tree	206933	23936	184901	14029	369131	7360650
dotty	65887	7185	62533	4121	120656	1824595
finagle-chirper	71465	13894	78437	6322	137705	1429201
finagle-http	65465	13122	72146	5835	126281	1169093
fj-kmeans	22425	3092	22061	1592	42584	461842
future-genetic	26198	3499	25430	1883	49263	508615
log-regression	163424	21841	161667	12057	307276	5569868
movie-lens	101483	14335	100517	8050	192950	5118756
naive-bayes	88885	12871	91563	7130	174908	1850846
neo4j-analytics	119743	22172	141185	11666	224669	1524820
page-rank	93537	13939	97078	7732	183346	1541349
philosophers	24617	3432	24161	1821	46714	494658
reactors	32644	4097	29610	2251	60899	1066392
rx-scrabble	25981	3752	25829	1958	49387	576353
scrabble	24333	3380	24176	1759	46212	484610
stm-bench7	28074	3829	27159	2083	52889	635890
streams-mnemonics	21830	3066	21757	1571	41799	455958
min	21830	3066	21757	1571	41799	455958
max	206933	23936	184901	14029	369131	7360650
geomean	55533.33	7842.22	55146.79	4212.47	105104.97	1358042.08

Table 5. CK metrics for Renaissance: Sum across all loaded classes of a benchmark.

Unlike some other suites whose goal was to simulate deployment in clusters and Cloud environments, such as Cloud-Suite [25], our design decision was to follow the philosophy

of DaCapo and ScalaBench, in which benchmarks are executed within a single JVM instance, whose execution characteristics can be understood more easily. Still, we found some

alternative suites useful: for example, we took the *movie-lens* benchmark for Apache Spark from CloudSuite, and we adapted it to use Spark's single-process mode.

Several other benchmarks were either inspired by or adapted from existing workloads. The *naive-bayes*, *log-regression*, *als*, *dec-tree* and *chi-square* benchmarks directly work with several machine-learning algorithms from Apache Spark ML-Lib, and some of these benchmarks were inspired by the SparkPerf suite [20]. The *Shakespeare plays Scrabble* benchmark [44] was presented by José Paumard at the Virtual Technology Summit 2015 to demonstrate an advanced usage of Java Streams, and we directly adopted it as our *scrabble* benchmark. The *rx-scrabble* is a version of the *scrabble* benchmark that uses the Reactive Extensions framework instead of Java Streams. The *streams-mnemonics* benchmark is rewritten from the *Phone Mnemonics* benchmark that was originally used to demonstrate the usage of Scala collections [41]. The *stm-bench7* benchmark is STMBenchmark7 [27] applied to ScalaSTM [14, 16], a software transactional memory implementation for Scala, while the *philosophers* benchmark is ScalaSTM's *Reality-Show Philosophers* usage example.

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Benchmark	WMC	DIT	CBO	NOC	RFC	LCOM
DaCapo						
avrora	13488	2328	13719	1145	25357	169973
batik	31205	4958	30436	2655	60275	333328
eclipse	66318	5753	45597	4346	97757	600483
fop	28162	4272	28427	2278	56725	324197
h2	20230	2358	16492	1200	37467	297210
jython	66079	3595	34583	2978	71881	616258
luindex	14361	1927	12737	1004	26549	181134
lusearch-fix	12466	1687	10640	857	22378	161333
pmd	24238	3406	21589	1746	46074	526595
sunflow	18088	2359	17493	1266	37288	245761
tomcat	63591	5347	37448	4239	85921	616524
tradebeans	122123	5108	36856	6347	74677	463044
tradesoap	124191	5120	36971	6421	75043	466569
xalan	18203	2852	16987	1364	35126	231540
min	12466	1687	10640	857	22378	161333
max	124191	5753	45597	6421	97757	616524
geomean	32470	3376.65	23275.3	2160.25	48461.37	336191.51
ScalaBench						
actors	41398	4900	34981	2848	76794	1216221
apparat	34994	4023	29838	2121	66309	1344756
factorie	24693	2657	19713	1481	45364	1080228
kiama	31925	4054	27664	2051	60955	1259018
scalac	57337	7789	66036	4111	124240	2298594
scaladoc	50655	6343	50616	3379	103649	2178195
scalalap	29661	3137	23638	1743	54480	1312560
scalariform	32871	3626	28467	2041	62891	1352823
scalatest	114544	4589	37128	6687	78209	1473601
scalaxb	30112	3402	25528	1884	57511	1180527
specs	150895	6548	50104	7890	105427	2215152
tmt	35875	3188	25590	1941	64142	1565153
min	24693	2657	19713	1481	45364	1080228
max	150895	7789	66036	7890	124240	2298594
geomean	44505.06	4290.27	32809.23	2734.69	71839.71	1489515.03
SPECjvm2008						
compiler.compiler	36385	4744	36421	2728	77428	598961
compiler.sunflow	36456	4745	36424	2728	77538	600724
compress	30586	3843	30009	2200	65819	546396
crypto.aes	33789	4134	31810	2413	69028	551637
crypto.rsa	32724	4089	31553	2381	68457	549741
crypto.signverify	30999	3930	30639	2250	66899	547493
derby	55044	5744	45745	3480	103373	1131251
mpegaudio	31370	3925	30483	2251	66884	552206
scimark.fft.large	30572	3835	29977	2192	65767	546563
scimark.fft.small	30572	3835	29977	2192	65767	546563
scimark.lu.large	30569	3833	29968	2191	65761	546558
scimark.lu.small	30569	3832	29967	2190	65761	546558
scimark.monte_carlo	30560	3833	29966	2191	65741	546482
scimark.sor.large	30565	3835	29975	2192	65755	546493
scimark.sor.small	30565	3835	29975	2192	65755	546493
scimark.sparse.large	30561	3833	29967	2191	65746	546486
scimark.sparse.small	30561	3833	29967	2191	65746	546486
serial	32690	3987	31200	2310	68584	570658
sunflow	31946	4003	31463	2324	69076	552092
xml.transform	43374	5654	40968	3154	86981	625179
xml.validation	34578	4378	34225	2545	74250	581626
min	30560	3832	29966	2190	65741	546396
max	55044	5744	45745	3480	103373	1131251
geomean	33194.67	4142.17	32187.12	2383.19	70279.58	578408.18

Table 6. CK metrics for DaCapo, ScalaBench and SPECjvm2008: Sum across all loaded classes of a benchmark.

Benchmark	WMC	DIT	CBO	NOC	RFC	LCOM
Renaissance						
akka-uct	12.83	1.83	13.11	1.01	24.71	250.09
als	13.51	1.88	13.36	1.05	25.85	706.54
chi-square	14.91	1.79	13.9	1.04	29.73	443.74
db-shootout	14.61	1.87	13.05	1.09	25.3	475.03
dec-tree	16.17	1.87	14.45	1.1	28.84	575.1
dotty	18.48	2.02	17.54	1.16	33.84	511.81
finagle-chirper	11.5	2.24	12.62	1.02	22.16	230
finagle-http	11.41	2.29	12.57	1.02	22	203.71
fj-kmeans	13.76	1.9	13.53	0.98	26.13	283.34
future-genetic	13.94	1.86	13.53	1	26.22	270.68
log-regression	14.39	1.92	14.23	1.06	27.05	490.31
movie-lens	13.31	1.88	13.18	1.06	25.31	671.4
naive-bayes	13.01	1.88	13.4	1.04	25.6	270.91
neo4j-analytics	11.07	2.05	13.06	1.08	20.78	141.02
page-rank	12.68	1.89	13.16	1.05	24.86	209
philosophers	13.29	1.85	13.05	0.98	25.22	267.09
reactors	14.54	1.82	13.19	1	27.13	475.01
rx-scrabble	13.2	1.91	13.12	0.99	25.08	292.71
scrabble	13.57	1.89	13.48	0.98	25.77	270.28
stm-bench7	13.36	1.82	12.93	0.99	25.17	302.66
stream-mnemonics	13.54	1.9	13.5	0.97	25.93	282.85
min	11.07	1.79	12.57	0.97	20.78	141.02
max	18.48	2.29	17.54	1.16	33.84	706.54
geomean	13.58	1.92	13.49	1.03	25.71	332.19

Table 7. CK metrics for Renaissance: Average across all loaded classes of a benchmark.

Benchmark	WMC	DIT	CBO	NOC	RFC	LCOM
DaCapo						
avrora	11.74	2.03	11.94	1	22.07	147.93
batik	12.2	1.94	11.9	1.04	23.57	130.36
eclipse	21.02	1.82	14.45	1.38	30.98	190.33
fop	12.67	1.92	12.79	1.02	25.52	145.84
h2	17.42	2.03	14.2	1.03	32.27	255.99
jython	22.81	1.24	11.94	1.03	24.81	212.72
luindex	14.68	1.97	13.02	1.03	27.15	185.21
lusearch-fix	15.13	2.05	12.91	1.04	27.16	195.79
pmd	14.31	2.01	12.74	1.03	27.2	310.86
sunflow	13.83	1.8	13.37	0.97	28.51	187.89
tomcat	22.76	1.91	13.4	1.52	30.75	220.66
tradebeans	41.89	1.75	12.64	2.18	25.62	158.85
tradesoap	42.43	1.75	12.63	2.19	25.64	159.4
xalan	13.57	2.13	12.67	1.02	26.19	172.66
min	11.74	1.24	11.9	0.97	22.07	130.36
max	42.43	2.13	14.45	2.19	32.27	310.86
geomean	17.97	1.87	12.88	1.2	26.82	186.05
ScalaBench						
actors	15	1.78	12.67	1.03	27.82	440.66
apparat	16.78	1.93	14.31	1.02	31.8	644.97
factorie	16.67	1.79	13.31	1	30.63	729.39
kiama	15.55	1.97	13.47	1	29.69	613.26
scalac	14.04	1.91	16.17	1.01	30.43	562.97
scaladoc	15.12	1.89	15.1	1.01	30.93	650.01
scalap	17.14	1.81	13.66	1.01	31.47	758.27
scalariform	16.18	1.79	14.02	1	30.97	666.09
scalatest	42.6	1.71	13.81	2.49	29.08	548.01
scalaxb	16.04	1.81	13.6	1	30.64	628.94
specs	40.1	1.74	13.31	2.1	28.02	588.67
tmt	19.16	1.7	13.67	1.04	34.26	836.09
min	14.04	1.7	12.67	1	27.82	440.66
max	42.6	1.97	16.17	2.49	34.26	836.09
geomean	18.85	1.82	13.9	1.16	30.43	631.02
SPECjvm2008						
compiler.compiler	13.55	1.77	13.56	1.02	28.83	222.99
compiler.sunflow	13.57	1.77	13.56	1.02	28.87	223.65
compress	13.83	1.74	13.57	1	29.77	247.13
crypto.aes	14.32	1.75	13.48	1.02	29.26	233.84
crypto.rsa	14	1.75	13.5	1.02	29.29	235.23
crypto.signverify	13.73	1.74	13.57	1	29.63	242.47
derby	16.9	1.76	14.04	1.07	31.73	347.22
mpegaudio	13.89	1.74	13.49	1	29.61	244.45
scimark.fft.large	13.87	1.74	13.6	0.99	29.84	247.99
scimark.fft.small	13.87	1.74	13.6	0.99	29.84	247.99
scimark.lu.large	13.88	1.74	13.6	0.99	29.85	248.1
scimark.lu.small	13.88	1.74	13.61	0.99	29.86	248.21
scimark.monte_carlo	13.87	1.74	13.6	0.99	29.84	248.06
scimark.sor.large	13.87	1.74	13.6	0.99	29.83	247.96
scimark.sor.small	13.87	1.74	13.6	0.99	29.83	247.96
scimark.sparse.large	13.87	1.74	13.6	0.99	29.84	248.06
scimark.sparse.small	13.87	1.74	13.6	0.99	29.84	248.06
serial	14.15	1.73	13.5	1	29.68	246.93
sunflow	13.69	1.72	13.49	1	29.61	236.64
xml.transform	14.31	1.86	13.51	1.04	28.69	206.19
xml.validation	13.62	1.72	13.48	1	29.24	229.08
min	13.55	1.72	13.48	0.99	28.69	206.19
max	16.9	1.86	14.04	1.07	31.73	347.22
geomean	14	1.75	13.58	1.01	29.65	244.03

Table 8. CK metrics for DaCapo, ScalaBench and SPECjvm2008: Average across all loaded classes of a benchmark.

workload	AC	DS	EAWA	GM	LV	LLC	MHS
akka-uct	+1% 38%	+2% 22%	+5% 0%	+1% 44%	+4% 1%	+1% 39%	+3% 4%
als	+0% 81%	+1% 33%	-1% 14%	+11% 0%	+10% 0%	+1% 29%	+0% 82%
chi-square	+4% 3%	+4% 4%	+5% 0%	+5% 0%	+3% 12%	+2% 33%	+4% 2%
db-shootout	-0% 35%	-0% 63%	+0% 14%	+5% 0%	+0% 24%	-0% 29%	+0% 48%
dec-tree	+0% 60%	+1% 0%	-0% 90%	+8% 0%	+3% 0%	-0% 35%	-0% 45%
dotty	+0% 1%	+2% 0%	+0% 85%	+3% 0%	+1% 0%	+0% 0%	+8% 0%
finagle-chirper	-1% 90%	-0% 96%	+24% 0%	-1% 88%	+0% 91%	+3% 23%	+4% 18%
finagle-http	-1% 5%	+4% 0%	-1% 12%	+0% 60%	-0% 25%	-0% 29%	-0% 95%
fj-kmeans	-0% 16%	-1% 0%	+0% 90%	+2% 0%	-0% 6%	+71% 0%	-0% 62%
future-genetic	+24% 0%	+0% 59%	+2% 1%	+2% 0%	+1% 0%	+1% 0%	+25% 0%
log-regression	-0% 89%	+1% 58%	+0% 73%	+15% 0%	+2% 6%	+2% 1%	+1% 28%
movie-lens	+1% 85%	+0% 99%	+1% 81%	+1% 84%	-1% 80%	-3% 18%	+1% 76%
naive-bayes	+1% 14%	-3% 0%	+1% 25%	+13% 2%	+1% 17%	+1% 27%	-0% 55%
neo4j-analytics	+0% 91%	-4% 37%	-7% 10%	+5% 24%	-3% 49%	-0% 100%	-4% 27%
page-rank	-1% 2%	-0% 51%	-1% 2%	+2% 0%	-0% 38%	-1% 0%	-1% 0%
philosophers	-5% 5%	-2% 32%	-1% 43%	+2% 9%	+2% 22%	-1% 64%	-1% 62%
reactors	-0% 42%	-2% 0%	-0% 11%	-1% 3%	-1% 1%	-1% 4%	-1% 16%
rx-scrabble	-0% 93%	+1% 6%	-0% 69%	-1% 0%	-1% 8%	-0% 38%	+1% 0%
scrabble	+1% 65%	+1% 32%	-2% 11%	+3% 6%	-1% 47%	-1% 31%	+22% 0%
stm-bench7	+1% 21%	+3% 0%	+1% 26%	+1% 6%	+0% 12%	+1% 1%	-0% 96%
streams-mnemonics	+0% 35%	+22% 0%	+1% 2%	+1% 3%	+2% 0%	+0% 59%	+7% 0%

Table 9. Optimization impact – Renaissance benchmarks.

workload	AC	DS	EAWA	GM	LV	LLC	MHS
avrora	+0% 3%	+0% 4%	+0% 90%	+0% 17%	+0% 19%	+0% 0%	+0% 7%
batik	-0% 35%	-0% 0%	+0% 91%	+1% 0%	+0% 81%	-0% 68%	-0% 3%
eclipse	+0% 26%	+5% 0%	-0% 39%	+1% 0%	+1% 0%	+0% 10%	+0% 11%
fop	+0% 90%	+1% 0%	+0% 63%	+0% 83%	+1% 0%	-0% 84%	+0% 72%
h2	+0% 29%	+2% 0%	-0% 65%	+1% 4%	+0% 20%	+0% 8%	+1% 1%
jython	-1% 26%	+5% 0%	+1% 65%	+2% 9%	-0% 96%	+1% 42%	+0% 96%
luindex	-0% 39%	+3% 0%	-0% 5%	+2% 0%	+0% 0%	-0% 70%	-1% 0%
lusearch	-0% 17%	+1% 0%	-0% 9%	-0% 76%	-0% 1%	-0% 80%	-0% 62%
pmd	-0% 10%	-0% 58%	+0% 28%	-1% 0%	-0% 63%	+0% 76%	+0% 81%
sunflow	+1% 1%	+4% 0%	+0% 78%	+0% 24%	+2% 2%	+2% 1%	+2% 1%
tomcat	+0% 6%	-0% 40%	+0% 76%	-0% 54%	+0% 40%	-0% 85%	-0% 91%
tradebeans	+0% 19%	+7% 0%	+0% 46%	-0% 33%	+1% 0%	+0% 78%	+0% 85%
tradesoap	+3% 1%	-2% 0%	-2% 4%	-0% 80%	+1% 35%	+0% 70%	-3% 0%
xalan	+1% 4%	+1% 0%	+0% 52%	+0% 1%	+0% 6%	+0% 42%	+0% 2%

Table 10. Optimization impact – DaCapo benchmarks.

workload	AC	DS	EAWA	GM	LV	LLC	MHS
actors	+0% 51%	+1% 0%	+1% 0%	+0% 35%	+0% 5%	-0% 86%	+0% 4%
apparat	+1% 2%	-1% 14%	-1% 19%	+0% 83%	+1% 10%	-0% 62%	-0% 74%
factorie	+2% 0%	+7% 0%	+1% 1%	-2% 0%	+1% 30%	+1% 7%	+1% 27%
kiama	-0% 37%	+4% 0%	-0% 24%	+1% 0%	+1% 0%	+0% 24%	+0% 60%
scalac	-0% 77%	+1% 0%	+0% 38%	-0% 96%	+0% 20%	-0% 32%	-0% 10%
scaladoc	-2% 0%	+0% 65%	-3% 0%	-2% 0%	-1% 23%	-1% 10%	-1% 40%
scalalap	-0% 1%	+1% 0%	-0% 0%	+9% 0%	+2% 0%	-0% 7%	-0% 0%
scalariform	+0% 5%	+1% 0%	-0% 49%	+0% 1%	+0% 2%	+0% 64%	-0% 22%
scalatest	+0% 90%	-1% 19%	-1% 34%	+0% 83%	+1% 2%	+1% 41%	+0% 100%
scalaxb	+1% 88%	+8% 5%	+1% 87%	+6% 15%	+6% 18%	+7% 8%	+2% 72%
specs	-0% 16%	+0% 18%	-0% 11%	+0% 2%	+0% 78%	-0% 20%	-0% 45%
tmt	+0% 10%	+1% 0%	+0% 0%	+13% 0%	+1% 0%	+0% 6%	+0% 42%

Table 11. Optimization impact – ScalaBench benchmarks.

workload	AC		DS		EAWA		GM		LV		LLC		MHS	
compiler.compiler	+0%	8%	+1%	0%	-0%	10%	+3%	0%	+1%	0%	-0%	35%	-0%	73%
compiler.sunflow	-0%	42%	+1%	0%	+0%	39%	+2%	0%	+1%	0%	-0%	39%	+0%	12%
compress	-0%	33%	-2%	0%	+0%	77%	+2%	0%	+4%	0%	-0%	82%	-0%	35%
crypto.aes	-0%	5%	-0%	67%	-0%	37%	+1%	0%	+1%	0%	-0%	8%	-0%	4%
crypto.rsa	-0%	20%	+0%	2%	-0%	36%	+0%	77%	-0%	34%	-0%	29%	-0%	15%
crypto.signverify	-0%	92%	+0%	69%	-0%	64%	+9%	0%	-0%	74%	-0%	100%	+0%	87%
derby	+0%	44%	+0%	59%	-0%	48%	-1%	1%	-1%	18%	+0%	58%	+0%	72%
mpegaudio	-0%	84%	-3%	0%	+0%	26%	+5%	0%	+0%	69%	+0%	50%	+0%	31%
scimark.fft.large	-3%	1%	-2%	3%	-3%	2%	-1%	19%	-3%	0%	-2%	7%	-1%	49%
scimark.fft.small	-1%	44%	+2%	33%	-3%	9%	-1%	65%	-2%	22%	-3%	4%	-1%	68%
scimark.lu.large	-0%	11%	-0%	57%	-0%	8%	+69%	0%	+29%	0%	-0%	6%	+0%	81%
scimark.lu.small	+0%	40%	+1%	0%	+0%	16%	+137%	0%	+58%	0%	+0%	92%	+0%	1%
scimark.monte_carlo	+2%	30%	+7%	0%	-0%	83%	-0%	83%	+0%	89%	+1%	61%	+1%	62%
scimark.sor.large	+0%	4%	-0%	21%	+0%	0%	+34%	0%	-0%	25%	+0%	13%	-0%	44%
scimark.sor.small	-0%	64%	-0%	44%	+0%	65%	+36%	0%	+0%	20%	-0%	32%	+0%	38%
scimark.sparse.large	+0%	4%	+1%	0%	+0%	4%	+16%	0%	+0%	2%	+0%	46%	+0%	16%
scimark.sparse.small	-0%	2%	-0%	0%	-0%	6%	-10%	0%	-0%	0%	+0%	1%	-0%	6%
serial	+0%	94%	+2%	0%	+1%	4%	+4%	0%	+1%	5%	-1%	11%	+0%	39%
sunflow	+1%	32%	+2%	1%	+1%	19%	+1%	17%	+2%	1%	+1%	29%	+1%	16%
xml.transform	+0%	73%	+2%	0%	-0%	60%	+3%	0%	+0%	24%	+0%	83%	+0%	54%
xml.validation	-1%	0%	+1%	6%	-1%	10%	-1%	13%	-1%	1%	-1%	2%	-1%	5%

Table 12. Optimization impact – SPECjvm2008 benchmarks.

optimization	compilation time change
Atomic-Operation Coalescing	0.6%
Dominance-Based Duplication Simulation	19.6%
Loop-Wide Lock Coarsening	6.7%
Method-Handle Simplification	7.2%
Speculative Guard Motion	5.8%
Loop Vectorization	5.1%
Escape Analysis with Atomic Operations	6.9%

Table 13. Compilation time associated with individual optimizations.