Graph Coverage for Design Elements

Isaac Griffith

CS 4422 and CS 5522
Department of Computer Science
Idaho State University

Outcomes

At the end of Today's Lecture you will be able to:

- Understand approaches and limitations of OO Testing

Inspiration

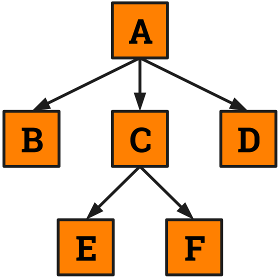
"Testers don't like to break things; they like to dispel the illusion that things work." – Kaner, Bach, Pettichord

OO Software and Designs

- Emphasis on modularity and reuse puts **complexity** in the **design connections**
- Testing **design relationships** is more important than before
- Graphs are based on the **connections** among the software components
  - Connections are dependency relations, also called **couplings**

Call Graph

- The most common graph for structural design testing
- **Nodes:** Units (in Java - methods)
- **Edges:** Calls to units



Example Call Graph

Node Coverage : call every unit at least once (method coverage)

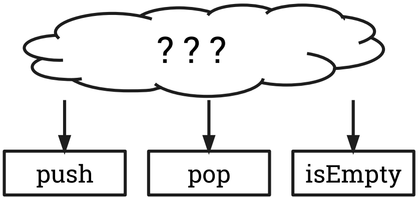
Edge Coverage : execute every call at least once (call coverage)

Call Graphs on Classes

- Node and edge coverage of class call graphs often do not work very well
- Individual methods might not call each other at all!

Class Stack

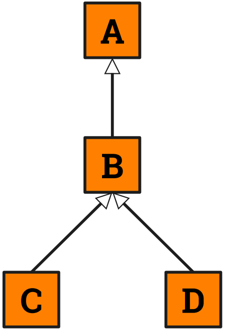
```
public void push(Object o)
public Object pop()
public boolean isEmpty()
```



Other types of testing are needed - do <u>not</u> use graph criteria

Inheritance & Polymorphism

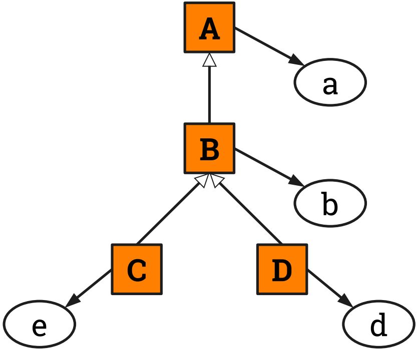
Caution: Ideas are preliminary and not widely used



Example Inheritance Hierarchy Graph

- Classes are not executable so this graph is not directly testable

- We need objects



- What is coverage on this graph?

Coverage on Inheritance Graph

- Create an object for each class?
  - This seems weak because there is no execution
- Create an object for each class and apply call coverage?
  - **OO Call Coverage:** TR contains each reachable node in the call graph of an object instantiated for each class in the class hierarchy
  - **OO Object Call Coverage:** TR contains each reachable node in the call graph of every object instantiated for each class in the class hierarchy.
- Data flow is probably more appropriate …

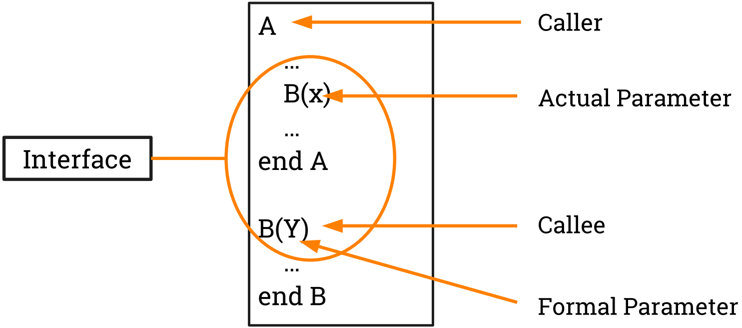
Data Flow at the Design Level

- Data flow couplings among units and classes **are more complicated** than control flow couplings
  - When values are passed, they "change names"
  - Many different ways to share data
  - Finding defs and uses can be difficult - finding which uses a def can reach is very difficult
- When software gets complicated … testers should get interested
  - That's where the faults are!

Preliminary Definitions

- **Caller**: A unit that invokes another unit
- **Callee**: The unit that is called
- **Callsite**: Statement or node where the call appears
- **Actual parameter**: Variable in the caller
- **Formal parameter**: Variable in the callee

Example Call Site

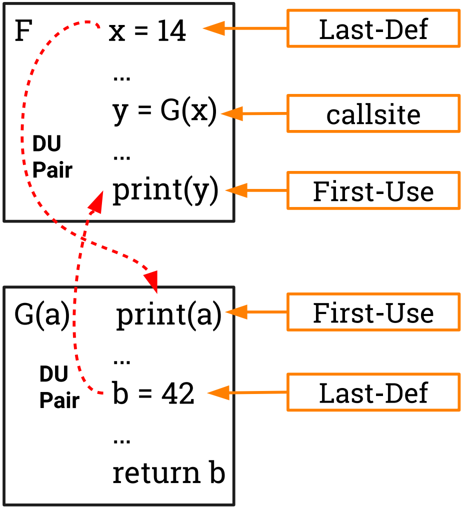


- Applying data flow criteria to def-use pairs between units is **too expensive**
- Too many possibilities
- But this is integration testing, and we really only care about the **interface** ...

Inter-procedural DU Pairs

- If we focus on the interface, then we just need to consider the **last definitions** of variables before calls and returns and **first uses** inside units and after calls
- **Last-def**: the set of nodes that define a variable x and has a def-clear path from the node through a callsite to a use in the other unit
  - Can be from caller to callee (parameter or shared variable) or from callee to caller as a return value
- **First-use**: The set of nodes that have uses of a variable y and for which there is a def-clear and use-clear path from the callsite to the nodes

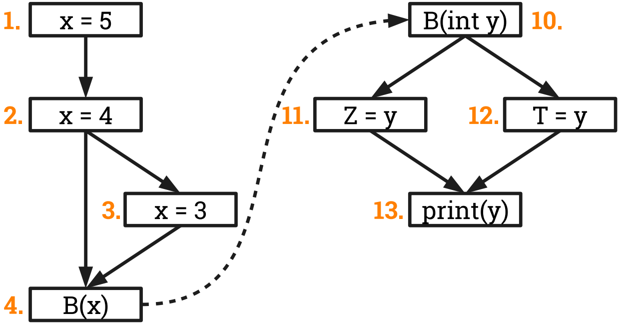
Inter-procedural DU Pairs Example



Inter-procedural DU Pairs Example

DU Pairs

(A, x, 2) – (B, y, 11)
(A, x, 2) – (B, y, 12)
(A, x, 3) – (B, y, 11)
(A, x, 3) – (B, y, 12)



Last Defs
2, 3

First Uses
11, 12

Example - Quadratic

```java
// Program to compute the quadratic root for two numbers
import java.lang.Math;

class Quadratic
{
   private static float Root1, Root2;

   public static void main (String[] argv)
   {
     int X, Y, Z;
     boolean ok;
     int controlFlag = Integer.parseInt (argv[0]);
     if (controlFlag == 1)
     {
          X = Integer.parseInt (argv[1]);
          Y = Integer.parseInt (argv[2]);
          Z = Integer.parseInt (argv[3]);
     }
     else
     {
           X = 10;
           Y = 9;
           Z = 12;
     }
     ok = Root (X, Y, Z);
     if (ok)
       System.out.println
         ("Quadratic: " + Root1 + Root2);
     else
       System.out.println ("No Solution.");
   }

// Three positive integers, finds quadratic root
   private static boolean Root (int A, int B, int C)
   {
      double D;
      boolean Result;
      D = (double) (B*B) -  (double) (4.0*A*C );
      if (D < 0.0)
      {
         Result = false;
         return (Result);
      }
      Root1 = (double) ((-B + Math.sqrt(D))/(2.0*A));
      Root2 = (double) ((-B - Math.sqrt(D))/(2.0*A));
      Result = true;
      return (Result);
   } // End method Root
} // End class Quadratic
```

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Example - Quadratic

```java
// Program to compute the quadratic root for two numbers
import java.lang.Math;

class Quadratic
{
 private static float Root1, Root2; // shared variables

 public static void main (String[] argv)
 {
    int X, Y, Z;
    boolean ok;
    int controlFlag = Integer.parseInt (argv [0]);
    if (controlFlag == 1)
    {
       X = Integer.parseInt (argv [1]); // last defs
       Y = Integer.parseInt (argv [2]); // last defs
       Z = Integer.parseInt (argv [3]); // last defs
    }
    else
    {
       X = 10; // last defs
       Y = 9;  // last defs
       Z = 12; // last defs
    }
    ok = Root (X, Y, Z);
    if (ok) // first use
      System.out.println
        ("Quadratic: " + Root1 + Root2); // first use
    else
      System.out.println ("No Solution.");
 }

 // Three positive integers, finds the quadratic root
 private static boolean Root (int A, int B, int C)
 {
    double D;
    boolean Result;
    D = (double) (B*B) - (double) (4.0*A*C); // first use A,B,C
    if (D < 0.0)
    {
      Result = false; // last def
      return (Result);
    }
    Root1 = (double) ((-B + Math.sqrt (D)) / (2.0*A)); // last def
    Root2 = (double) ((-B - Math.sqrt (D)) / (2.0*A)); // last def
    Result = true; // last def
    return (Result);
 } / /End method Root
} // End class Quadratic
```

ROAR

Quadratic - Coupling DU-pairs

Pairs of locations: **method** name, **variable** name, **statement**

(main(), X, 15) – (Root(), A, 38)

(main(), Y, 16) – (Root(), B, 38)

(main(), Z, 17) – (Root(), C, 38)

(main(), X, 21) – (Root(), A, 38)

(main(), Y, 22) – (Root(), B, 38)

(main(), Z, 23) – (Root(), C, 38)

(Root(), Root1, 44) – (main(), Root1, 28)

(Root(), Root2, 45) – (main(), Root2, 28)

(Root(), Result, 41) – (main(), ok, 26)

(Root(), Result, 46) – (main(), ok, 26)

Coupling Data Flow Notes

- Only variables that are **used or defined** in the callee
- **Implicit initializations** of class and global variables
- **Transitive** DU-pairs are too expensive to handle
  - A calls B, B calls C, and there is a variable defined in A and used in C
- **Arrays**: a reference to one element is considered to be a reference to all elements

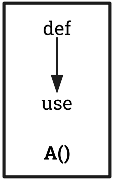
Inheritance, Polymorphism & Dynamic Binding

- Additional **control and data connections** make data flow analysis more complex
- The defining and using units may be in **different call hierarchies**
- When inheritance hierarchies are used, a def in one unit could reach uses in **any class** in the inheritance hierarchy
- With **dynamic binding**, the same location can reach different uses depending on the current type of the using object
- The same location can have different definitions or uses at different points in the execution!

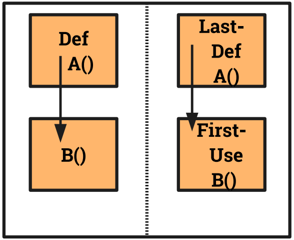
Additional Definitions

- **Inheritance**: If class **B** inherits from class **A**, then all variables and methods in **A** are implicitly in **B**, and **B** can add more
  - A is the **parent** or **ancestor**
  - B is the **child** or **descendant**
- An object reference `obj` that is declared to be of type `A` can be assigned an object of either type `A`, `B`, or any of `B`'s descendants
  - **Declared type**: Type used in the declaration: `A obj;`
  - **Actual type**: Type used in object assignment: `obj = new B();`
- **Class (State) Variables**: The variables declared at the class level, often private

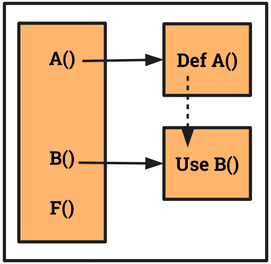
Types of Def-Use Pairs



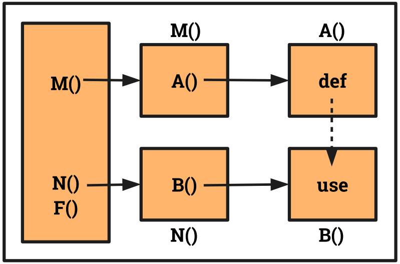
Intra-procedural data flow
(within the same unit)



Inter-procedural data flow



Object-oriented direct coupling

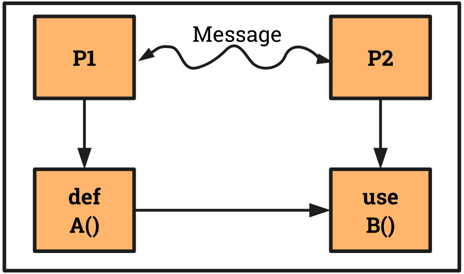


Object-oriented indirect coupling data flow

OO Data Flow Summary

- The defs and uses could be in the **same class**, or **different** classes
- **Researchers** have applied data flow testing to the direct coupling OO situation
  - Has not been used in practice
  - No tools available
- Indirect coupling data flow testing has **not been tried** either in research or in practice
  - Analysis cost may be prohibitive

Web Applications and Other Distributed Software



Distributed software data flow

- “message” could be HTTP, RMI, or other mechanism
- A() and B() could be in the same class or accessing a persistent variable such as in a web session
- Beyond current technologies

Summary - What Works?

- **Call graphs** are common and very useful ways to design integration tests
- **Inter-procedural data flow** is relatively easy to compute and results in effective integration tests
- The ideas for **OO software** and **web applications** are preliminary and have not been used much in practice

Are there any questions?