Logic Coverage from Source Code

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The original slides are taken from Chap. 8 of Intro. to SW Testing 2nd ed by Ammann and Offutt

Logic Expressions from Source

- Predicates are derived from decision statements in programs
- In programs, most predicates have less than four clauses
  - Wise programmers actively strive to keep predicates simple
- When a predicate only has one clause, COC, ACC, ICC, and CC all collapse to predicate coverage (PC)
- Applying logic criteria to program source is hard because of reachability and controllability:
  - *Reachability* : Before applying the criteria on a predicate at a particular statement, we have to get to that statement
  - *Controllability* : We have to find input values that indirectly assign values to the variables in the predicates
  - Variables in the predicates that are not inputs to the program are called *internal variables*
- These issues are illustrated through the triangle example in the following slides …

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```
30  private static int Triang (int s1, int s2, int s3)
31  {
32    int result;
33
34    // result is output from the routine:
35    // result = 1 if triangle is scalene
36    // result = 2 if triangle is isosceles
37    // result = 3 if triangle is equilateral
38    // result = 4 if not a triangle
39
40    // After a quick confirmation that it's a legal
41    // triangle, detect any sides of equal length
42    if (s1 <= 0 || s2 <= 0 || s3 <= 0)
43    {
44      result = 4;
45      return (result);
46    }
47
48    result = 0;
49    if (s1 == s2)
50      result = result + 1;
51    if (s1 == s3)
52      result = result + 2;
53    if (s2 == s3)
54      result = result + 3;
55    if (result == 0)
56    {  // Confirm it's a legal triangle before declaring
57      // it to be scalene
59      if (s1+s2<=s3||s2+s3 <= s1
60          || s1+s3 <= s2)
61        result = 4;
62      else
63        result = 1;
64      return (result);
65    }

67    /* Confirm it's a legal triangle before declaring
68      it to be isosceles or equilateral  */
69
70    if (result > 3)
71      result = 3;
72    else if (result == 1 && s1+s2 > s3)
73     result = 2;
74    else if (result == 2 && s1+s3 > s2)
75     result = 2;
76    else if (result == 3 && s2+s3 > s1)
77     result = 2;
78    else
79     result = 4;
80    return (result);
81  } // end Triang
```

Ten Triangle Predicates

42: (s1 <= 0 || s2 <= 0 || s3 <= 0)

49: (s1 == s2)

51: (s1 == s3)

53: (s2 == s3)

55: (result == 0)

59: (s1+s2 <= s3 || s2+s3 <= s1 ||
s1+s3 <= s2)

70: (result > 3)

72: (result == 1 && s1+s2 > s3)

74: (result == 2 && s1+s3 > s2)

76: (result == 3 && s2+s3 > s1)

Reachability for Triang Predicates

42: True

49: P1 = s1>0 && s2>0 && s3>0

51: P1

53: P1

55: P1

59: P1 && result = 0

70: P1 && result != 0

72: P1 && result != 0 && result <= 3

74: P1 && result != 0 && result <= 3 && (result !=1 || s1+s2<=s3)

76: P1 && result != 0 && result <= 3 && (result !=1 || s1+s2<=s3)
&& (result !=2 || s1+s3<=s2)

Need to solve for the internal variable *result*

Solving for Internal Variable *result*

At line 55, result has a value in the range (0 .. 6)

result = 0 s1!=s2 && s1!=s3 && s2!=s3

1 s1=s2 && s1!=s3 && s2!=s3

2 s1!=s2 && s1=s3 && s2!=s3

3 s1!=s2 && s1!=s3 && s2=s3

4 s1=s2 && s1!=s3 && s2=s3 — ***Contradiction***

5 s1!=s2 && s1=s3 && s2=s3 — ***Contradiction***

6 s1=s2 && s1=s3 && s2=s3

Reachability for Triang Predicates (solved for result – reduced)

42: True

49: P1 = s1>0 && s2>0 && s3>0

51: P1

53: P1

55: P1

59: P1 && s1 != s2 && s2 != s3 && s2 != s3 (result = 0)

70: P1 && P2 = (s1=s2 || s1=s3 || s2=s3) (result != 0)

72: P1 && P2 && P3 = (s1!=s2 || s1!=s3 || s2!=s3) (result <= 3)

74: P1 && P2 && P3 && (s1 != s2 || s1+s2<=s3)

76: P1 && P2 && P3 && (s1 != s2 || s1+s2<=s3)
&& (s1 != s3 || s1+s3<=s2)

Looks complicated, but a lot of redundancy

Predicate Coverage

These values are "don't care", needed to complete the test.

	T			F		
	s1	s2	s3	s1	s2	s3
p42: (s1 <= 0 || s2 <= 0 || s3 <= 0)	0	0	0	1	1	1
p49: (s1 == s2)	1	1	1	1	2	2
p51: (s1 == s3)	1	1	1	1	2	2
p53: (s2 == s3)	1	1	1	2	1	2
p55: (result == 0)	1	2	3	1	1	1
p59: (s1+s2 <= s3 || s2+s3 <= s1 || s1+s3 <= s2)	1	2	3	2	3	4
p70: (result > 3)	1	1	1	2	2	3
p72: (result == 1 && s1+s2 > s3)	2	2	3	2	2	4
p74: (result == 2 && s1+s3 > s2)	2	3	2	2	4	2
p76: (result == 3 && s2+s3 > s1)	3	2	2	4	2	2

Clause Coverage

	T				F			
	S1	s2	s3	EO	s1	s2	s3	EO
p42: (s1 <= 0)	0	1	1	4	1	1	1	3
(s2 <= 0)	1	0	1	4	1	1	1	3
(s3 <= 0)	1	1	0	4	1	1	1	3
p59: (s1+s2 <= s3)	2	3	6	4	2	3	4	1
(s2+s3 <= s1)	6	2	3	4	2	3	4	1
(s1+s3 <= s2)	2	6	3	4	2	3	4	1
p72: (result == 1)	2	2	3	2	2	3	2	2
(s1+s2 > s3)	2	2	3	2	2	2	5	4
p74: (result == 2)	2	3	2	2	3	2	2	2
(s1+s3 > s2)	2	3	2	2	2	5	2	4
p76: (result == 3)	3	2	2	2	1	2	1	4
(s2+s3 > s1)	3	2	2	2	5	2	2	4

CACC Coverage (also RACC)

	c1	c2	c3	P	s1	s2	s3	EO
p42: (s1 <= 0 || s2 <= 0 || s3 <= 0)	T	f	f	t	0	1	1	4
	F	F	F	f	1	1	1	3
	f	T	f	t	1	0	1	4
	f	f	T	t	1	1	0	4
p59: (s1+s2 <= s3 || s2+s3 <= s1 || s1+s3 <= s2)	T	f	f	t	2	3	6	4
	F	F	F	f	2	3	4	1
	f	T	f	t	6	2	3	4
	f	f	T	t	2	6	3	4
p72: (result == 1 && s1+s2 > s3)	T	T		t	2	2	3	2
→ s1=s2 && s1!=s3 && s2!=s3	F	t		f	2	3	3	2
	t	F		f	2	2	5	4
p74: (result == 2 && s1+s3 > s2)	T	T		t	2	3	2	2
→ s1!=s2 && s1=s3 && s2!=s3	F	t		f	2	3	3	2
	t	F		f	2	5	2	4
p76: (result == 3 && s2+s3 > s1)	T	T		t	3	2	2	2
→ s1!=s2 && s1!=s3 && s2=s3	F	t		f	1	2	2	4
	t	F		f	5	2	2	4

Program Transformation Issues

```
if ((a && b) || c) {
    s1;
}
else {
    s2;
}
```

Transform (1)?

```
if (a) {
    if (b)
        s1;
    else {
        if (c)  /* c1 */
            s1;
        else
            s2;
    }
}
else {
    if (c)   /* c2 */
        s1;
    else
        s2;
}
```

Transform (2)?

```
d = a && b;
if (d||c) {
    s1;
}
else {
    s2;
}
```

Problems with Transformed Programs (1/2)

- Maintenance is certainly harder with Transform (1)
  - Not recommended!
- Coverage on Transform (1)
  - PC on the transform does not imply CACC on the original
    - A test suit to satisfy PC on the transform (1):
      - a:any element of {1,2,3,4}x{5,6,7,8}
      - b:any element of {1,2}x{3,4}
      - c1:{(3,4)}
      - c2:any element of {5,7}x{6,8}
      - ex. {1,3,4,5,8}
  - CACC on the original does not imply PC on the transform
    - Ex. {(2,6),(2,4),(3,4)} does not satisfy PC on the transform due to c2

	a	b	c	(a∧b)∨c	CACC	PC(1)
1	T	T	T	T		O
2	T	T	F	T	O	
3	T	F	T	T	O	O
4	T	F	F	F	O	O
5	F	T	T	T		O
6	F	T	F	F	O	
7	F	F	T	T		
8	F	F	F	F		O

$(a \wedge b) \vee c$

a as major clause: p_a: $b \wedge \neg c$

- test inputs satisfying CACC =(**2**,6)

b as major clause: p_b: $a \wedge \neg c$

- test inputs satisfying CACC=(2,4)

c as major clause: p_c: $\neg(a \wedge b)$

- test inputs satisfying CACC = a pair in {3,5,7}x{4,6,8}

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Problems with Transformed Programs (2/2)

- Coverage on Transform (2)
  - Structure used by logic criteria is “lost”
  - Hence CACC on the transform 2 only requires 3 tests
- Therefore, it may not be meaningful to transform a program to increase coverage

	a	b	d	c	(a∧b)∨c	CACC	PC(1)	CACC(2)
1	T	T	T	T	T		O	
2	T	T	T	F	T	O		O
3	T	F	F	T	T	O	O	O
4	T	F	F	F	F	O	O	
5	F	T	F	T	T		O	
6	F	T	F	F	F	O		O
7	F	F	F	T	T			
8	F	F	F	F	F		O	

d || c

d as major clause: p_d: ¬c

- test inputs satisfying CACC = a pair in {(**2**,4),(2,6),(2,8)}

c as major clause: p_c: ¬d

- test inputs satisfying CACC = a pair in {3,5,7}x{4,6,8}

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Summary : Logic Coverage for Source Code

- Predicates appear in decision statements
  - if, while, for, etc.
- Most predicates have less than four clauses
  - But some applications have predicates with many clauses
- The hard part of applying logic criteria to source is resolving the internal variables
- Non-local variables (class, global, etc.) are also input variables if they are used
- If an input variable is changed within a method, it is treated as an internal variable thereafter
- To maximize effect of logic coverage criteria:
  - Avoid transformations that hide predicate structure

Restricted Active Clause Coverage

					s1	s2	s3	EO
p42: (s1 <= 0 || s2 <= 0 || s3 <= 0)	T	f	f	t	0	1	1	4
	F	F	F	f	1	1	1	3
	f	T	f	t	1	0	1	4
	f	f	T	t	1	1	0	4
p59: (s1+s2 <= s3 || s2+s3 <= s1 || s1+s3 <= s2)	T	f	f	t	2	3	6	4
	F	f	f	f	2	3	4	1
	f	T	f	t	6	2	3	4
	f	f	T	t	2	6	3	4
p72: (result == 1 && s1+s2 > s3)	T	t		t	2	2	3	2
s1=s2 && s1!=s3 && s2!=s3	F	t		f	2	3	3	2
	t	F		f	2	2	5	4
p74: (result == 2 && s1+s3 > s2)	T	t		t	2	3	2	2
s1!=s2 && s1=s3 && s2!=s3	F	t		f	2	3	3	2
	t	F		f	2	5	2	4
p76: (result == 3 && s2+s3 > s1)	T	t		t	3	2	2	2
s1!=s2 && s1!=s3 && s2=s3	F	t		f	1	2	2	4
	t	F		f	5	2	2	4