Intro to Software Testing
Chapter 7.3

Graph Coverage for Source Code

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SWE 437

Adapted from slides by Paul Ammann & Jeff Offutt

Overview

A common application of graph criteria is to program **source**

Graph: Usually the control flow graph (CFG)

Node coverage: Execute every statement

Edge coverage: Execute every branch

Loops: Looping structures such as for loops, while loops, etc.

Data flow coverage: Augment the CFG

- defs are statements that assign values to variables
- uses are statements that use variables

Control Flow Graphs

A **CFG** models all executions of a method by describing control structures

Nodes: statements or sequences of statements (basic blocks)

Edges: Transfers of control

Basic block: A sequence of statements such that if the first statement is executed, all statements will be (no branches)

CFGs are sometimes annotated with extra information

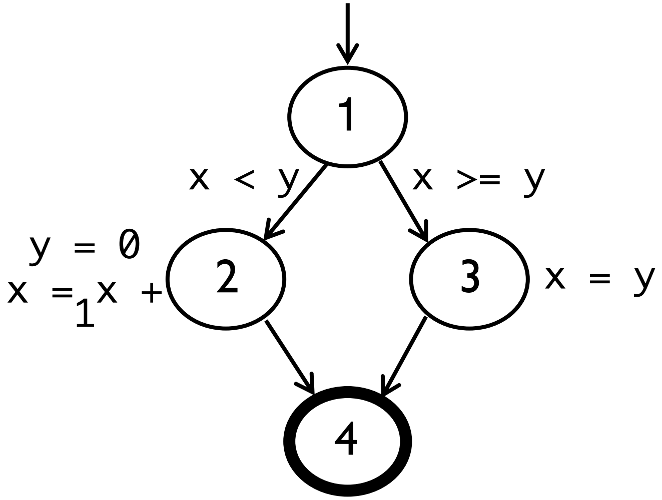
- branch predicates
- defs
- uses

Rules for translating statements into graphs…

CFG: The `if` Statement

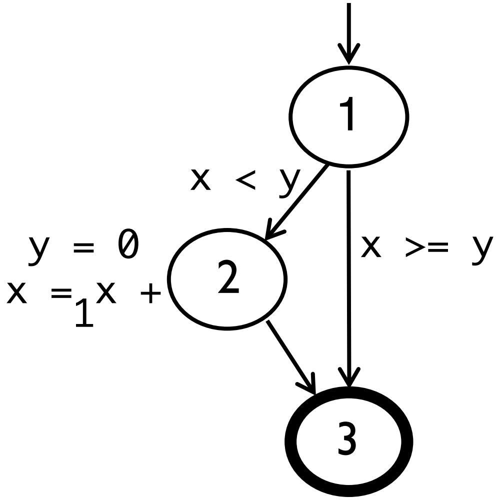
```
if (x < y)
{
   y = 0;
   x = x +
1;
}
else
{
   x = y;
}
```

Draw the graph. Label the edges with the Java statements.




```
if (x < y)
{
   y = 0;
   x = x +
1;
}
```

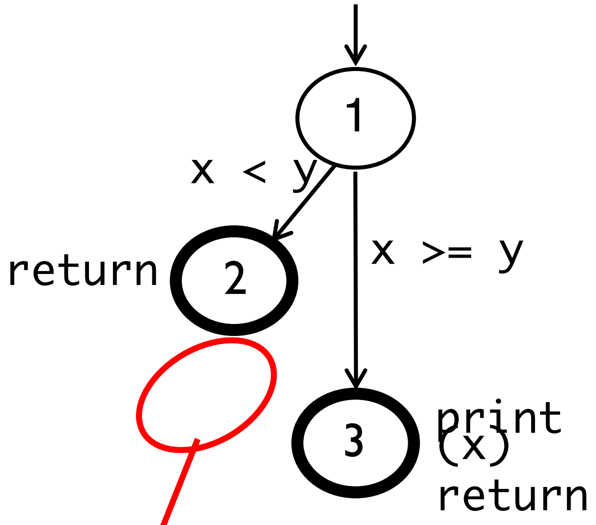
Draw the graph and label the edges.



CFG: The `if-return` Statement

```
if (x < y)
{
   return;
}
print (x);
return;
```

Draw the graph and label the edges.



No edge from node 2 to 3.
The return nodes must be distinct.

Loops

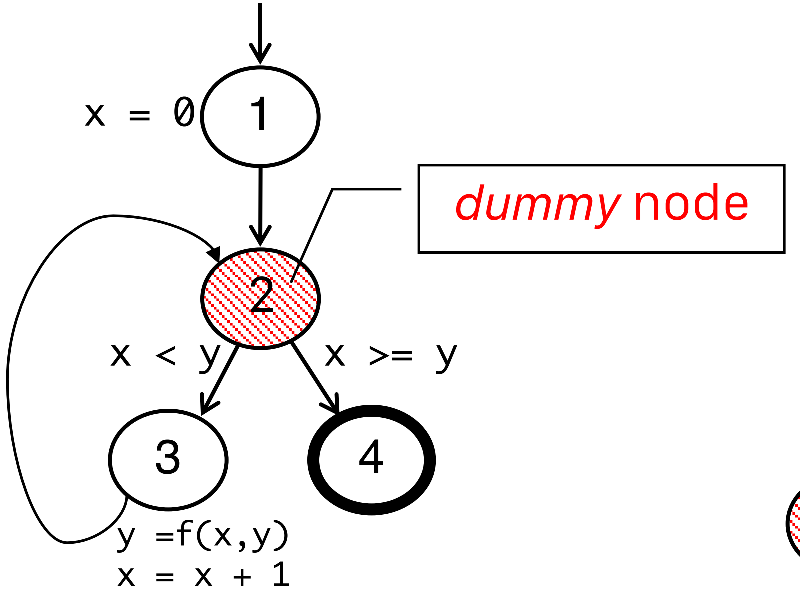
Loops require “extra” nodes to be added

Nodes that **do not** represent statements or basic blocks

CFG: `while` and `for` loops

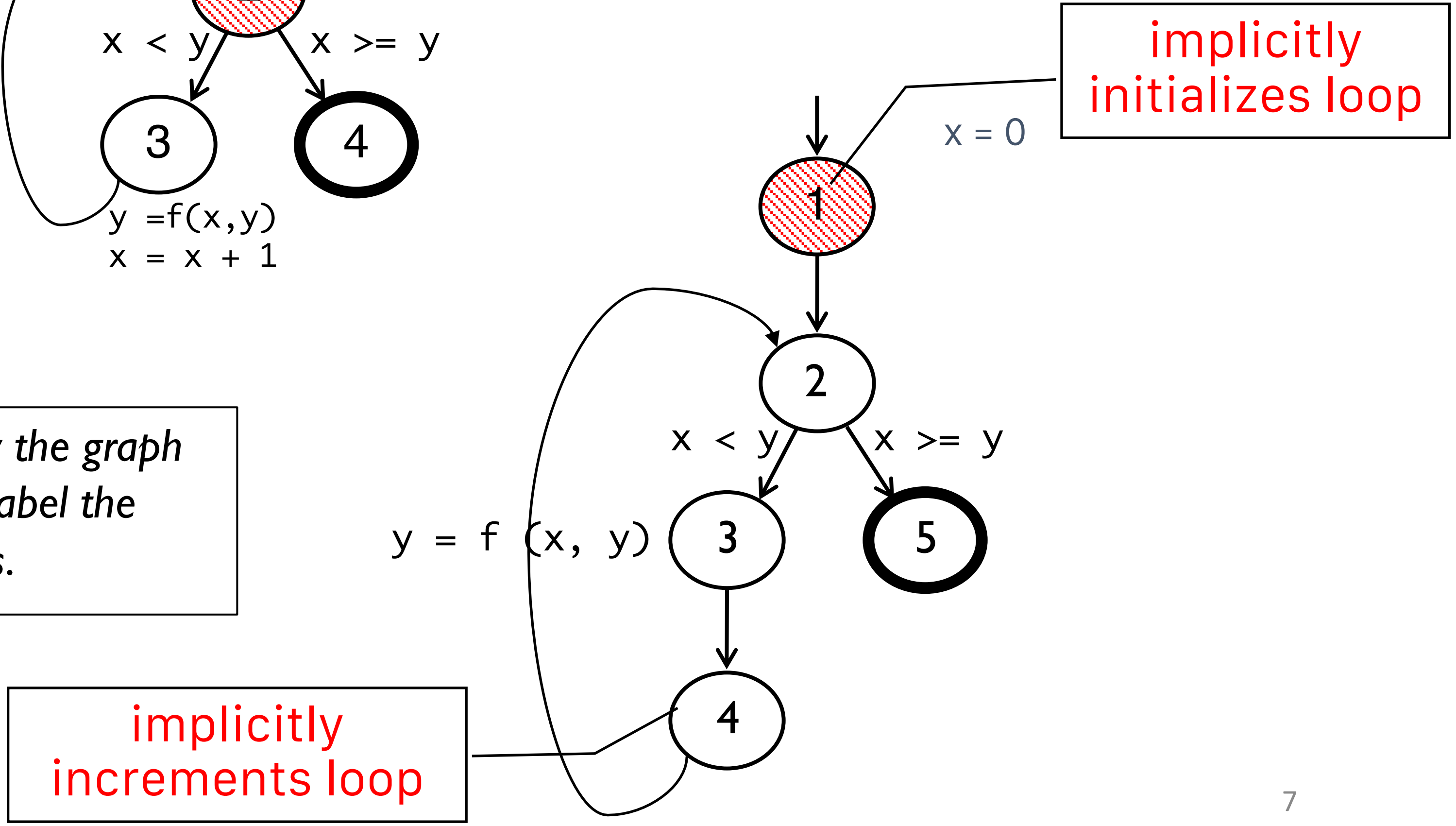
```
x = 0;
while (x < y)
{
    y = f (x,
y);
    x = x + 1;
}
return (x);
```

Draw the graph and label the edges.




```
for (x = 0; x < y; x++)
{
    y = f (x, y);
}
return (x);
```

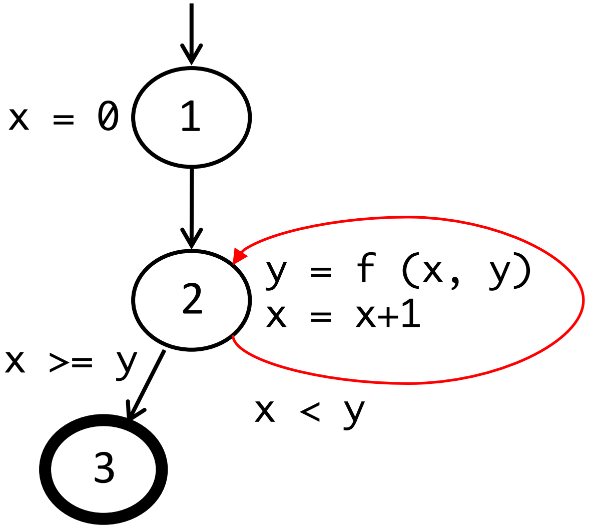
Draw the graph and label the edges.



CFG: do loop, break, and continue

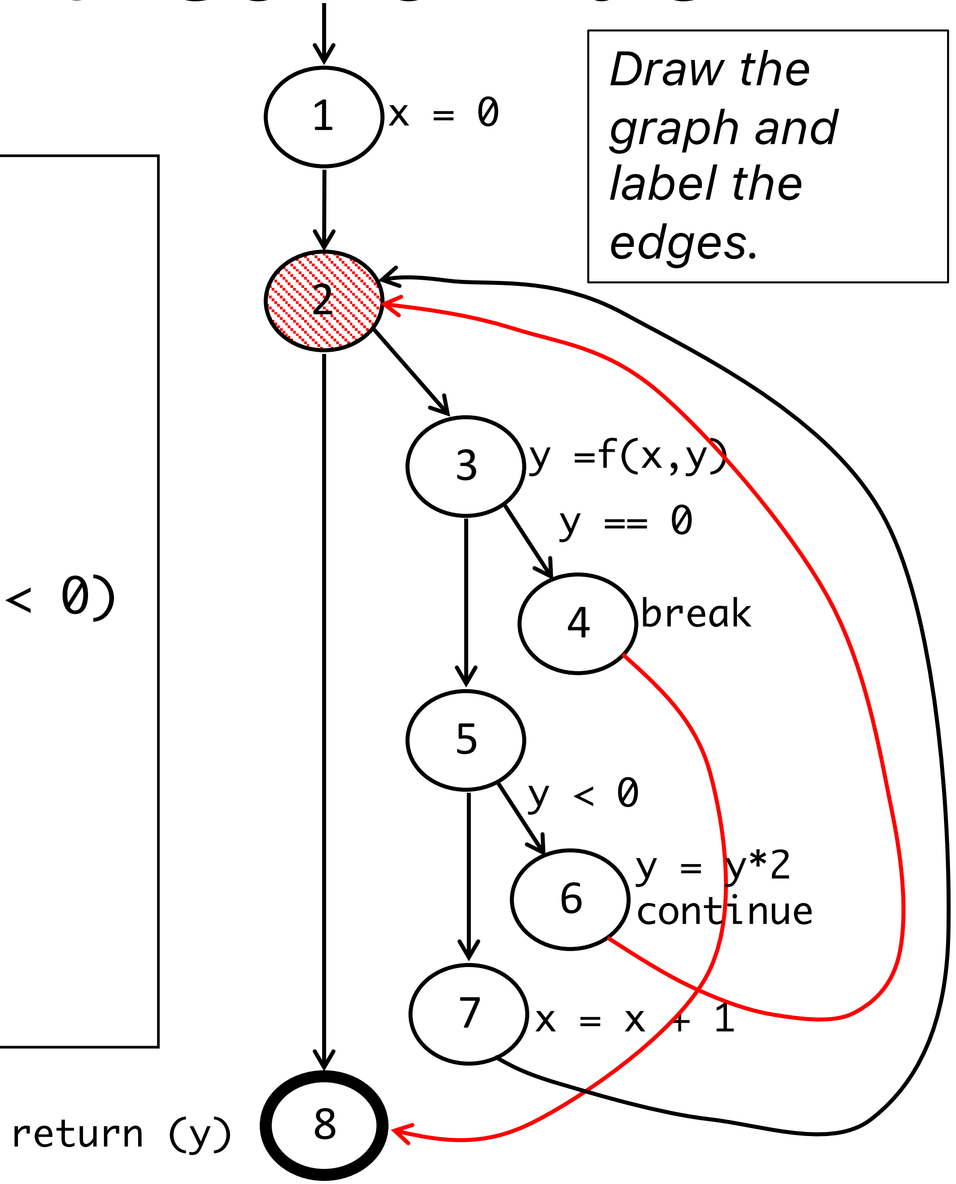
```
x = 0;
do
{
   y = f (x, y);
   x = x + 1;
} while (x < y);
return (y);
```

Draw the graph and label the edges.




```
x = 0;
while (x < y)
{
   y = f (x, y);
   if (y == 0)
   {
      break;
   } else if (y < 0)
   {
      y = y*2;
      continue;
   }
   x = x + 1;
}
return (y);
```

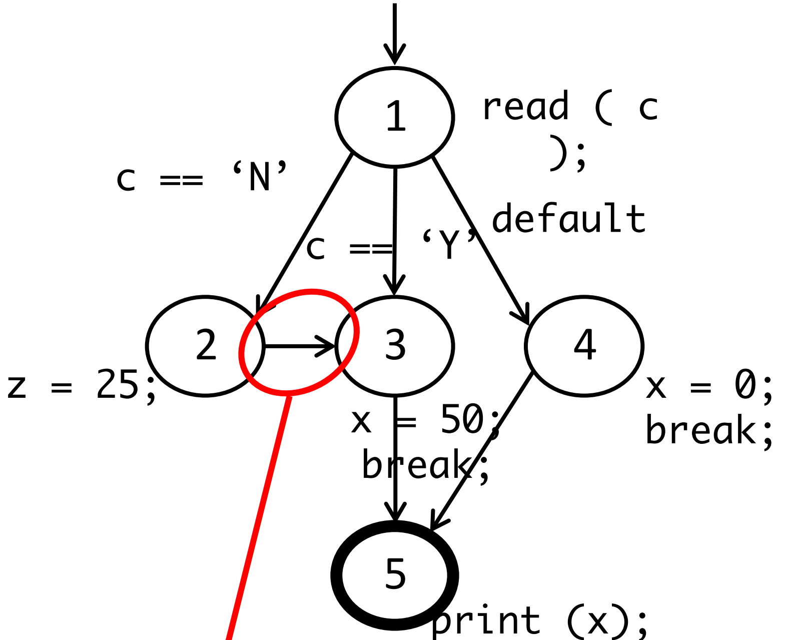
Draw the graph and label the edges.



CFG: The case (switch) Structure

```
read ( c) ;
switch ( c )
{
   case 'N':
      z = 25;
   case 'Y':
      x = 50;
      break;
   default:
      x = 0;
      break;
}
print (x);
```

Draw the graph and label the edges.

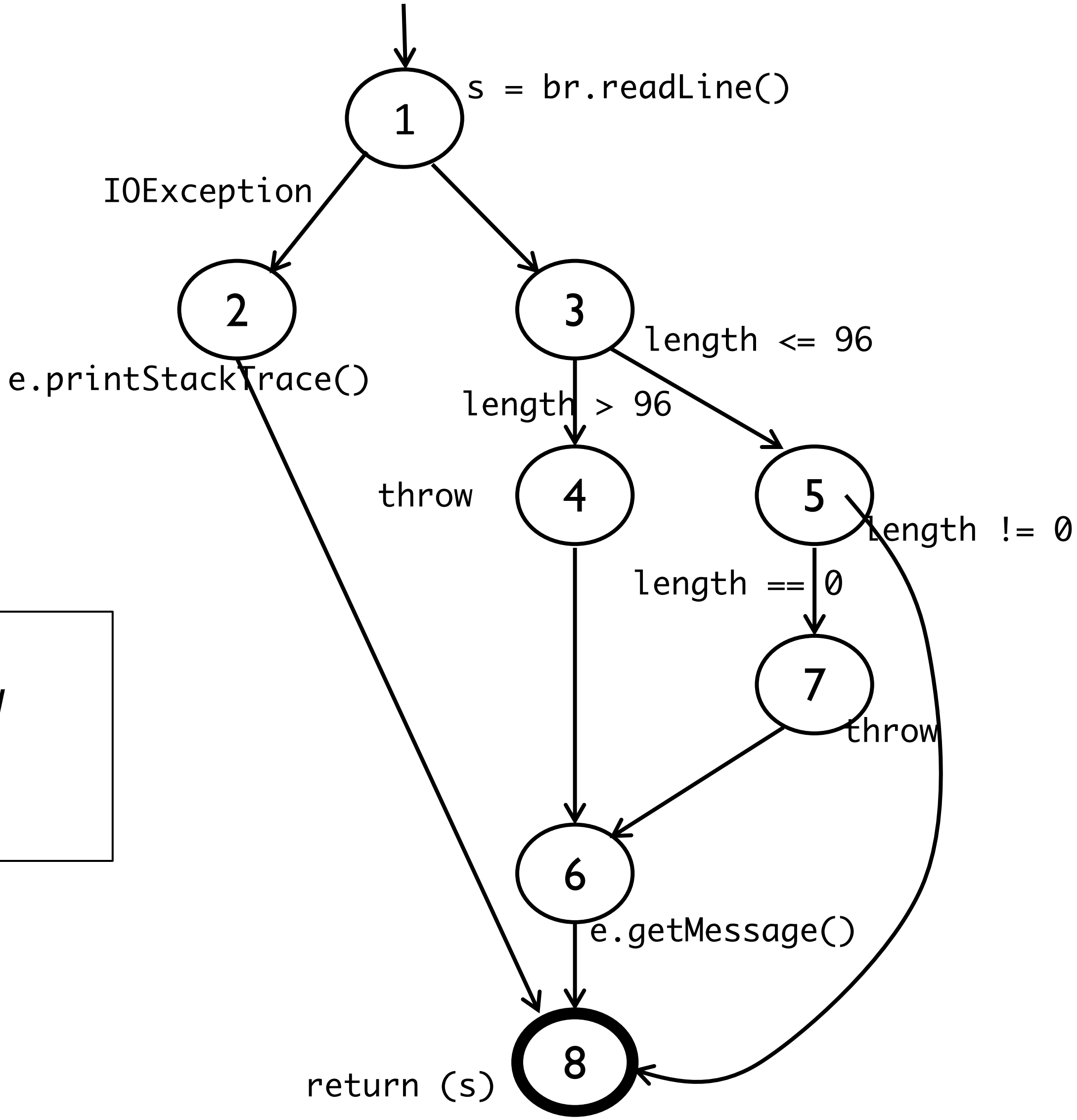


Cases without breaks fall through to the next case

CFG: Exceptions (try/catch)

```
try
{
   s = br.readLine();
   if (s.length() > 96)
      throw new Exception
         ("too long");
   if (s.length() == 0)
      throw new Exception
         ("too short");
} (catch IOException e) {
   e.printStackTrace();
} (catch Exception e) {
   e.getMessage();
}
return (s);
```

Draw the graph and label the edges.

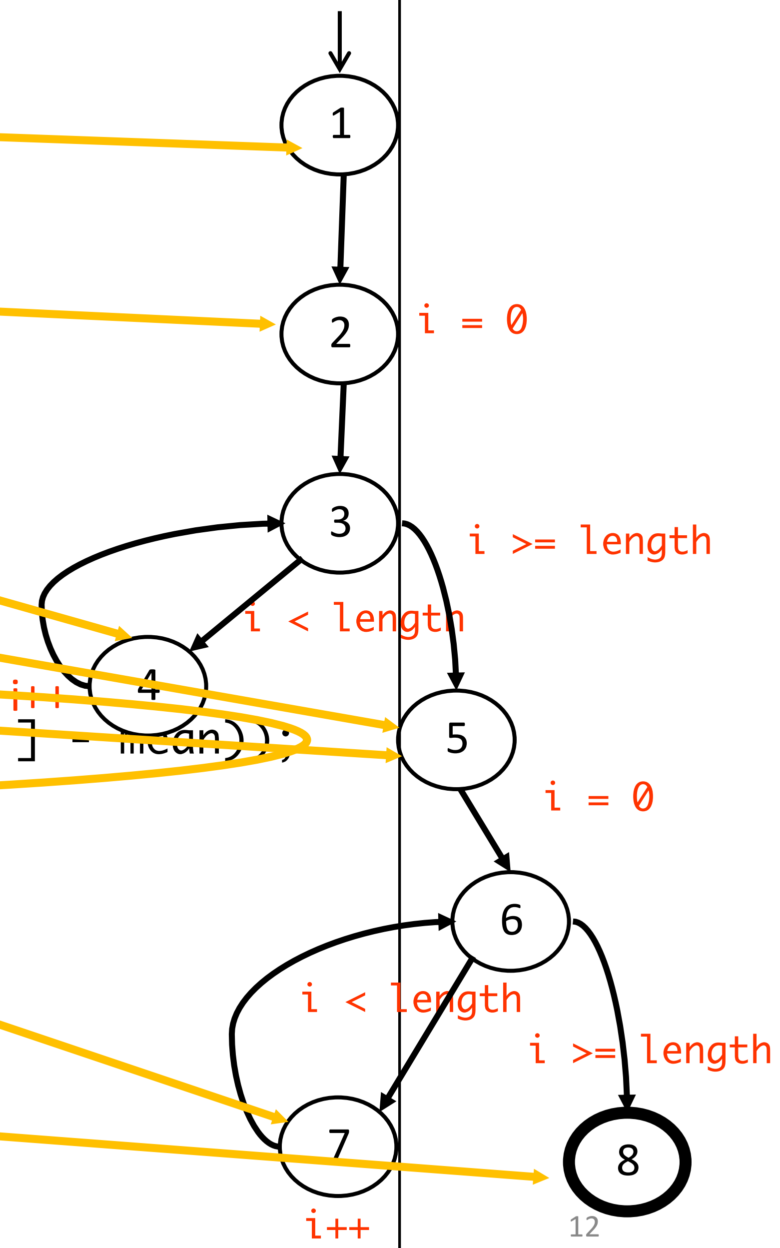


Example Control Flow – Stats

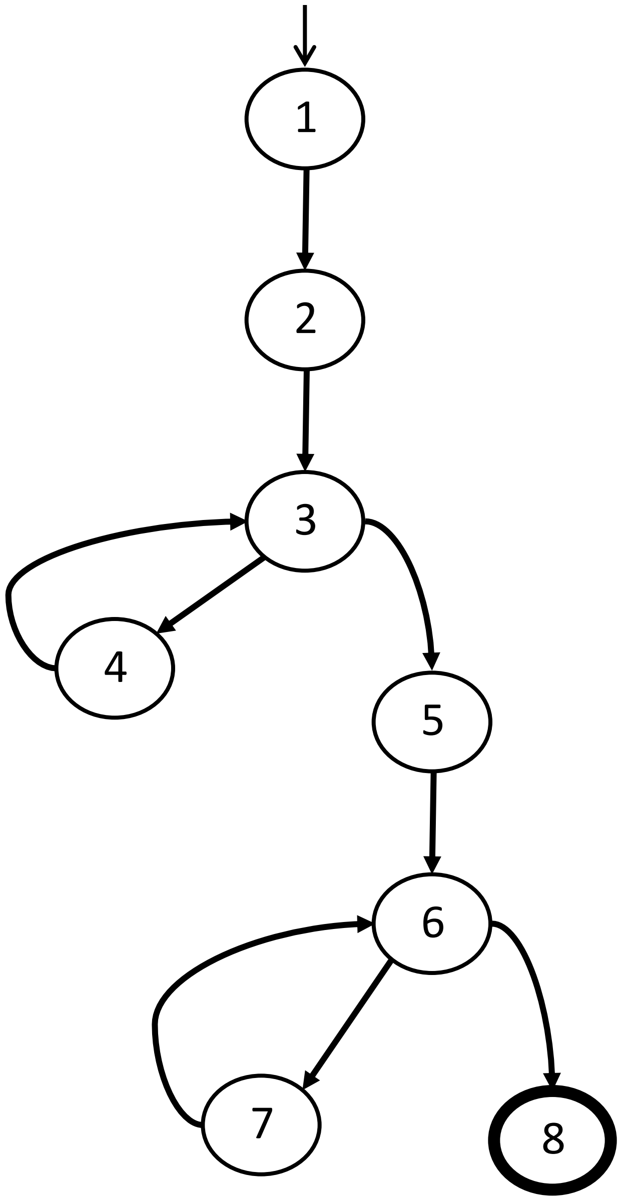
```
public static void computeStats (int [ ] numbers)
{
     int length = numbers.length;
     double med, var, sd, mean, sum, varsum;

     sum = 0;
     for (int i = 0; i < length; i++)
     {
          sum += numbers [ i ];
     }
     med   = numbers [ length / 2];
     mean = sum / (double) length;

     varsum = 0;
     for (int i = 0; i < length; i++)
     {
          varsum = varsum  + ((numbers [ i ] - mean) * (numbers
[ i ] - mean));
     }
     var = varsum / ( length - 1.0 );
     sd  = Math.sqrt ( var );

     System.out.println ("length:                  " + length);
     System.out.println ("mean:                   " + mean);
     System.out.println ("median:                " + med);
     System.out.println ("variance:              " + var);
     System.out.println ("standard deviation: " + sd);
}
```

Draw the graph and label the edges.

```java
public static void computeStats (int [ ] numbers)
{
     int length = numbers.length;
     double med, var, sd, mean, sum, varsum;

     sum = 0;
for (int i = 0; i < length; i++)
     {
          sum += numbers [ i ];
     }
     med    = numbers [ length / 2];
     mean = sum / (double) length;

     varsum = 0;
     for (int i = 0; i < length; i++)
     {
          varsum = varsum  + ((numbers [ i ] - mean) * (numbers [ i ] - mean));
     }
     var = varsum / ( length - 1.0 );
     sd  = Math.sqrt ( var );

     System.out.println ("length:                      " + length);
     System.out.println ("mean:                        " + mean);
     System.out.println ("median:                      " + med);
     System.out.println ("variance:                    " + var);
     System.out.println ("standard deviation: " + sd);
}
```



Control Flow TRs and Test Paths - EC

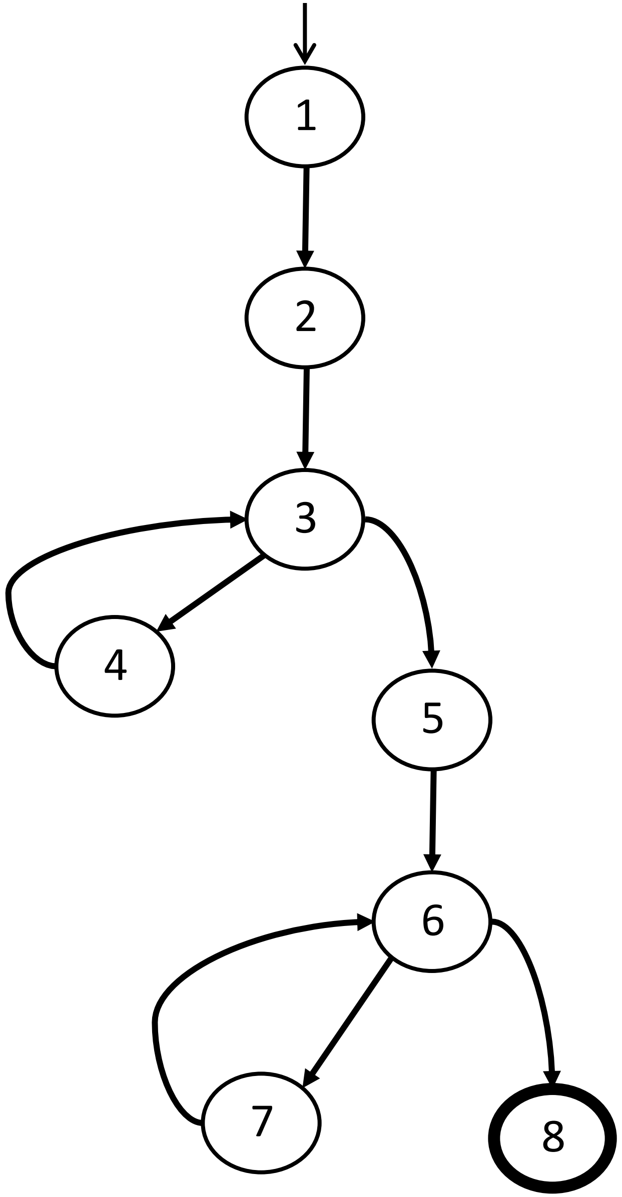


Write down the TRs for EC.

Edge Coverage	
TR	Test Path
A. [1, 2] B. [2, 3] C. [3, 4] D. [3, 5] E. [4, 3] F. [5, 6] G. [6, 7] H. [6, 8] I. [7, 6]	[1, 2, 3, 4, 3, 5, 6, 7, 6, 8]

Write down test paths that tour all edges.

Control Flow TRs and Test Paths - EPC



Write down the TRs for EPC.

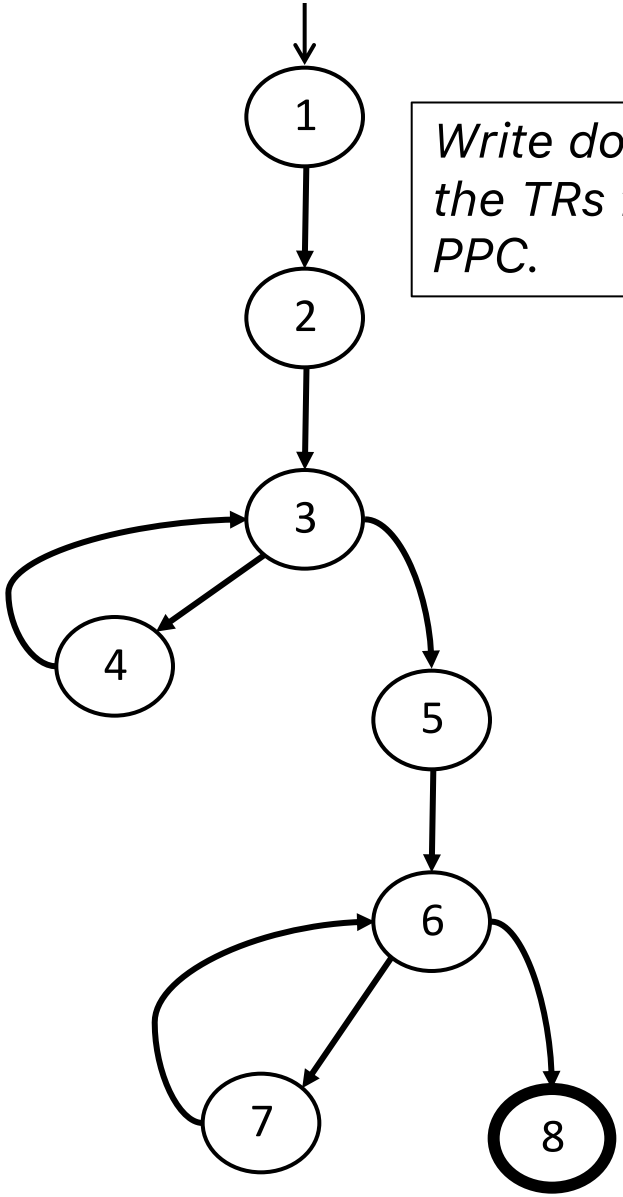
Edge-Pair Coverage	
TR	Test Path
A. [1, 2, 3] B. [2, 3, 4] C. [2, 3, 5] D. [3, 4, 3] E. [3, 5, 6] F. [4, 3, 5] G. [5, 6, 7] H. [5, 6, 8] I. [6, 7, 6] J. [7, 6, 8] K. [4, 3, 4] L. [7, 6, 7]	i. [1, 2, 3, 4, 3, 5, 6, 7, 6, 8] ii. [1, 2, 3, 5, 6, 8] iii. [1, 2, 3, 4, 3, 4, 3, 5, 6, 7, 6, 7, 6, 8]

Write down test paths that tour all edge pairs.

TP	TRs toured	*sidetrips*
~~i~~	~~A, B, D, E, F, G, I, J~~	~~C, H~~
ii	A, C, E, H	
iii	A, B, D, E, F, G, I, J, K, L	C, H

TP iii makes TP i redundant. A *minimal* set of TPs is cheaper.

Control Flow TRs and Test Paths - PPC



Write down the TRs for PPC.

Prime Path Coverage

TR	Test Path
A. [3, 4, 3] B. [4, 3, 4] C. [7, 6, 7] D. [7, 6, 8] E. [6, 7, 6] F. [1, 2, 3, 4] G. [4, 3, 5, 6, 7] H. [4, 3, 5, 6, 8] I. [1, 2, 3, 5, 6, 7] J. [1, 2, 3, 5, 6, 8]	i. [1, 2, 3, 4, 3, 5, 6, 7, 6, 8] ii. [1, 2, 3, 4, 3, 4, 3, 5, 6, 7, 6, 7, 6, 8] iii. [1, 2, 3, 4, 3, 5, 6, 8] iv. [1, 2, 3, 5, 6, 7, 6, 8] v. [1, 2, 3, 5, 6, 8]

Write down test paths that tour all prime paths.

TP	TRs toured	*sidetrips*
~~i~~	~~A, D, E, F, G~~	~~H, I, J~~
ii	A, B, C, D, E, F, G,	H, I, J
iii	A, F, H	J
iv	D, E, F, I	J
v	J	

TP ii makes TP i redundant.

Data Flow Coverage for Source

def: a location where a value is stored into **memory**

- x appears on the **left side** of an assignment (x=44;)
- x is an **actual parameter** in a call and the method **changes** its value
- x is a **formal parameter** of a method (implicit def when method starts)
- x is an **input** to a program

use: a location where variable's value is **accessed**

- x appears on the **right side** of an assignment
- x appears in a conditional **test**
- x is an **actual parameter** to a method
- x is an **output** of the program
- x is an output of a method in a **return** statement

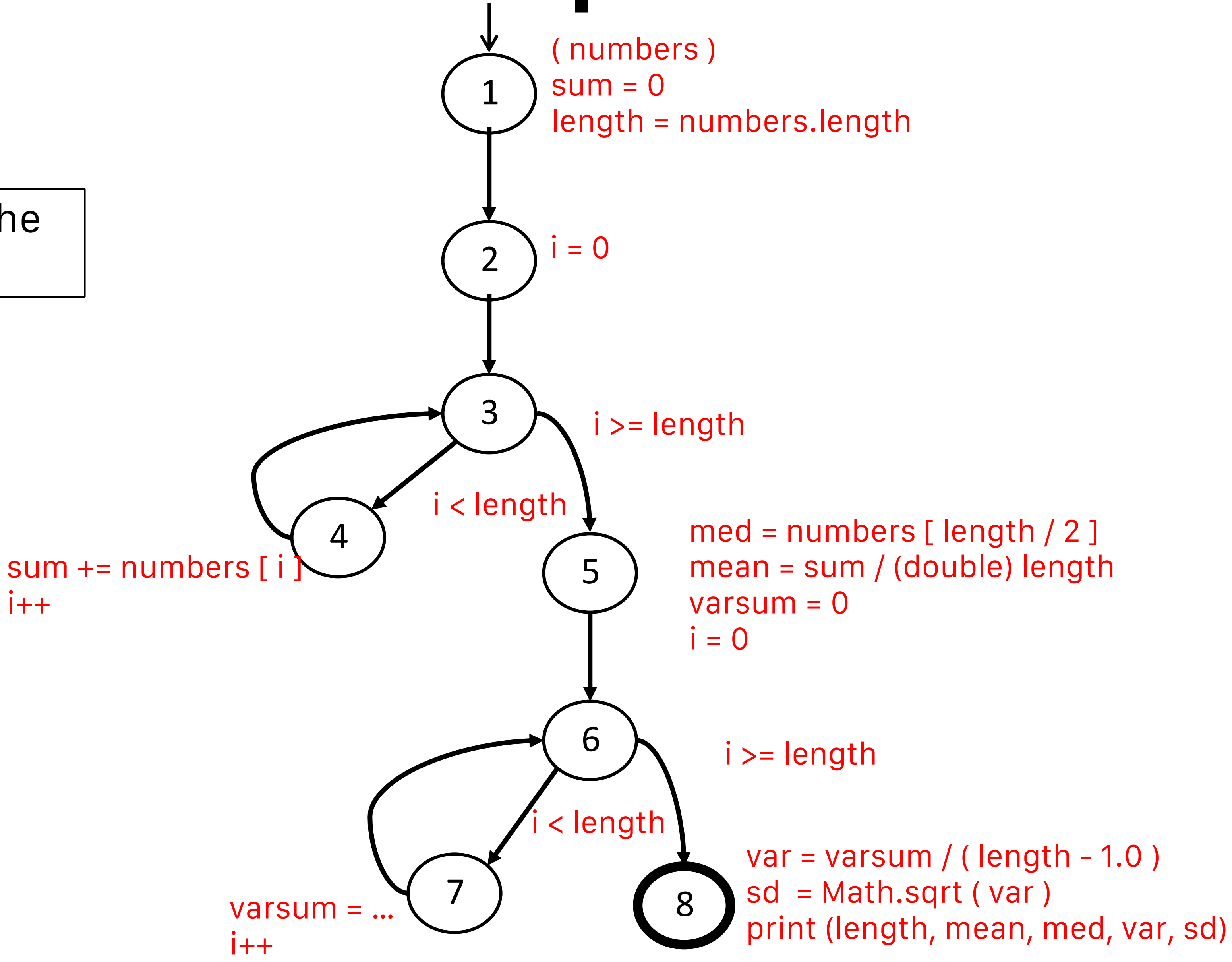
If a def and a use appear on the **same node**, then it is only a DU-pair if the def occurs **after** the use and the node is in a loop

Example Data Flow – Stats

```
public static void computeStats (int [ ] numbers)
{
     int length = numbers.length;
     double med, var, sd, mean, sum, varsum;

     sum = 0.0;
     for (int i = 0; i < length; i++)
     {
          sum += numbers [ i ];
     }
     med   = numbers [ length / 2 ];
     mean = sum / (double) length;

     varsum = 0.0;
     for (int i = 0; i < length; i++)
     {
          varsum = varsum  + ((numbers [ i ] - mean) * (numbers [ i ] - mean));
     }
     var = varsum / ( length - 1 );
     sd  = Math.sqrt ( var );

     System.out.println ("length:                   " + length);
     System.out.println ("mean:                    " + mean);
     System.out.println ("median:                 " + med);
     System.out.println ("variance:               " + var);
     System.out.println ("standard deviation: " + sd);
}
```

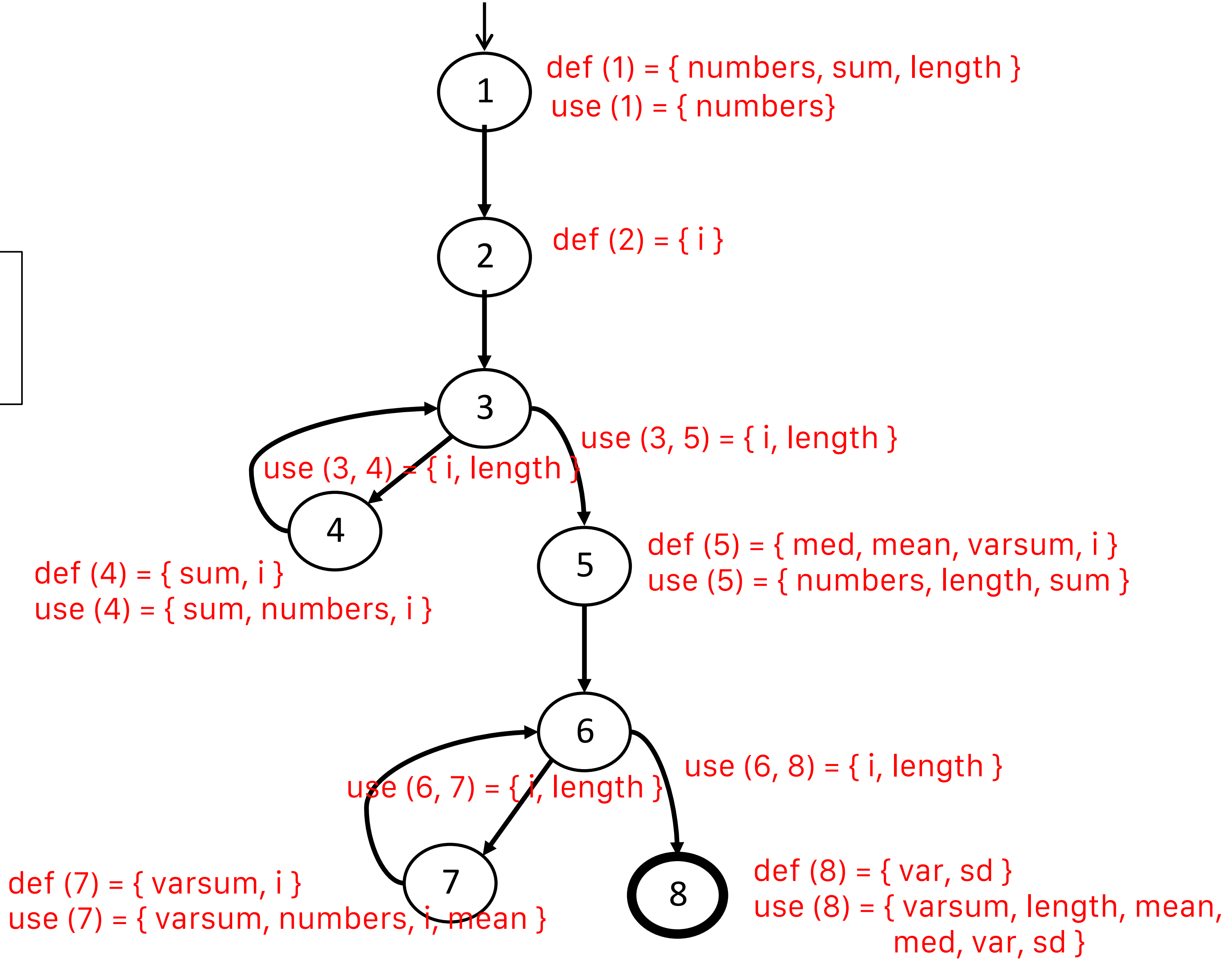
Control Flow Graph for Stats

Annotate with the statements …



CFG for Stats – with defs and uses

Turn the annotations into def and use sets
...



Def and Uses tables for Stats

Node	Def	Use
1	{ numbers, sum, length }	{ numbers }
2	{ i }	
3		
4	{ sum, i }	{ numbers, i, sum }
5	{ med, mean, varsum, i }	{ numbers, length, sum }
6		
7	{ varsum, i }	{ varsum, numbers, i, mean }
8	{ var, sd }	{ varsum, length, var, mean, med, var, sd }

Edge	Use
(1, 2)	
(2, 3)	
(3, 4)	{ i, length }
(4, 3)	
(3, 5)	{ i, length }
(5, 6)	
(6, 7)	{ i, length }
(7, 6)	
(6, 8)	{ i, length }

Summary

Applying the graph test criteria to **control flow graph** is relatively straightforward

- Most Of the developmental **research** work was done with CFGs

A few **subtle decisions** must be made to translate control structures into the graph

Some tools will assign each statement to a **unique node**

- These slides and the book use **basic blocks**
- Coverage is the same, although the **bookkeeping** will differ