Programming Languages and Techniques (CIS120)

Bonus Lecture

April 13, 2012

Consequences of "Code is Data"

Code is Data

Note: most images have been removed from this version of the presentation.

Code is Data

- A Java source file is just a sequence of characters.
- We can represent programs with Strings!

```
String p_0 = “class C { public static void
  main(String args[]) {…}”
String p_1 = “class D { public static void
  main(String args[]) {…}”
…
String p_123123 = // solution to HW09
…
String p_93919113414 = // code for Eclipse
…
```

Consequence 1: Tools and Compilers

Tools and Compilers

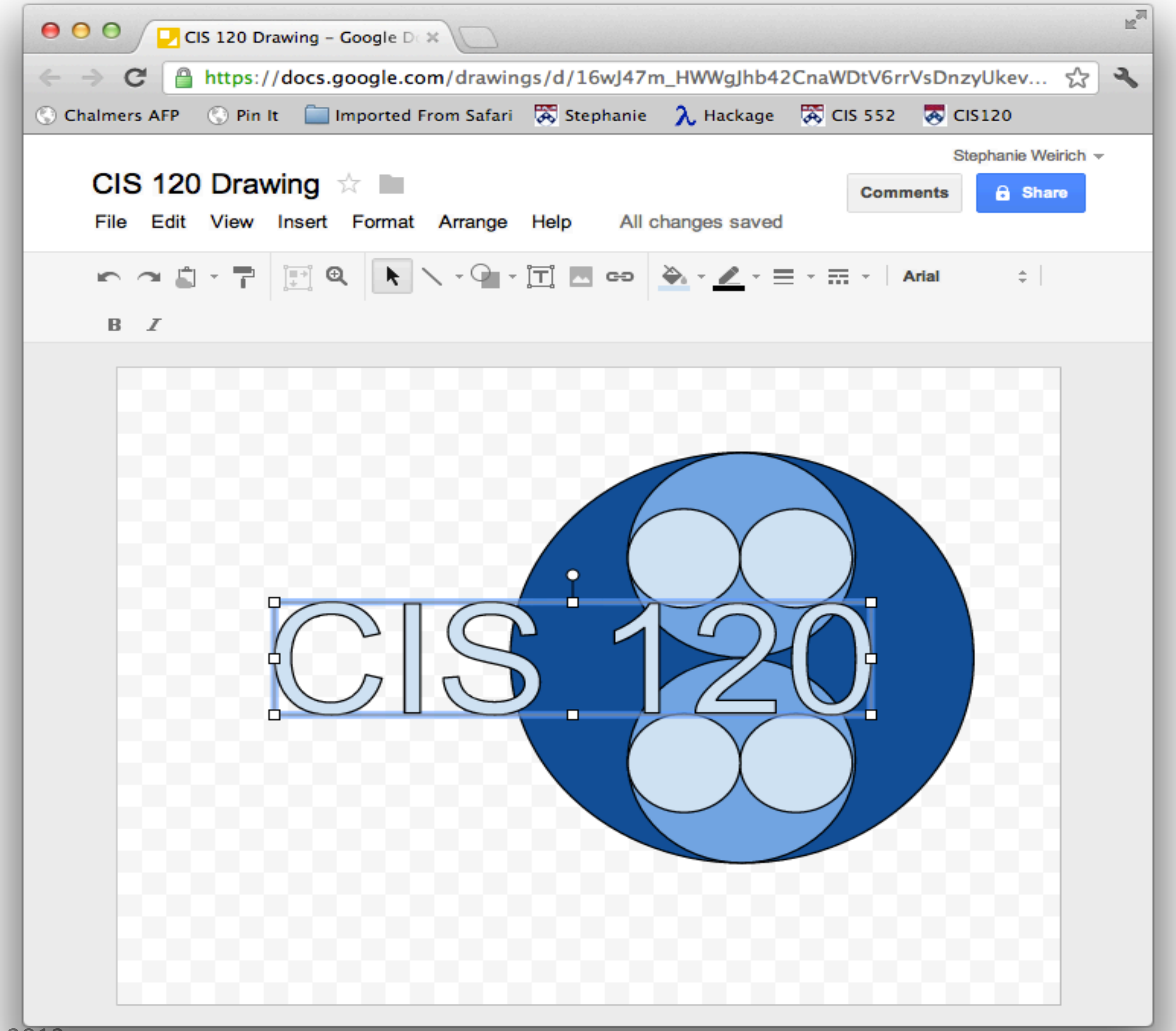
- We can create *programs* that manipulate *programs*.
- Example 1: Eclipse
  - Note that Eclipse manipulates a representation of Java programs
  - Eclipse is written in Java itself
  - You could use Eclipse to edit the code for Eclipse… ?!
- Example 2: Compiler
  - The Java compiler takes a representation of a Java program
  - It outputs a "low-level" representation of the program as a .class file (i.e. Java byte code)
  - Could also compile to other representations, e.g. x86 "machine" code

Example Compilation: Java to X86

```
class Point {
  int x;
  int y;
  Point move(int dx,
  int dy) {
    x = x + dx;
    y = y + dy;
    return this;
  )
}
```

```
.globl __fun__Point.move
__fun__Point.move:
    pushl %ebp
    movl %esp, %ebp
    subl $4, %esp
__5:
    movl 8(%ebp), %eax
    movl 4(%eax), %eax
    movl %eax, -4(%ebp)
    movl 12(%ebp), %ecx
    addl %ecx, -4(%ebp)
    movl -4(%ebp), %ecx
    movl 8(%ebp), %eax
    movl %ecx, 4(%eax)
    movl 8(%ebp), %eax
    movl 0(%eax), %eax
    movl %eax, -4(%ebp)
    movl 16(%ebp), %ecx
    addl %ecx, -4(%ebp)
    movl -4(%ebp), %ecx
    movl 8(%ebp), %eax
    movl %ecx, 0(%eax)
    movl 8(%ebp), %eax
    movl %ebp, %esp
    popl %ebp
    ret
```

Example 3: Interpreters



Consequence 2: Malware

Consequence 2: Malware

- Why does Java do array bounds checking?
- Unsafe language like C and C++ don't do that checking;
  - They will happily let you write a program that "writes past" the end of an array.
- Result:
  - viruses, worms, "jailbreaking"
    mobile phones, Spam, botnets, …
- Fundamental issue:
  - Code is data.
  - Why?

Consider this C Program

```
void m() {
  char[10] buffer;

  char c = read();
  int i = 0;
  while (c != -1) {
    buffer[i] = c;
    c = read();
    i++;
  }
  process(buffer);
}

void main() {
  m();
  // do some more stuff
}
```

Notes:

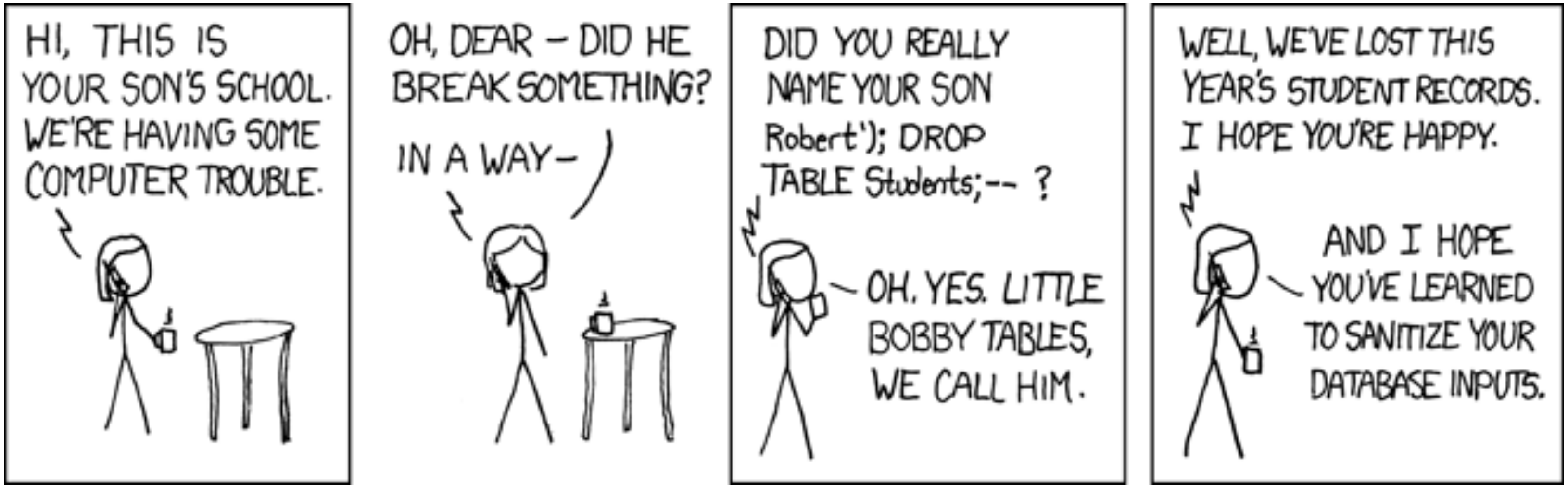
- C doesn’t check array bounds
- Unlike Java, it stores arrays directly on the stack
- What could possibly go wrong?

Abstract Stack Machine

“Stack Smashing Attack”

Code Injection Attacks

```
void registerStudent() {
  print(“Welcome to student registration.”);
  print(“Please enter your name:”);
  String name = readLine();
  evalSQL(“insert into Students(‘“ + name + “’)”  );
}
```


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

http://xkcd.com/327/

Consequence 3: Undecidability

Undecidability Theorem

It is impossible to write a method

```
      boolean halts(String prog)
```

such that for any valid Java program P represented as a string `p_P`

```
      halts(p_P)
```

returns true exactly when the program P halts on all inputs, and false otherwise.

Halt Detector

- Suppose we could write such a program:

```
class HaltDetector {
  public static boolean halts(String javaProgram) {
    // ...do something wonderful...
    // return true if javaProgram halts on all inputs
    // return false if javaProgram does not
  }
}
```

- HaltDetector.halts(p) ⇒ true means “p halts on all inputs”
- HaltDetector.halts(p) ⇒ false means “p does not halt on some input”
- HaltDetector.halts never raises an exception or loops

Do these methods always halt?

```
“boolean m(String x){ return false; }”
=> YES
“boolean m(String x){ return m(x); }”
=> NO
“boolean m(String x){
   if (x.length() == 3) return true;
   else return false; }”
=> YES
“boolean m(String x){
   if (x.length() == 3) return m(x);
   else return false; }”
=> NO
“boolean m(String x){
   if (x.length() == 3) return m(x + \“a\”);
   else return false; }”
=> YES
```

Consider this Program called Q:

```
class HaltDetector {
  public static boolean halts(String javaProgram) {
    // ...do something wonderful...
    // return true if javaProgram halts on all inputs
    // return false if javaProgram does not
  }
}

class Q {
  String p_Q = ??? // string for program Q itself

  public static void main(String[] args) {
     if (HaltDetector.halts(p_Q)) {
       while (true) {/* infinite loop! */ }
     }
  }
}
```

What happens when we run it?

HaltDetector.halts(p_Q) ⇒ true then Q ⇒ infinite loop

HaltDetector.halts(p_Q) ⇒ false then Q ⇒ always halts

This is a *contradiction*!

(Related to the "Russell's Paradox" of set theory…)

Potential Hole in the Proof

- What about the ??? in the program Q?
- It is supposed to be a String representing the program Q itself.
- How can that be possible?
- Answer: code is data!

- See Quine.java

YO, I'M M.C. QUINE AND I'M HERE TO SAY, "YO, I'M M.C. QUINE AND I'M HERE TO SAY!"

Profound Consequences

- Halts is *undecidable*
  - *There are problems that cannot be solved by a computer program!*
- Rice's Theorem:
  - Any "sufficiently interesting" property about computer programs is undecidable!
- You can't write a perfect virus detector!
  - Three possibilities:
  - (1) virus detector might go into an infinite loop
  - (2) it gives you false positives (i.e. says something is a virus when it isn't)
  - (3) it gives you false negatives (i.e. it says a program is not a virus when it is)
- Corollary: You can't write a perfect autograder!

Recommended Reading

- Logicomix: An Epic Search for Truth. Apostolos Doxiadis and Christos Papadimitriou
- Secure Coding in C and C++. Robert C. Seacord
- Goedel, Escher, Bach: An eternal golden braid. Douglas Hofstadter
- I am a Strange Loop. Douglas Hofstadter