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Improving the Performance of Your Java Application: Getting Beyond the Basics

Yukon Maruyama and Marty Itzkowitz

Performance Analyzer Leads

Oracle Solaris Studio

October 29, 2015

Program Agenda

- Introduction: What is a Performance Problem
- Performance Analysis Tools
- Profiling Accuracy: a Simple Example
- Understanding Java Execution
- Identifying Programming Inefficiencies

What is a Performance Problem?

- Objective (quantitative) criteria:
  - It can't handle the required load
  - It consumes too many resources to do its work
- Is it worth fixing?
- Subjective (qualitative) criteria:
  - It takes too long to finish
  - It responds too slowly
  - Cost of fixing vs. aggregate cost of problem
- Most untuned codes have low-hanging fruit!

Triaging Performance Problems

- Is there a problem?
  - **`/bin/time`**, stopwatch, wall clock reveal problems
- Can you do repeatable performance runs?
  - With realistic data and scale, and test case for any specific problems
- Is it a scaling problem?
  - Most programs have some intrinsic scale factor N
    - Compare times with small, medium, and large N
      - ~ N? ~ ln N? ~ N^2? ~ N^m?
- Is it a global performance issue or a corner-case?
- Is it a problem with average performance, or distribution?

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Diagnosing Performance Problems

- Diagnosis needs repeatable test cases
- As in medical diagnosis, performance diagnosis requires measurement
  - Medical diagnosis
    - Blood pressure, temperature, blood chemistry, ...
    - X-ray, MRI, CT-Scan -- relate to body structure
    - Angiography -- time-based behavior
  - Program performance diagnosis
    - Resource usage, run-time, transactions/second, ...
    - Performance data relating to program structure
    - Time-based picture of execution
- Tools are needed to do the measurements

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Performance Analysis Tools: Requirements, I

- Accuracy
  - Preserve behavior of the application being tested
    - Some tools and technologies are better than others
    - Minimize increase in running time under measurement
  - Capture key data to show what happened
  - Data collected should be unbiased
    - No difference in the relative weights of elements in the application
    - Accurate representation of what execution would be without measurement
- Accuracy is NOT a given
  - Some tools distort behavior and the measured data

Performance Analysis Tools: Requirements, II

- Scalability
  - To target problem size
    - *e.g.*, size of database being queried
    - *e.g.*, number of clients accessing a server
  - Program size – multi-GB executables, 100,000 source files
  - Thread and CPU count – potentially 1000's of each in modern systems
  - Running time – 10's of seconds to many hours

Data Collection Options: Statistical Sampling

- Statistical sampling
  - Pro: very scalable: can throttle profile rate as needed
    - Millions of instructions between samples
  - Con: risk of non-representative sampling
    - May miss non-repeating short-duration events (but are they significant for performance?)
    - Behavior correlated with sampling mechanism
- Trigger by profiling clock-tick
  - Shows where CPU time is spent
  - On Solaris, also shows why program is not running: wait for I/O, page -fault, *etc.*
- Trigger by HW Counter overflow: CPU Stalls, cache misses, *etc.*
- Recommended for general performance analysis

Data Collection Options: Tracing

- Tracing interesting events
  - Mechanisms
    - Instrumentation of key methods
    - Interposition on library functions
    - JVMTI event generation
  - Pro: data based on the behavior traced
    - Memory allocation/deallocation
    - I/O operation tracing
    - Synchronization operations
  - Con: requires careful interposition
    - Scales poorly: can distort behavior significantly
- Recommended <u>only</u> if necessary to get the specific data needed

Data Collection Options: Capturing the Callstack

- Callstack capture can be expensive
  - However, unwind cost for sampling is usually only a few percent
- Full callstack capture is recommended
  - Provides dynamic calltree with performance metrics
    - Inclusive time (total time) is time in the function + time in all the functions it calls
    - Exclusive time (self time) is time in the function only
  - Essential for identifying hot branches (*e.g.*, callers of access functions)
- Java stack unwind is not supported equally by all tools
  - Deferred sampling to avoid JVM safepoints will give incorrect data
  - JIT inlining can be difficult for a tool to understand and represent
  - Callstacks after native calls (JNI) are often not supported

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Profiling Accuracy: a Simple Example

- Example code does the same calculation two ways
  - One with an explicit triple-nested loop doing a sum
  - One with each level of the loop calling a method for the next level
    - The inner-most level does the sum
  - Expected performance of the two is about the same
- Data collected with three different profilers
  - Java Flight-Recorder (from Java SE 1.8.0_40)
  - NetBeans Profiler (NB 8.0.1, run with Java SE 1.8.0_40)
  - Studio Performance Analyzer (run with Java SE 1.8.0_40)
- Source code on the next two slides
  - Try your own favorite tool

Profiling Accuracy: Source Code, I

```
// Some profilers may not identify that ~50% of time is spent in innerSum()
public class InliningTest {
    public static void main(String[] args) {
        InliningTest test = new InliningTest();
        for (int i = 0; i < 20; i++) {
            test.computeSimple();
            test.computeDeep();
        }
    }
// - computeSimple() - Computes a sum in a triply nested loop
    public double sum = 0.0;
    public void computeSimple() {
        for (int i = 0; i < 1000; i++) {                      // outer
            for (int j = 0; j < 1000; j++) {                  // middle
                for (int k = 0; k < 1000; k++) {              // inner
                    sum += 1.0;               // ~48% of time // sum
                }
            }
        }
    }
```

Profiling Accuracy: Source Code, II

```
// - computeDeep() - Computes the same sum, but implements the
//             outer, middle, and inner loops as nested methods.
    public double sum_deep = 0.0;
    public void computeDeep() {
        for (int i = 0; i < 1000; i++) { nested_level_1(); }  // outer
    }
    private void nested_level_1() {
        for (int i = 0; i < 1000; i++) { nested_level_2(); }  // middle
    }
    private void nested_level_2() {
        for (int i = 0; i < 1000; i++) { innerSum(); }        // inner
    }
    private void innerSum() {
        sum_deep += 1.0;                     // ~48% of time // sum
    }
}
```

Profiling Accuracy: Expanded Calltree (NetBeans Profiler)

(Runtime dilated from 34 to 40.5 seconds)

Call Tree - Method	Total Time
main	40,531 ... (100%)
InliningTest.main (String[])	40,531 ... (100%)
InliningTest.computeDeep ()	39,449 ...(97.3%)
Self time	39,344 ...(97.1%)
InliningTest.nested_level_1 ()	104 ms (0.3%)
InliningTest.computeSimple ()	876 ms (2.2%)
Self time	205 ms (0.5%)

97% Self time is shown in `computeDeep()`? 2% in `computeSimple()`?
(Wrong answer)

Profiling Accuracy: Hot Functions (NetBeans Profiler)

Hot Spots - Method	Self Time
InliningTest.**computeDeep** ()	39,344 ... (97.1%)
InliningTest.**computeSimple** ()	876 ms (2.2%)
InliningTest.**main** (String[])	205 ms (0.5%)
InliningTest.**nested_level_1** ()	104 ms (0.3%)

97 % Self Time in `computeDeep()`? `inner_sum()` is missing?
(Same wrong answer as in Calltree)

Profiling Accuracy: Calltree (Java Flight-Recorder)

Stack Trace	Sample Count	Percentage
InliningTest.main(String[])	158	100.00%
InliningTest.computeSimple()	157	99.37%
InliningTest.computeDeep()	1	0.63%
InliningTest.nested_level_1()	1	0.63%
InliningTest.nested_level_2()	1	0.63%

99% Samples shown in `computeSimple()`; `inner_sum()` is missing?
(Wrong answer)

Profiling Accuracy: Calltree (Java Flight-Recorder)
Run with `-XX:+DebugNonSafepoints` setting

Stack Trace	Sample Count	Percentage
InliningTest.main(String[])	3,047	100.00%
InliningTest.computeSimple()	1,514	49.69%
InliningTest.computeDeep()	1,533	50.31%
InliningTest.nested_level_1()	1,533	50.31%
InliningTest.nested_level_2()	1,532	50.28%
InliningTest.innerSum()	1,500	49.23%

With a non-default setting, JFR gives the right answer

CPU time is <u>not</u> provided; hard to tell if calltree is complete

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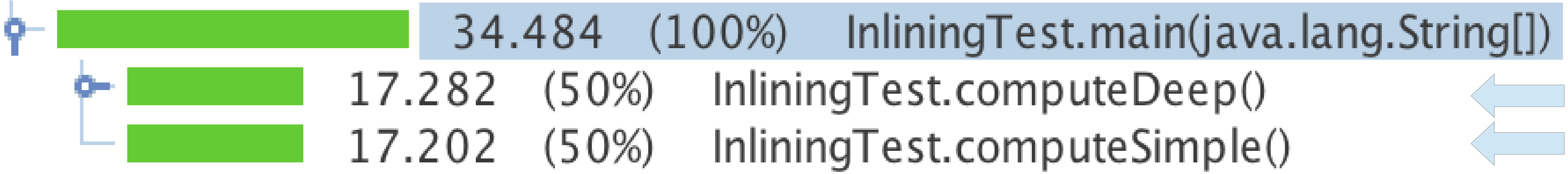
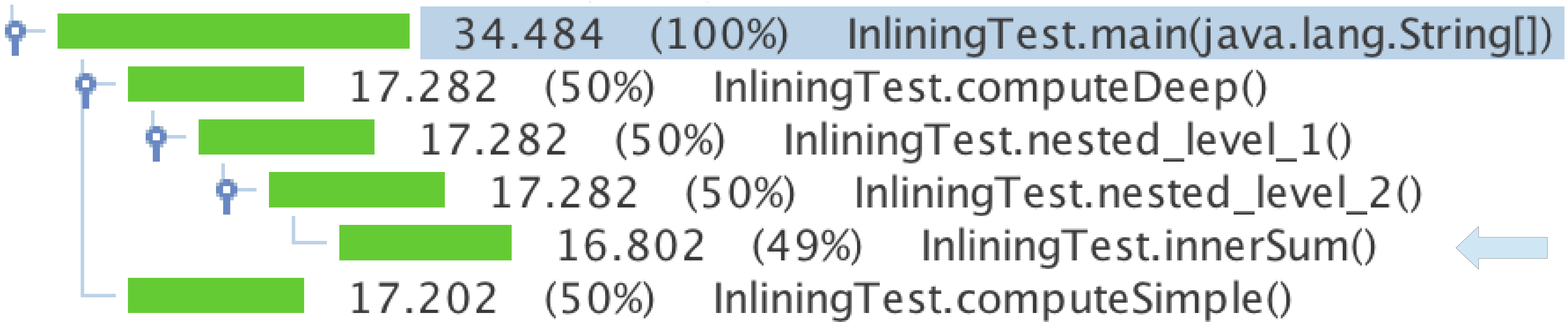
Profiling Accuracy: Calltree (Performance Analyzer)



Compute branches have equal time despite nesting in `computeDeep()`
Performance is the same thanks to JIT compilation

Run time of 34.5 seconds is about the same as run time without data collection

Profiling Accuracy: Expanded Calltree (Performance Analyzer)



Expansion shows time in `computeDeep()` comes from `innerSum()`

Profiling Accuracy: Hot Functions (Performance Analyzer)

Name	Excl. Total CPU (sec.)	Excl. Total CPU (%)
<Total>	34.484	100.00
InliningTest.computeSimple()	17.202	49.88
InliningTest.innerSum()	16.802	48.72
InliningTest.nested_level_2()	0.480	1.39
InliningTest.computeDeep()	0.	0.
InliningTest.main(java.lang.String[])	0.	0.
InliningTest.nested_level_1()	0.	0.

Exclusive Total CPU time (Self time) is split evenly between `innerSum()` and `computeSimple()`

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Understanding Java Execution

- JVM execution is complicated
  - Some code is executed by Interpreter
  - Some code is dynamically constructed into JVM's data space
    - HotSpot-compiled methods; the Interpreter
  - Application has two callstacks: Java callstack and Native callstack
    - Synthesis of the two is required to give a true callstack in the user's model
  - JVM consumes resources
    - Garbage Collection: induces stalls in user Java code execution
    - Many threads on CPU (User and JVM System threads)
  - Safepoints during execution can induce sampling bias

Profiler must deal with all these complications

The Studio Performance Analyzer

- A set of tools for collecting and examining performance data
- Runs on Linux and Solaris, x86 and SPARC
- Collects data on a wide variety of applications
  - Supports C, C++, Fortran, Java, OpenMP, MPI
  - Can deal with complex enterprise-scale applications
- GUI and command-line interfaces
  - Many views of the data are available
  - Drill down by filtering in each view
    - Timeline, Processes, Threads, Functions, Memory Pages, ...

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Performance Analyzer Goals

- Collect accurate data
  - Use internal JVM interfaces, captures inlined methods
  - Avoid sampling-bias with respect to safepoints
- Show Java source-level abstraction and hardware-level execution
  - Show source code line-level metrics
  - Allow seamless navigation between Java and JNI/Native code
  - Present data at the bytecode level for user Java
  - Present data at machine-code level for HotSpot-compiled methods and the JVM
- Expose internal JVM activity that uses resources
  - HotSpot compilation, Garbage collection, *etc.*

Java Source-Level Visualization (“User-mode”)

- Show user-Java threads only
  - Show complete Java callstack
    - Show all Java methods, even methods inlined by JIT
    - Show native portion of mixed Java/Native JNI callstacks
  - For Disassembly of Java, show bytecode
- Account for cases where Java stack cannot be unwound by JVM
  - Typically happens less than 3% of the time
  - Time attributed to `<no Java callstack recorded>`
  - Preferable to throwing away or deferring a sample
- Account for time in JVM runtime as `<JVM-System>`

Machine-Level Visualization ("Machine-mode")

Show what really happened...

- Show all versions of JIT compiled methods separately
  - Show `Interpreter` for interpreted methods
- Show all threads, both user-Java and JVM-internal
  - System threads identified by functions in callstack
    - Garbage collector
    - HotSpot compiler
- For Disassembly, show machine code

Understanding Java Execution: Source View, I

```
 (sec.)     (%)     Load Object: InliningTest.class (found as          experiments.demos/1509
 0.         0.      public class InliningTest {
                    <Function: InliningTest.<init>()>
                        public static void main(String[] args) {
 0.         0.              InliningTest test = new InliningTest();
                    <Function: InliningTest.main(java.lang.String[])>
 0.         0.              for (int i = 0; i < 20; i++) {
17.202     49.50                test.computeSimple();
17.282     49.73                test.computeDeep();
                            }
 0.         0.          }
                    // - computeSimple() - Computes a sum in a triply nested loop
 0.         0.          public double sum = 0.0;
                        public void computeSimple() {
 0.         0.              for (int i = 0; i < 1000; i++) {                    // outer
                    <Function: InliningTest.computeSimple()>
 0.         0.                  for (int j = 0; j < 1000; j++) {                // middle
 0.300      0.86                    for (int k = 0; k < 1000; k++) {            // inner
16.902     48.63                        sum += 1.0;            // ~48% of time // sum
                                    }
                                }
                            }
 0.         0.          }
```

Equal time spent in `computeSimple()` and `computeDeep()`

Hot line in `computeSimple()` shown

Understanding Java Execution: Source View, II

(sec.)	(%)	Load Object: InliningTest.class (found as experiments.demos/1509
		21. // – computeDeep() – Computes the same sum, but implements the
		22. // outer, middle, and inner loops as nested methods.
0.	0.	23. public double sum_deep = 0.0;
		24. public void computeDeep() {
17.282	49.73	25. for (int i = 0; i < 1000; i++) { nested_level_1(); } // outer
		<Function: InliningTest.computeDeep()>
0.	0.	26. }
		27. private void nested_level_1() {
17.282	49.73	28. for (int i = 0; i < 1000; i++) { nested_level_2(); } // middle
		<Function: InliningTest.nested_level_1()>
0.	0.	29. }
		30. private void nested_level_2() {
17.282	49.73	31. for (int i = 0; i < 1000; i++) { innerSum(); } // inner
		<Function: InliningTest.nested_level_2()>
0.	0.	32. }
		33. private void innerSum() {
16.802	48.34	34. sum_deep += 1.0; // ~48% of time // sum
		<Function: InliningTest.innerSum()>
0.	0.	35. }
		36. }

Correct data on each source line

Understanding Java Execution: Bytecode

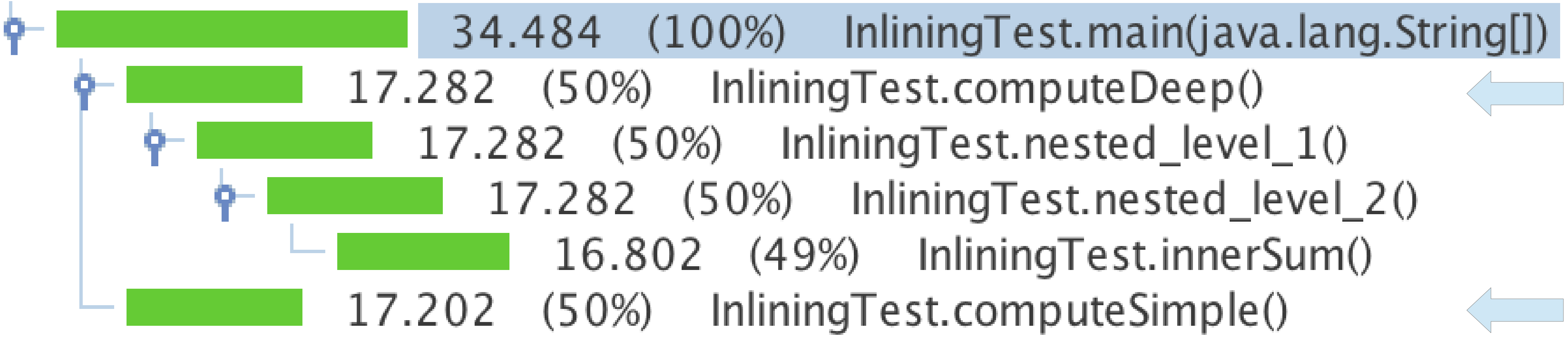
(sec.)	(%)	Load Object: InliningTest.class (found as experiments.demos/1509.
		33. private void innerSum() {
		34. sum_deep += 1.0; // ~48% of time // sum
		<Function: InliningTest.innerSum()>
0.	0.	[34] 00000000: aload_0
0.	0.	[34] 00000001: dup
0.030	0.00	[34] 00000002: getfield #3
0.	0.	[34] 00000005: dconst_1
15.621	0.00	[34] 00000006: dadd
1.151	0.00	[34] 00000007: putfield #3
		35. }
0.	0.	[35] 0000000a: return
		36. }

Attr. Total CPU (sec.)	(%)	InliningTest.innerSum() is called by
16.802	100.00	InliningTest.nested_level_2()

Most time on a single bytecode -- `dadd`

Called-by shows `innerSum()` called from `nested_level_2()`

Understanding Java Execution: Calltree, User-mode

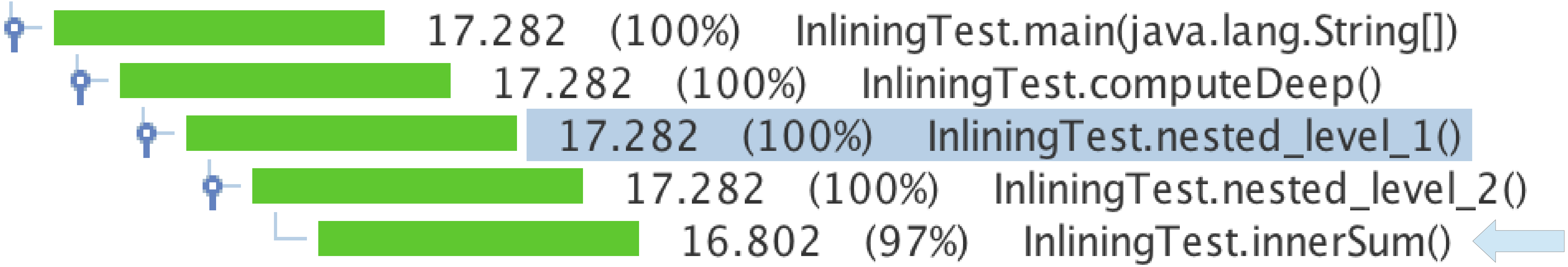


34.48 seconds in `main()` comes from two branches:

17.28 seconds from `computeDeep()`

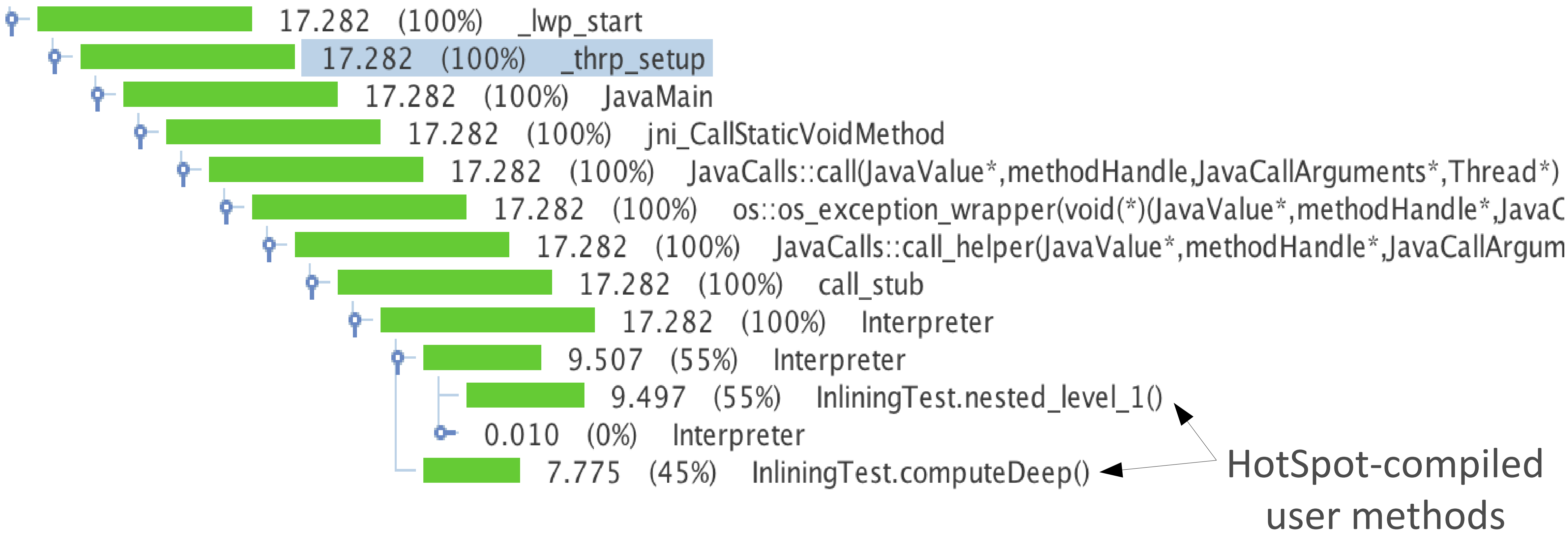
17.20 seconds from `computeSimple()`

Understanding Java Execution: Calltree, User-mode, Filtered



Calltree after filtering to include only callstacks containing `computeDeep()`

Understanding Java Execution: Calltree, Machine Mode, Filtered

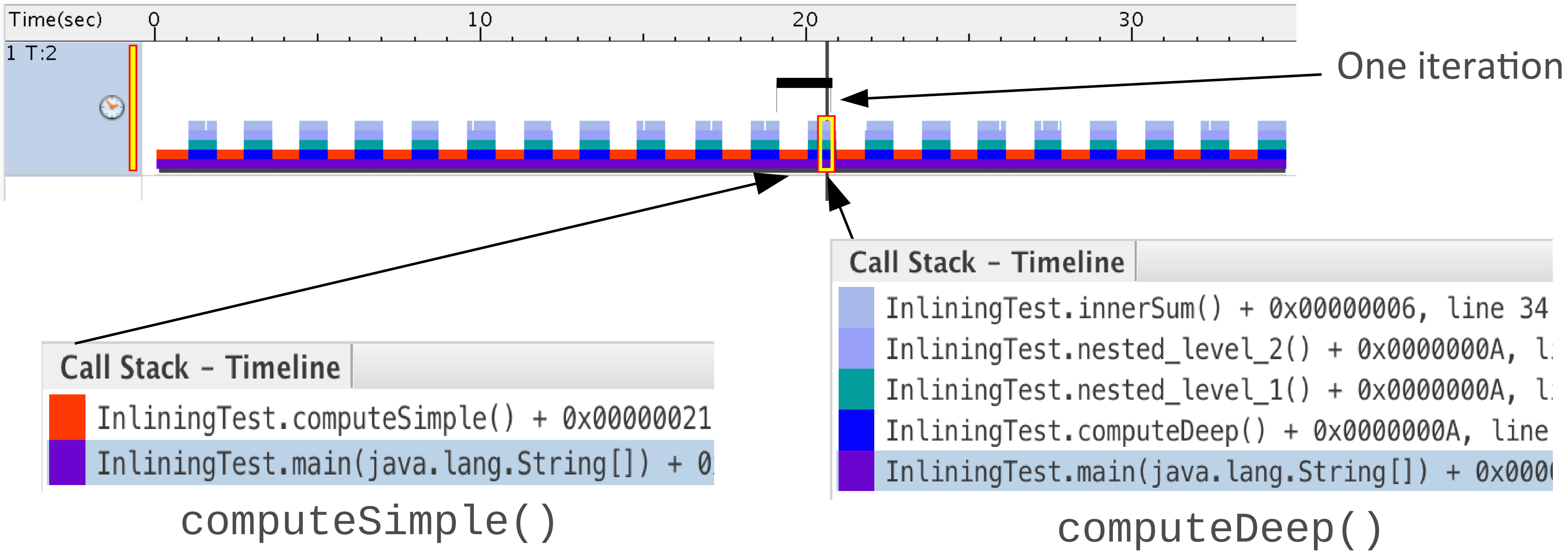


Machine-mode version of previous calltree: what the machine really executed

Only two frames are user methods

Others are in the JVM, from `libc.so`, or in the Java Interpreter

Understanding Java Execution: User-mode Timeline

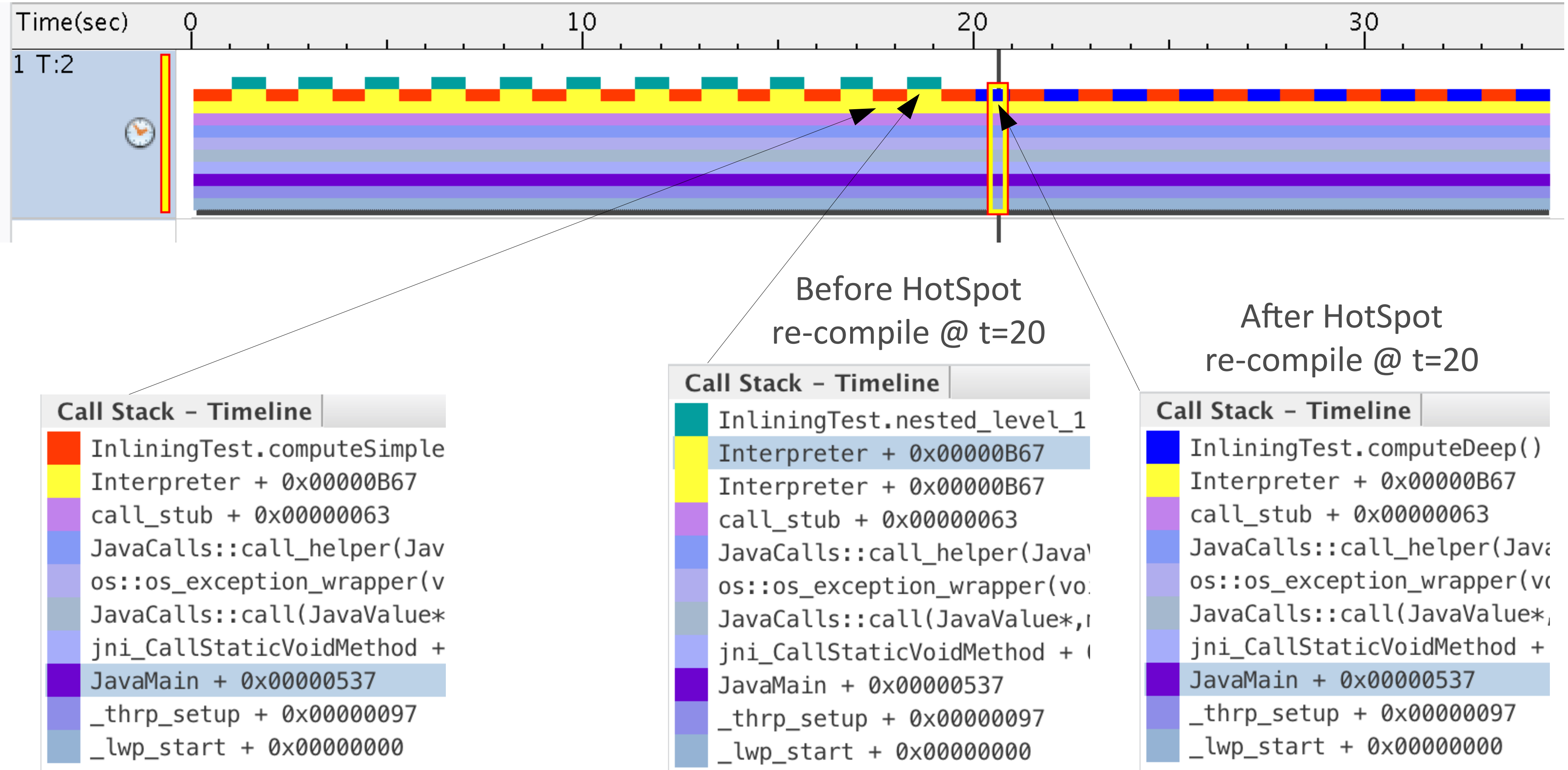


Callstacks shown on timeline

Name of method in each frame color-coded in representation

Twenty iterations of loop in `main()` shown

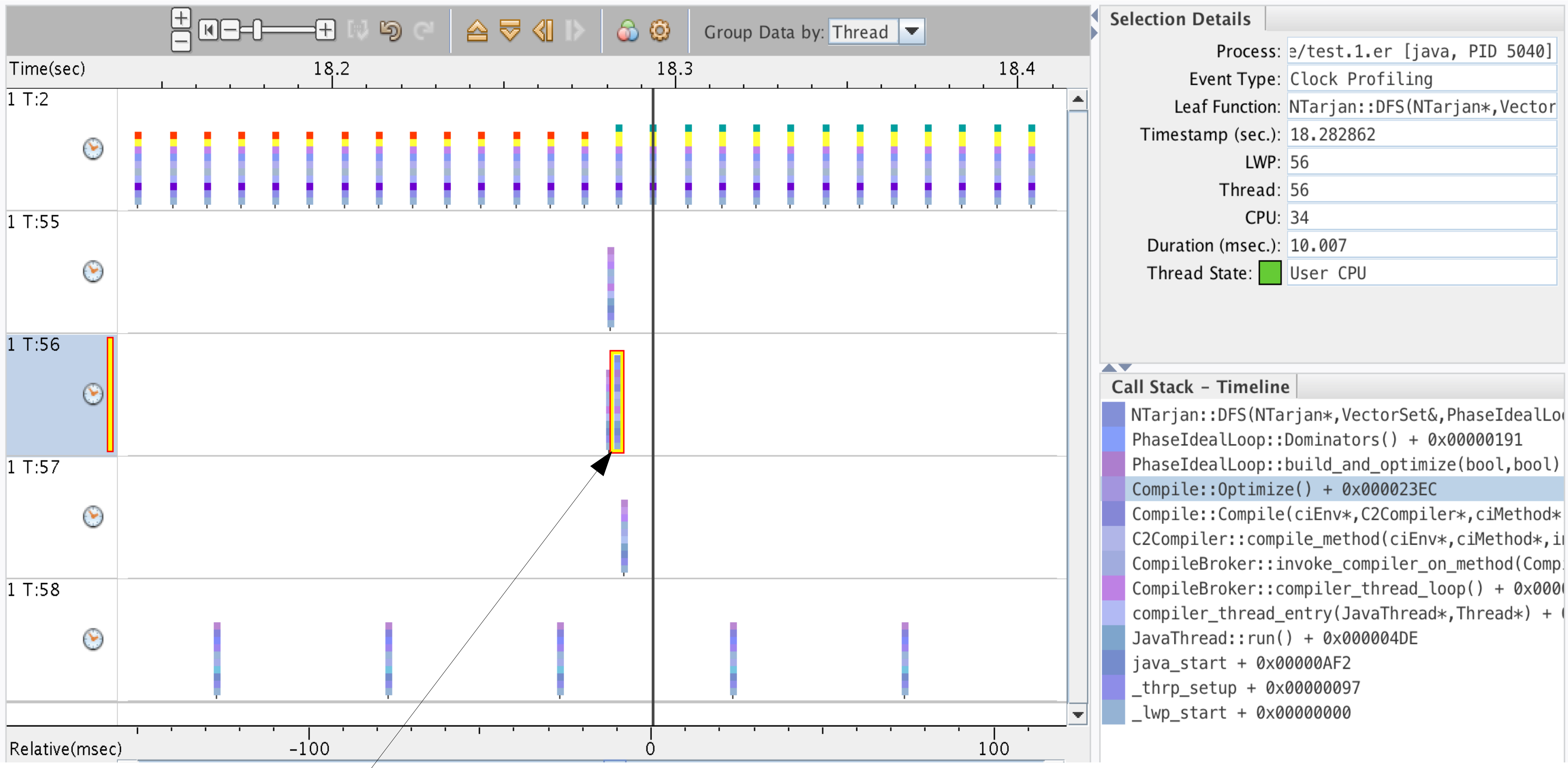
Understanding Java Execution: Machine-mode Timeline



`computeSimple()`

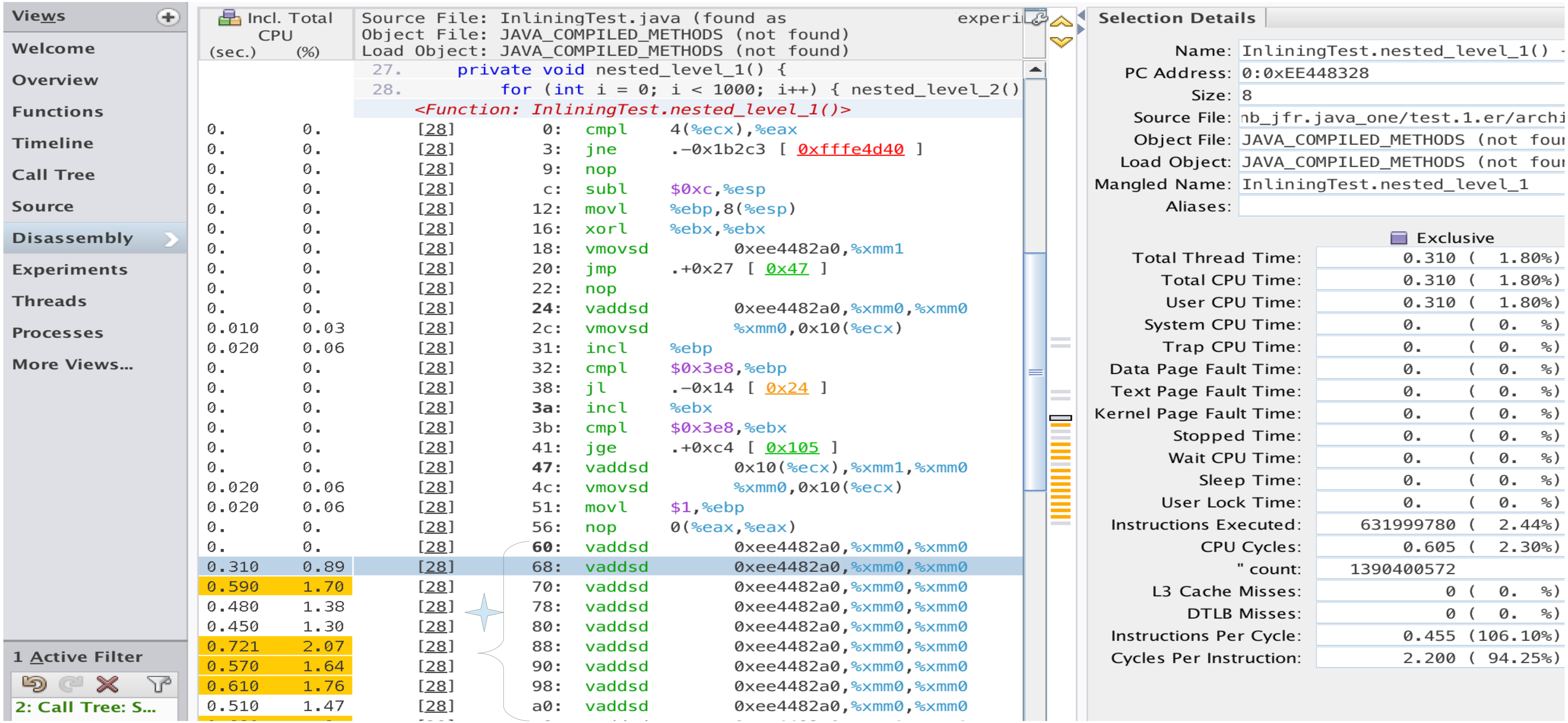
`ComputeDeep()`
`(two machine-stack variants)`

Understanding Java Execution: HotSpot Compilation



Selected event shows when HotSpot re-compile was triggered

Understanding Java Execution: Machine Mode Disassembly



Inner loop has been inlined and unrolled

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Workflow for Identifying Inefficiencies

- Pick a repeatable test case for measurements
- Find the CPU hot-spots: collect performance data
  - What are the hot methods, call-paths, source-lines, instructions?
  - If the CPU pipeline is stalled:
    - If waiting for data: TLB misses, cache misses, memory latency ==> Memory access issues
    - If waiting for instruction completion: floating-point ops, divide, ...?
  - If CPU pipeline is not stalled:
    - If there are high call counts, there is too much overhead in call/return
    - If there is non-productive CPU time, *e.g.*, busy wait on a lock, there is wasted computation
- Fix the performance problems revealed in the data
  - Strategies for improvement depend on the cause

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Finding CPU Pipeline Stalls

- Using HW counters
  - Counters that directly measure stalls
    - Direct (statistical) measurement of time lost
    - SPARC commit-stalls has exactly one instruction skid
      - Useful for memory stalls and other pipeline stalls
  - Computing instructions-per-cycle (IPC) or cycles-per-instruction (CPI)
    - Profile with both instruction-counter and cycle-counter
      - Available on many chips
    - Low IPC or high CPI indicate inefficient use of the machine pipeline
    - Difficult to use to estimate time lost
    - Noisy when measured at source-line or instruction level

Reducing CPU Stalls due to Memory Access

- Memory access stalls include cache-miss and memory latency times
- Stalls can be reduced by:
  - Increasing data density so hot data fits in caches
  - Reducing levels of indirection
  - Co-locating the hot fields of a structure on the same cache-line
  - Fetching data in order to exploit HW pre-fetching

CPU Tuning Example

- An older benchmark code (SPECjbb2005)
  - Note: source changes are not allowed for published benchmark results
- Models a three-tier business system
  - Random input models user transactions for the first tier
  - Application to be measured implements the middle tier
  - Java Collections used for the third tier
  - Benchmark does no disk or network I/O

CPU Tuning Example: Finding a Hot Spot

Total CPU Time		Stall Cycles Time	Lines
EXCLUSIVE sec.	INCLUSIVE sec.	EXCLUSIVE #	Function, line # in "sourcefile"
478.054	478.054	299.348	<Total>
42.029	42.510	40.267	*<Function: java.util.HashMap.getNode(int, java.l*
33.974	69.298	33.012	spec.jbb.Warehouse.retrieveStock(int), line 121
54.428	54.428	17.645	java.util.TreeMap.successor(java.util.TreeMap$Er
12.549	59.301	13.522	spec.jbb.CustomerReportTransaction.process(), li
11.618	11.618	10.456	java.util.TreeMap.successor(java.util.TreeMap$Er
10.677	10.677	10.256	*<Function: java.lang.String.length(), instructic*

Hottest source line

Hot spot in line 121 in method `retrieveStock()`

CPU Tuning Example: Hot Spot in Source

Total CPU Time INCLUSIVE sec.	spec/jbb/Warehouse.java
	119.
	120. public Stock retrieveStock(int inItemId) {
69.298	121. return (Stock) stockTable.get(inItemId);
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
	122. }
	123.

Hot spot in one-line access method

CPU Tuning Example: Hot Spot in Bytecode

Total CPU Time INCLUSIVE sec.	Stall Cycles Time INCLUSIVE #	spec/jbb/Warehouse.java
		119.
		120. public Stock retrieveStock(int inItemId) {
		121. return (Stock) stockTable.get(inItemId);
		<Function: spec.jbb.Warehouse.retrieveStock(int)>
0.	0.	[121] 00000000: aload_0
3.472	3.689	[121] 00000001: getfield #8
0.	0.	[121] 00000004: iload_1
0.751	0.189	[121] 00000005: invokestatic valueOf()
36.486	34.645	[121] 00000008: invokeinterface #29, 2) #29
28.590	27.789	[121] 0000000d: checkcast spec.jbb.Stock
0.	0.	[121] 00000010: areturn
		122. }
		123.

Total C... ATTRIBUTED sec.	spec.jbb.Warehouse.retrieveStock(int) calls
34.584	spec.jbb.MapDataStorage.get(java.lang.Object)
0.741	java.lang.Integer.valueOf(int)

35 stall seconds on `invokeinterface` bytecode; call goes to two places

Most time attributed to `MapDataStorage.get()` call

CPU Tuning Example: Hot Spot due to Memory Access

- Data structure being referenced is in `stockTable()`
  - Underlying data structure is `MapDataStorage()`
    - It is based on `HashMap()` class
    - Index is consecutive integers
- Choice of storage class can be critical for performance
  - In this particular case, replace `HashMap()` with `ArrayList()`
    - Optimization 1

CPU Tuning Example: Effect of Optimization 1

Before

Total CPU Time INCLUSIVE sec.	spec/jbb/Warehouse.java
	119.
	120. public Stock retrieveStock(int inItemId) {
69.298	121. return (Stock) stockTable.get(inItemId);
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
	122. }
	123.

After

Total CPU Time INCLUSIVE sec.	spec/jbb/Warehouse.java
	119.
	120. public Stock retrieveStock(int inItemId) {
45.512	121. return (Stock) stockTable.get(inItemId);
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
	122. }
	123.

Improvement of overall application time of ~18%

CPU Tuning Example: Type Casting

Total CPU Time INCLUSIVE sec.	spec/jbb/Warehouse.java
	119.
	120. public Stock retrieveStock(int inItemId) {
	121. return (Stock) stockTable.get(inItemId);
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
0.	[121] 00000000: aload_0
3.753	[121] 00000001: getfield #8
0.	[121] 00000004: iload_1
0.610	[121] 00000005: invokestatic valueOf()
2.522	[121] 00000008: invokeinterface #29, 2) #29
38.627	[121] 0000000d: checkcast spec.jbb.Stock
0.	[121] 00000010: areturn
	122. }
	123.

`checkcast` bytecode verifies a cast, taking ~39 seconds

Type-safety for Java Generics comes at a cost

Optimization 2: replace `stockTable.get(id)` with `stockTable[id]`

CPU Tuning Example: Effect of Optimization 2, I

Before

	120. public Stock retrieveStock(int inItemId) {
	121. return (Stock) stockTable.get(inItemId);
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
0.	[121] 00000000: aload_0
3.753	[121] 00000001: getfield #8
0.	[121] 00000004: iload_1
0.610	[121] 00000005: invokestatic valueOf()
2.522	[121] 00000008: invokeinterface #29, 2} #29
38.627	[121] 0000000d: checkcast spec.jbb.Stock
0.	[121] 00000010: areturn
	122. }

After

	123. public Stock retrieveStock(int inItemId) {
	124. return stockTable[inItemId];
	<Function: spec.jbb.Warehouse.retrieveStock(int)>
0.	[124] 00000000: aload_0
4.313	[124] 00000001: getfield #7
0.	[124] 00000004: iload_1
0.340	[124] 00000005: aaload
0.	[124] 00000006: areturn
	125. }

Time in `checkcast` is gone…

…but overall throughput did not change much!

JavaOne ORACLE

CPU Tuning Example: Effect of Optimization 2, II

Before

Total CPU Time INCLUSIVE sec.	Stall Cycles Time INCLUSIVE #	spec/jbb/DeliveryTransaction.java	
3.502	3.256	140.	`int itemId = orderline.getItemId();`
41.239	39.578	141.	`Stock stock = warehousePtr.retrieveStock(itemId);`
3.492	2.478	142.	`int availableQuantity = stock.getQuantity();`
0.140	0.067	143.	`if (availableQuantity >= requiredQuantity) {`
0.580	0.378	144.	`stock.changeQuantity(-requiredQuantity);`
0.	0.022	145.	`break;`
		146.	`}`

After

Total CPU Time INCLUSIVE sec.	Stall Cycles Time INCLUSIVE #	spec/jbb/DeliveryTransaction.java	
3.562	3.311	140.	`int itemId = orderline.getItemId();`
0.360	0.211	141.	`Stock stock = warehousePtr.retrieveStock(itemId);`
34.624	33.489	142.	`int availableQuantity = stock.getQuantity();`
0.050	0.011	143.	`if (availableQuantity >= requiredQuantity) {`
0.430	0.411	144.	`stock.changeQuantity(-requiredQuantity);`
0.	0.	145.	`break;`
		146.	`}`

Stall time has moved to caller line 142!

Stall was due to first-touch cache miss; stalls simply moved to the next access

Lessons from the CPU Tuning Example

- Using a more efficient storage class saved 18%
  - Replaced `HashMap()` with `ArrayList()`
- Eliminating an expensive type check did not help
  - Memory access cost moved, but did not go away
  - CPU hardware counters can be used to confirm cache misses
- Memory latency can dwarf other inefficiencies

- Understanding can not be achieved without good tools!

When to consider Studio Performance Analyzer

- General CPU-time performance tuning
  - Java and Native (C, C++, Fortran)
- To measure real behavior of production code, production-scale runs
- To drill-down with views and filtering
- For Linux and Solaris
  - Supports cross-platform Linux/Solaris and x86/SPARC analysis
  - Supports remote analysis with GUI on Windows and MacOS

Advantages of Performance Analyzer Approach

- Collects accurate data
  - Uses internal JVM interfaces, captures inlined methods
  - Avoids sampling-bias with respect to safepoints
- Shows Java source-level abstraction and hardware-level execution
  - Shows source code line-level metrics
  - Allows seamless navigation between Java and JNI/Native code
  - Presents data at the bytecode level for user Java
  - Presents data at machine-code level for HotSpot-compiled methods and the JVM
- Exposes internal JVM activity that uses resources
  - HotSpot compilation, Garbage collection, *etc.*

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For More Information

- Studio Website
  - http://www.oracle.com/technetwork/server-storage/solarisstudio/overview/index.html
- Community
  - http://www.oracle.com/technetwork/server-storage/solarisstudio/community/index.html
- Related Sessions
  - CON 8216: Inoculating Software, Boosting Quality: SAS & Oracle Experience with Application Data Integrity
    - Maureen Chew, Chandra Garud, and Sheldon Lobo
  - CON 8337: Developer Cloud Made Simple: How to Build an OpenStack Developer Cloud
    - Deepankar Bairagi, Liang Chen, and Nasser Nouri

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