cs2220: Engineering Software

Class 19: Java Security

Fall 2010
UVa
David Evans

Image: Elisabeth Sparkman

Plan for Today

Java Security

Java Byte Codes (JVML) and Verification

Reminder:
Project Team Requests are due **before midnight tomorrow**
Project Idea Proposals are due **in class Tuesday**

from Class 2...

Buzzword Description

"A ~~**simple**~~, **object-oriented**, has reasonable mechanisms (but not good) distributed, interpreted, robust, secure, architecture neutral, portable, high-performance, **multithreaded**, ✓ and dynamic language." [Sun95]

As the course proceeds, we will discuss how well it satisfies these "buzzwords". You should especially be able to answer how well it satisfies each of the blue ones in your final interview.

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

Sometimes people use "type safety" to mean *all* of these.

Is Java the first language to have them?

No way! LISP had them all before 1960.

What happens if you don't have type/memory safety?

Image: Elisabeth Sparkman

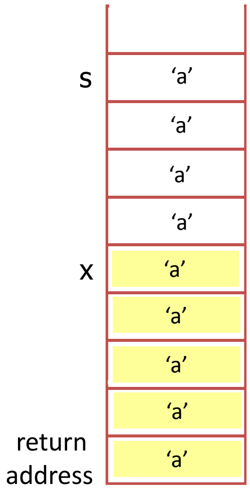
Lack of Safety in C++

```
# include <iostream>
using namespace std;

int main (void) {
  int x = 9;
  char s[4];

  cin >> s;
  cout << "s is: " << s << endl;
  cout << "x is: " << x << endl;
}
```

```
> g++ -o bounds bounds.cc
> bounds
> bounds
cs205          <- User input
s is: cs205
x is: 9
> bounds
cs2220
s is: cs2220
x is: 9
> bounds
cs2222222220
s is: cs2222222220
x is: 0
> bounds
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
s is: aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
x is: 1633771873
Segmentation fault (core dumped)
```



```
# include <iostream>
using namespace std;

int main (void) {
  int x = 9;
  char s[4];

  cin >> s;
  cout << "s is: " << s << endl;
  cout << "x is: " << x << endl;
}
```

```
> bounds
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
s is: aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
x is: 1633771873
Segmentation fault (core dumped)
```

When main returns, execution jumps to the return address stored on the stack.

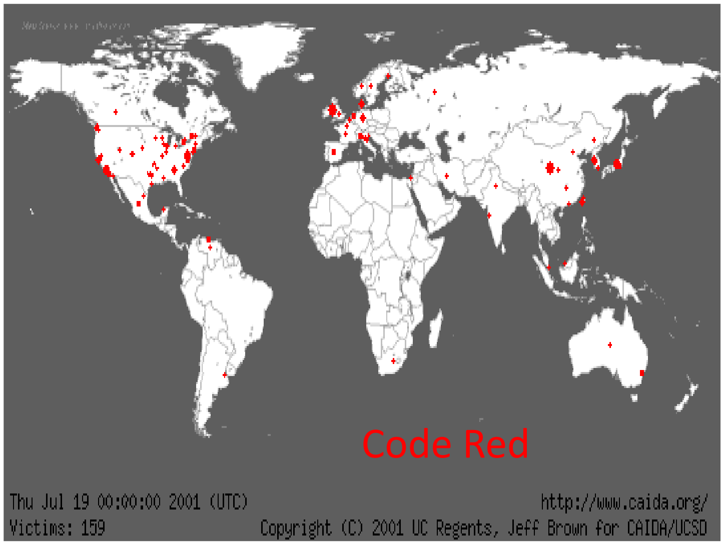
But, the input overwrote that return address!

When things go really bad…

If person entering input is clever and mean, they can put what they want in the return address, and their own code after that to jump to!

Buffer Overflow Attack

"Stack Smashing"


Code Red
Thu Jul 19 00:00:00 2001 (UTC)
Victims: 159
http://www.caida.org/
Copyright (C) 2001 UC Regents, Jeff Brown for CAIDA/UCSD

Buffer Overflows

- Code Red: exploited buffer overflow in Microsoft's IIS (web server)
- Attacker sends excessively long request to web server, overflows buffer and puts virus code on stack
- Until about 5 years ago: cause of most security problems
- Now: still a serious problem

Is the Java Programming Language safe?

Type Safety

Compiler and run-time environment ensure that bits are treated as the type they represent

static type checking
run-time cast, array store

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

✓

Is the Java Programming Language safe?

Java Programming Language

Type Safety

Compiler and run-time environment ensure that bits are treated as the type they represent

Most types checked statically

Coercions, array assignments type checked at run time

Memory Safety

Compiler and run-time environment ensure that program cannot access memory outside defined storage

No direct memory access (e.g., pointers)

Primitive array type with mandatory run-time bounds checking

Control Flow Safety

Can't jump to arbitrary addresses

Structured control flow, no arbitrary jumps

Malicious Code

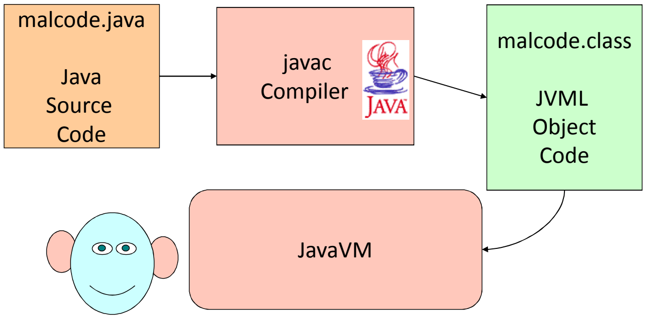
Can a safe programming language protect you from malicious code?

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



malcode.java

Java Source Code

javac Compiler

malcode.class

JVML Object Code

JavaVM

Alice User

Alice wants to know JVML code satisfies Java PL's safety properties.

Does JVML satisfy Java PL's safety properties?

Java Virtual Machine

- Small and simple to implement
- All VMs will run all programs the same way
- Secure

Implementing the JavaVM

```
load class into memory
set the instruction pointer to point to the
beginning of main
while (there is more to do) {
   fetch the next instruction
   execute that instruction
 }
```

Some other issues we will talk about later... (e.g., Garbage collection – need to reclaim unused storage)

Java Byte Codes

- **Stack-based** virtual machine
- Small instruction set: 202 instructions (all are 1 byte opcode + operands)
  - Intel x86: ~280 instructions (1 to 17 bytes long!)
- **Memory is typed** (but imprecisely)
- Every Java class file begins with magic number 3405691582

= **`0xCAFEBABE`** in base 16

Stack-Based Computation

push – put something on the top of the stack

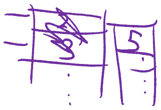
pop – get and remove the top of the stack

Stack

2 5
3

push 2
push 3
add

Does 2 pops, pushes sum



Some Java Instructions

Opcode	Mnemonic	Description
0	nop	Does nothing
1	aconst_null	Push null on the stack
3	iconst_0	Push int 0 on the stack
4	iconst_1	Push int 1 on the stack
…		

Some Java Instructions

Opcode	Mnemonic	Description
18	**ldc** <*value*>	Push a one-word (4 bytes) constant onto the stack

Constant may be an **int**, **float** or **String**

ldc 0 ≡ iconst_0

ldc "Hello"
ldc 2220

The String is really a reference to an entry in the string constant table! The strange String semantics should make more sense now.

Arithmetic

Opcode	Mnemonic	Description
96	**iadd**	Pops two integers from the stack and pushes their sum

iconst_2
iconst_3
iadd

Arithmetic

Opcode	Mnemonic	Description
96	**iadd**	Pops two integers from the stack and pushes their sum
97	**ladd**	Pops two long integers from the stack and pushes their sum
…		
106	**fmul**	Pops two floats from the stack and pushes their product
…		
119	**dneg**	Pops a double from the stack, and pushes its negation

Java Byte Code Instructions

0: nop

1-20: putting constants on the stack

96-119: arithmetic on ints, longs, floats, doubles

What other kinds of instructions do we need?

Other Instruction Classes

Control Flow (~20 instructions)

if, goto, return

Method Calls (4 instructions)

Loading and Storing Variables (65 instructions)

Creating objects (1 instruction)

Using object fields (4 instructions)

Arrays (3 instructions)

```
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
```

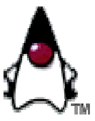
iconst_0
aconst_null
~~iadd~~ iadd

iconst_0
iadd

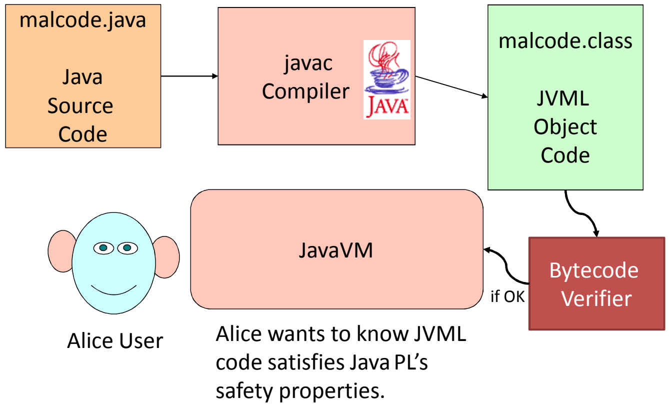
Does JVML satisfy Java^PL's safety properties?

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.



JVML



Alice wants to know JVML code satisfies Java PL's safety properties.

Charge

- Next: what the verifier does, security policies in Java

Remember to send your team requests by Friday, and be ready to present your project ideas next class.