Java Just-in-Time Compilation

Seminar: Java vs. C++

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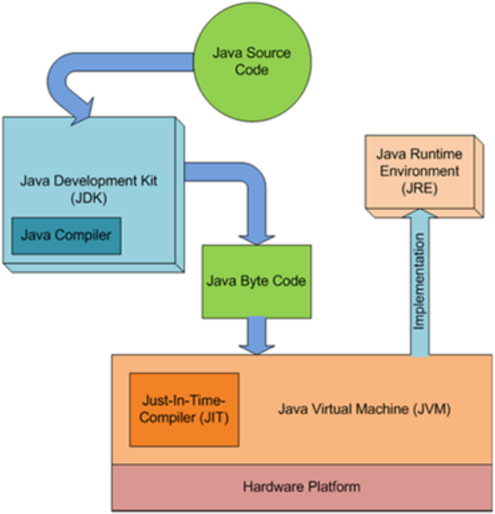
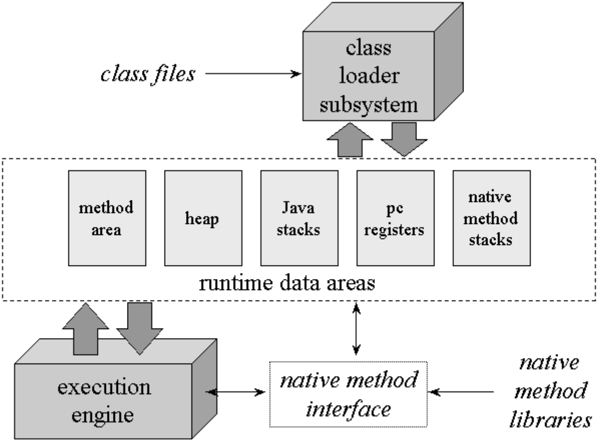
Outline

Overview – the Java components



JVM internal architecture



Execution Engine

- behavior is defined in terms of an instruction set (bytecode)
- specification describes in detail `what` todo but little about `how`

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How could an implementation execute bytecode?

- interpret
- just-in-time compile
- execute natively in silicon
- use a combination of these
- or ... maybe someone comes up with some new techniques

Recall Compiler Structure

Frontend

1. lexical analysis (scanner)
2. syntactical analysis (parser)
3. semantical analysis

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Backend

1. generate intermediate representation (IR)
2. optimization
3. assembly code generation

Interpreter

Does only the frontend part

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- syntactical analysis (parser)
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Workflow

- reads bytecode by bytecode in a loop
- calls function associated to op-code
- or use TemplateTable (openJDK)

TemplateTable – Interpreter

- the interpreter is generated at runtime
- there are two dispatch tables
- 1. is the normal mode table
- 2. is used to bring interpreter to a safepoint
  (e.g. when a GC should be made, or synchronization)
- TT holds generator functions for each kind of bytecode
- per bytecode generate and dispatch assembly code

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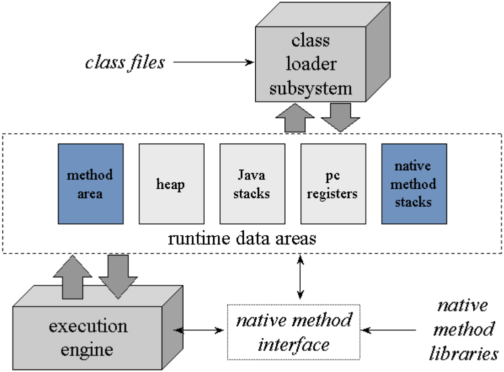
Code example – generator function

```
void TemplateTable::iconst(int value) {
 transition(vtos, itos);
 if (value == 0) { __xorl(rax, rax);
 } else { __movl(rax, value);
}}
```

Just-In-Time Compiler



- compiles bytecode to assembly
- compiles per method
- dynamic bind compiled code

Recall – Method Area

Stores method information

- the method's name
- the method's return type (or void)
- the number and types (in order) of the method's parameters
- the method's modifiers (some subset of public, private, protected, static, final, synchronized, `native`, abstract)
- the method's bytecode (in case modifier is not native or abstract)

Problems

Interpreter

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Just-in-time compiler

- tradeoff compilationtime vs. runtime

Combination – Adaptive Compilation

Workflow of the Sun HotspotVM

1. interpreting bytecode
2. profiles code-usage
3. find hotspots
4. just-in-time compile hotspot code while still interpreting
5. caching compiled code
6. switching to/reuse compiled code

Hot Spot Detection

Hotspots

- application spends 80% of time in 20% of code
- compilation from many loop-iteration on
- compilation from many method-calls on
- many $:=$ 10.000

Method Inlining

What does it do?

- replace method call with corresponding method block

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And why?

- JIT compilation is performed per method
- for small method reduce method invocation overhead (e.g. method which only returns a value)
- compiler gets larger blocks which significantly increases optimization

Example – Method Inlining

Code example

```
class A {
 final int foo() { return 3; }
 }
```

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Benefit – inlining a.foo()

- no method call
- no dynamic dispatch
- possible to constant-fold the value
  (`a.foo()+2` becomes 5 with no code executed at runtime)
- because of dynamic deoptimization JVM can inline without `final`-keyword

Dynamic Deoptimization

What is the intension?

- OO-language are dynamic
  (dynamic dispatch or virtual method invocation)
- so compiled code can become incorrect til runtime

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What does it do?

- jit-compiler records all of the assumptions that the code makes
- so JVM can undo compilation(+optimization) to get bytecode (for interpretation/recompilation)
- JVM switch back from native to bytecode while method is still running

Example – Dynamic Deoptimization

Code example

```
class B {
 int foo() { return 3; }
 }
class C extends B {
 int foo() { return 6; }
 }
```

Example – Dynamic Deoptimization

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class B {
 int foo() { return 3; }
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```

Result

- as long no override for `int foo()` everything is fine
- problem arises when `class C` is dynamical loaded
- code with inlined `B.foo()` is incorrect
- variable in the code of type B can point to objects of either class B or C

On Stack Replacement

What is the intension?

- hotspots (like loop-iterations) could be in functions which will be called only once
- so the compiled version would never be executed

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- hotspots (like loop-iterations) could be in functions which will be called only once
- so the compiled version would never be executed

What does it do?

- the exact opposite of dynamic deoptimization
- JIT compiles code
- interpreted frame is turned into a compiled frame while method is still running

Example – On Stack Replacement

Code example

```
public class D {
 public static void main(String[] arg) {
  int sum = 0;
  for (int index = 0; index < 10*1000*1000; index += 1) {
   sum += index;
}}}
```

Example – On Stack Replacement

Code example

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 public static void main(String[] arg) {
  int sum = 0;
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```

Timeline without OSR

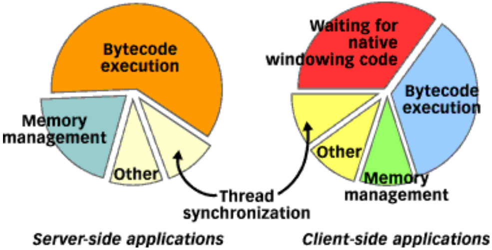
- Interpreter starts interpreting `main()` method
- Counter hits 10.000, and compilation begins, but still interpreting `main()`
- Compilation finishes, still interpreting `main()`
- `main()` finishes

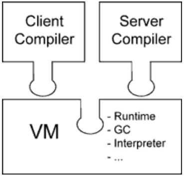
Example – On Stack Replacement

Timeline with OSR

- Interpreter starts interpreting `main()` method
- Counter hits 10.000, and compilation begins, but still interpreting `main()`
- Compilation finishes, still interpreting `main()`
- Counter hits 14.000, and interpreting stops
- `main()` is compiled a second time via OSR to allow entry in the middle of the loop
- `main()` resumes in the compiled code
- `main()` finishes

JVM time spend, Sun HotspotVM





Sun HotspotVM Compiler

Client-Compiler

is a simple, fast three-phase compiler

1. front end constructs high-level intermediate representation (HIR) from BCs

   HIR uses static single assignment (SSA)
2. platform-specific back end generates low-level intermediate representation (LIR) from HIR
3. performs register allocation on LIR and generates machine code from it

Sun HotspotVM Compiler

Server-Compiler

is a high-end fully optimizing compiler

- uses an advanced static single assignment (SSA)-based IR for optimizations
- optimizations: dead code elimination, loop invariant hoisting, common subexpression elimination, constant propagation, global value numbering, and global code motion
- java specific: null-check and range-check elimination, optimization of exception throwing paths
- register allocator is a global graph coloring allocator

Sun HotspotVM Compiler

Compiler Optimizations of both JITCs

- Deep inlining and inlining of potentially virtual calls
- Fast instanceof/checkcast
- Range check elimination
- Loop unrolling
- Feedback-directed optimizations

Time measurement

Code example

```
public class E {
 public static void main(String[] arg) {
  int sum = 0;
  for (int i = 0; i < 10*1000*1000*1000; i += 1) {
   sum += i;
  }
 }
}
```

Time measurement

Code example

```
public class E {
 public static void main(String[] arg) {
  int sum = 0;
  for (int i = 0; i < 10*1000*1000*1000; i += 1) {
   sum += i;
  }
 }
}
```

Assesments?!

```
[jan@hyperBox ~]$ vim E.java
[jan@hyperBox ~]$ javac E.java
[jan@hyperBox ~]$ time java E

real    0m1.462s
user    0m1.273s
sys     0m0.143s
[jan@hyperBox ~]$ time java -XX:+PrintCompilation -Djava.compiler=NONE E

real    0m23.500s
user    0m23.018s
sys     0m0.307s
[jan@hyperBox ~]$ time java -XX:+PrintCompilation -client E
  1       java.lang.String::hashCode (64 bytes)
  1%      E::main @ 4 (21 bytes)

real    0m1.466s
user    0m1.270s
sys     0m0.160s
[jan@hyperBox ~]$ time java -XX:+PrintCompilation -server E
  1%      E::main @ 4 (21 bytes)

real    0m0.196s
user    0m0.037s
sys     0m0.117s
[jan@hyperBox ~]$
```

Choosing Compiler – Sun HotspotVM

Using . . . compiler

- none: java -Djava.compiler=NONE [classfile]
- client: java -client [classfile]
- server: java -server [classfile]

Choosing Compiler – Sun HotspotVM

Using . . . compiler

- none: java -Djava.compiler=NONE [classfile]
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Some compiler information

- java -XX:+PrintCompilation [classfile]

See what the compiler do

Tools – part of Hotspot

- IdealGraphVisualizer – tool for examining IR of server compiler
- LogCompilation tool – parse LogCompilation output of the JVM
- hsdis – disassembler used by hotspot for debugging

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Tools – 3rd party

Client Compiler Visualizer: Tool for examining the HIR, LIR, and linear scan register allocation of the client compiler

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