SENG 438
Software Testing, Reliability & Quality

Chapter 5B: White-box Testing
Data-flow Coverage & Coverage Tools

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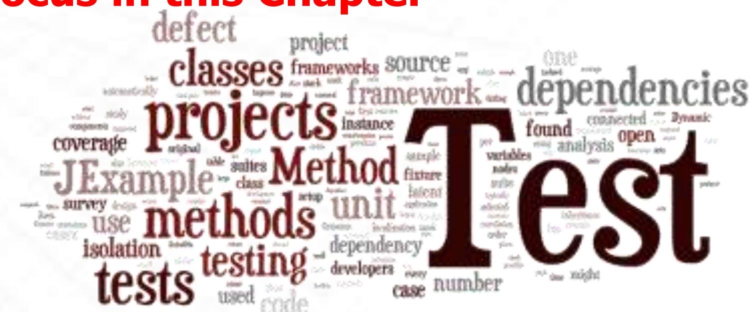
Our focus in this Chapter



What We've Learnt So Far?

- Statement/Decision/Condition/Path coverage → using control flow graph
- Acceptance criteria:
  - Statement, decision, basic and compound condition adequacy, MC/DC, path adequacy
- **Deficiencies:**
  - Node and edge coverage don't test interactions
  - Path-based criteria require impractical number of test cases and only a few paths uncover additional faults
- Need to distinguish "*important*" paths

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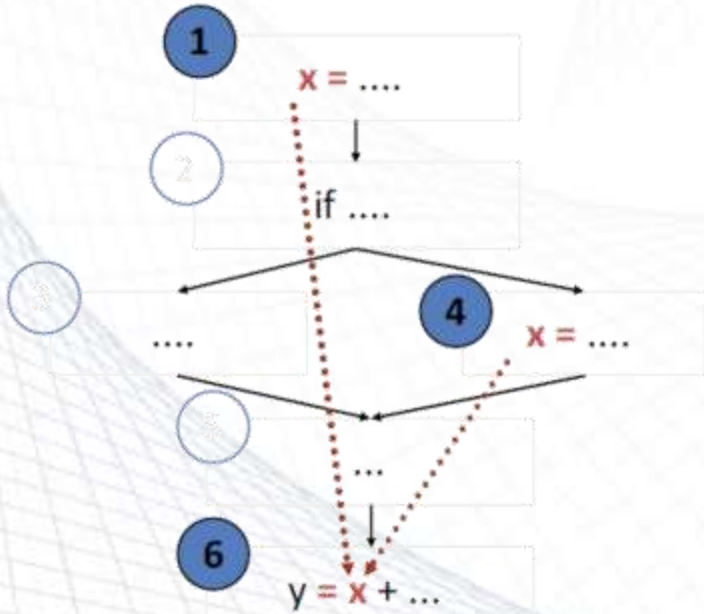
Section 4

Data Flow Coverage

How to enhance a test suite by finding "meaningful" paths to test?

Motivation

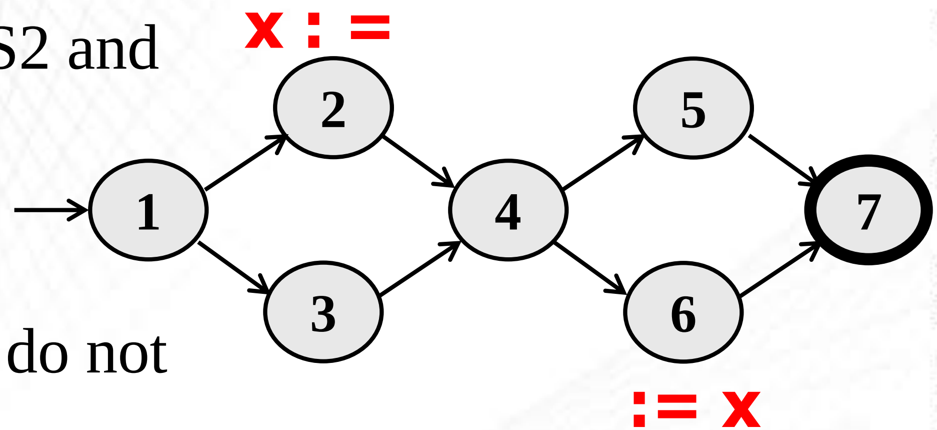
- **Intuition:** Statements interact through *data flow*
  - Value computed in one statement, used in another
  - Bad value computation revealed only when it is used



- Value of x at 6 could be computed at 1 or at 4
- Bad computation at 1 or 4 could be revealed only if they are used at 6
- (1,6) and (4,6) are *def-use (DU) pairs*
  - defs at 1,4
  - use at 6

Data Flow: What is?

- Suppose we define x in S2 and have ref to it in S6



- The two branches tested do not exercise the relationship between the definition of x in S2 and the use of x in S6

Branches tested:
1, 2, 4, 5, 7
1, 3, 4, 6, 7

- Does this cause a problem?

We need to know where the value for a given variable is defined and where it is used (correctly)

Data-flow-based Testing

- **Basic idea**: test the connections between variable **definitions** (“write”) and variable **uses** (“read”)
- Starting point: **variation of** the control flow graph annotated with location of defined and used variables
  - Set `def(n)`: contains variables that are defined at node n (i.e., they are written)
  - Set `use(n)`: variables that are read

Example 1

- L7,L8,L9: define objects and variables
- L16 variable i is both defined and used
- L21 day defined
- L22 and L25 day used
- Etc.

There is a possibility in some programs that a "used" value is modified somewhere on the way between "def" and "use" and that may cause a program failure

```
01. import java.util.*;
02. public class CalendarTest
03. {
04. public static void main(String[] args)
05. {
06. // construct d as current date
07. GregorianCalendar d = new GregorianCalendar();
08. int today = d.get(Calendar.DAY_OF_MONTH);
09. int month = d.get(Calendar.MONTH);
10. // set d to start date of the month
11. d.set(Calendar.DAY_OF_MONTH, 1);
12. int weekday = d.get(Calendar.DAY_OF_WEEK);
13. // print heading
14. System.out.println("Sun Mon Tue Wed Thu Fri Sat");
15. // indent first line of calendar
16. for (int i = Calendar.SUNDAY; i < weekday; i++ )
17. System.out.print(" ");
18. do
19. {
20. // print day
21. int day = d.get(Calendar.DAY_OF_MONTH);
22. if (day < 10) System.out.print(" ");
23. System.out.print(day);
24. // mark current day with *
25. if (day == today)
26. System.out.print("* ");
27. else
28. System.out.print(" ");
29. // start a new line after every Saturday
30. if (weekday == Calendar.SATURDAY)
31. System.out.println();
32. // advance d to the next day
33. d.add(Calendar.DAY_OF_MONTH, 1);
34. weekday = d.get(Calendar.DAY_OF_WEEK);
35. }
36. while (d.get(Calendar.MONTH) == month);
37. // the loop exits when d is day 1 of the next month
38. // print final end of line if necessary
39. if (weekday != Calendar.SUNDAY)
40. System.out.println();
41. }
42. }
```

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Need for Data Flow Testing

- Let's see the need for data-flow-based testing

```
int calculate(int x, int y)
{
  double z=0;
  if (x<>0)      // x neq 0
    z=z+y;
  else
    z=z-y;
  if (y<>0)      // y neq 0
    z=z/x;
  else
    z=z*x;
  return z;
}
```

Test	x	y	z
t_1	0	0	0.0
t_2	1	1	1.0

- Here is a MC/DC-adequate test set
  - i.e., coverage=100%
- **Exercise:** Verify that it is MC/DC-adequate

Note where the value for x is defined and then used may belong to different paths not traversed by the test suite

Need for Data Flow Testing

- The given test suite does not reveal the fault (the chance for division by zero)
- Neither of the two test cases forces the use of x at L9, defined on L1, and with value of x=0
- In larger programs this will be more problematic

```
1:  int calculate(int x, int y)
2:  {
3:    double z=0;
4:    if (x<>0)        // x neq 0
5:      z=z+y;
6:    else
7:      z=z-y;
8:    if (y<>0)        // y neq 0
9:      z=z/x;              ← Use x
10:   else
11:     z=z*x;              ← Use x
12:   return z;
13: }
```

Test	x	y	z
t_1	0	0	0.0
t_2	1	1	1.0

Need for Data Flow Testing

- To do so, we need a test case that causes condition at L8 to be true, and x=0
- An MC/DC-adequate test does not force the execution of this path with x=0 and hence the "divide by zero" defect will not be detected
- Again, consider large systems with > thousands LOC

```
1:  int calculate(int x, int y)
2:  {
3:    double z=0;
4:    if (x<>0)       // x neq 0
5:      z=z+y;
6:    else
7:      z=z-y;
8:    if (y<>0)       // y neq 0
9:      z=z/x;                ← Use x
10:   else
11:     z=z*x;                ← Use x
12:   return z;
13: }
```

Test	x	y	z
t_1	0	0	0.0
t_2	1	1	1.0

Therefore, %100 MC/DC coverage cannot guarantee that the program dose not fail

Data Flow Analysis - Definition

- In Data Flow Analysis, we focus on paths that are significant for the data flow in the program
- Focus of testing is on the assignment of values to objects/variables and their uses
- Analysis of occurrences of variables:
  - **Definition occurrence:** a value is written (bound) to a variable
  - **Use occurrence:** value of a variable is read (referred)
    - **Predicate use (p-use):** a variable is used to decide whether a predicate evaluates to true or false
    - **Computational use (c-use):** compute a value for defining other variables or output values

Data Flow Analysis - Example

- Let's see an example

```
public int factorial(int x){
   int i, result = 1;
   for (i=2; i<=x; i++) {
      result = result * i;
   }
   return result;
}
```

Def-Use Table

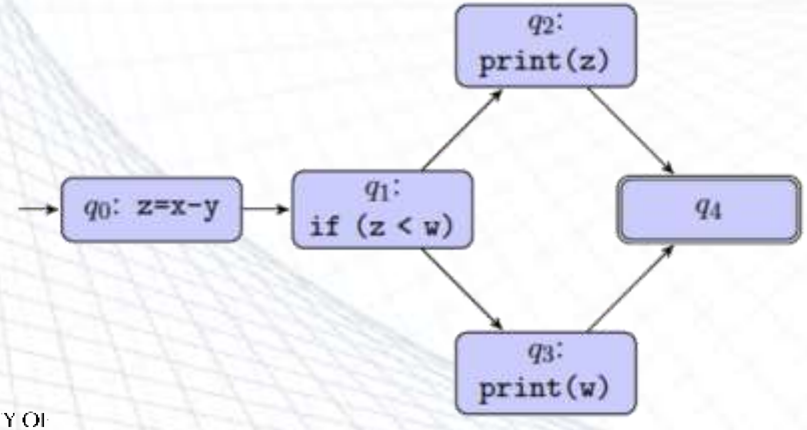
Variable	Def-line	Use-line

Def and Use

- **Goal:** Try to ensure that values of the declared variables are assigned and used correctly
- def: a location where a value for a variable is stored
  use: a location where a variable's value is accessed (read – evaluate – compute)
- def(n): The set of variable defined by node n
- use(n): the set of variable used by node n
  - We usually differentiate between computational (c-use) and predicate (p-use) type

Def and Use Path

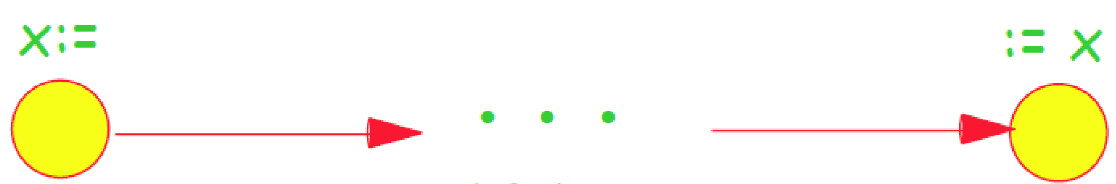
- A **definition-clear path (def-clear)** **`p`** with respect to **`x`** is a sub-path where **`x`** is not defined at any of the nodes in **`p`**
- A **du-path** is a simple path where the initial node of the path is the only defining node of **`x`** in the path
- **Reach**: if there is a def-clear path from the nodes **`m`** to **`p`** with respect to **`x`**, then the def of **`x`** at **`m`** reaches the use at **`p`**



Example for z:
- du-path: q_0,q_1,q_2
- def-clear: q_1,q_2,q_4
- q_0 reaches q_2

Def and Use Coverage

- **All-Defs-Coverage (ADC):**
  - **Some** def-clear sub-path from **each definition** to **some** use reached by that definition



x = ... is a *definition* of x
= x ... is a *use* of x

All-Defs Coverage Example

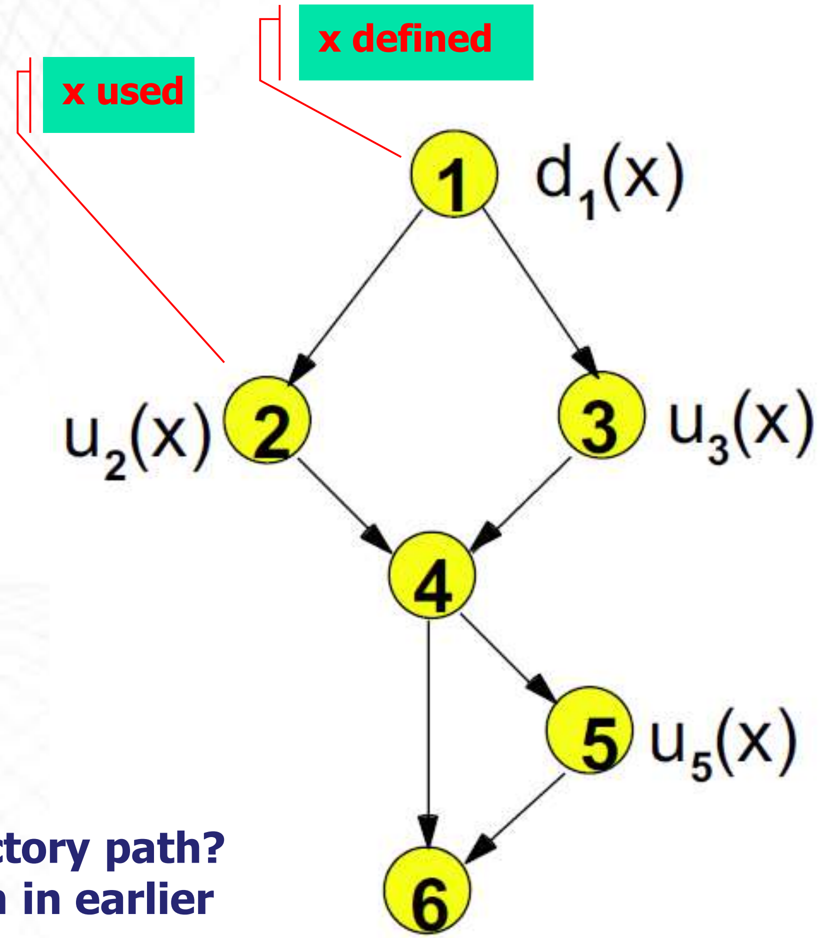
- Requires:

  $d_1(x)$ to a use

- Satisfactory Path:

  [1, 2, 4, 6]

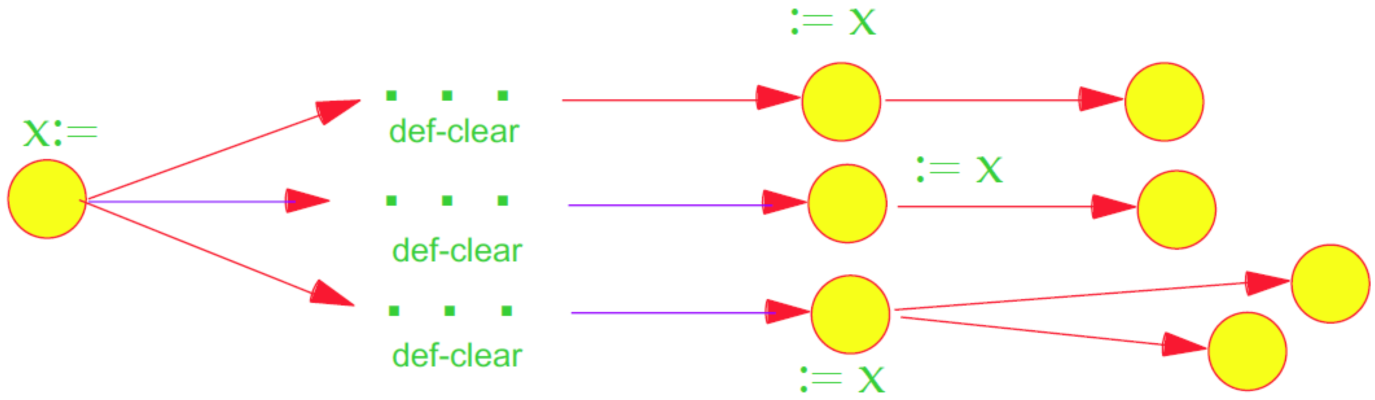
  [1, 3, 4, 6]



Q. Why 5 is not part of ADC satisfactory path?
A. Because value of x is overwritten in earlier nodes 2 or 3

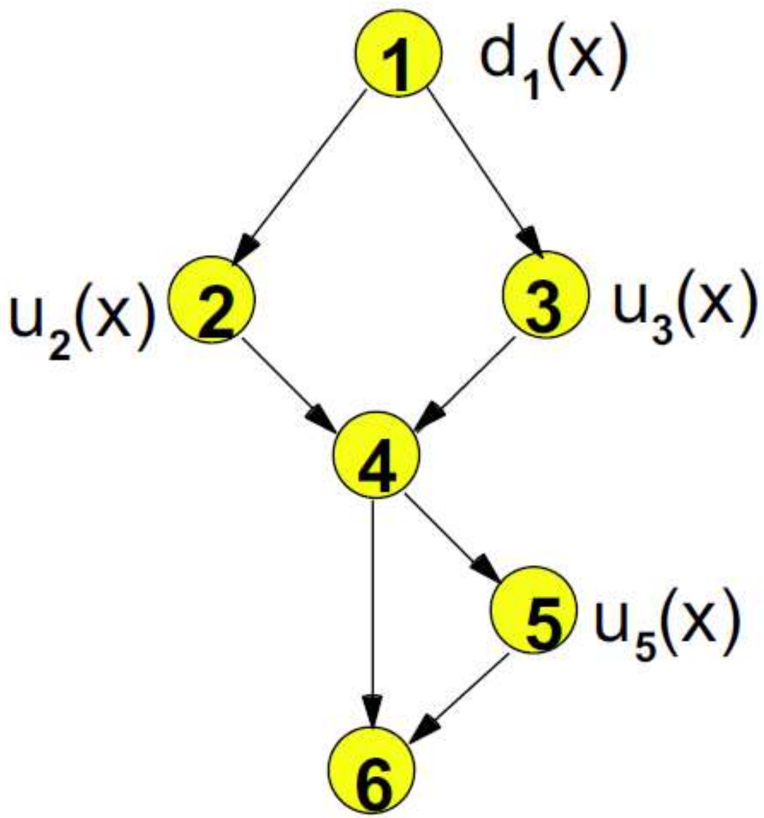
Def and Use Coverage

- **All-Uses Coverage (AUC)**
  - **Some** definition-clear subpath from **each** definition to **each** use reached by that definition and each successor node of the use



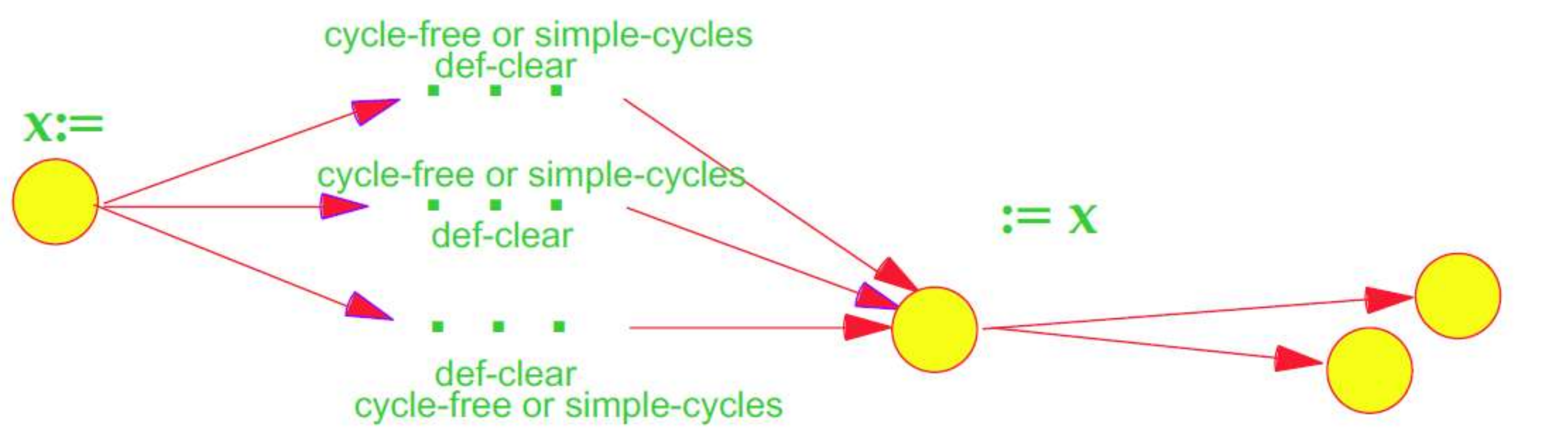
All-Uses Coverage Example

- Requires:
  - $d_1(x)$ to $u_2(x)$
  - $d_1(x)$ to $u_3(x)$
  - $d_1(x)$ to $u_5(x)$
- Satisfactory Path:
  - [1, 2, 4, 5, 6]
  - [1, 3, 4, 6]



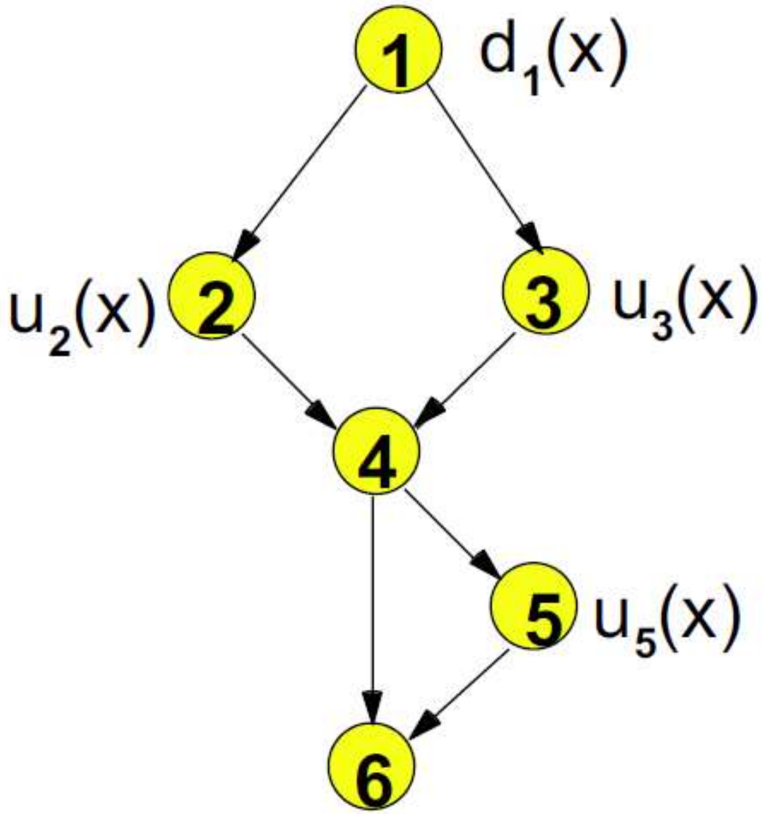
Def and Use Coverage

- **All-Du-Paths Coverage (ADUPC):**
  - **All** def-clear sub-paths that are cycle-free or simple-cycles from **each definition** to **each use** reached by that definition and each successor node of the use



All-Du-Path Coverage Example

- Requires:
  - All $d_1(x)$ to $u_2(x)$: [1,2]
  - All $d_1(x)$ to $u_3(x)$: [1,3]
  - All $d_1(x)$ to $u_5(x)$: [1,2,4,5], [1,3,4,5]

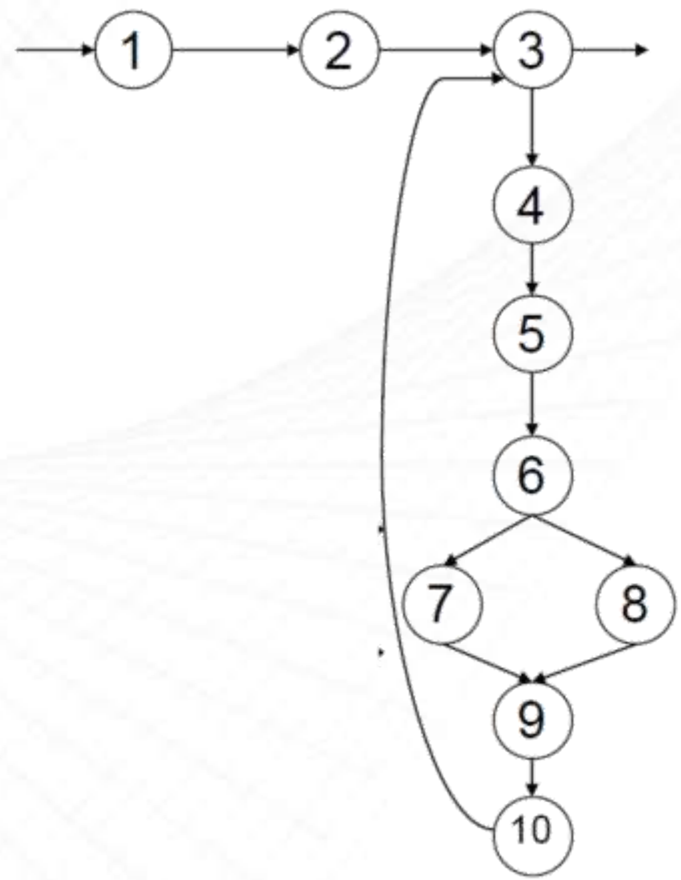


- Satisfactory Path:
  - [1, 2, 4, 5, 6]
  - [1, 3, 4, 5, 6]

Exercise: Def and Use

- Assume **y** is already initialized

```
1:    s:= 0;
2:    x:= 0;
3:    while (x<y) {
4:    x:=x+3;
5:    y:=y+2;
6:       if (x+y<10)
7:          s:=s+x+y;
      else
8:          s:=s+x-y;
9:       endif
10:   }
```



Exercise: Reach

- A definition of variable s at node n_1 reaches node n_2 if and only if there is a path between n_1 and n_2 that does not contain a definition of s

DEF(1) := {s}, USE(1) := ∅
DEF(2) := {x}, USE(2) := ∅
DEF(3) := ∅ , USE(3) := {x,y}
DEF(4) := {x}, USE(4) := {x}
DEF(5) := {y}, USE(5) := {y}
DEF(6) := ∅ , USE(6) := {x,y}
DEF(7) := {s}, USE(7) := {s,x,y}

DEF(8) := {s}, USE(8) := {s,x,y}
DEF(9) := ∅ , USE(9) := ∅
DEF(10) := ∅ , USE(10) := ∅

Reaches nodes 2,3,4,5,6,7,8, but not 9 and 10.

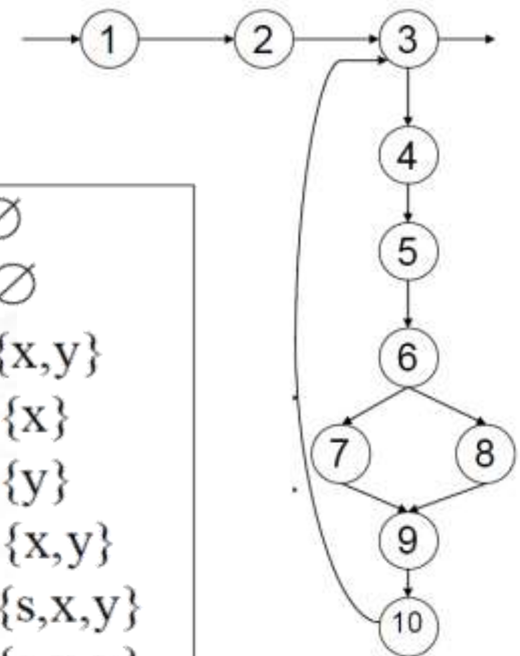
```
1:    s:= 0;
2:    x:= 0;
3:    while (x<y) {
4:    x:=x+3;
5:    y:=y+2;
6:      if (x+y<10)
7:          s:=s+x+y;
         else
8:          s:=s+x-y;
9:      endif
10:   }
```

This is called a Def-Use table

Exercise: Def and Use Pairs

Reaches nodes 2, 3, 4, 5, 6, 7, 8, but not 9,10

This is called a CFG



For this definition, two DU pairs: 1-7, 1-8

DEF(1) := {s}, USE(1) := $\varnothing$
DEF(2) := {x}, USE(2) := $\varnothing$
DEF(3) := $\varnothing$, USE(3) := {x,y}
DEF(4) := {x}, USE(4) := {x}
DEF(5) := {y}, USE(5) := {y}
DEF(6) := $\varnothing$, USE(6) := {x,y}
DEF(7) := {s}, USE(7) := {s,x,y}
DEF(8) := {s}, USE(8) := {s,x,y}

This is called a Def-Use table

DU pair tests:
- TC1: x=0, y=3 (for L7)
- TC2: x=0, y=6 (for L8)

Data Flow Based Testing

Adequacy Criteria

- **All DU pairs**: Each DU pair is exercised by at least one test case
- **All DU paths**: Each *simple* (non looping) DU path is exercised by at least one test case
  - Remember that for each DU pair there can be several DU paths
- **All definitions**: For each definition, there is at least one test case which exercises a DU pair containing it
  - (Every defined value is used somewhere)
- Corresponding coverage fractions can also be defined

All DU paths > All DU pairs > All definitions

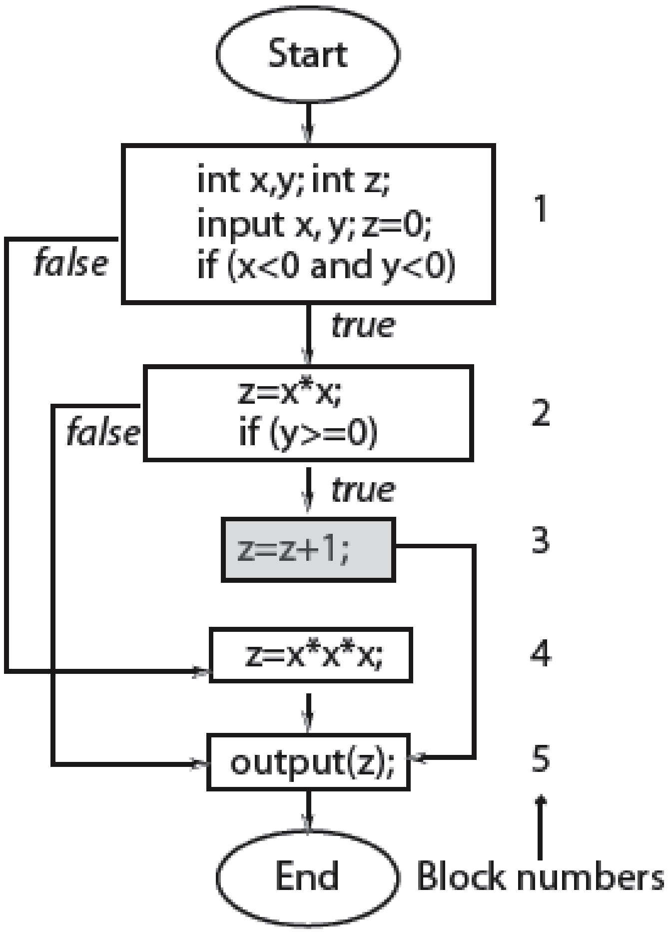
Data Flow Based Testing

- How to enhance test suite using Data Flow based testing?
  - If a variable is defined at node-m and used at node-n, then the path between node m and n should be tested
  - If a variable is modified (c-use) within the path between m and n, say in node-q, then we should have separate tests for
    - m to q (called def-coverage)
    - q to n and m to n (called use-coverage)
  - The def+use coverage is combining both

You can use the program itself, DFD and Def-Use table for this purpose

Data Flow Graph (DFG): Example

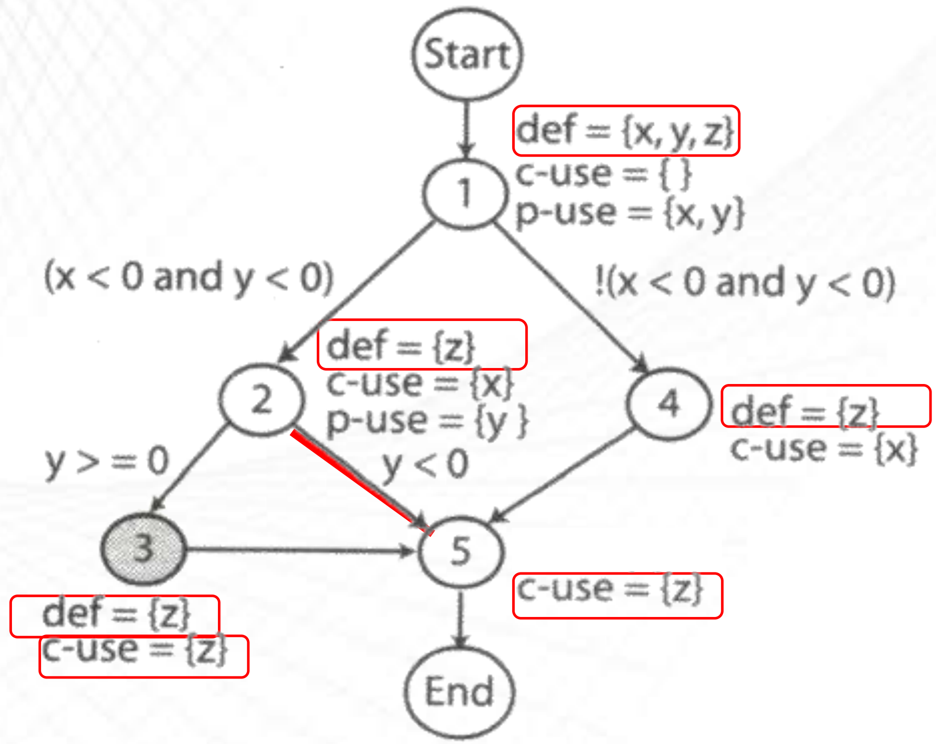
- Let's derive the DFG for this given flowchart
- First the def-use table
- Then, the data flow graph (DFG)



Definition-clear (def-clear) Path

- Any path starting from a node at which a variable is defined and ending at a node at which that variable is used, without redefining the variable anywhere else along the path, is a def-clear path for that variable

This is called a DFG



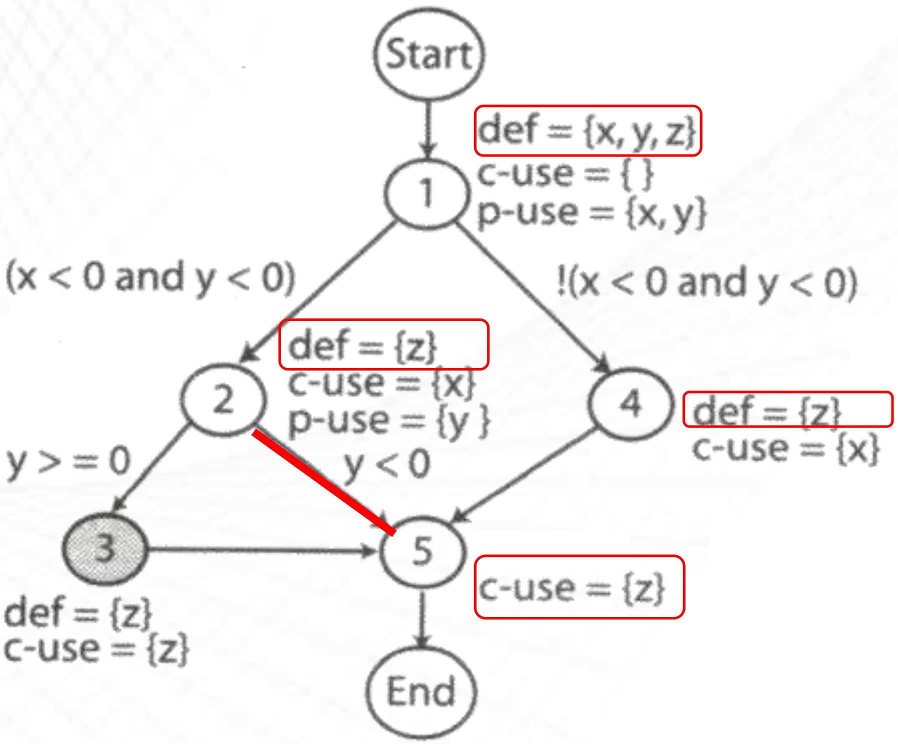
Therefore, any values set for z at L1 is redefined at L2, L3, L4 and L5.
But anything defined at L2 or L4, is still alive at L5

c-use: computational use
p-use: predicate use

Definition-clear (def-clear) Path

Example:

- Path 2-5 is def-clear for variable z defined at node 2 and used at node 5
- Path 1-2-5 is NOT def-clear for variable z defined at node 1 and used at node 5 (since it is redefined at node 2)
- The definition of z at node 2 is live at node 5,
- … while the definition of z at node 1 is not live at node 5

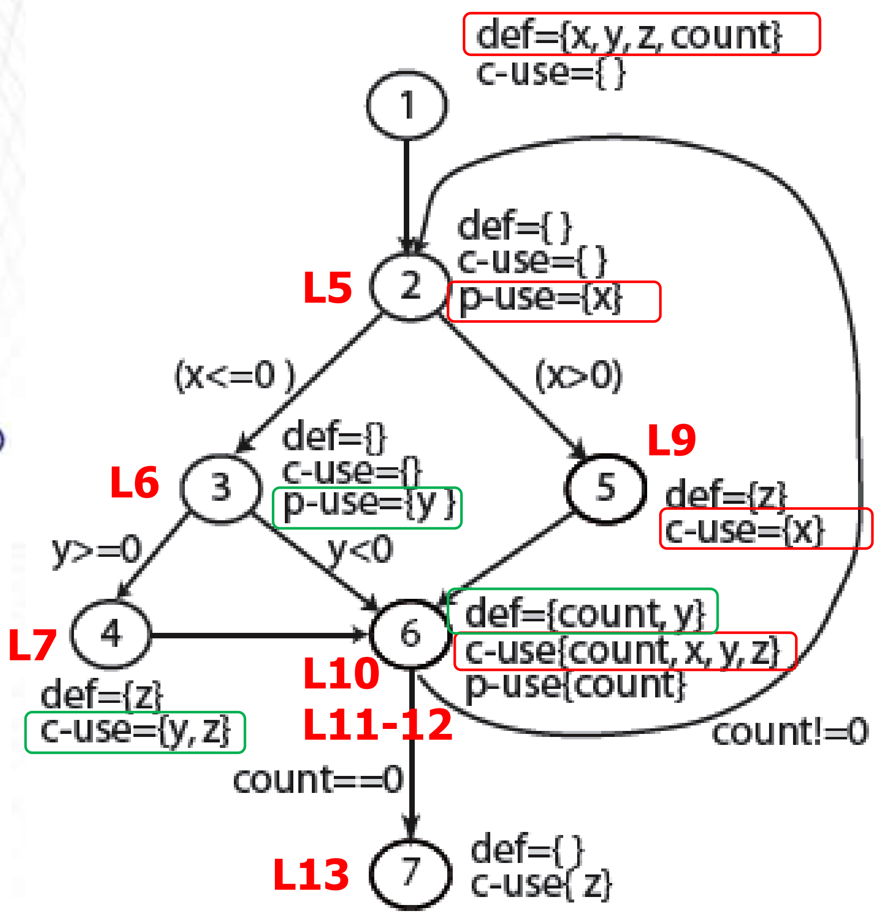


c-use: computational use
p-use: predicate use

Example 2: Def-clear Path

- Draw DFG for the program given below
- Find the def-clear paths for x and y and z
- Which definitions are live at node 4?

```c
double calculate(int x, int y, int count)
{
    double z=0.0;
    do {
        if (x<=0)
            if (y>=0)
                z=y*z+1;
        else
            z=1/x;
        y=(int) (x*y+z);
        count--;
    } while (count >0);
    return z;
}
```

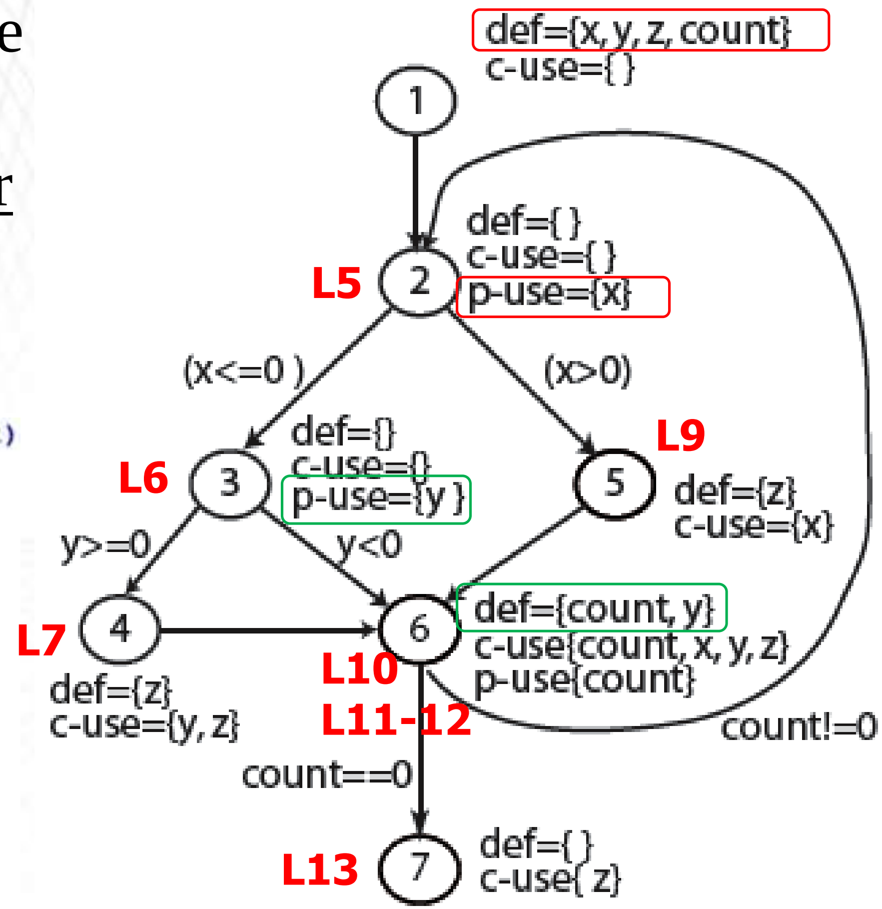


Program 6.16 from the reference book (by Mathur)

Example 2: Def-use Pairs

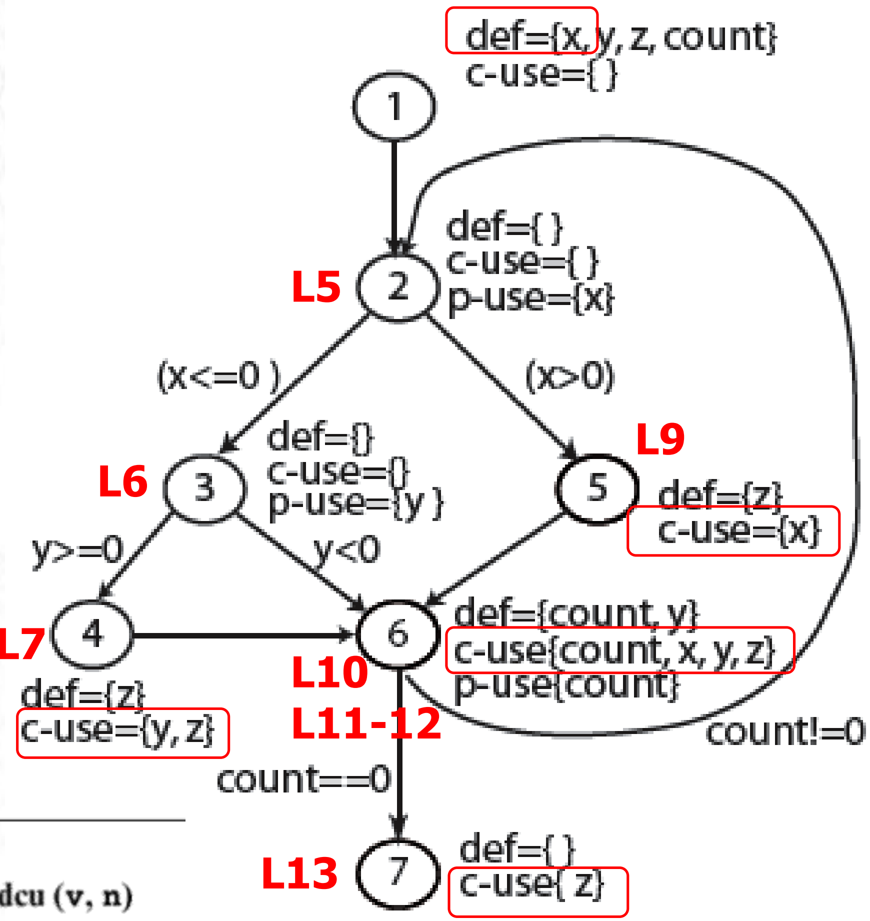
- Definitions of a variable L_{11} and its use at L_{12} constitute a def-use pair
- (L_{11} and L_{12} can be the same, e.g., y=++x;)

```
1  double calculate(int x, int y, int count)
2  {
3      double z=0.0;
4      do {
5          if (x<=0)
6              if (y>=0)
7                  z=y*z+1;
8          else
9              z=1/x;
10         y=(int) (x*y+z);
11         count--;
12     } while (count >0);
13     return z;
14 }
```



Example 2: Def-use Measure

- **Definition c-use pairs dcu(di(x)):** denotes the set of all nodes using variable x from the live definitions of the variable at a given previous node i, di(x)

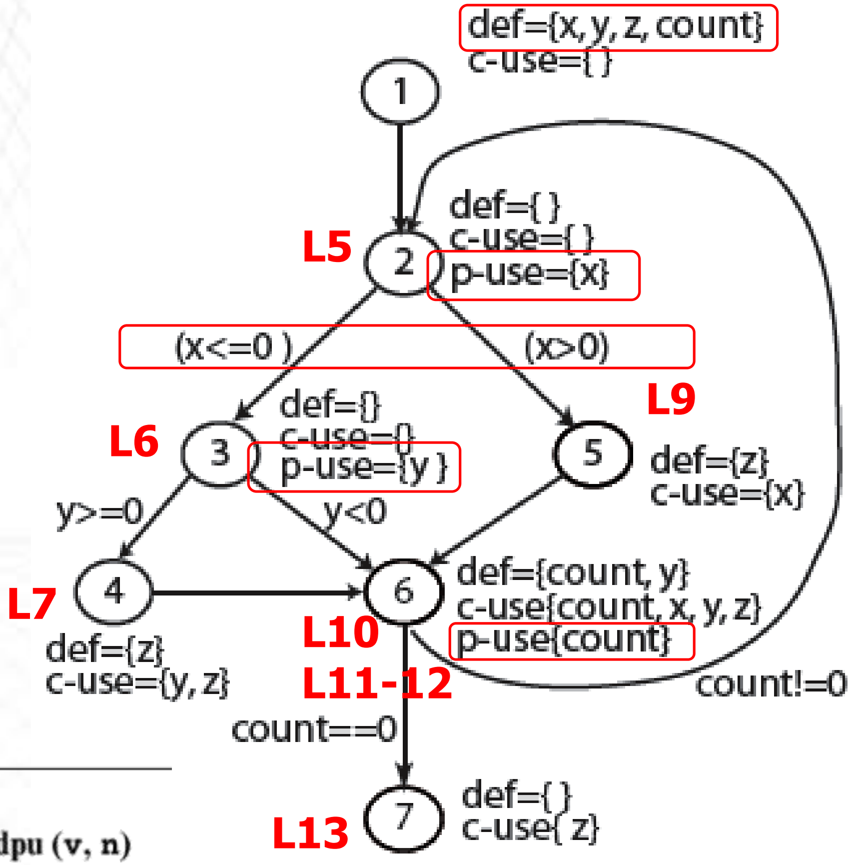


Variable (v)	Defined at node (n)	dcu (v, n)
x	1	{5, 6}

Therefore, tests for (1-5), (1-6) and (5-6) should be added

Example 2: Def-use Measure

- **Definition p-use pairs dpu(di(x)):** denotes the set of all <u>edges</u> (k, l) such that there is a def-clear path from node i to edge (k, l) and x is used at node k

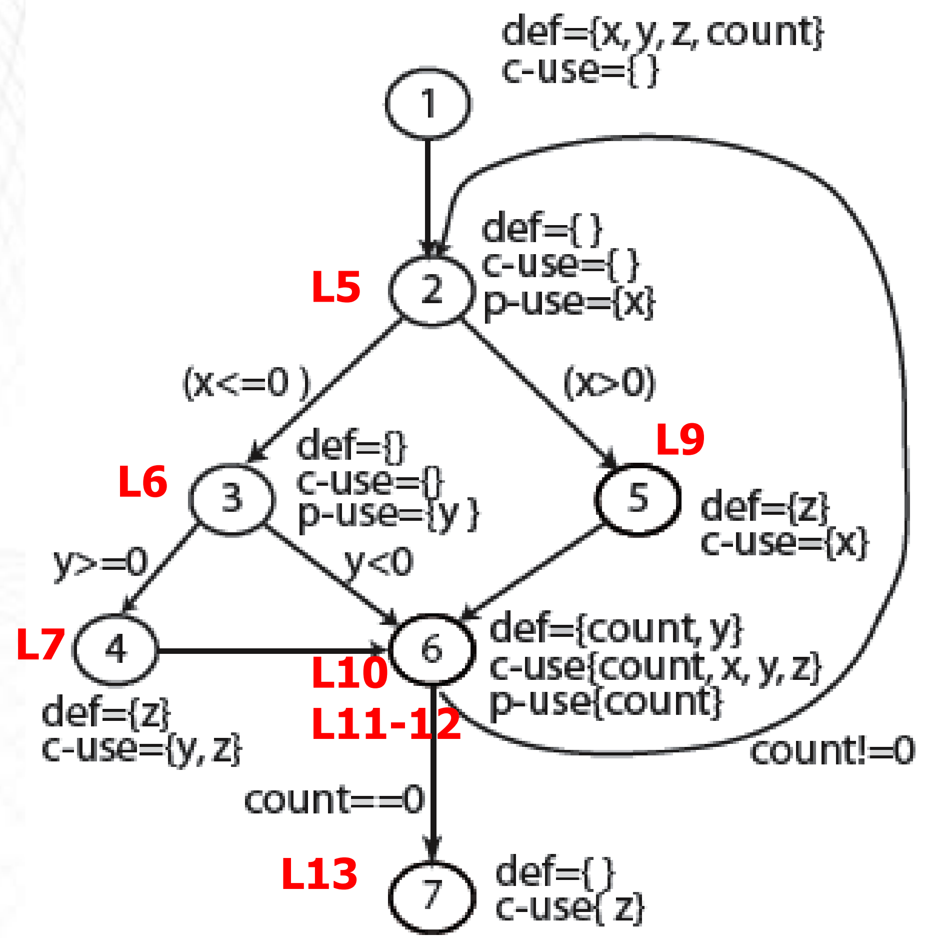


Variable (v)	Defined at node (n)	dcu (v, n)	dpu (v, n)
x	1	{5, 6}	{(2, 3), (2, 5)}

Therefore, tests for (2-3) and (2-5) should be added

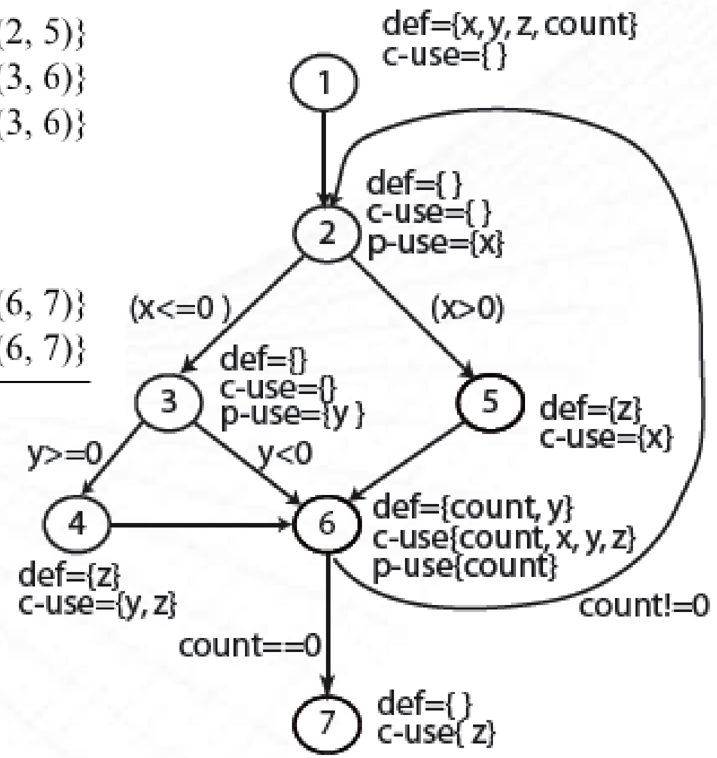
Example 2: Def-use Measure

- Let's derive:
  - dn(v)
  - dcu(v, n)
  - dpu(v, n)



Example 2: Answer

Variable (v)	Defined at node (n)	dcu (v, n)	dpu (v, n)
x	1	{5, 6}	{(2, 3), (2, 5)}
y	1	{4, 6}	{(3, 4), (3, 6)}
y	6	{4, 6}	{(3, 4), (3, 6)}
z	1	{4, 6, 7}	{ }
z	4	{4, 6, 7 }	{ }
z	5	{4, 6, 7}	{ }
count	1	{6}	{(6, 2), (6, 7)}
count	6	{6 }	{(6, 2), (6, 7)}



Data-flow Coverage Measure

- To calculate data-flow test coverage, we should measure how many c-uses and p-uses we have in total

$$CU = \sum_{i=1}^{n} \sum_{\forall n} \left| dcu(v_i, n) \right|$$

$$PU = \sum_{i=1}^{n} \sum_{\forall n} \left| dpu(v_i, n) \right|$$

Loop for variables **Loop for all nodes defining a variable**

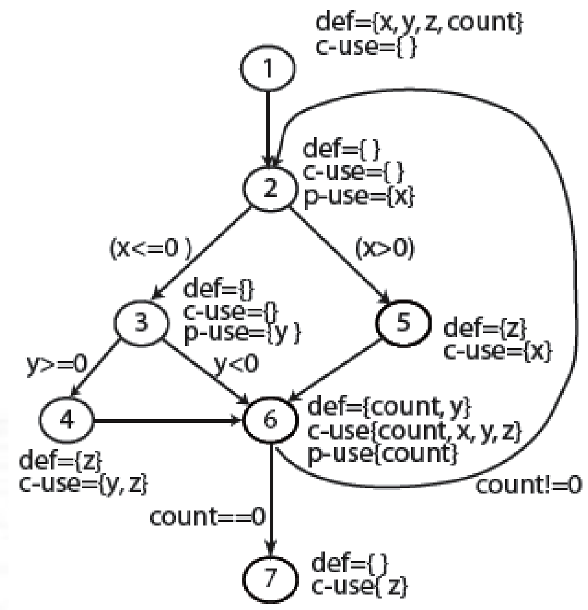
- CU: total number of c-uses in a program
- PU: total number of p-uses
- Given a total of n variables $v_1, v_2 \ldots v_n$

Data-flow Coverage: Example

- Calculate CU and PU

$$CU = \sum_{i=1}^{n} \sum_{\forall n} |dcu(v_i, n)|$$

$$PU = \sum_{i=1}^{n} \sum_{\forall n} |dpu(v_i, n)|$$



Variable (v)	Defined in node (n)	dcu (v, n)	dpu (v, n)
x	1	{5, 6}	{(2, 3), (2, 5)}
y	1	{4, 6}	{(3, 4), (3, 6)}
y	6	{4, 6}	{(3, 4), (3, 6)}
z	1	{4, 6, 7}	{ }
z	4	{4, 6, 7 }	{ }
z	5	{4, 6, 7}	{ }
count	1	{6}	
count	6	{6}	{(6, 2), (6, 7) }
Total:		**17**	**8**

All-uses Coverage Measure

- All-uses coverage is computed as

$$\frac{(CU_c + PU_c)}{((CU + PU) - (CU_f + PU_f))}$$

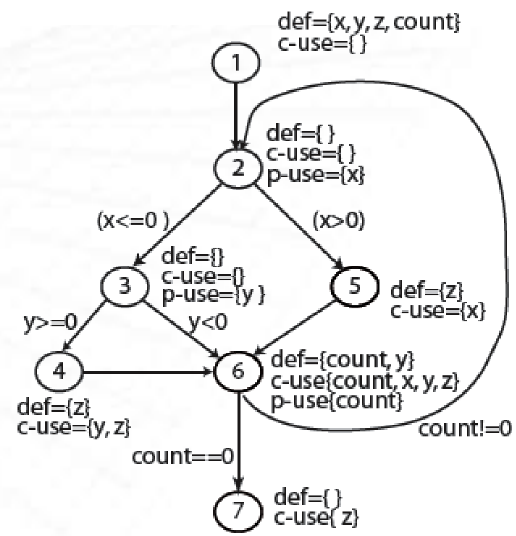
- Where CU is the total c-uses, CU_c is the number of c-uses covered, PU_c is the number of p-uses covered, CU_f the number of infeasible c-uses and PU_f the number of infeasible p-uses
- It is considered adequate with respect to the all-uses coverage criterion if the c-use coverage is %100

All-uses Coverage – Example

Exercise: For the following DFG, show by analysis whether T={TC1, TC2} is adequate w.r.t. to all-uses coverage. Calculate all-uses coverage ratio. If coverage ratio is not 100%, what def-use pairs need to be covered, and what test cases should be added to cover them?

- TC1:<x=5, y=-1, count=1>
- TC2:<x=-2, y=-1, count=3>

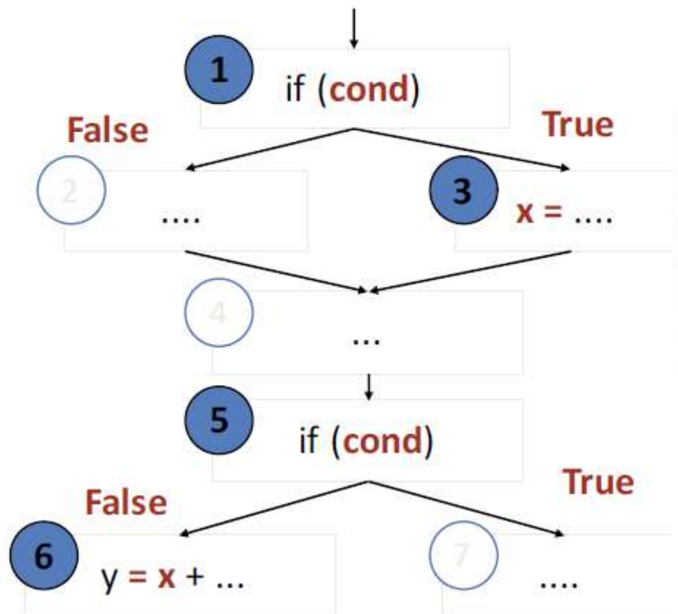
```
double calculate(int x, int y, int count)
{
    double z=0.0;
    do {
        if (x<=0)
            if (y>=0)
                z=y*z+1;
        else
            z=1/x;
        y=(int) (x*y+z);
        count--;
    } while (count >0);
    return z;
}
```



Variable (v)	Defined in node (n)	dcu (v, n)	dpu (v, n)
x	1	{5, 6}	{(2, 3), (2, 5)}
y	1	{4, 6}	{(3, 4), (3, 6)}
y	6	{4, 6}	{(3, 4), (3, 6)}
z	1	{4, 6, 7}	{ }
z	4	{4, 6, 7 }	{ }
z	5	{4, 6, 7}	{ }
count	1	{6}	
count	6	{6}	{(6, 2), (6, 7) }

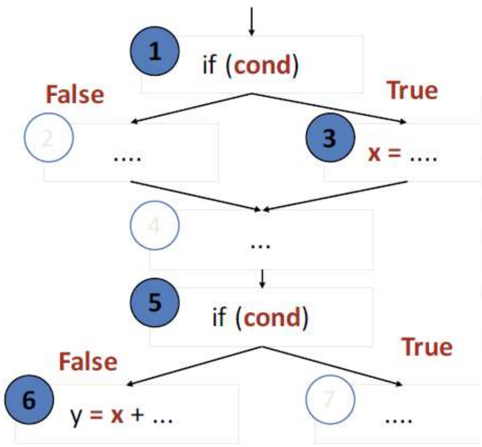
Infeasibility

- Suppose *cond* has not changed between 1 and 5
  - Or the conditions could be different, but the first implies the second
- Then (3,6) is not a (feasible) DU pair
  - But it is difficult or impossible to determine which pairs are infeasible
- Infeasible test obligations are a problem
  - No test case can cover them



Infeasibility

- The path-oriented nature of data flow analysis makes the infeasibility problem especially relevant
  - Combinations of elements matter!
  - Impossible to (precisely) distinguish feasible from infeasible paths
  - More paths = more work to check manually.
- In practice, reasonable coverage is often, not always achievable
  - Number of paths is linear (often) or exponential (worst case)
- All DU *paths* is more often impractical



Summary - Data Flow

- Data flow testing attempts to distinguish “important” paths: Interactions between statements
  - Intermediate between simple statement and branch coverage and more expensive path-based structural testing
- Cover Def-Use (DU) pairs: From computation of value to its use
  - Intuition: Bad computed value is revealed only when it is used
  - Levels: All DU pairs, all DU paths, all defs (some use)
- Limits: Aliases, infeasible paths
  - Worst case is bad (undecidable properties, exponential blow up of paths), so pragmatic compromises are required

Section 5

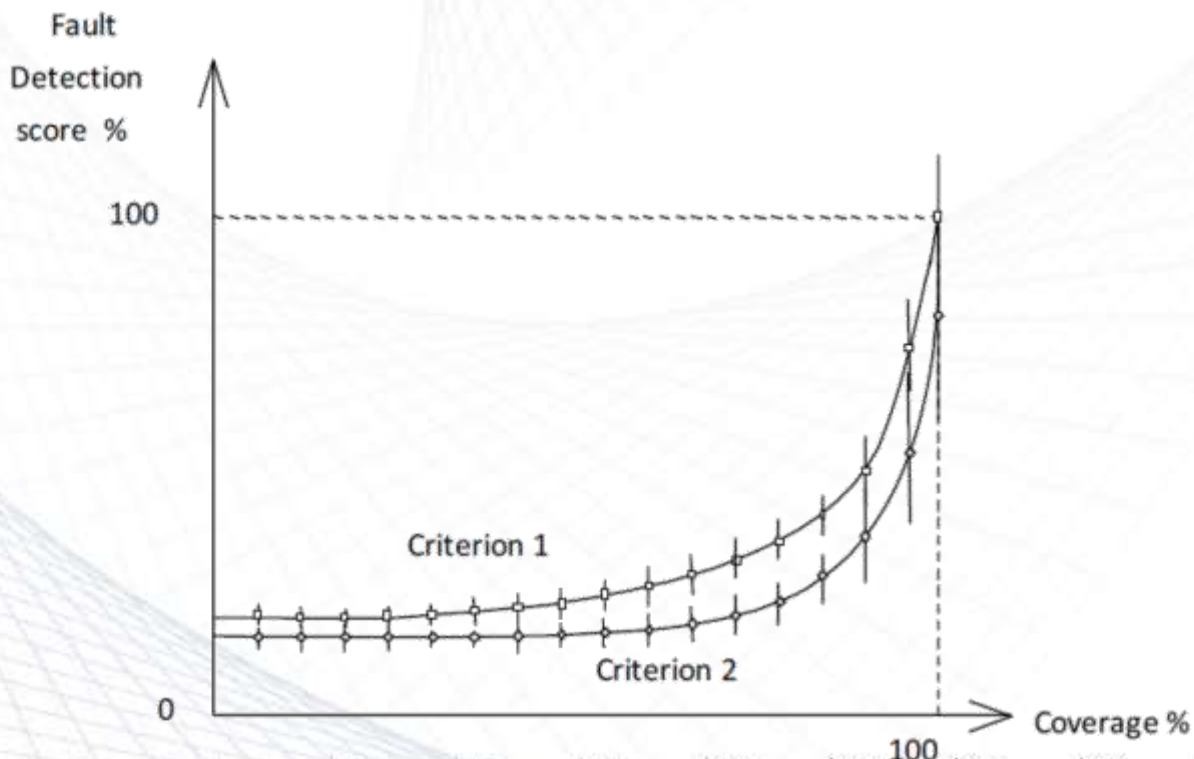
Coverage Tools

Measuring Test Coverage

- One advantage of coverage criteria is that it can be measured *automatically*
  - To control testing progress
  - To assess testing completeness in terms of remaining faults and reliability
- High coverage is not a guarantee of fault-free software, just an element of information to increase our confidence → statistical models

Analysis of Coverage Data

- Regardless of criterion used for WB testing, only higher coverage rates contribute to finding more faults ← e.g. try at least 60-80% coverage to find reasonable number of faults



Test Coverage: Benefits

- If you haven’t exercised part of the code, it could contain a bug
- Any coverage criteria performs better than random test selection – especially DU-coverage
- Helps us in measuring how much unit testing has been done and how much is left
- Significant improvements occurred as coverage increased from 90% to 100%
- Helps us in test case design (deriving test cases)
- We can prioritize the most critical modules (units) of the system and target higher coverage for those critical modules, would mean more rigorous testing for them

Test Coverage: Caveats

- Coverage tests that the code has been exercised (mostly in unit testing level), and that each unit has been verified
- But it does not tell us that we have built what the customer wanted
- If the logical structure of the code contains errors such as a missed case in a switch statement, the absence of code may not be detected
- 100% coverage alone is not a reliable indicator of the effectiveness of a test set – especially statement coverage
- Yet, 100% coverage is often unrealistic, especially for fine-grained coverage measures (e.g., condition coverage)
- Effort to achieve high coverage may be unjustified in large scale projects, in terms of time spent and producing unreliable test cases
- 60%-80% coverage is a “rule of thumb” (according to several surveys)

Test Coverage Measurement

- Two usages:
- Will help us derive test cases
- And to also know the progress of test activities

```java
public class absTestSuite {

    private absClass a;

    @Before
    public void setUp() throws Exception
    {
        a = new absClass();
    }

    @Test
    public void testAbsPositive() {
        assertTrue(a.abs(5)==5);
    }
```

Tests

Manual Tests

```java
public class absClass {

    public static int abs(int x){
        int a=1; // dummy code
        if (x>0)
            return x;
        else
            return -x;
    }
```

Problems | Javadoc | Declaration

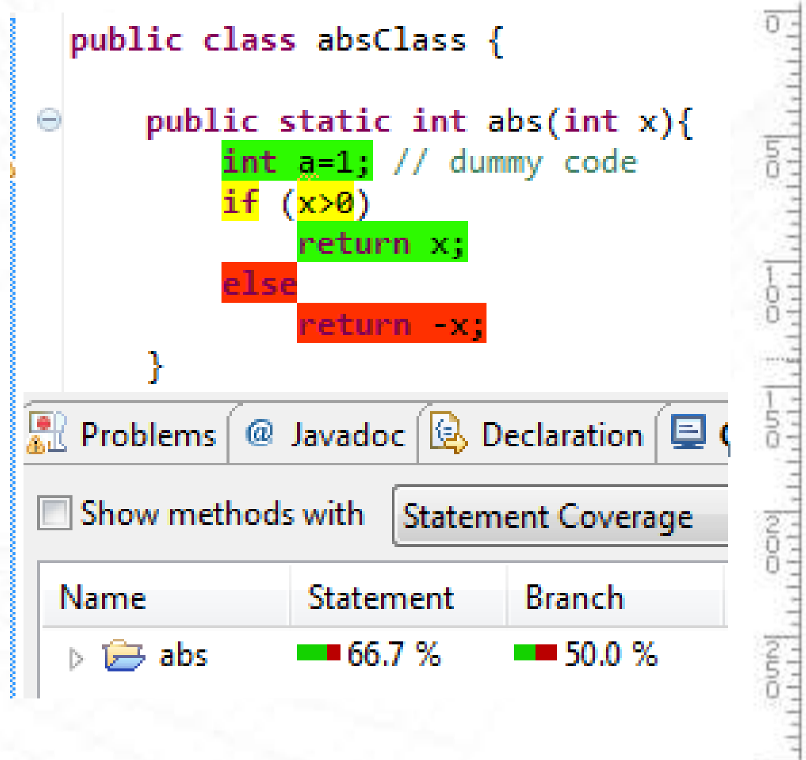
Show methods with Statement Coverage

Name	Statement	Branch
abs	66.7 %	50.0 %

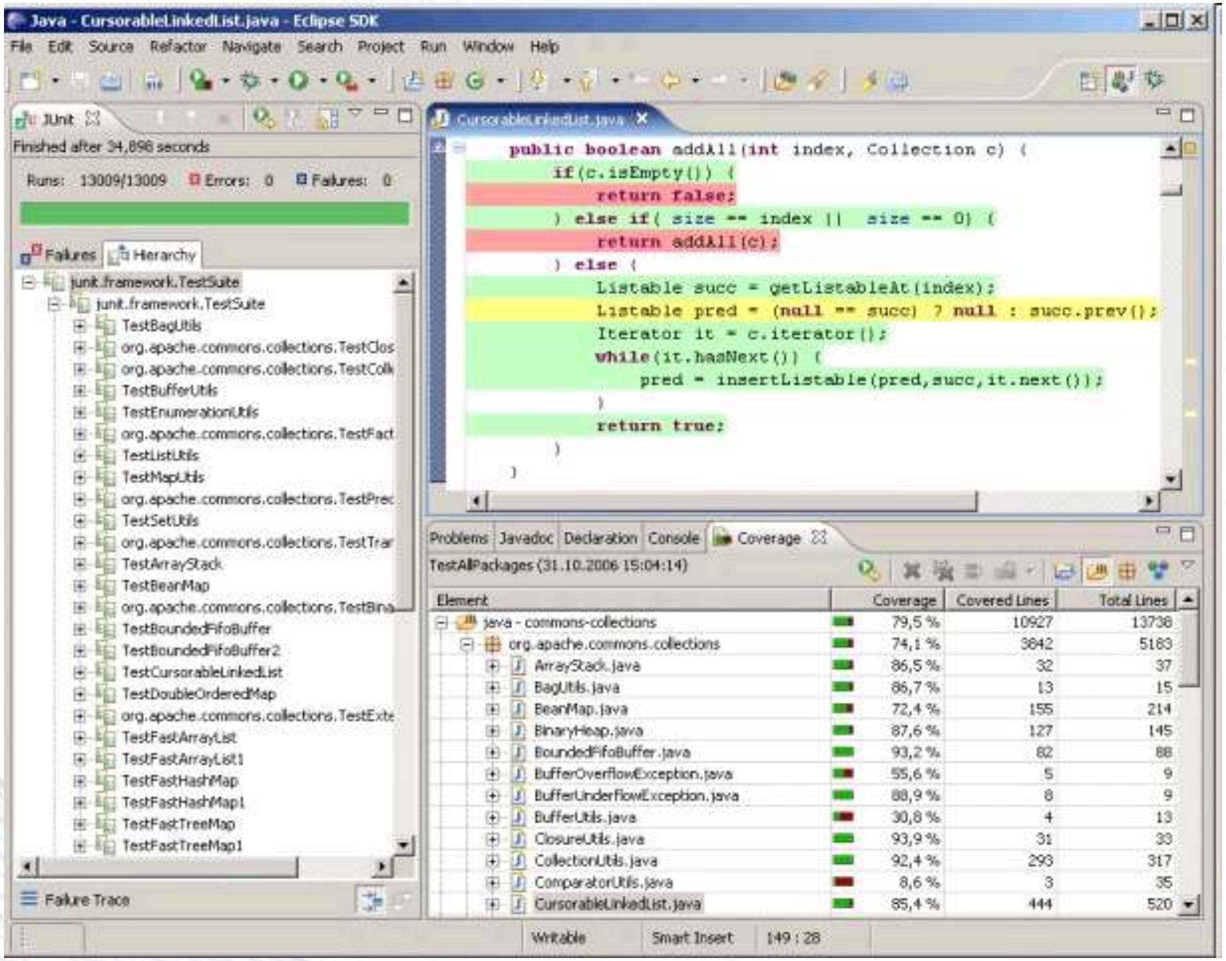
2/3

Test Coverage Tools

- Most established languages have solid test coverage tools available for them, but the depth of functionality differs significantly from one to another
- Python has sys.settrace to tell you directly which lines are executing
- Emma (for Java) has a ClassLoader which re-writes byte-code on the fly



Code Coverage Tools



Emma (command line) and EclEmma

Emma

- Open-source tool
- Supports class, method, block, and line coverage
- Eclipse plug-in EclEmma also available
  - http://www.eclemma.org
- Uses byte-code instrumentation
  - Classes can be instrumented in advance, or during class loading
- Tool keeps a metadata file to associate byte-code with source code

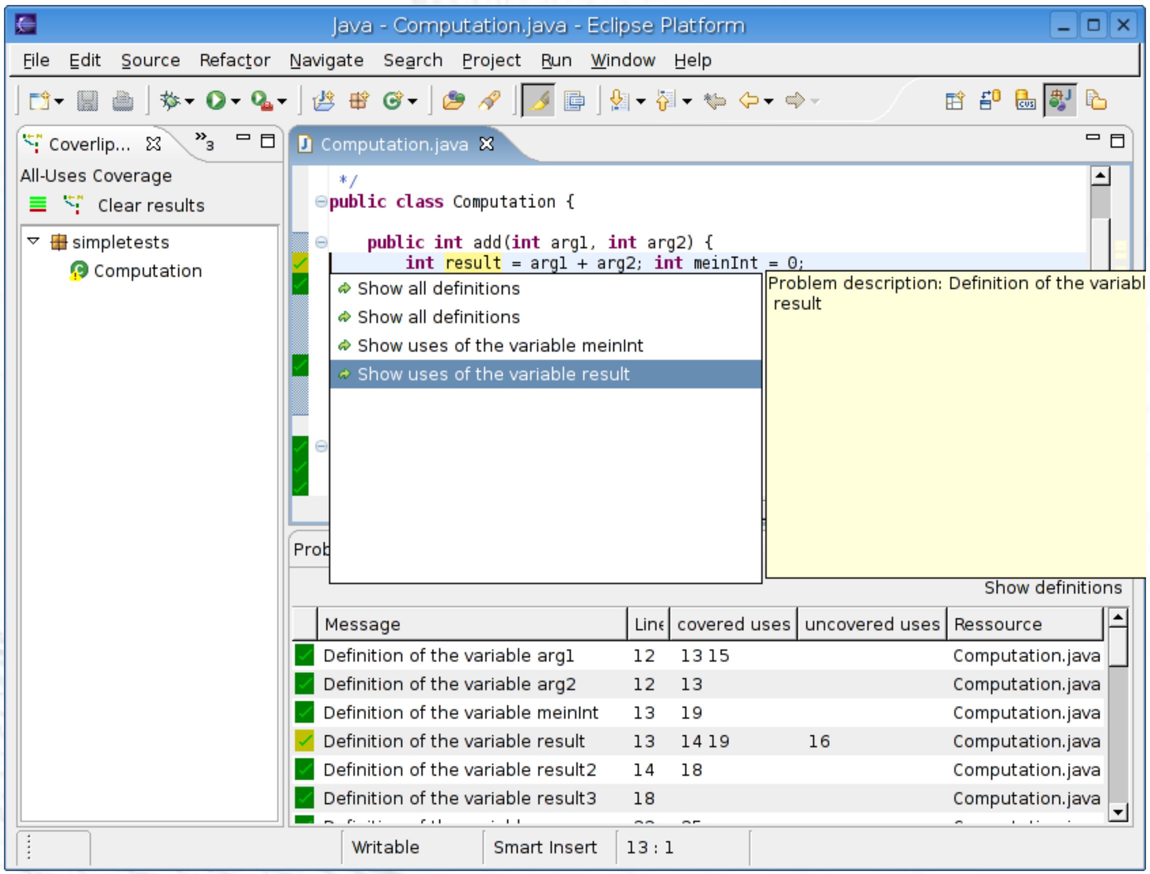
CodeCover

- CodeCover is an open-source code coverage tool for Java under Eclipse
- It can be used inside Eclipse
- There are many other code coverage tool out there, but this is one of the lightest and powerful ones
- See the list @ http://java-source.net/open-source/codecoverage

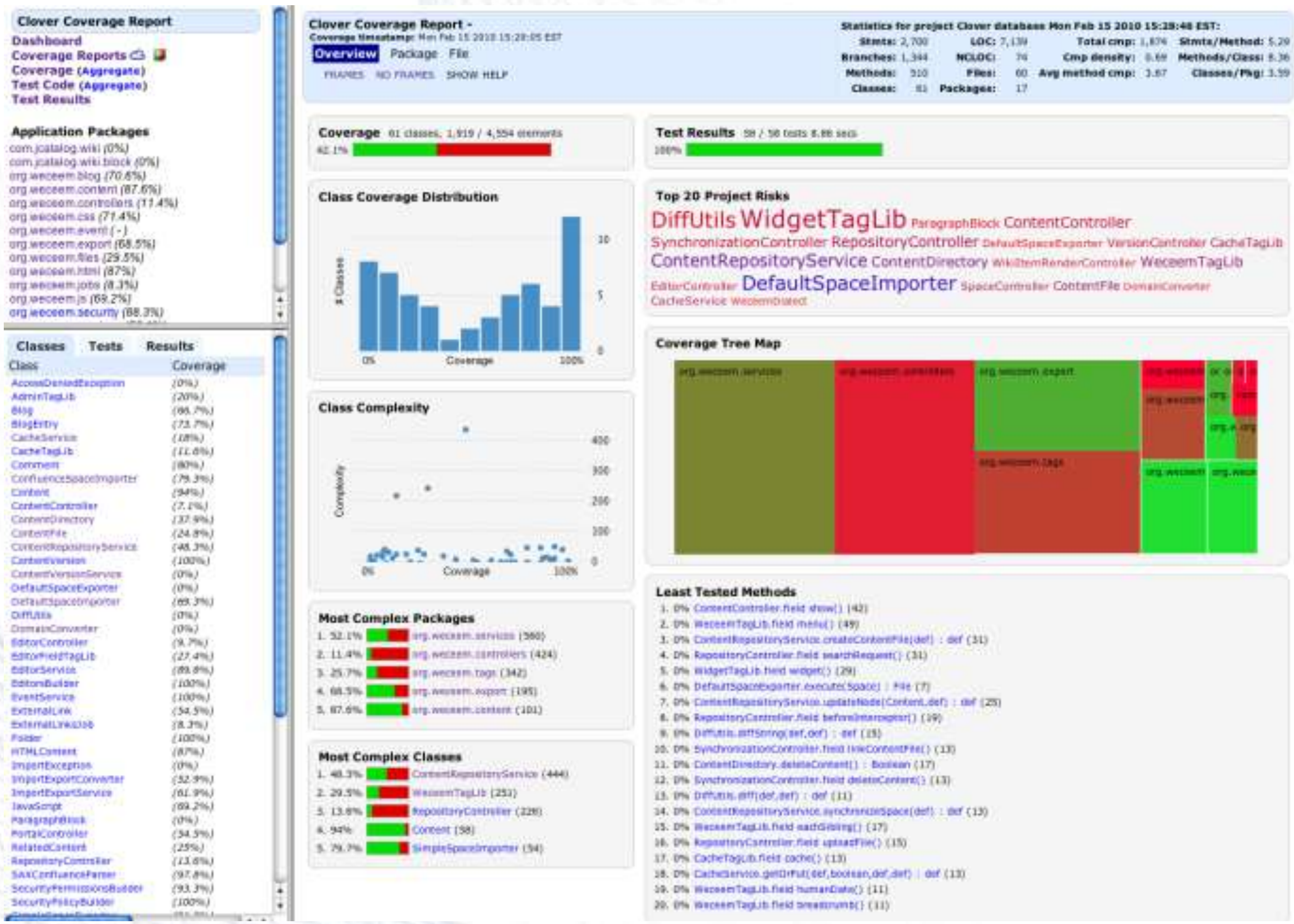
http://www.codecover.org

Code Coverage Tools - CoverLipse

CoverLipse (supports data-flow based testing)



Code Coverage Tools - Clover



Comparison of Coverage Tools

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Proc .of CSIT vol.5 (2011) © (2011) IACSIT Press, Singapore

An Evaluation of Test Coverage Tools in Software Testing

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Comparison of Coverage Tools

Table 1 Tools With Supported Language

Tools	Java	C/C++	Other
JavaCodeCoverage	×		
JFeature	×		
JCover	×		
Cobertura	×		
Emma	×		
Clover	×		.Net
Quilt	×		
Code Cover	×		COBOL
Jester	×		
GroboCodeCoverage	×		
Hansel	×		
Gretel	×		
BullseyeCoverage		×	
NCover			.Net
Testwell CTC++		×	
TestCocoon		×	C#
eXVantage	×	×	
OCCF	×	×	×
JAZZ	×		

Table 3 Coverage Measurement Level

Tools	Statement/ Block	Branch / Decision	Method/ Function	Class	Requirement
JavaCodeCoverage	×	×	×		
JFeature			×		×
JCover	×	×	×	×	
Cobertura	×	×			
Emma	×		×	×	
Clover	×	×	×	×	
Quilt	×	×			
Code Cover	×	×			
Jester					
GroboCodeCoverage				×	
Hansel		×			
Gretel	×				
BullseyeCoverage		×	×		
NCover			×	×	
Testwell CTC++		×			
TestCocoon					
eXVantage	×	×	×		
OCCF	×	×			
JAZZ		×			

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Resources

- Code Coverage and Test Tools

  www.opensourcetesting.org

- Code Coverage of Eclipse Code-base

  http://relengofthenerds.blogspot.com/2011/03/sdk-code-coverage-with-jacoco.html

- Demo of test coverage for Python code

  www.youtube.com/watch?v=jGJa_2UyHrY (video)

Etc.

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Conclusion

- Coverage is a measure of WB testing effort to detect potential faults
- 100% statement coverage means that you tested for every bug that can be revealed by simple execution of a line of code
- 100% branch coverage means you will find every fault that can be revealed by testing each branch
- 100% coverage means that you tested for every possible fault, which is obviously impossible for larger projects