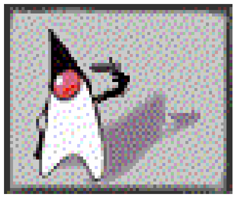
CS216: Program and Data Representation
University of Virginia Computer Science
Spring 2006 David Evans

Lecture 18: Code Safety and Virtual Machines


(Duke suicide picture by Gary McGraw)

http://www.cs.virginia.edu/cs216

JVML Instruction Set

pushing constants	20	getstatic, putstatic	2
loads, stores (0-3 for each iload, lload, fload, dload, aload)	66	newarray, anewarray, multianewarray,arraylength	4
pop, dup, swap, etc.	9	invoke methods, throw	5
arithmetic	37	new	1
conversion (e.g., i2l)	15	getfield, putfield	2
comparisons (lcmp)	5	checkcast	1
goto, jsr, goto_w, jsr_w, ret	5	instanceof	1
tableswitch, lookupswitch	2	monitorenter, monitorexit	2
returns (e.g., ireturn)	6	wide	1
conditional jumps (ifeq, ifnull, ifnonnull)	16	nop, breakpoint, unused, implementation dependent	5

(205 out of 256 possible opcodes used)

How to get more than 256 local variables!

wide <opcode> <byte1> <byte2>

- Opcode is one of *iload*, *fload*, *aload*, *lload*, *dload*, *istore*, *fstore*, *astore*, *lstore*, *dstore*, or *ret*
- Modifies instruction to take 2 byte operand (byte1 << 8 | byte2)

Method Calls

- **invokevirtual <method>**
  - Invokes the method <method> on the parameters and object on the top of the stack.
  - Finds the appropriate method at run-time based on the actual type of the this object.

```
invokevirtual <Method void println(java.lang.String)>
```


Method Calls

- **invokestatic <method>**
  - Invokes a static (class) method <method> on the parameters on the top of the stack.
  - Finds the appropriate method at run-time based on the actual type of the this object.

Example

```
public class Sample1 {
   static public void main (String args[]) {
      System.err.println ("Hello!");
      System.exit (1);
   }
}
```

```
public class Sample1 {
    static public void main (String args[]) {
        System.err.println ("Hello!");
        System.exit (1); } }
```

```
> javap -c Sample1
Compiled from Sample1.java
public class Sample1 extends java.lang.Object {
    public Sample1();
    public static void main(java.lang.String[]);
}

Method Sample1()
   0 aload_0
   1 invokespecial #1 <Method java.lang.Object()>
   4 return
Method void main(java.lang.String[])
   0 getstatic #2 <Field java.io.PrintStream err>
   3 ldc #3 <String "Hello!">
   5 invokevirtual #4 <Method void println(java.lang.String)>
   8 iconst_1
   9 invokestatic #5 <Method void exit(int)>
  12 return
```


Cast Instruction

```
public class Cast {
    static public void main (String args[]) {
        Object x;
        x = (Object) args[0];
        System.out.println ("result: " + (String) x);
    }
}
```



```
Method void main(java.lang.String[])
   0 aload_0
   1 iconst_0
   2 aaload
   3 astore_1
   4 getstatic #2 <Field java.
   7 new #3 <Class java.lang
  10 dup
  11 invokespecial #4 <Meth
  14 ldc #5 <String "result: ">
  16 invokevirtual #6 <Method java.lang.StringBuffer
append(java.lang.String)>
  19 aload_1
  20 checkcast #7 <Class java.lang.String>
  23 invokevirtual #6 <Method java.lang.StringBuffer append(java.lang.String)>
  26 invokevirtual #8 <Method java.lang.String toString()>
  29 invokevirtual #9 <Method void println(java.lang.String)>
  32 return
```

```
public class Cast {
    static public void main (String args[]) {
        Object x;
        x = (Object) args[0];
        System.out.println ("result: " + (String) x);
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The Worst Instruction

http://java.sun.com/docs/books/vmspec/2nd-edition/html/Instructions2.doc7.html

jsr [branchbyte1] [branchbyte2]
Forms
jsr = 168 (0xa8)
Operand Stack
... ⇒ ..., *address*
Description
The *address* of the opcode of the instruction immediately following this *jsr* instruction is pushed onto the operand stack as a value of type returnAddress. The unsigned *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset, where the offset is (*branchbyte1* << 8) | *branchbyte2*. Execution proceeds at that offset from the address of this *jsr* instruction. The target address must be that of an opcode of an instruction within the method that contains this *jsr* instruction.
Notes
The *jsr* instruction is used with the *ret* instruction in the implementation of the finally clauses of the Java programming language. Note that *jsr* pushes the address onto the operand stack and *ret* gets it out of a local variable. This asymmetry is intentional.

Try-Catch-Finally

```
public class JSR {
    static public void main (String args[]) {
        try {
            System.out.println("hello");
        } catch (Exception e) {
            System.out.println ("There was an exception!");
        } finally {
            System.out.println ("I am finally here!");
        }

    }
}
```

```
Method void main(java.lang.String[])
   0 getstatic #2 <Field java.io.PrintStrean
   3 ldc #3 <String "hello">
   5 invokevirtual #4 <Method void println
   8 jsr 35
  11 goto 46
  14 astore_1
  15 getstatic #2 <Field java.io.PrintStrear
  18 ldc #6 <String "There was an excepti
  20 invokevirtual #4 <Method void println(java.lang.String)>
  23 jsr 35
  26 goto 46
  29 astore_2
  30 jsr 35
  33 aload_2
  34 athrow
  35 astore_3
  36 getstatic #2 <Field java.ic
  39 ldc #7 <String "I am final
  41 invokevirtual #4 <Method
  44 ret 3
  46 return
```

```
public class JSR {
   static public void main (String args[]) {
      try {
         System.out.println("hello");
      } catch (Exception e) {
         System.out.println ("... exception!");
      } finally {
         System.out.println ("I am finally");
      }

   }
}
```

Exception table:

from	to	target	type
0	8	14	<Class java.lang.Exception>
0	11	29	any
14	26	29	any
29	33	29	any

Java™: Programming Language

compared to C++, not to C   sort of

"A simple, object-oriented, distributed, interpreted, robust, secure, architecture neutral, portable, high-performance, multithreaded, and dynamic language." [Sun95]

Java: int is 32 bits
C: int is >= 16 bits

What is a secure *programming language*?

1. Language is designed so it cannot express certain computations considered insecure.
   A few attempt to do this: PLAN, packet filters
2. Language is designed so that (accidental) program bugs are likely to be caught by the compiler or run-time environment instead of leading to security vulnerabilities.

Safe Programming Languages

- Type Safety
  - Compiler and run-time environment ensure that bits are treated as the type they represent
- Memory Safety
  - Compiler and run-time environment ensure that program cannot access memory outside defined storage
- Control Flow Safety
  - Can't jump to arbitrary addresses

Which of these does C/C++ have?
Is Java the first language to have them?
No way! LISP had them all in 1960.

Java™ Safety

- Type Safety
  - Most types checked statically
  - Coercions, array assignments type checked at run time
- Memory Safety
  - No direct memory access (e.g., pointers)
  - Primitive array type with mandatory run-time bounds checking
- Control Flow Safety
  - Structured control flow, no arbitrary jumps

Malicious Code

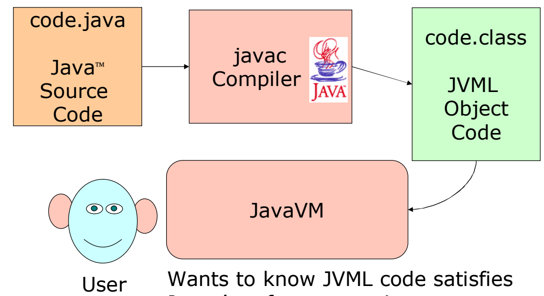
Can a safe programming language protect you from malcode?

1. Code your servers in it to protect from buffer overflow bugs
2. Only allow programs from untrustworthy origins to run if the are programmed in the safe language

Safe Languages?

- But how can you tell program was written in the safe language?
  - Get the source code and compile it (most vendors, and all malicious attackers refuse to provide source code)
  - Special compilation service cryptographically signs object files generated from the safe language (SPIN, [Bershad96])
  - Verify object files preserve safety properties of source language (Java)

JVML



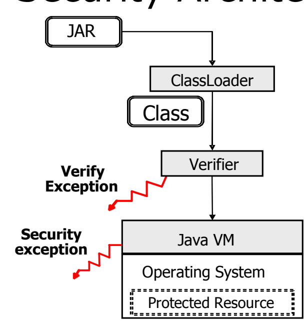
Wants to know JVML code satisfies Java™'s safety properties.

Does JVML satisfy Java™'s safety properties?

iconst_2	*push integer constant 2 on stack*
istore_0	*store top of stack in variable 0 as int*
aload_0	*load object reference from variable 0*

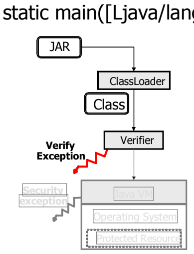
No! This code violates Java™'s type rules.

Java Security Architecture



Mistyped Code

```
.method public static main([Ljava/lang/String;)V
  …
  iconst_2
  istore_0
  aload_0
  iconst_2
  iconst_3
  iadd
  …
.end method
```



> java Simple
Exception in thread "main" java.lang.VerifyError: (class: Simple, method: main signature: ([Ljava/lang/String;)V) **Register 0 contains wrong type**

Verifier error before any code runs

Runtime Error

```
public class Cast {
  static public void main (String args[]) {
    Object o = new Object ();
    String s;
    s = (String) o;
    System.out.println(s);
    return;
  }
}
```

```
Method void main(java.lang.String[])
   0 new #2 <Class java.lang.Object>
   3 dup
   4 invokespecial #1 <Method java.lang.Object()>
   7 astore_1
   8 aload_1
   9 checkcast #3 <Class java.lang.String>
  12 astore_2
  13 getstatic #4 <Field java.io.PrintStream out>
  16 aload_2
  17 invokevirtual #5 <Method void println(java.lang.String)>
  20 return
```

Bytecode Verifier

- Checks class file is formatted correctly
  - Magic number: class file starts with 0xCAFEBABE
  - String table, code, methods, etc.
- Checks JVML code satisfies safety properties
  - Simulates program execution to know types are correct, but doesn't need to examine any instruction more than once

Verifying Safety Properties

- Type safe
  - Stack and variable slots must store and load as same type
  - Only use operations valid for the data type
- Memory safe
  - Must not attempt to pop more values from stack than are on it
  - Doesn't access private fields and methods outside class implementation
- Control flow safe
  - Jumps must be to valid addresses within function, or call/return

Charge

- PS6 will be out (electronically) on Friday
- If you would like to be assigned a partner for PS6, send me email as soon as possible