Client Compiler for the Java HotSpot™ Virtual Machine

Technology and Application

Tom Rodriguez, Ken Russell
Sun Microsystems, Inc.

Overall Presentation Goal

Learn about compilation in the Java HotSpot™ Virtual Machine, and the Client Compiler

Understand how the Client Compiler deals with specific Java™ programming language features

Get to know tuning and trouble-shooting techniques

Learning Objectives

- As a result of this presentation, you will be able to:
  - Understand "Java HotSpot compilation"
  - Write better code in the Java programming language
  - Improve the performance of your applications
  - See what's new in 1.4 and what's coming

Speaker's Qualifications

- Tom Rodriguez is the technical lead for the Java HotSpot Client Compiler
- Ken Russell has worked on the Java HotSpot runtime and compiler for over two years

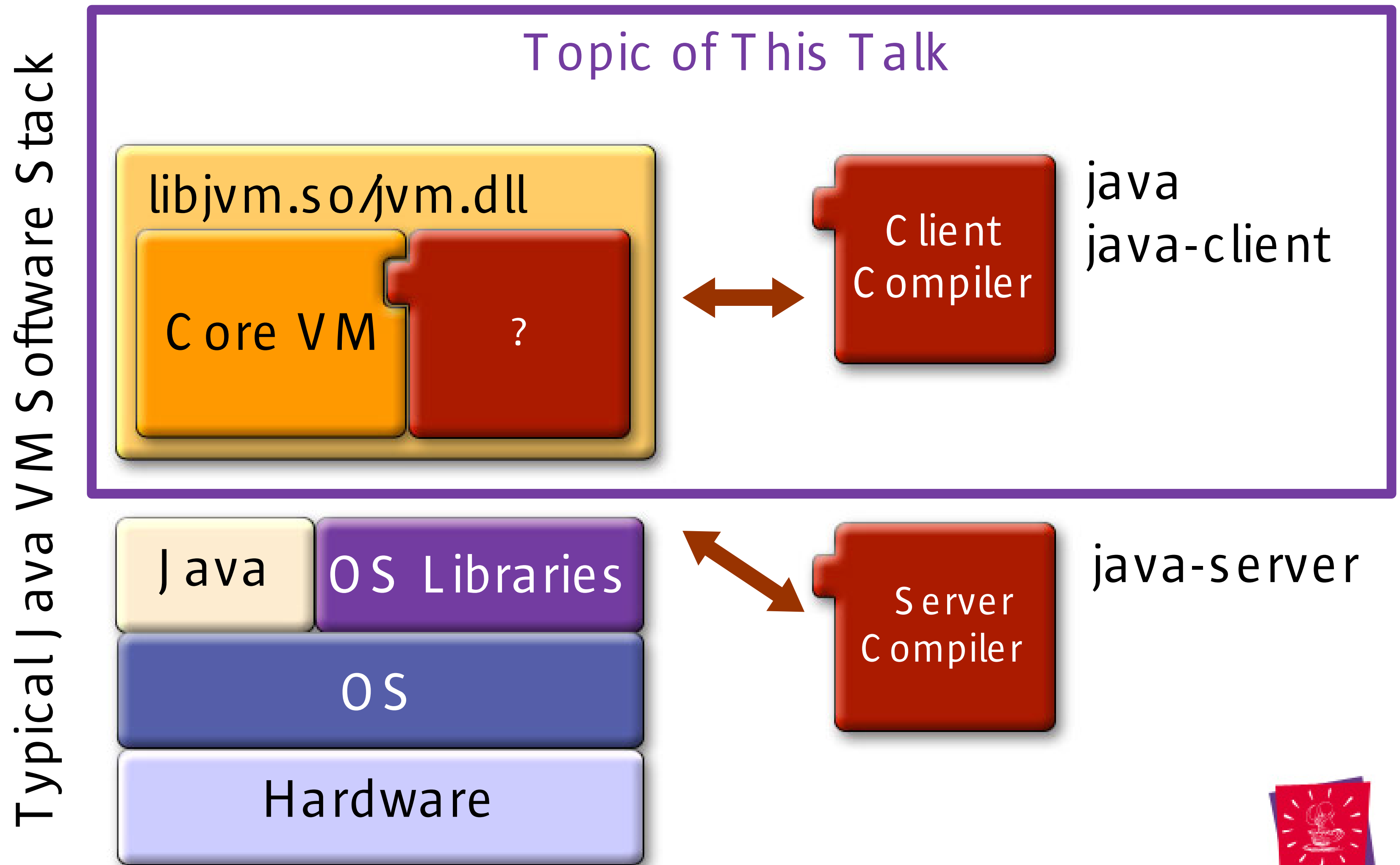
Presentation Agenda

- Compilation in the Java HotSpot™ VM
- Structure of the Client Compiler
- Implications for Code written in the Java™ Programming Language
- Miscellaneous
- Summary
- Q&A

Compilation in the Java HotSpot™ VM

- VM Configurations
- Compilation Steps
- On-Stack Replacement
- Class Hierarchy Analysis
- Deoptimization
- Quick Summary

VM Configurations



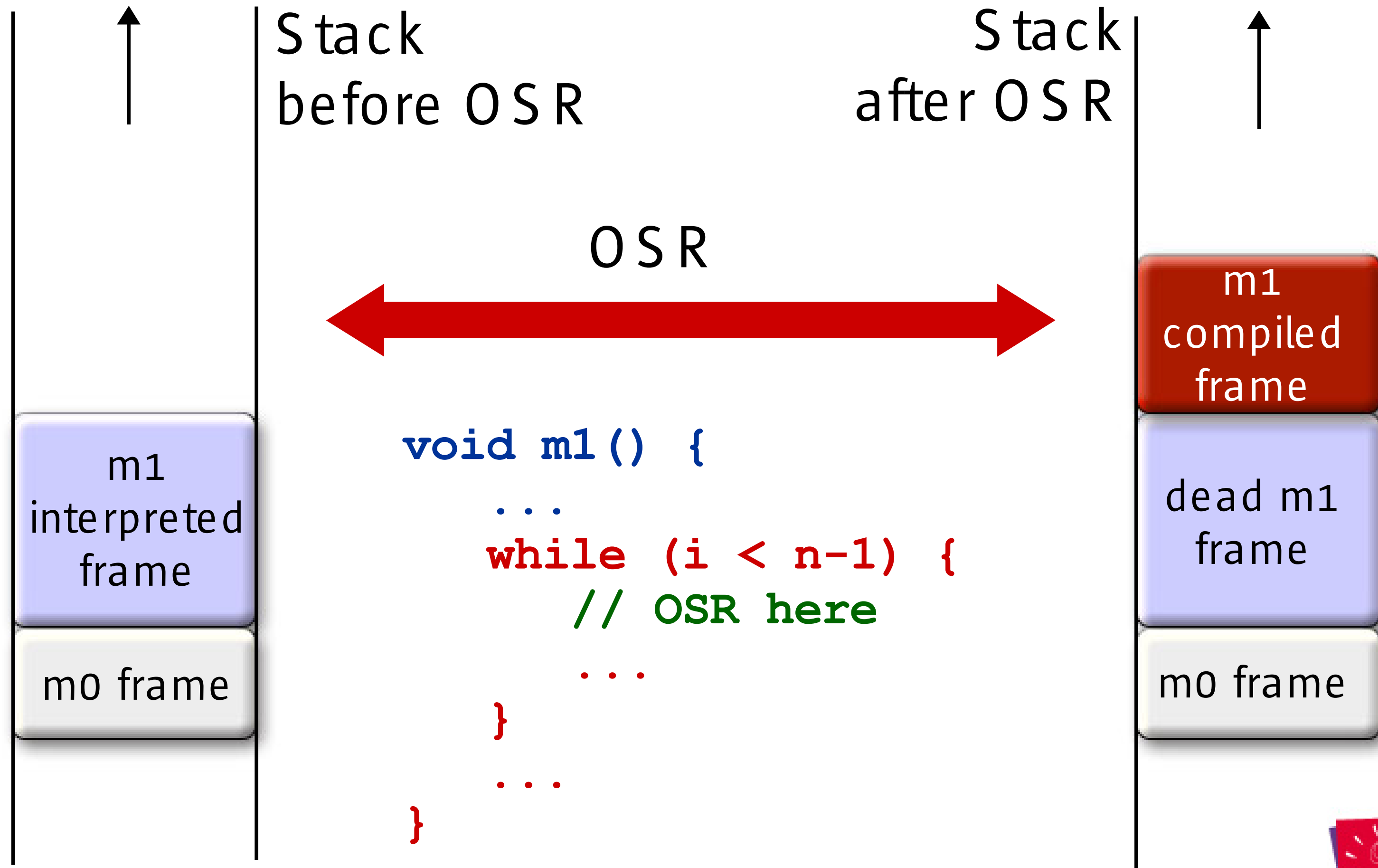
Compilation Steps

- Every method is interpreted first
- Hot methods are scheduled for compilation
  - Method invocations
  - Loops
- Compilation can be foreground/background
  - Foreground compilation default for Client VM
  - Background compilation in parallel

On-Stack Replacement (1)

- Choice between interpreted/compiled execution
- Problem with long-running interpreted methods
  - Loops!
- Need to switch to compiled method in the middle of interpreted method execution
  - On-Stack Replacement (OSR)

On-Stack Replacement (2)



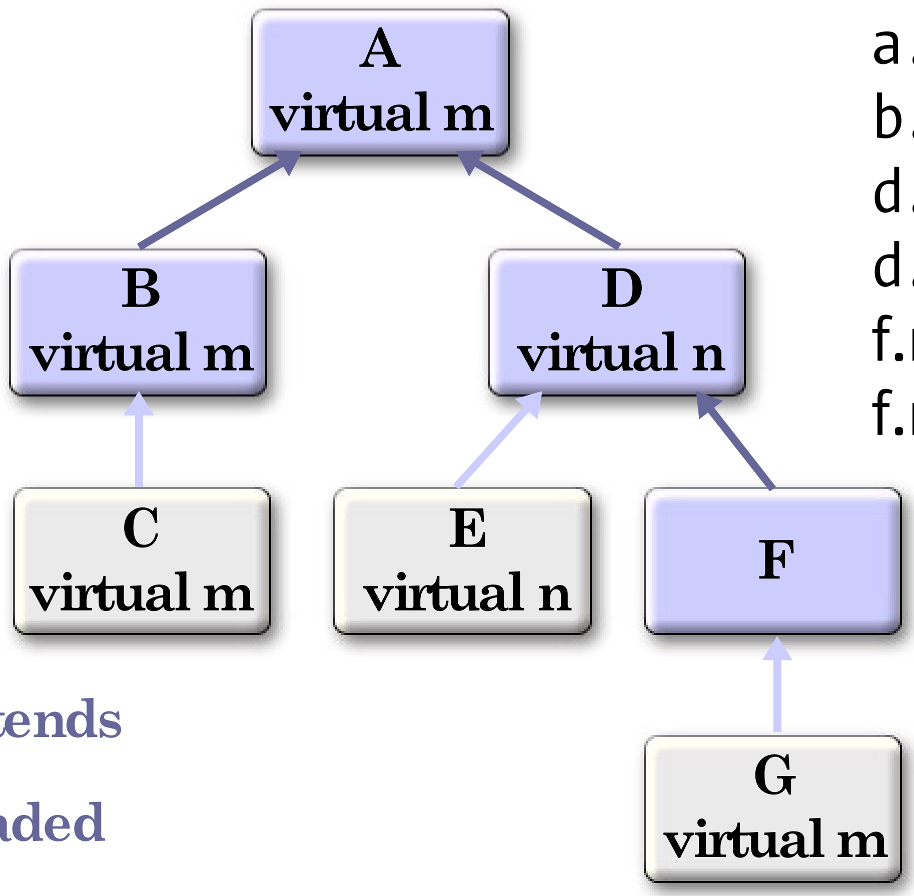

```
void m1() {
    ...
    while (i < n-1) {
        // OSR here
        ...
    }
    ...
}
```

Class Hierarchy Analysis (1)

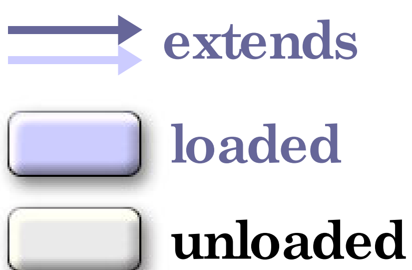
- Dynamic pruning of receiver class set
  - Static calls instead of virtual calls
  - Inlining across virtual calls
  - Faster type tests
- Class Hierarchy Analysis (CHA)
  - Analysis of loaded classes
  - Can change over time
  - Effective

Class Hierarchy Analysis (2)

```
A a;
B b;
C c;
D d;
E e;
F f;
G g;
```



a.m → A.m, B.m
b.m → B.m
d.m → A.m
d.n → D.n
f.m → A.m
f.n → D.n



Deoptimization (1)

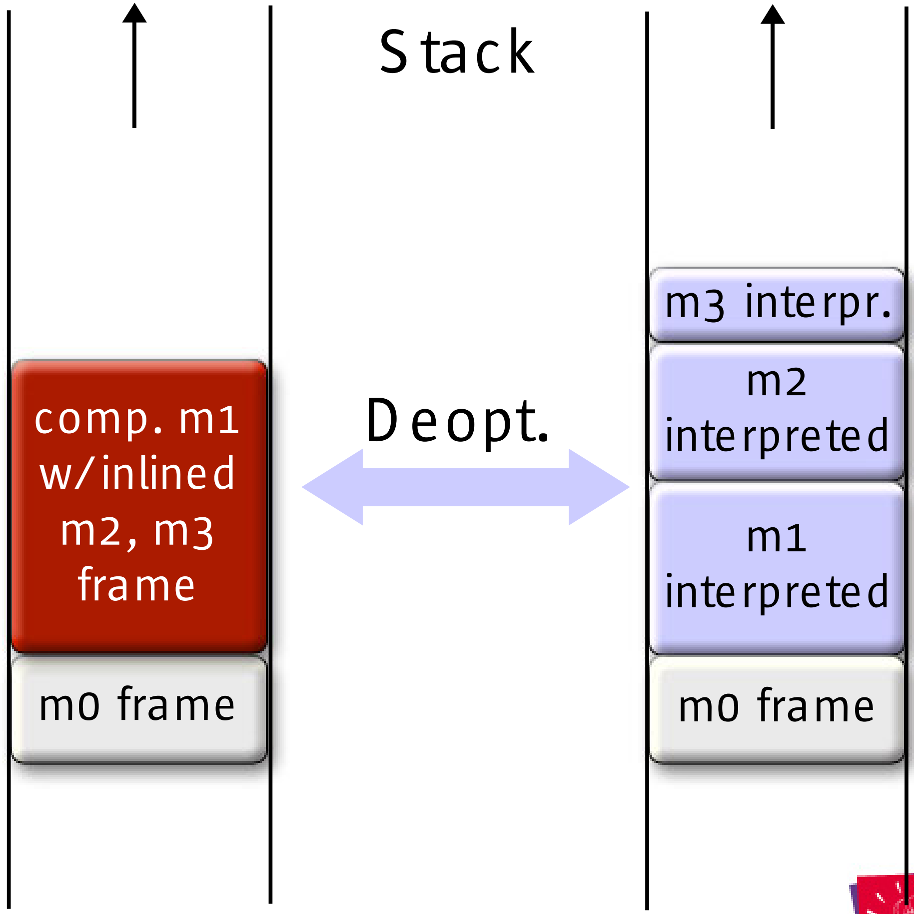
- Compile-time assumptions may become invalid over time
  - Class loading
- Debugging of program desired
  - Single-stepping
- Active compiled methods become invalid
- Need to switch to interpreted method in the middle of compiled method execution
  - Deoptimization

Deoptimization (2)

```
T3 m3(...) {
     ...
     // Deopt. here
}

T2 m2(...) {
     m3(...);
}

T1 m1() {
     ...
     m2(...);
     ...
}
```



Quick Summary

- Client VM differs from Server VM in compiler
- Hotspots trigger compilation
  - Compiled method invocation
  - OSR
- Class loading, debugging changes compile-time assumptions
  - Deoptimization

What's New in 1.4

- Low-level Intermediate Representation
- Deoptimization
- Inlining
- Improved Debugging and Profiling Support

Deoptimization and Inlining

- 1.3.x client compiler inlined simple accessors
- 1.4 uses deoptimization and CHA
  - More inlining possibilities
- 1.4.0 client compiler does not inline:
  - Methods with exception handlers
  - Synchronized methods

Improved Debugging and Profiling

- Full-speed debugging
  - Compiler no longer disabled when using debuggers (-Xdebug)
  - Application runs at full speed
    - Breakpoint setting causes deoptimization
  - Server compiler support coming in 1.4.1
- Profiling
  - Substantial work on JVMPI robustness
  - Existing tools work much better with 1.4

Structure of the Client Compiler

- Representation of bytecodes
- Frontend
- Backend
- Machine code generation

Representation of Code

- High Level Intermediate (HIR)
  - Closely mimics bytecode
  - Directed graph to enforce evaluation order
- Low Level Intermediate (LIR)
  - Close to machine instructions
  - Some high level instructions
    - Virtual calls
    - Type checks
    - Intrinsics

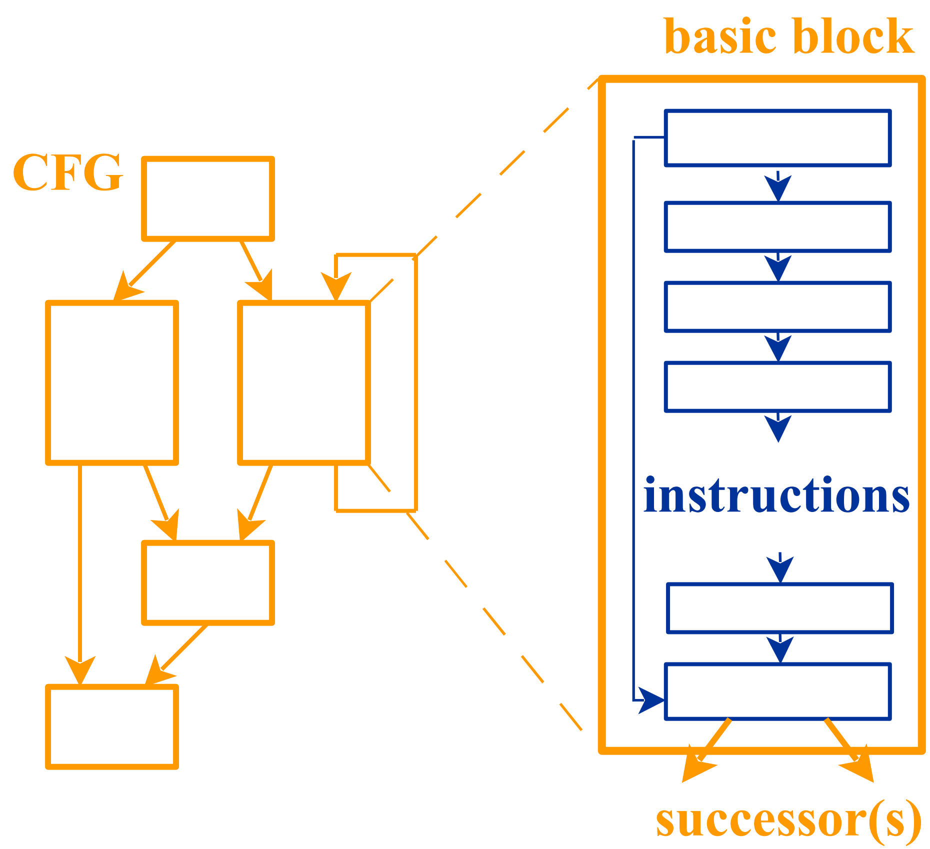
Frontend

- Parse bytecodes into HIR
  - Eliminate loads (copy propagation)
  - Local value numbering
  - Constant folding and identities
  - Inline
  - Use CHA to optimize calls
- Global Optimizations
  - Block merging
  - Eliminate null checks

Intermediate Representation

Bytecodes

```
 0 aload_1
 1 bipush 46
 3 invokevirtual #139
 6 istore_2
 7 iload_2
 8 ifgt 18
11 aload_0
12 getfield #2
15 invokevirtual #93
18 aload_1
19 iconst_0
20 ...
```



Backend

- Generate LIR by walking HIR
  - Expression level register allocation
- Optimize LIR
  - Assign locals to registers
    - Loop focused
  - Peephole optimizer
- Emit machine code from LIR
  - Generate object maps for use by GC
  - Generate information for deoptimization

JavaOne

Code Generation

LIR:

```
 label  [label:0x8176838]
  move  [edi|I] [eax|I]
  move  [int:4|I] [esi|I]
  idiv  [eax|I] [esi|I]
        [edx|I] [eax|I] [bci:8]
   cmp  [eax|I] [int:0|I]
  move  [int:0|I] [esi|I]
branch  [NE] [label:0x8182d60]
  move  [int:1|I] [esi|I]
 label  [label:0x8182d60]
  move  [esi|I] [eax|I]
return  [eax|I]
```

Machine code:

```
movl    %edi,%eax
movl    0x4,%esi
cmpl    0x80000000,%eax
jne     -0x252e6b7b
xorl    %edx,%edx
cmpl    -1,%esi
je      -0x252e6b78
cltd
idivl   %esi,%eax
cmpl    0,%eax
movl    0x0,%esi
jne     -0x252e6b65
movl    0x1,%esi
movl    %esi,%eax
movl    %ebp,%esp
popl    %ebp
ret
```

Quick Summary

- Frontend does
  - Parse and analyze bytecodes
  - Build and optimize IR
  - Use CHA for very effective OO optimizations
  - Reorder CFG for code generation
- Backend does
  - LIR
  - Register allocation, low-level optimizations
  - Code generation

Implications for Code Written in the Java™ Programming Language

- Accessors
- Usage of **`final`**
- Object Allocation (**`new`**)
- Exception Handling
- Other Issues
- Quick Summary

Accessors

- Use accessors
  - `XType getX()           { return _x; }`
  - `void setX(XType x) { _x = x; }`
- Abstracts from implementation
- Easier to maintain
- No performance penalty
  - Inlining!

Usage of `final`

- Don't use **`final`** for performance tuning
- CHA will do the work
  - Where CHA can't do it, **`final`** doesn't help either
- Keep software extensible
- No performance penalty
  - Static calls
  - Inlining

Object Allocation (new)

- Object allocation (**`new`**) inlined
  - Works in most cases
  - Extremely fast (~ 10-20 clock cycles)
- Do not manage memory yourself
  - GC will slow down
  - Larger memory footprint
- Keep software simple

Exception Handling

- Exception object creation is very expensive
- Exception handling is not optimized
  - Use it for exceptional situations
  - Don't use it as programming paradigm
  - Don't use instead of regular **`return`**
- Exception handling costs only when used
  - Safe to declare exceptions
- If you must use exceptions for control flow:
  - Preallocate exception object

Other Issues

- Client Compiler optimized for clean OO code
  - "Hand-tuning" often counterproductive
  - Generated code can be problematic
    - Obfuscators
- Do not optimize prematurely
  - Use profiling information

Quick Summary

- Write clean OO code
  - Use accessors
  - Use **`final`** by design only
  - Use **`new`** for object allocation
  - Use exception handling for exceptional cases
- Keep it simple, keep it clean

Miscellaneous

- Built-in Profiler
- When to use the Client Compiler
- What's coming in 1.4.1
- Quick Summary

Built-In Profiler

- Option: -Xprof
  - E.g.: java -Xprof -jar Java2Demo.jar
- Statistical (sampling) flat profiler
  - Not hierarchical
- Per thread
  - Output when thread terminates

Sample Profiler Output

```
Flat profile of 27.38 secs (2574 total ticks): AWT-EventQueue-0

  Interpreted + native   Method
  7.2%        0  +    90   sun.java2d.loops.Blit.Blit
  0.7%        0  +     9   sun.awt.windows.Win32BlitLoops.Blit
  ...
 19.8%       72  +   174   Total interpreted (including elided)

     Compiled + native   Method
  9.2%      115  +     0   java.awt.GradientPaintContext.clip...
  ...
 15.0%      179  +     8   Total compiled (including elided)

  Thread-local ticks:
 51.7%     1330            Blocked (of total)
  0.2%        2            Class loader
  0.3%        4            Interpreter
 10.0%      124            Compilation
  0.5%        6            Unknown: running frame
  0.2%        2            Unknown: thread_state
```

When to Use the Client Compiler

- Client Compiler characteristics
  - Fast compilation
    - Quick startup time
  - Small footprint
- Use for apps with same expectations
- Recommendation
  - Try client and server, choose best
    - java -client
    - java -server

What's New in 1.4.1

- Better peephole optimization
- Reduced footprint for compiled code
- New fast subtype check
- Inlining of jsrs
- Improved exception handling
  - Better full-speed debugging
- Reduced footprint on the Solaris™ OE

Overall Summary

- Compilation with the Java HotSpot™ VM
- Client Compiler Internals
- Programming and Tuning Hints

References

- Robert Griesemer, Srdjan Mitrovic: "A Compiler for the Java HotSpot™ Virtual Machine", in *The School of Niklaus Wirth— The Art of Simplicity*, Morgan Kaufmann Publishers, 2000, ISBN 1-55860-723-4
- Java HotSpot™ Technology Documents, http://java.sun.com/products/hotspot/2.0/docs.html

Demo

Q&A

JavaOne[SM]

Sun's 2002 Worldwide Java Developer Conference

BEYOND BOUNDARIES

Session 3198