DA-IICT

IT 314: Software Engineering

White-Box Test Case Design
Data Flow Analysis

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DA-IICT

The following C program fragment sets r to x^y for $y > 0$.
How can it be (slightly) optimised?

```
 1 int y1 = 1;
 2 int r = x;
 3 while (y1 != y) {
 4   int t = y1*2;
 5   if (t <= y) {
 6     r = r*r;
 7     y1 = y1*2;
 8   } else {
 9     r = r*x;
10     y1 = y1+1;
11  }
12 }
```

White-Box Test Case Design Techniques

Control Flow Testing	Data Flow Testing
Statement coverage	All p-use
Decision coverage	All c-use
Condition coverage	All d-use
Decision-Condition coverage	All uses
Multiple condition coverage	
Basis Path Testing	
Loop testing	

Overview

- The most 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

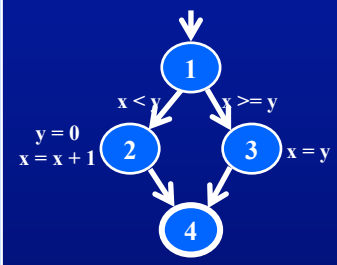
Control Flow Graphs

- 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)

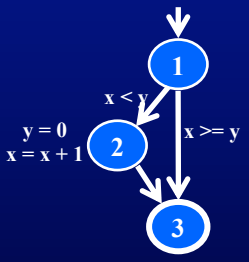
- CFGs are sometimes annotated with extra information
  - branch predicates
  - defs
  - uses
- Rules for translating statements into graphs …

CFG : The if Statement

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

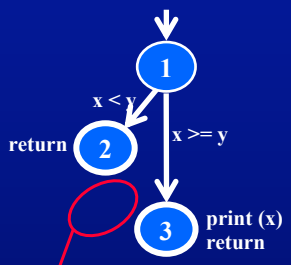



```
if (x < y)
{
   y = 0;
   x = x + 1;
}
```



CFG : The if-Return Statement

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



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

Data Flow Analysis

- What is it?
  - A form of static analysis based on the definition and usage of variables
- How it is performed?
  - Analysis of data use
    - The usage of data on paths through the program code is checked
- Use to detect data flow anomalies
  - Unintended or unexpected sequence of operations on a variable
- What is an anomaly?
  - An inconsistency that can lead to failure, but does not necessarily so
  - May be flagged as a risk

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Data Flow Analysis

- Examples of data flow anomalies
  - Reading variables without previous initialization
  - Not using the values of a variable at all
- The usage of every single variable is inspected
- Three types of usage or states of variables
  - Defined (d) : the variable is assigned a value
  - Reference (r) : the value of the variable is read and/or used
  - Undefined (u) : the variable has no defined value

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Data Flow Analysis

- Three types of data flow anomalies
  - ur-anomaly : an undefined value (u) of a variable is read on a program path (r)
  - du-anomaly : the variable is assigned a value (d) that becomes invalid/undefined (u) without having been used in the meantime
  - dd-anomaly : the variable receives a value for the second time (d) and the first value had not been used (d)

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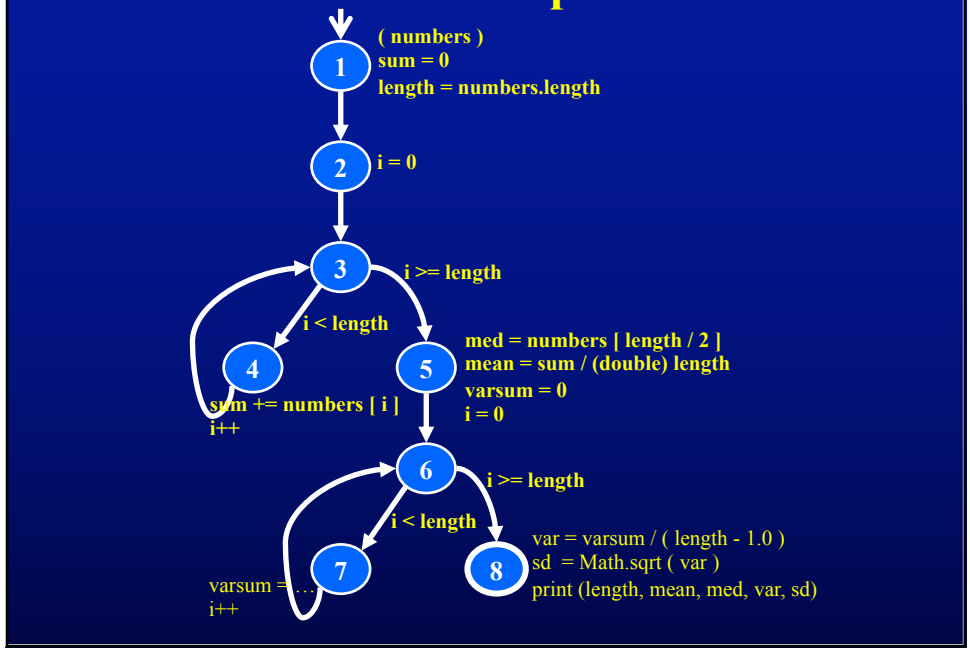
Data Flow Coverage for Source

- **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

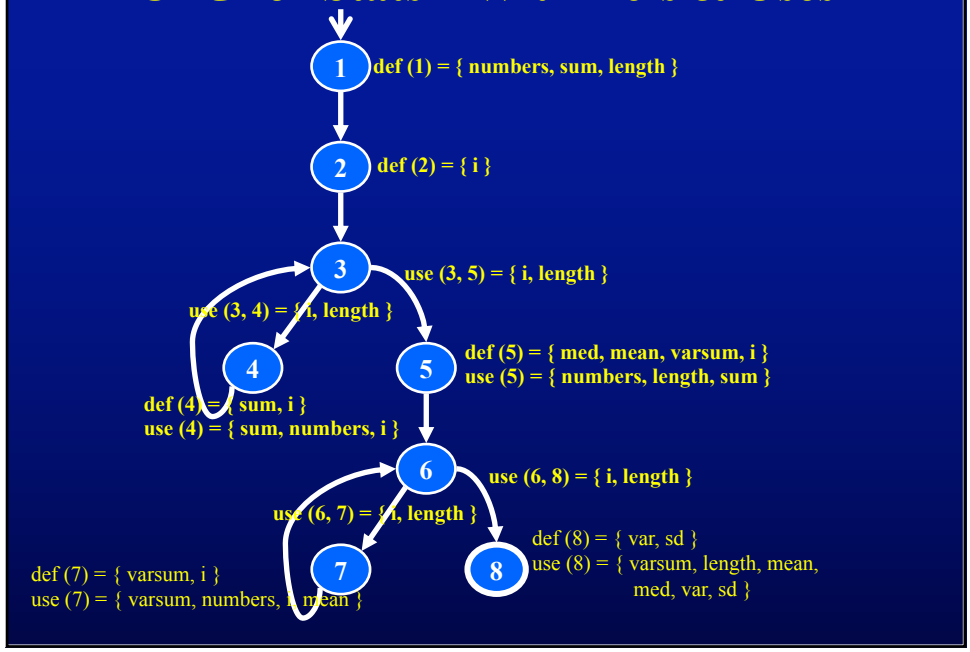
Example Data Flow – Stats

```
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



CFG for Stats – With Defs & Uses



Defs 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 }

DU Pairs for Stats

variable	DU Pairs
numbers	(1, 4) (1, 5) (1, 7)
length	(1, 5) (1, 8) (1, (3,4)) (1, (3,5)) (1, (6,7)) (1, (6,8))
med	(5, 8)
var	(8, 8)
sd	(8, 8)
mean	(5, 7) (5, 8)
sum	(1, 4) (1, 5) (4, 4) (4, 5)
varsum	(5, 7) (5, 8) (7, 7) (7, 8)
i	(2, 4) (2, (3,4)) (2, (3,5)) ~~(2, 7) (2, (6,7)) (2, (6,8))~~
	(4, 4) (4, (3,4)) (4, (3,5)) ~~(4, 7) (4, (6,7)) (4, (6,8))~~
	(5, 7) (5, (6,7)) (5, (6,8))
	(7, 7) (7, (6,7)) (7, (6,8))

defs come before uses, do not count as DU pairs

defs after use in loop, these are valid DU pairs

No def-clear path … different scope for i

No path through graph from nodes 5 and 7 to 4 or 3

DU Paths for Stats

variable	DU Pairs	DU Paths
numbers	(1, 4) (1, 5) (1, 7)	[1, 2, 3, 4] [1, 2, 3, 5] [1, 2, 3, 5, 6, 7]
length	(1, 5) (1, 8) (1, (3,4)) (1, (3,5)) (1, (6,7)) (1, (6,8))	[1, 2, 3, 5] [1, 2, 3, 5, 6, 8] [1, 2, 3, 4] [1, 2, 3, 5] [1, 2, 3, 5, 6, 7] [1, 2, 3, 5, 6, 8]
med	(5, 8)	[5, 6, 8]
var	(8, 8)	*No path needed*
sd	(8, 8)	*No path needed*
sum	(1, 4) (1, 5) (4, 4) (4, 5)	[1, 2, 3, 4] [1, 2, 3, 5] [4, 3, 4] [4, 3, 5]

variable	DU Pairs	DU Paths
mean	(5, 7) (5, 8)	[5, 6, 7] [5, 6, 8]
varsum	(5, 7) (5, 8) (7, 7) (7, 8)	[5, 6, 7] [5, 6, 8] [7, 6, 7] [7, 6, 8]
i	(2, 4) (2, (3,4)) (2, (3,5)) (4, 4) (4, (3,4)) (4, (3,5)) (5, 7) (5, (6,7)) (5, (6,8)) (7, 7) (7, (6,7)) (7, (6,8))	[2, 3, 4] [2, 3, 4] [2, 3, 5] [4, 3, 4] [4, 3, 4] [4, 3, 5] [5, 6, 7] [5, 6, 7] [5, 6, 8] [7, 6, 7] [7, 6, 7] [7, 6, 8]

Questions?

Next Lecture….
Levels of Testing, Junit Testing Framework