The Java Virtual Machine (JVM)

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COMP 3002

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Outline

- Topic 1
- Topic 2
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  - Subtopic 2.2
- Topic 3

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What is the JVM?

- The JVM is a specification of a computing machine
  - Instruction set
  - Primitive data types
  - Memory layout of primitive data types
- The JVM allows portable binary software
  - Authors need only write code for the JVM and it will run on any machine that has a JVM interpreter
- Hardware implementations of the JVM also exist
  - picoJava

Bytecodes: JVM Instructions

- A JVM instruction is a *opcode* followed by a variable number of operands
- An opcode is one byte
  - 225 different opcodes
- JVM byte codes are small compared to other instruction sets
  - On average, a JVM instruction is 1.8 bytes long
  - RISC instructions typically require 4 bytes

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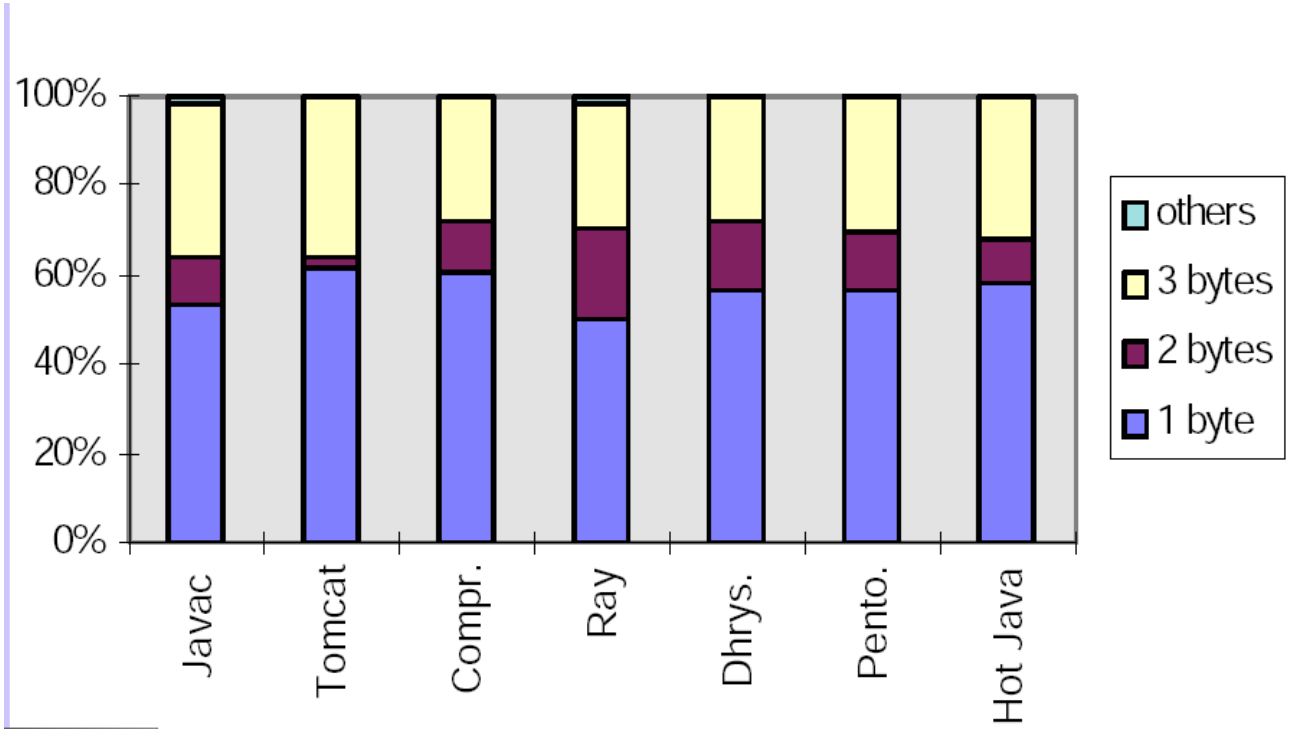
Distribution of Bytecode Lengths

- Source: Sun Microsystems



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JVM Datatypes

- Integers:
  - byte (8 bits)
  - short (16 bits)
  - int (32 bits)
  - long (64 bits)
- Floating point
  - float (32 bits)
  - double (64 bits)
- Others
  - char (16 bits!)
  - reference (not defined)
  - returnAddress (not defined)

Parts of the JVM

- pc Register
  - Keeps track of the current instruction
- Stack
  - Stores stack frames
- Heap
  - Stores dynamically allocated memory (garbage collected)
- Method area
  - Stores program code (JVM instructions)
- Runtime constant pool
  - Stores constants and method/field references

What, no registers?

- The JVM has only one register, used to keep track of the program counter
- The JVM is a *stack machine*
  - All operations operate on the top few elements of the stack
- This is what allows for such short bytecodes
  - Eg. An integer division operation
    - in a 32 register RISC machine requires 32*31=992 different opcodes (one for each pair of registers)
    - in a stack machine requires only 1 opcode (it always operates on the top 2 elements)

The Jasmin Assembler

- Rather than manipulate bytecodes directly, we generate assembly language and use an assembler to assemble the byte codes
- The assembler we use is Jasmin
  - http://jasmin.sourceforge.net/

Hello World

```
; public static void main(String args[]) {
;    System.out.println(“Hello World!”);
; }
.method public static main([Ljava/lang/String;)V
   .limit stack 50

   ; push System.out onto the stack
   getstatic java/lang/System/out Ljava/io/PrintStream;
   ; push a string constant onto the stack
   ldc "Hello World!"
   ; Call System.out.println
   invokevirtual java/io/PrintStream/println(Ljava/lang/String;)V

   return
.end method
```

Observe

- .method defines a new method
  - The parameters and return value are defined
- .limit stack defines the size (in 32 bit words) of the stack frame for this method
- getstatic loads a static (class) variable onto the stack
- invokevirtual calls a virtual (instance) method
- We return with an explicit return statement

Printing a Float

```
; public static void printFloat(float x) {
;   System.out.println( Float.toString(x) );
; }
.method public static printFloat(F)V
   .limit stack 2
   .limit locals 2
   getstatic java/lang/System/out Ljava/io/PrintStream;
   fload 0
   invokestatic java/lang/Float/toString(F)Ljava/lang/String;
   invokevirtual java/io/PrintStream/println(Ljava/lang/String;)V
   return
.end method
```

Local Variables

- .locals specifies the number of local variables
  - This includes function parameters
- Each local variable is a 32 bit quantity, indexed starting at 0
- Local variables are loaded onto and stored from the stack using *load and *store instructions

load and store operations

- The JVM has several load and store operations
  - *x*load <index>
    - x defines the type of operand (f, i, l, d, a …)
    - index defines its index in the current stack frame
- The stack frame is indexed starting at 0
  - Starting with function arguments
  - Each index specifies a 4 byte quantity
    - byte, char, short, int, float, reference
  - “wide” data types are loaded in 2 steps
    - E.g., dload_0 0 dload_1 1
- store operations store the top element into the specified local variable

Operations

- The JVM includes many operations for arithmetic and logic
  - Add: iadd, ladd, fadd, dadd.
  - Subtract: isub, lsub, fsub, dsub.
  - Multiply: imul, lmul, fmul, dmul.
  - Divide: idiv, ldiv, fdiv, ddiv.
  - Remainder: irem, lrem, frem, drem.
  - Negate: ineg, lneg, fneg, dneg.
  - Comparison: dcmpg, dcmpl, fcmpg, fcmpl, lcmp.
  - and more ....
- They all operate on the top 1 or 2 stack elements and leave their result on the top of the stack

Labels and Jump Instructions

```
;;; return true (1) if arg1 >= arg2 and false (0) otherwise
.method public static cmpGE(FF)I
   .limit locals 4
   .limit stack 4
   fload 0
   fload 1
   fcmpl
   ifge true_label
   ldc 0
   goto done
true_label:
   ldc 1
done:
   ireturn
.end method
```

Summary

- The JVM is a stack-based virtual machine
  - Being stack-based allows for compact instruction encoding
  - Being a virtual machine makes it portable
  - Hardware implementations exist, but are not the fastest computers around
- We have not covered
  - Array instructions
  - Dynamic memory allocation
  - Exceptions
  - Interfaces
  - Type conversions
  - Threads

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