cs2220: Engineering Software

Class 21: Hair-Dryer Attacks

Fall 2010
UVa
David Evans

Image from www.clean-funny.com, GoldenBlue LLC.

Plan for Today

- Recap: Java Platform Security
- Trusted Computing Base: should we trust Java's?
- Hair-Dryer Attacks

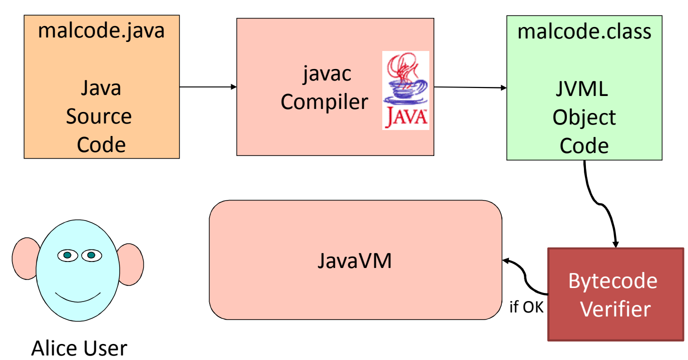
Project Design Documents

Due: on paper, beginning of class Tuesday

1. A **description of your project**: what it will do and why it is useful, fun, or interesting.
2. A high-level **description of your design**, including a **module dependency diagram** showing the most important modules.
3. A description of your **implementation *and* testing strategy** including:
   - how you will **divide the work** amongst your team
   - how you will **order the work** to support incremental development
   - how you will do **unit testing** and **integration testing**
   - a list of **milestones** and a **schedule** for achieving them, leading to a completed project on December 7
4. A list of questions

Schedule Design Review meetings (link on course site)

Recap: Java Platform



Running Mistyped Code

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

> java **–noverify** Simple
result: 5

Running Mistyped Code

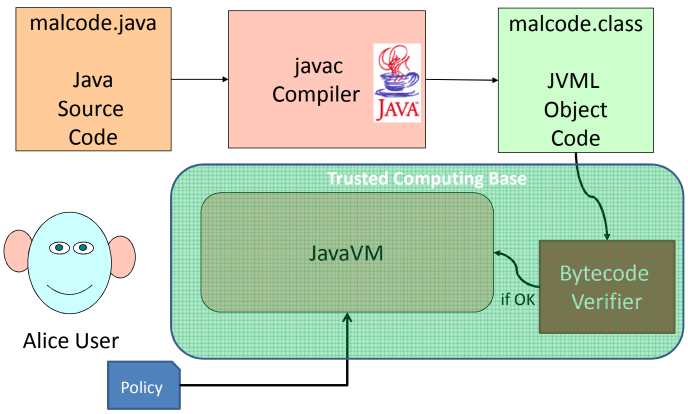
```
.method public static main([Ljava/lang/String;)V
   …
   ldc 2220
   istore_0
   aload_0
   iconst_2
   iconst_3
   iadd
   …
.end method
```

> java –noverify Simple
Unexpected Signal : EXCEPTION_ACCESS_VIOLATION (0xc0000005) occurred at PC=0x809DCEB
Function=JVM_FindSignal+0x1105F
Library=C:\j2sdk1.4.2\jre\bin\client\jvm.dll

Current Java thread:
at Simple.main(Simple.java:7)
…

```
#
# HotSpot Virtual Machine Error : EXCEPTION_ACCESS_VIOLATION
# Error ID : 4F530E43505002EF
# Please report this error at
# http://java.sun.com/cgi-bin/bugreport.cgi
#
# Java VM: Java HotSpot(TM) Client VM (1.4.2-b28 mixed mode)
```

Recap: Trusted Computing Base



Trusted Computing Base

- The part of the system that must be trusted to behave correctly for the desired security properties to be guaranteed
- Should we *trust* the Java platform TCB?

Building Trust

- Simplicity

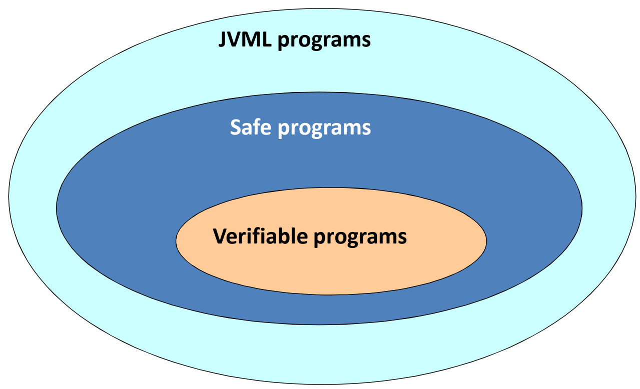
  There are two ways of constructing a software design: One way is to make it so simple there are obviously no deficiencies and the other way is to make it so complicated that there are no obvious deficiencies. Tony Hoare

- Extensive validation
- Design Process

Boeing 787 Dreamliner delay conspiracy theories

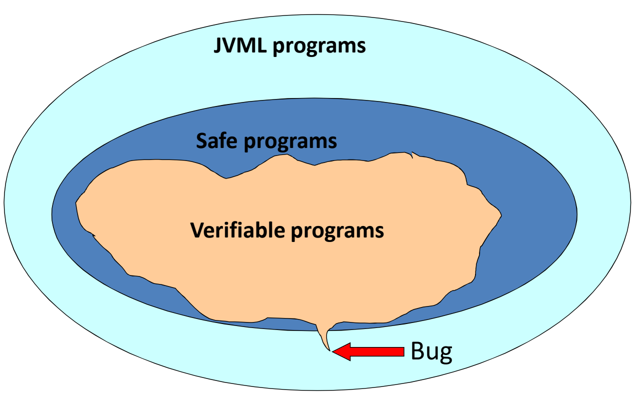
"Rather, he thinks avionics software is hung up by the effects of the **RTCA/DO-178b standard**, which certifies avionics software and in his opinion causes unnecessary delays in the delivery of same. In yesterday's call, Boeing executives … downplayed the avionics software lag, but conceded they welcome more time to test it."

Verifier (should be) Conservative



(Slide from Nate Paul's ACSAC talk)

Complexity Increases Risk



(Slide from Nate Paul's ACSAC talk)

The Worst JVML Instruction

jsr [branchbyte1] [branchbyte2]

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

Note that *jsr* pushes the address onto the operand stack and *ret* gets it out of a local variable. This asymmetry is intentional.

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

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!");
      }
   }
}
```

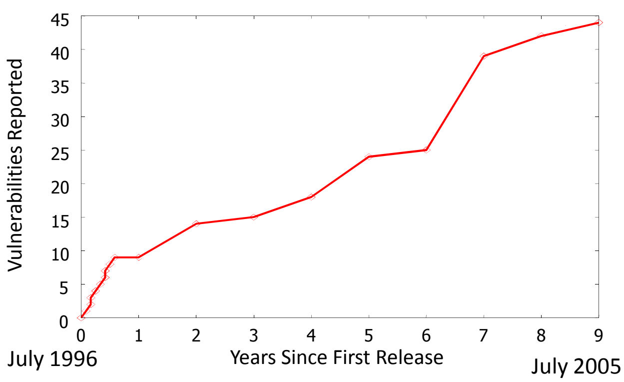
```
Method void main(java.lang.String[])
  0 getstatic #2 <Field java.io.PrintStream out>
  3 ldc #3 <String "hello">
  5 invokevirtual #4 <Method void println(java.lang.S
  8 jsr 35
 11 goto 46
 14 astore_1
 15 getstatic #2 <Field java.io.PrintStream out>
 18 ldc #6 <String "There was an exception!">
 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.io.PrintStream out>
 39 ldc #7 <String "I am finally here!">
 41 invokevirtual #4 <Method void println(java.lang.String)>
 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

Vulnerabilities in JavaVM



From Nathanael Paul and David Evans, **Comparing Java and .NET security: Lessons Learned and Missed,** Computers & Security, 2006. http://www.cs.virginia.edu/~evans/pubs/cs06/

Where are They?

Verification	12
API bugs	10
Class loading	8
Other or unknown	2
Missing policy checks	3
Configuration	4
DoS attacks (crash, consumption)	5

several of these were because of **jsr** complexity

Low-level vs. Policy Security

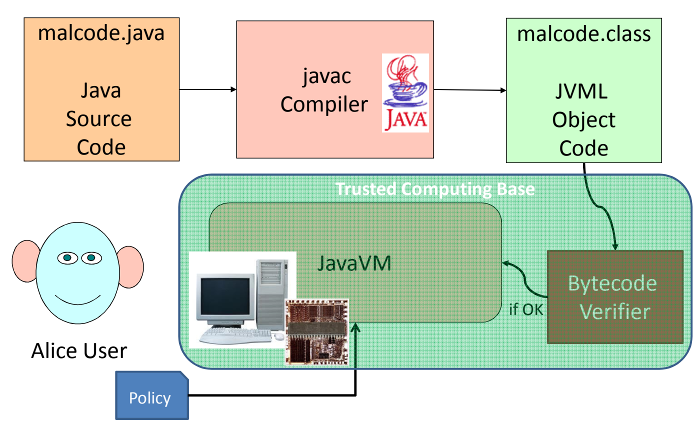
Low-level Code Safety

- Type safety, memory safety, control flow safety
- Enforced by Java bytecode verifier and run-time checks in VM
- Needed to prevent malcode from circumventing any policy mechanism

Policy Security

- Control access and use of resources (files, network, display, etc.)
- Enforced by Java class
- Hard part is deciding on a good policy

Is this really the whole TCB?



Bytecode Verifier

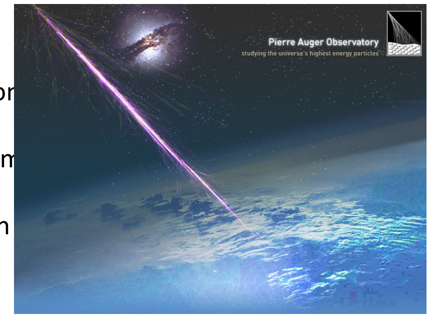
Checks JVML code satisfies safety properties:

- Simulates program execution to know types are correct, but doesn't need to examine any instruction more than once
- After code is verified, it is trusted: is not checked for type safety at run time (except for casts, array stores)

Key assumption: when a value is written to a memory location, the value in that memory location is the same value when it is read.

Violating the Assumption

```
…
        // The object or
astore_0
        // There is a Sim
aload_0
        // The value on
```



If a cosmic ray hits the right bit of memory, between the astore and aload, the assumption might be wrong.

Can you really blame cosmic rays when your program crashes?

- IBM estimate: one cosmic-ray bit error per 256 megabytes per month
- For people running big datacenters, this is a real problem
- If your processor is in an airplane or in space risk is much higher

But, can an attacker take advantage of this?

Improving the Odds

- Set up memory so that a single bit error is likely to be exploitable
- Mistreat the hardware memory to increase the odds that bits will flip

Following slides adapted (with permission) from Sudhakar Govindavajhala and Andrew W. Appel, *Using Memory Errors to Attack a Virtual Machine*, July 2003.

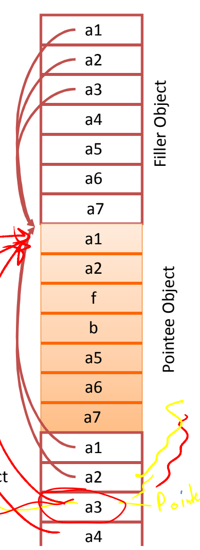
Making Bit Flips Useful

Fill up memory with Filler objects, and one Pointee object:

```
class Filler {          class Pointee {
  Pointee a1;             Pointee a1;
  Pointee a2;             Pointee a2;
  Pointee a3;             Filler f;
  Pointee a4;             int b;
  Pointee a5;             Pointee a5;
  Pointee a6;             Pointee a6;
  Pointee a7;             Pointee a7;
}                       }
```

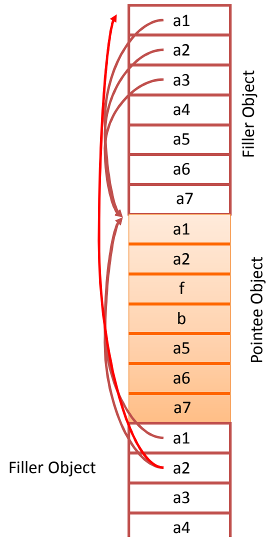
Filling Up Memory

```
Pointee p = new Pointee ();
ArrayList<Filler> fillers = new ArrayList<Filler> ();
try {
  while (true) {
    Filler f = new Filler ();
    f.a1 = p; f.a2 = p; f.a3 = p; …; f.a7 =p;
    fillers.add (f);
  }
} catch (OutOfMemoryException e) { ; }
```



Wait for a bit flip…

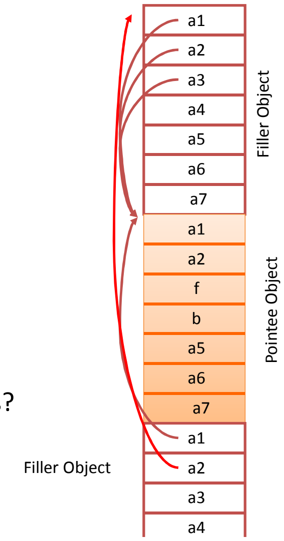
- Remember: there are lots of Filler objects (fill up all of memory)
- When a bit flips, good chance (~70%) it will be in a field of a **Filler** object and it will now point to a **Filler** object instead of a **Pointee** object



Type Violation

After the bit flip, the value of **f.a2** is a **Filler** object, but **f.a2** was declared as a **Pointee** object!

Can an attacker exploit this?



Finding the Bit Flip

```
Pointee p = new Pointee ();
ArrayList<Filler> fillers = new ArrayList<Filler> ();
try {
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    f.a1 = p; f.a2 = p; f.a3 = p; …; f.a7 =p;
    fillers.add (f);
  }
} catch (OutOfMemoryException e) { ; }

while (true) {
  for (Filler f : fillers) {
    if (f.a1 == p) {
    } else {
      zapped!
    }
}
```

```
class Filler {
  Pointee a1;
  :
  Pointee a7;
}
```

Finding the Bit Flip

```
Pointee p = new Pointee ();
ArrayList<Filler> fillers = new ArrayList<Filler> ();
try {
  while (true) {
    Filler f = new Filler ();
    f.a1 = p; f.a2 = p; f.a3 = p; …; f.a7 =p;
    fillers.add (f);
  }
} catch (OutOfMemoryException e) { ; }

while (true) {
  for (Filler f : fillers) {
    if (f.a1 != p) { // bit flipped!
      …
    } else if (f.a2 != p) {
      …
    }
}
```

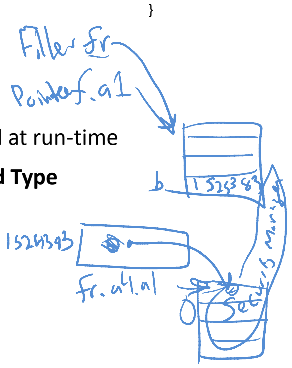
Violating Type Safety

```
class Filler {
  Pointee a1;
  Pointee a2;
  Pointee a3;
  Pointee a4;
  Pointee a5;
  Pointee a6;
  Pointee a7;
}

class Pointee {
  Pointee a1;
  Pointee a2;
  Filler f;
  int b;
  Pointee a5;
  Pointee a6;
  Pointee a7;
}
```

```
Filler f = (Filler) e.nextElement ();
  if (f.a1 != p) { // bit flipped!
    Object r = f.a1; //
    Filler fr = (Filler) r; // Cast is checked at run-time
    f.a1.b = 1524383;
    fr.a4.a1 = null, 1524383
```

	Declared Type
f.a1	Pointee
f.a1.b	int
fr == f.a1	Filler
fr.a4 == f.a1.b	Pointee



Violating Type Safety

```
class Filler {
  Pointee a1;
  Pointee a2;
  Pointee a3;
  Pointee a4;
  Pointee a5;
  Pointee a6;
  Pointee a7;
}

class Pointee {
  Pointee a1;
  Pointee a2;
  Filler f;
  int b;
  Pointee a5;
  Pointee a6;
  Pointee a7;
}
```

```
Filler f = (Filler) e.nextElement ();
  if (f.a1 != p) { // bit flipped!
    Object r = f.a1;
    Filler fr = (Filler) r;  // Cast is checked at run-time
    f.a1.b = 1524383;   // Address of the SecurityManager
    fr.a4.a1 = null;       // Set it to a null
    // Do whatever you want!  No security policy now…
    new File (“C:\thesis.doc”).delete ();
```

Getting a Bit Flip

- Wait for a Cosmic Ray
  - You have to be really, really patient… (or move machine out of Earth's atmosphere)
- X-Rays
  - Expensive, not enough power to generate bit-flip
- High energy protons and neutrons
  - Work great - but, you need a particle accelerator
- Hmm….

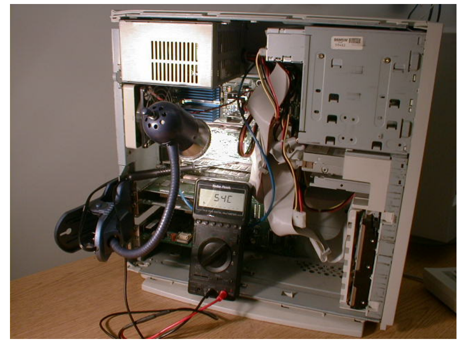
Using Heat

50-watt spotlight bulb

Between 80° -100°C, memory starts to have a few failures

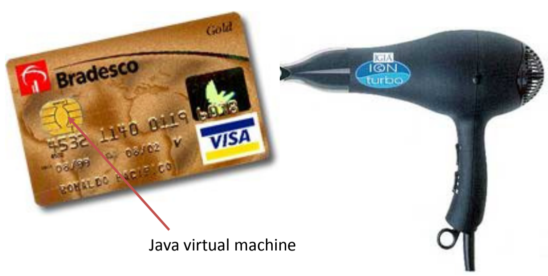
Attack applet is successful (at least half the time)!

Hairdryer works too, but it fries too many bits at once



Picture from Sudhakar Govindavajhala

Should Anyone be Worried?



Recap

Verifier assumes the value you write is the same value when you read it

By flipping bits, we can violate this assumption

By violating this assumption, we can violate type safety: get two references to the same storage that have inconsistent types

By violating type safety, we can get around all other security measures

Project Design Descriptions due **Tuesday**
Sign up for design review meetings