Introduction to Software Testing
Chapter 2.4
Graph Coverage for Design Elements

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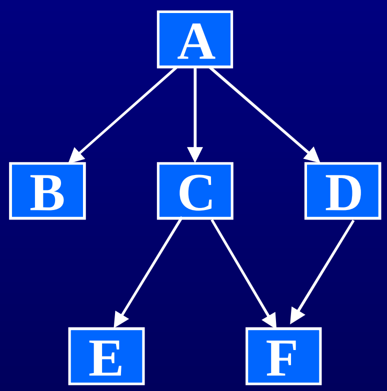
OO Software and Designs

- 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

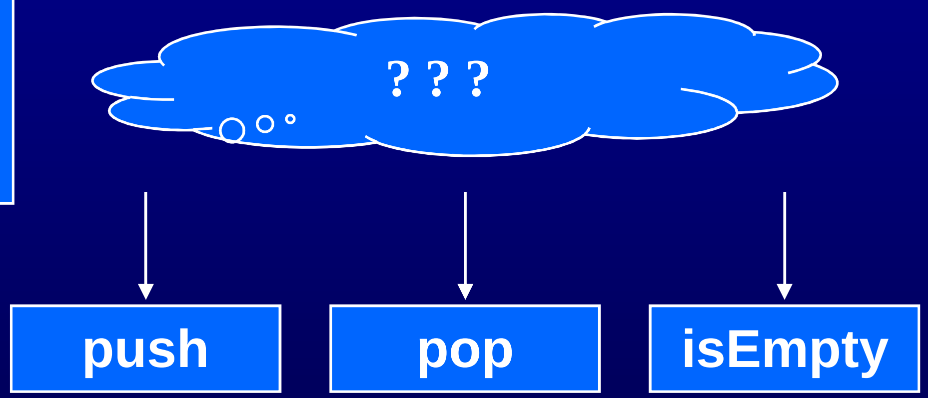
Node coverage : call every unit at least once (method coverage)

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!**

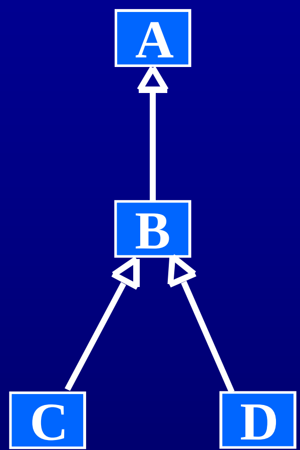
Class stack
public void push (Object o)
public Object pop ( )
public boolean isEmpty (Object o)



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

Inheritance & Polymorphism

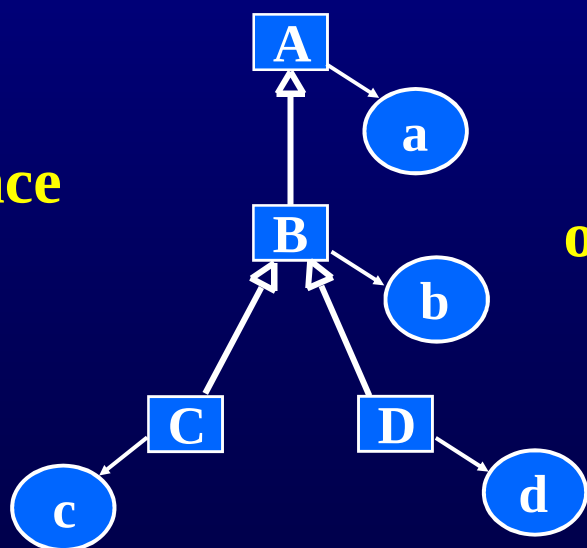
Caution : Ideas are preliminary and not widely used



Example inheritance hierarchy graph

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

We need objects



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?**

<u>OO Call Coverage</u> : TR contains each reachable node in the call graph of an object instantiated for each class in the class hierarchy.

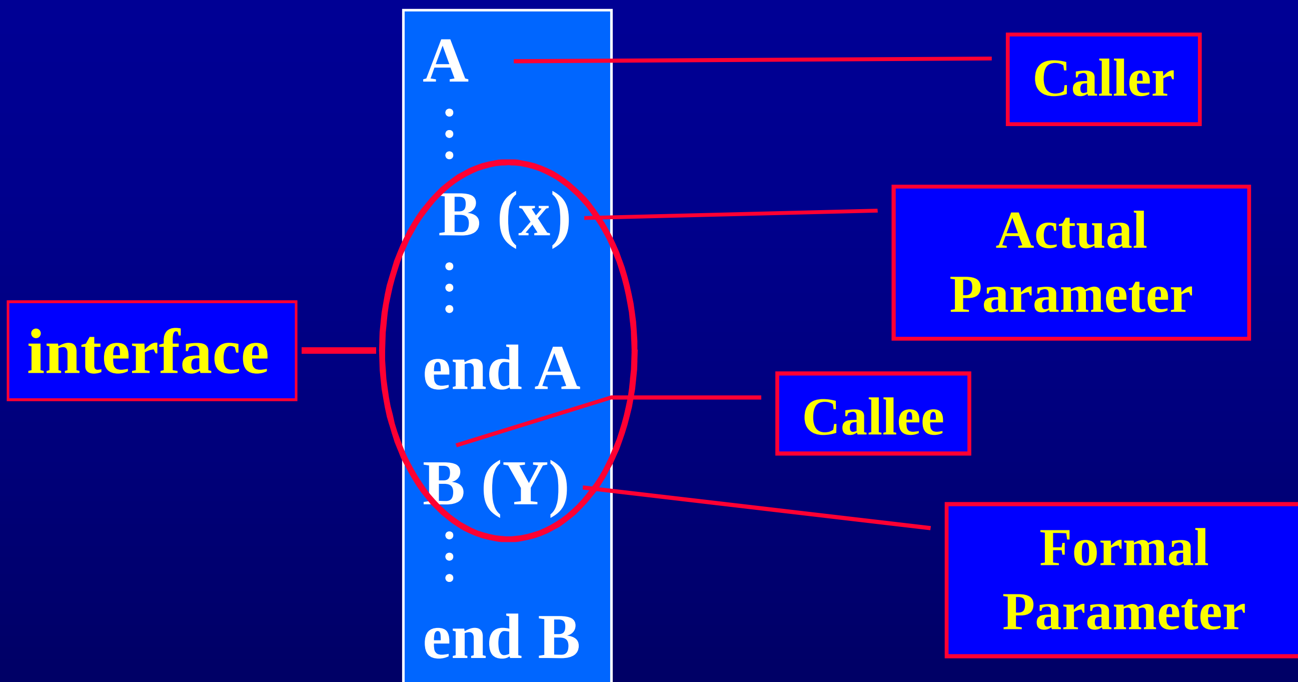
<u>OO Object Call Coverage</u> : TR contains each reachable node in the call graph of <u>every</u> object instantiated for each class in the class hierarchy.

- **Data flow is probably more appropriate …**

Data Flow at the Design Level

- **Data flow couplings among units and classes are <u>more complicated</u> than control flow couplings**
  - **When values are passed, they "<u>change names</u>"**
  - **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!**
- **<u>Caller</u> : A unit that invokes another unit**
- **<u>Callee</u> : The unit that is called**
- **<u>Callsite</u> : Statement or node where the call appears**
- **<u>Actual parameter</u> : Variable in the caller**
- **<u>Formal parameter</u> : Variable in the callee**

Example Call Site

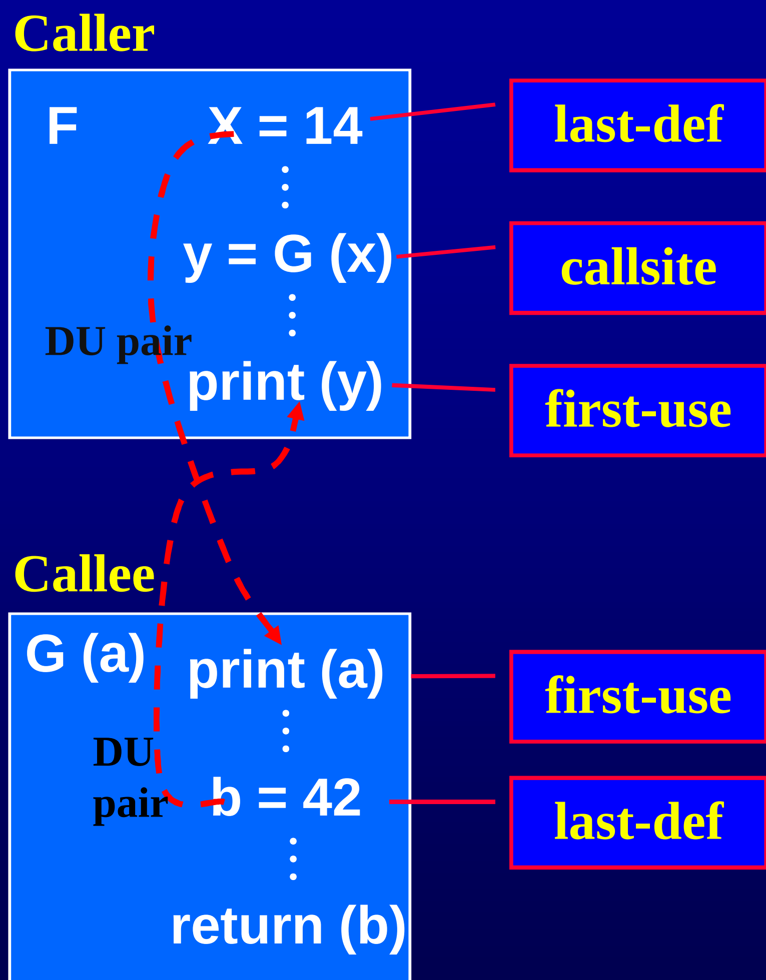


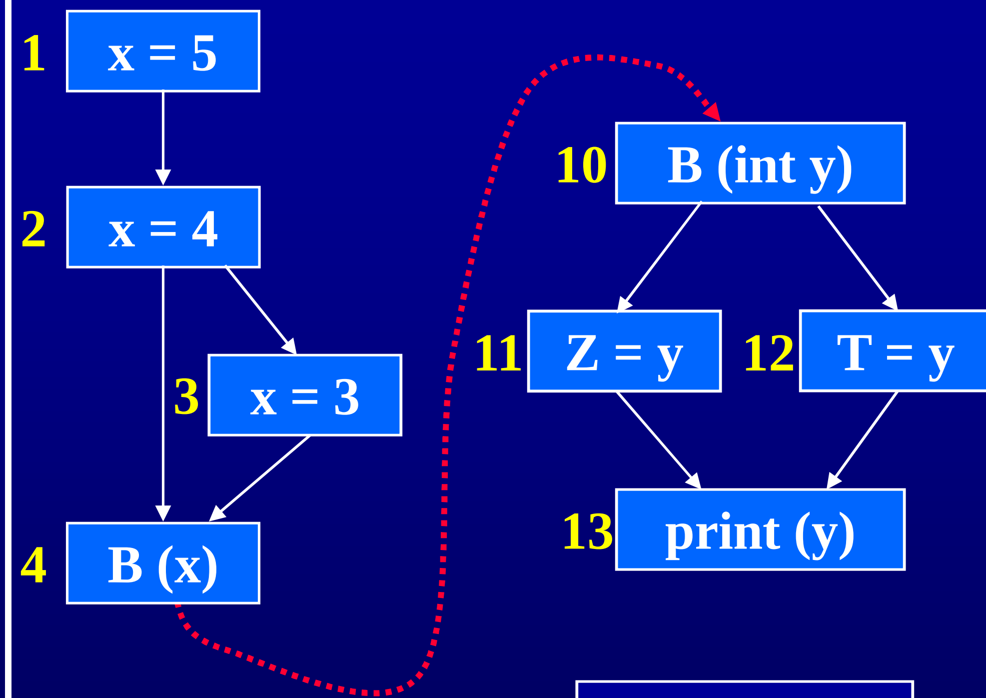
- Applying data flow criteria to def-use pairs between units is **too expensive**
- Too many possibilities
- But this is integration testing, and we really only care about the **interface** …

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

Example Inter-procedural DU Pairs





Last Defs
2, 3

First Uses
11, 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)
 {
     float D;
     boolean Result;
     D = (float) Math.pow ((double)B,
            (double2-4.0)*A*C );
     if (D < 0.0)
     {
        Result = false;
        return (Result);
     }
     Root1 = (float) ((-B + Math.sqrt(D))/(2.0*A));
     Root2 = (float) ((-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
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       }
       else
       {
          X = 10;
          Y = 9;
          Z = 12;
       }
```

shared variables

last-defs

first-use

first-use

last-def

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)
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    float D;
    boolean Result;
    D = (float) Math.pow ((double)B, (double2-4.0)*A*C);
    if (D < 0.0)
    {
        Result = false;
        return (Result);
    }
    Root1 = (float) ((-B + Math.sqrt(D)) / (2.0*A));
    Root2 = (float) ((-B – Math.sqrt(D)) / (2.0*A));
    Result = true;
    return (Result);
} / /End method Root

} // End class Quadratic
```

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 <u>used or defined</u> in the callee**
- **<u>Implicit initializations</u> of class and global variables**
- **<u>Transitive</u> 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**
- **<u>Arrays</u> : 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 !**

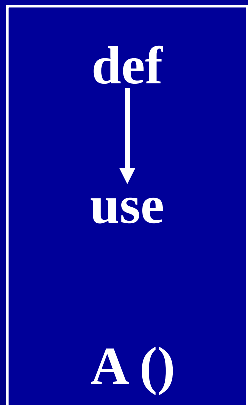
Additional Definitions

- **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 *descendent***

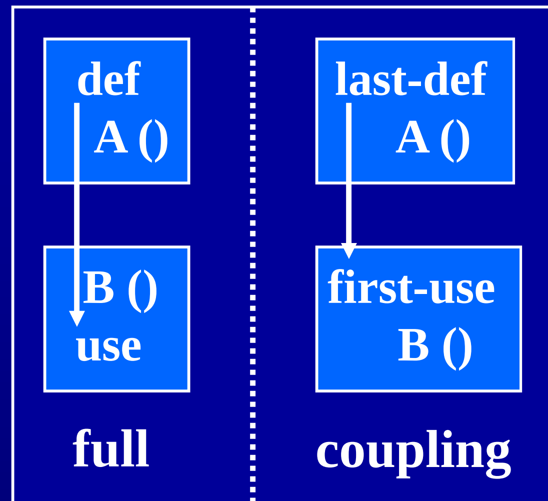
- **An object reference *obj* that is declared to be of type *A* can be assigned an object of either type *A*, *B*, or any of *B*'s descendents**
  - **Declared type : The type used in the declaration: *A obj;***
  - **Actual type : The type used in the object assignment: *obj = new B();***

- **Class (State) Variables : The variables declared at the class level, often private**

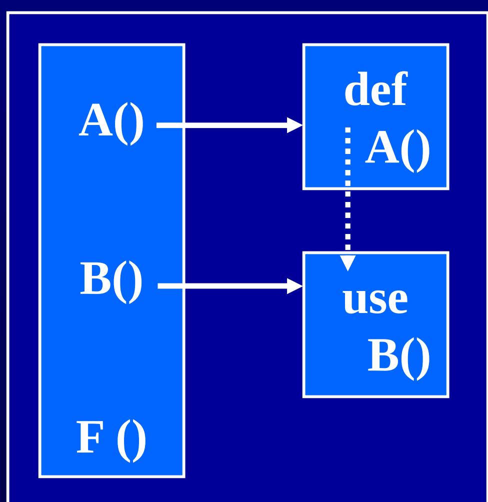
Types of Def-Use Pairs



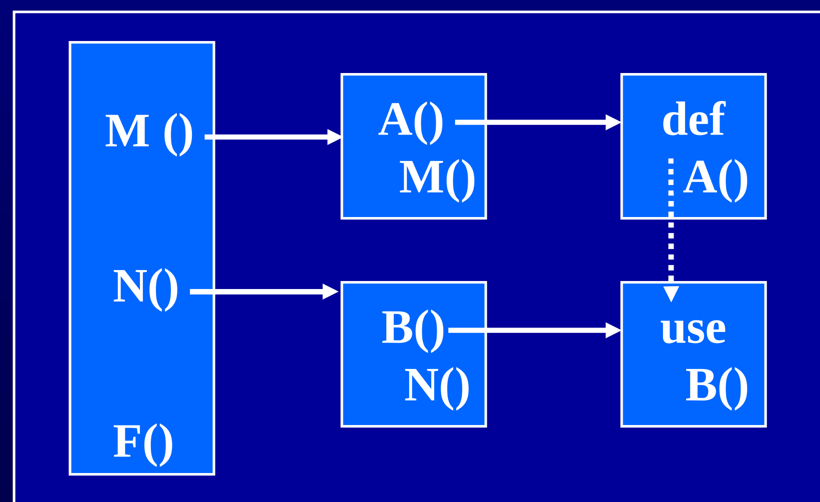
intra-procedural data flow
(within the same unit)



inter-procedural
data flow



object-oriented <u>direct</u>
coupling data flow

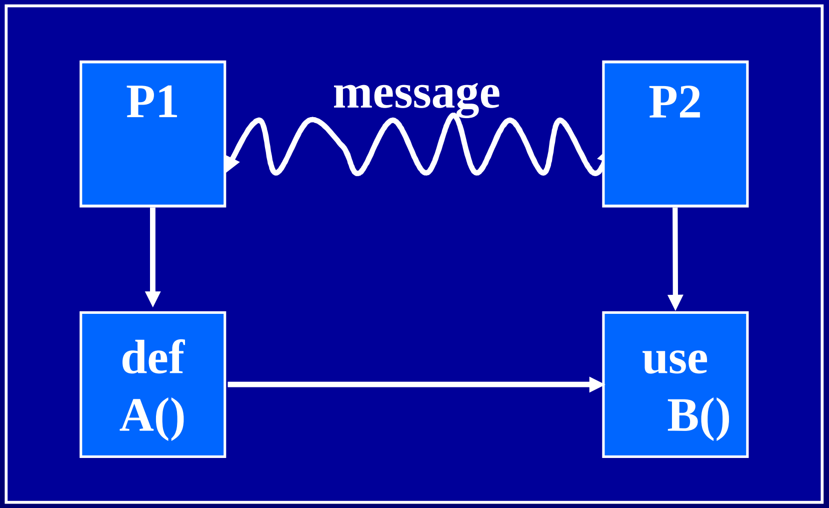


object-oriented <u>indirect</u>
coupling data flow

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