Introduction to Software Testing
(*2nd edition*)
Chapter 7.4

Graph Coverage for Design Elements

Paul Ammann & Jeff Offutt

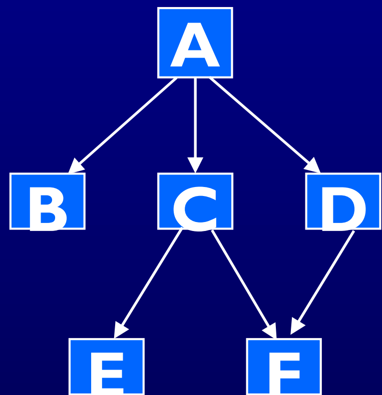
http://www.cs.gmu.edu/~offutt/softwaretest/

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)

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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!

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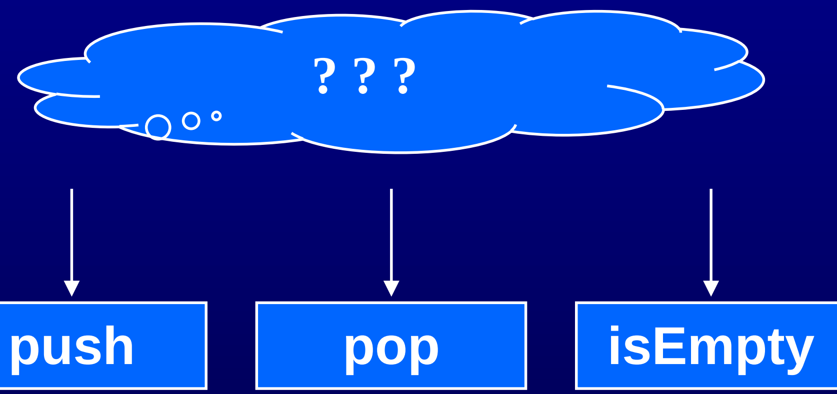
Class stack

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



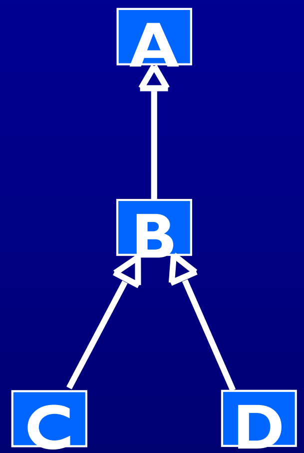
Other types of testing are needed – do not use graph criteria

Inheritance & Polymorphism

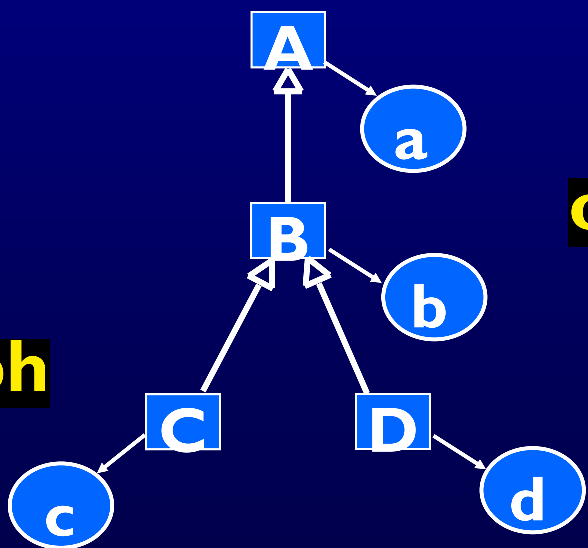
Caution : Ideas are preliminary and not widely used

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

We need objects



Example inheritance hierarchy graph



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

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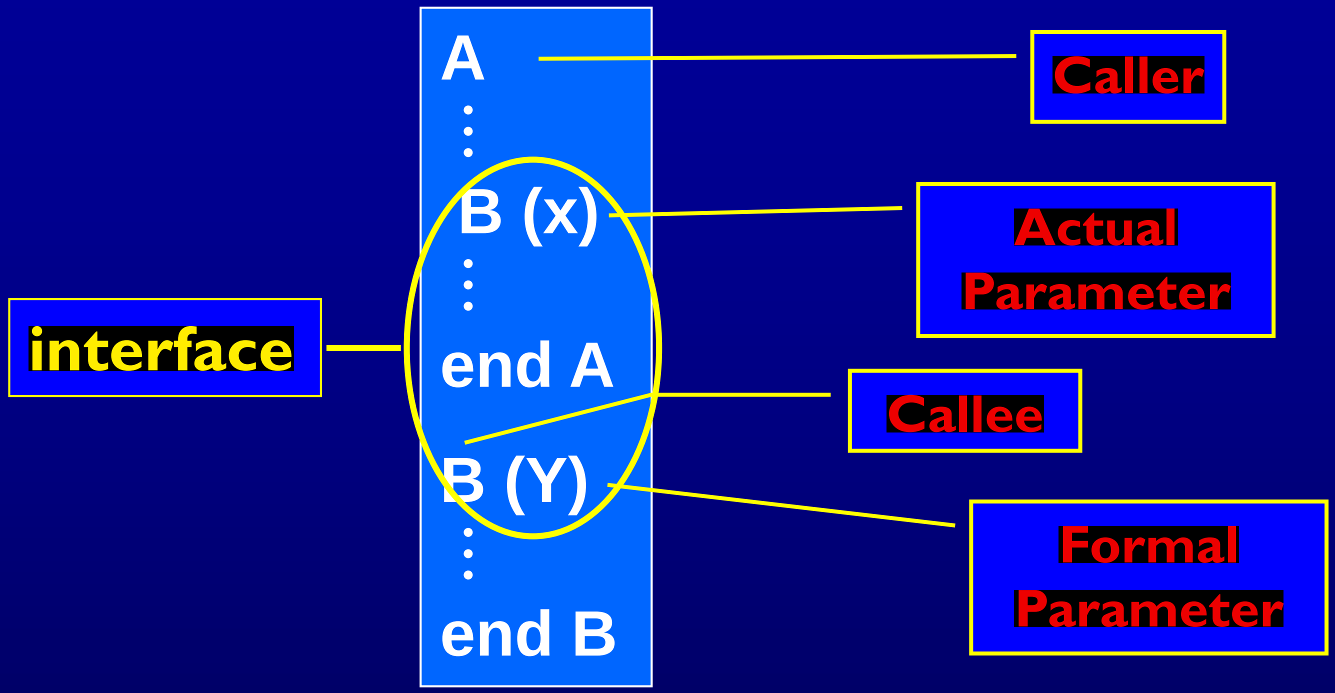
Example Call Site



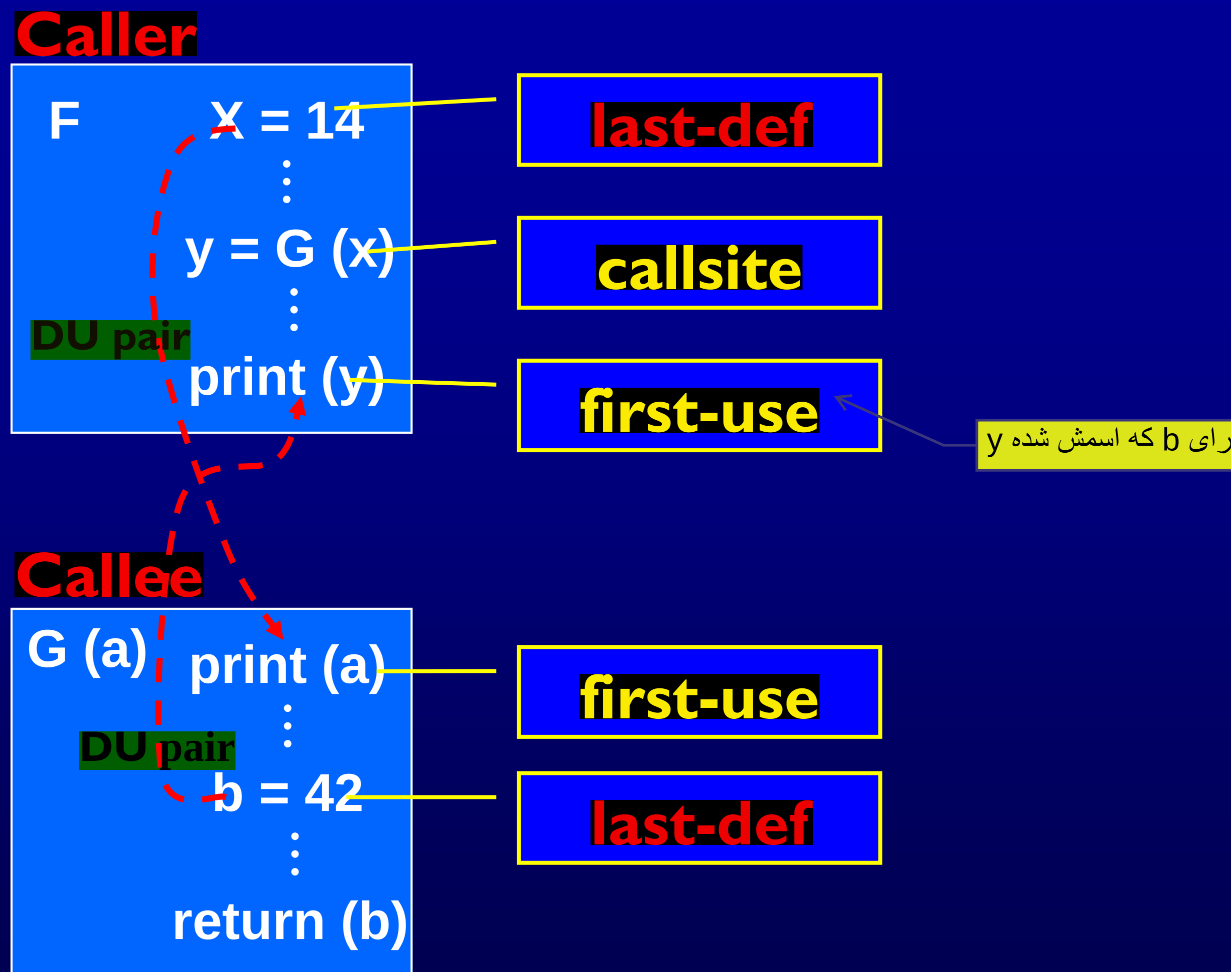
- Applying data flow criteria to def-use pairs between units is too expensive
- Too many possibilities
- But this is integration testing, and we really only care about the interface …

Inter-procedural DU Pairs

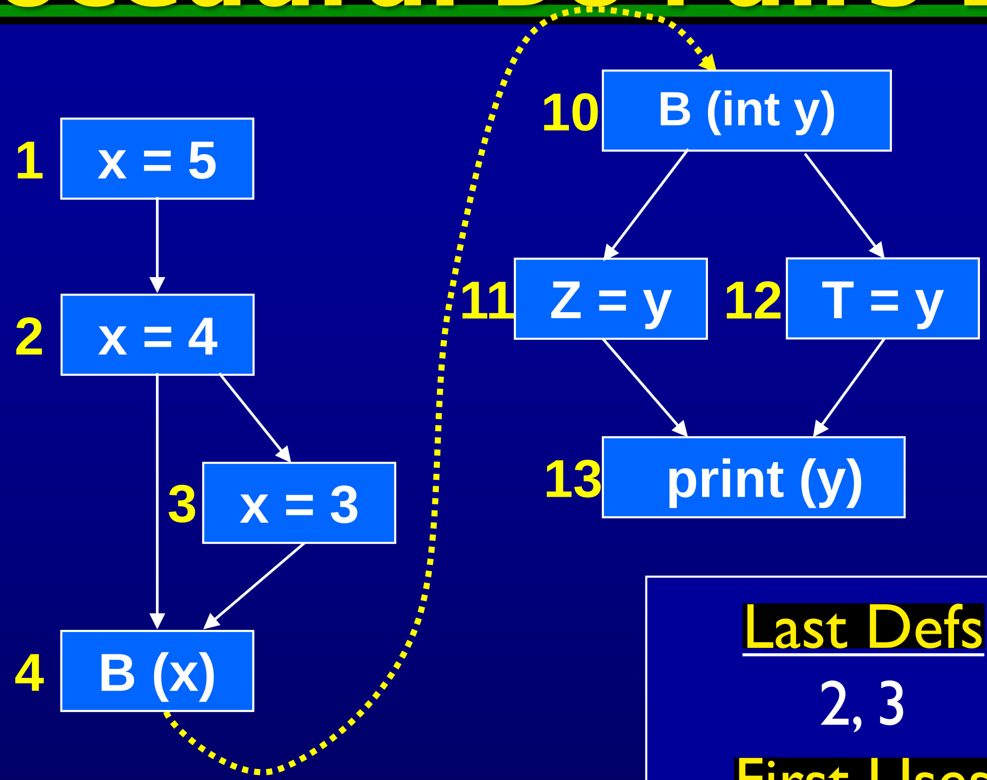
- If we focus on the interface, then we just need to consider the last definitions of variables before calls and returns and first uses inside units and after calls
- Last-def : The set of nodes that define a variable *x* and has a def-clear path from the node through a callsite to a use in the other 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.

A path from n_i to n_j is *use-clear* with respect to variable v if for every node n_k on the path, $k \neq i$ and $k \neq j$, v is not in $use(n_k)$.

Inter-procedural DU Pairs Example



Inter-procedural DU Pairs Example



Last Defs

2, 3

First Uses

11, 12

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)

Example – Quadratic

```
// 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
```

```
// 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;
     }
```

shared variables

last-defs

```
        ok = Root (X, Y, Z);
        if (ok)
          System.out.println
              ("Quadratic: " + Root1 + Root2);
        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);
       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
```

first-use

first-use

last-def

last-defs

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

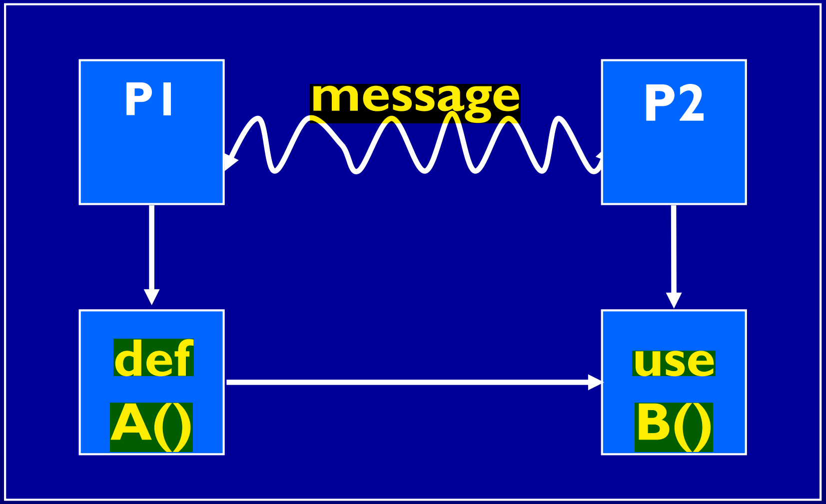
Inheritance, Polymorphism & Dynamic Binding

- 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 !

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