Testing Methods: White Box Testing II

Outline

- Today we continue our look at white box testing with more code coverage methods, and a data coverage method

- We'll look at :

  - code coverage testing

    - decision coverage
    - condition coverage
    - branch coverage
    - loop coverage
    - path coverage

  - data coverage testing

    - data flow coverage

Decision Coverage

Decision (Branch) Coverage Method

- Causes every decision (if, switch, while, etc.) in the program to be made both ways (or every possible way for switch)

- System: Design a test case to exercise each decision in the program each way (true / false)

- Completion criterion: A test case for each side of each decision

  - Can be checked by instrumentation injection to track branches taken in execution

Example: Decision Coverage

```
        // calculate numbers less than x
        //   which are divisible by y

        int x, y;
        x = c.readInt ();
        y = c.readInt ();

1       if (y == 0)
            c.println ("y is zero");
        else
2           if (x == 0)
                c.println ("x is zero");
            else
            {
                for (int i = 1; i <=x ; i++)
                {
3                   if (i % y == 0)
                        c.println (i);
                }
            }
```

Example: Decision Coverage

Decision Coverage Tests

- We make one test for each side of each decision

Decision	x input	y input
1 true	0	0
1 false	0	1
2 true	0	1
2 false	1	1
3 true	1	1
3 false	2	3

Condition Coverage

Condition Coverage Method

- Like decision coverage, but causes every condition expression to be exercised both ways (true / false)

- A condition is any true / false subexpression in a decision

  Example:

```
if (( x == 1 || y > 2) && z < 3)
```

  Requires separate condition coverage tests for each of:

`x == 1`	true / false
`y > 2`	true / false
`z < 3`	true / false

- More effective than simple decision coverage since exercises

Loop Coverage

Loop Coverage Method

- Most programs do their real work in do, while and for loops

- This method makes tests to exercise each loop in the program in four different states :

  - execute body zero times (do not enter loop)
  - execute body once (i.e., do not repeat)
  - execute body twice (i.e., repeat once)
  - execute body many times

- Usually used as an enhancement of a statement, block, decision or condition coverage method

- System: Devise test cases to exercise each loop with zero, one, two and many repetitions

- Completion criterion: A test for each of these cases for each loop

  - Can be verified using instrumentation injection in the code

Example: Loop Coverage

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is zero");
else if (x == 0)
    c.println ("x is zero");
else
{
    for (int i=1; i<=x ; i++)
    {
        if (i % y == 0)
            c.println (i);
    }
}
```

Loop Body	x	y
zero times	N/A	
once	1	1
twice	2	1
many times	10	1

Execution Paths

Execution Paths

- An execution path is a sequence of executed statements starting at the entry to the unit (usually the first statement) and ending at the exit from the unit (usually the last statement)

- Two paths are independent if there is at least one statement on one path which is not executed on the other

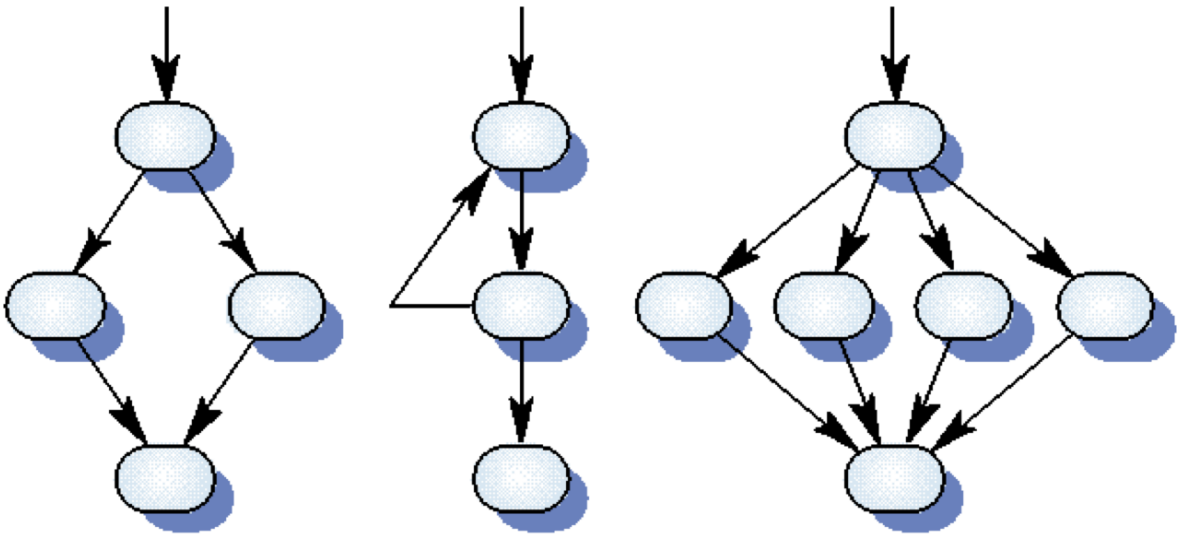
- Path analysis (also know as cyclomatic complexity* analysis) identifies all the independent paths through a unit

* - a code metric we will look at later in the course

Execution Path Analysis

Flow Graphs

- It is easiest to do path analysis if we look at the execution flow graph of the program or unit
- The flow graph simply shows program control flow between



if-then-else do-while switch

Path Coverage Testing

Advantages

- Covers all basic blocks (does all of basic block testing)
- Covers all conditions (does all of decision/condition testing)
- Does all of both, but with fewer tests!
- Can be automated (actually, in practice requires automation)

Disadvantages

- Does not take data complexity into account at all

Path Coverage Testing

Disadvantages

- Example: These fragments should be tested the same way, since they actually implement the same solution - but the one on the left gets five tests, whereas the one on the right gets only one

```
// control-centric solution
switch (n) {
     case 1:
          s = "One";
          break;
     case 2:
          s = "Two";
          break;
     case 3:
          s = "Three";
          break;
     case 4:
          s = "Four";
          break;
     case 5:
          s = "Five";
          break;
}
```

```
// data-centric solution
String numbers[] =
     {"One", "Two",
      "Three", "Four", "Five"};

s = numbers[n];
```

White Box Data Coverage

Data Coverage Methods

- Data coverage methods explicitly try to cover the data aspects of the program code, rather than the control aspects

- In this course we will cover data flow coverage including several different data flow coverage test criteria.

(Won't do these in detail, just overview)

White Box Data Coverage

Data Flow Coverage

- Data flow coverage is concerned with variable definitions and uses along execution paths
- A variable is defined if it is assigned a new value during a statement execution
  - A variable definition in one statement is alive in another if there is a path between the two statements that does not redefine the variable
- There are two types of variable uses
  - A P-use of a variable is a predicate use (e.g. if statement)
  - A C-use of a variable is a computation use or any other use (e.g. I/O statements)

Example: Definition, P-Use, C-Use of Variables

```
static int find (int list[], int n, int key)
{
    // binary search of ordered list
    int lo = 0;
    int hi = n - 1;
    int result = -1;
    while (hi >= lo)
    {
        if (result != -1)
            break;
        else
        {
            final int mid = (lo + hi) / 2;
            if (list[mid] == key)
                result = mid;
            else if (list[mid] > key)
                hi = mid - 1;
            else  // list[mid] < key
                lo = mid + 1;
        }
    }
    return result;
}
```

<- Definition of result

<- P-Use of result

<- Definition of result

Example: Definition, P-Use, C-Use of Variables

```
static int find (int list[], int n, int key)
{
    // binary search of ordered list
    int lo = 0;
    int hi = n - 1;
    int result = -1;
    while (hi >= lo)
    {
        if (result != -1)
            break;
        else
        {
            final int mid = (lo + hi) / 2;
            if (list[mid] == key)
                result = mid;
            else if (list[mid] > key)
                hi = mid - 1;
            else  // list[mid] < key
                lo = mid + 1;
        }
    }
    return result;
}
```

<- Definition of hi

<- P-Use of hi

<- C-Use of hi

<- Definition of hi

White Box Data Coverage

Data Flow Coverage

- There are a variety of different testing strategies related to data flow:
  - All-Uses coverage: test all uses of each definition
  - All-Defs coverage: test each definition at least once
  - All C-Uses/Some P-Uses coverage: test all computation uses. If no computation uses for a given definition then test at least one predicate use
  - All P-Uses/Some C-Uses coverage: test all predicate uses. If no predicate uses for a given definition then test at least one computation use
  - All P-Uses coverage: Test each predicate use

White Box Data Coverage

Data Flow Coverage

- We have covered definitions of data, uses of data, and testing strategies for data flow coverage.

- System: Identify definitions (and uses) of variables and testing strategy. design a set of test cases that cover the testing strategy

- Completion criterion: Depends on the test strategy. For example, in All-Defs we are done when we have a test case for each variable definition

Summary

Testing Methods: White Box Testing II

- Code coverage methods:
  - Decision analysis methods
    (decision, condition, loop coverage, path coverage)
- Data coverage methods:
  - data flow coverage

Next Time

- Mutation testing