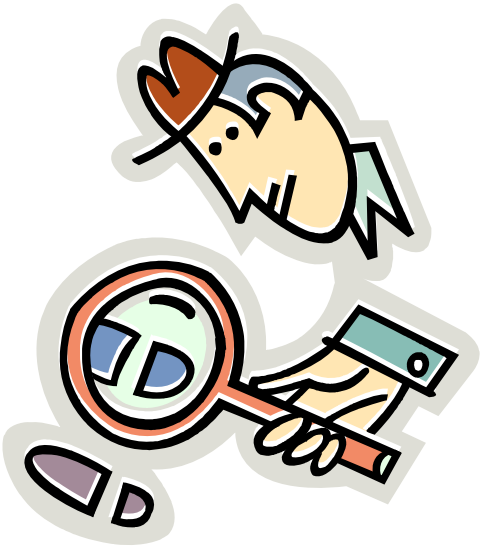
Software Tools
Static Analysis

Part II - Lecture 11

Today's Outline

- Introduction to Static Analysis
- Static Analysis with JLint
- Detecting Null Pointers

Introduction to Static Analysis



"Use the source, Luke."

Static Analysis

- Analyzing programs by looking at their code (i.e. before running them)
- Sad result from theory:
  In general, many analysis problems are undecidable, e.g. Turing's halting problem
- However:
  - Many important cases that occur in practice can be analyzed and **errors** detected
  - For most cases analysis can be approximated, i.e. we can give **warnings** if something is likely to be wrong
- Static analysis is usually done on the AST

False Positives and False Negatives

False Positive:

- The analysis tool gives a warning but there is no error
- More work for the developers (distinguishing true positives from the false positives)

False Negative:

- There is an error but the analysis tool does not give a warning
- Errors go undetected

Conservative analysis means no false negatives are produced (i.e. no errors are missed)

Control Flow and Data Flow Analysis

Control Flow Analysis

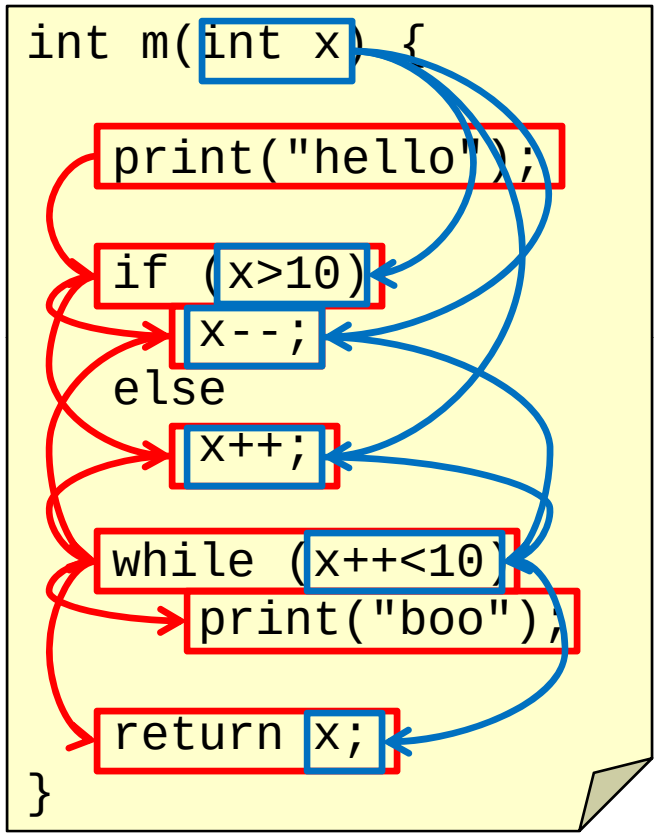
Looking at the different paths of execution in a program

E.g. the red arrows

Data Flow Analysis

Looking at the possible values that occur at certain points in a program

E.g. the blue arrows



Pseudo-Evaluation

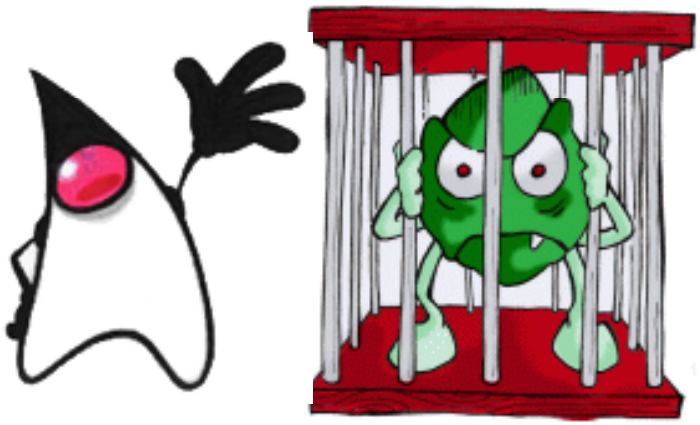
Analyzing a program by simulating its execution (with simplified execution semantics, e.g. only one iteration is executed per loop)

Example: Coverity Prevent

coverity

- Commercial tool for static analysis through pseudo evaluation, e.g. to detect:
  - Buffer overrun: trying to write over end of array
  - Memory leaks: allocating but never freeing memory
  - Use after free: freeing memory and then accessing
  - Uninitialized variables: using variable before init
  - Dead code/data: code or data never used
- Uses mostly heuristics, not precise analysis rules
- Produces false positives and false negatives
- Has helped many open-source projects to fix numerous bugs

JLint



JLint

- JLint is a simple static checker for Java
- It works directly on the compiled classes
  - Does not require the source code
  - Does not require human specification
  - Very easy to use, but limited capabilities
- JLint can give warnings for some concurrency, data flow and code clarity problems
- Some warnings might be false alarms
- Call JLint from the command line with a class file e.g. **`jlint MyClass.class`**
- Call JLint without parameters to get help information

Data Flow Problems

- **Null-pointers**
  - A method is possibly invoked with null as parameter but the method does not check for null argument
  - Value of dereferenced variable may be null
- **Value range**
  - Range of assigned expression value has no intersection with target type range
  - Possible overflow, e.g. `int z = (int)x * (int)y;`
- **Redundancy**
  - Comparison always produces the same result e.g. `1+1==3` will always be false

Unclear Code Problems

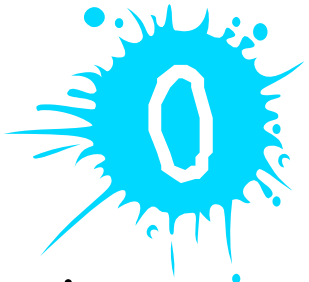
- Checked with a separate tool called AntiC
- Unclear operator precedence, e.g. `x || y == z`
- = and == possibly confused, e.g. `if (x = y) {}`
- Unclear nested block structure

```
while (x != 0)
  x >>= 1;
  n += 1;
return x;
```

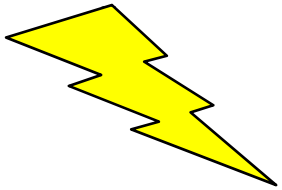
- Unclear else-association,
  e.g. `if (x) if (y) i++; else j++;`
- Method is overridden by method with the same name but different parameters
- Field in class shadows field of superclass
- Local variable name shadows field of class

Detecting Null Pointers

Null Pointers

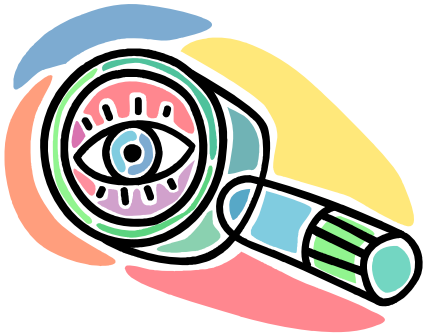


- Null pointers are one of the main causes for runtime errors
- In Java, if a null reference is dereferenced then a NullPointerException is thrown
  - Method call: x.m() and x==null
  - Field access: x.y and x==null



- Often problems in code that lead to null pointer errors are quite simple, e.g.
  - Forgot to initialize variable properly
  - Forgot an if-statement checking for a special case
- Can we detect potential null pointer errors?

Detecting Null Pointers



- Define analysis functions:

  MayReturnNull: Method → {true, false}
  VarMaybeNull: Variable → {true, false}
  ExprMaybeNull: Expression → {true, false}

- For every method M:
  MayReturnNull(M) tells us if M may return null
- At every point in the program, for every variable X defined at that point: VarMaybeNull(X) tells us if X may be null (depends on program state)
- For every expression E defined in a program:
  ExprMaybeNull(E) tells us if E may be null (depends on VarMaybeNull and MayReturnNull)
- If an expression that may be null is dereferenced, then generate a warning

VarMaybeNull Example

We calculate MaybeNull at all positions in a program:

```
void m(String t, int n) {  // VarMaybeNull(t)==true
   String s = null;        // VarMaybeNull(s)==true
   if (n / 10 + 1 > 100)
      s = "hello1";        // VarMaybeNull(s)==false
   else
      s = t;               // VarMaybeNull(s)==true
   // VarMaybeNull(s)==true
   s.substring(1);         // Warning!!!
}
```

- If we don't know much about x: VarMaybeNull(x) is true
- After assigning non-null value to x: VarMaybeNull(x) is false
- VarMaybeNull(x)==true after an if-statement, if VarMaybeNull(x)==true after the if- or after the else-part
- If we dereference variable x and VarMaybeNull(x)==true then give warning ("NullPointerException may happen")

Defining ExprMaybeNull

Defined on a simple Java subset using MayReturnNull and VarMaybeNull:

- Constant expressions: `c`

  ExprMaybeNull(`c`) = (`c` == "null")

  If a constant is null, then true, otherwise false
- Method calls: `m(…)`

  ExprMaybeNull(`m(…)`) = MayReturnNull(`m`)

  If `m` may return null, then the expression may be null
- Variable access: `x`

  ExprMaybeNull(`x`) = VarMaybeNull(`x`)

  The expression may be null if the variable may be null
- Most other expressions can never be null, e.g. `x + y`

Defining VarMaybeNull

Go through the statements one by one:

- Most statements do not affect VarMaybeNull(x),
  e.g. statements where variable x is not involved
- Assignment: `x = expr;`
  VarMaybeNull(x) = ExprMaybeNull(expr)
  If the expression may be null, then the var may be null
- If: `if(…) s1; else s2;`
  VarMaybeNull(x) = VarMaybeNull(x) after s1;
  || VarMaybeNull(x) after s2;
- For loop: `for(…) s1;`
  VarMaybeNull(x) = VarMaybeNull(x) after s1;
  || VarMaybeNull(x) before `for`
  If the loop is executed, then look at the loop body;
  if it is not executed then VarMaybeNull is unchanged

Defining MayReturnNull

Look at all return statements "`return e;`" in method m:

- If for all these statements ExprMaybeNull(e)==false, then MayReturnNull(m)==false
- If for least one statement ExprMaybeNull(e)==true, then MayReturnNull(m)==true
- If we do not know enough about a method m (e.g. we don't have the source code) then let's be careful and say MayReturnNull(m)==true
- Similar with VarMaybeNull for method parameters: we do often not know what actual parameters a method gets, so we say VarMaybeNull(parameter)==true

Null Pointer Detection Example

```
String m1(int n) {
   String s = null;   // VarMaybeNull(s)==true
   for (int i=0; i<n; i++)
      s = "hello"+i;  // VarMaybeNull(s)==false
   // VarMaybeNull(s)==true
   return s;          // MayReturnNull(m1)==true
}

int m2(String x) {    // VarMaybeNull(x)==true
   String y = "foo";  // VarMaybeNull(y)==false
   if (x.equals("hello"))
      y = "hello";    // VarMaybeNull(y)==false
   else
      y = x;          // VarMaybeNull(y)==true
   // VarMaybeNull(y)==true

   return y.length;   // Warning: y may be null !!!
}
```

Summary

Today's Summary

- Static Analysis:
  Analyzing programs by looking at their code
- Tools can do it automatically, e.g. finding resource leaks, buffer overruns, dead code
- Many analysis problems are undecidable; heuristics are used that produce false positives and false negatives
- Null pointer detection can be done by defining functions on variables, expressions and methods

References:

- Security Report. Static Analysis Tools.
  http://www.securityinnovation.com/security-report/november/staticAnalysis1.htm
- Peter Schachte. A Gentle Introduction to Static Analysis.
  http://www.cs.mu.oz.au/~schachte/lpanalysis.html

Quiz

1. What are false positives and false negatives?
2. What are controls flow and data flow analysis?
3. Take a small Java program and try to do the null pointer detection on it.