Advanced Software Testing

Understanding Code Coverage

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Advanced Software Testing

- A series of webinars, this one excerpted from *Advanced Software Testing: V3*, a book for technical test analysts, programmers, and test engineers
- Black box techniques are useful for checking behavior
- Static analysis allows us to scrutinize the code to look directly for defects
- White box techniques are useful for checking code coverage

Control Flow Coverage

- Many different levels of control flow coverage have been identified
  - Statement (instruction, code) coverage: every statement in the module is executed at least once
  - Decision (branch) coverage: every decision in the module has been tested for both outcomes
  - Condition coverage: each condition making up a decision is evaluated at least once (with two additional variants common)
  - Multiple condition coverage: all possible combinations of outcomes for individual conditions within a decision are tested
- Let's look at these types of coverage…

Statement Coverage Testing

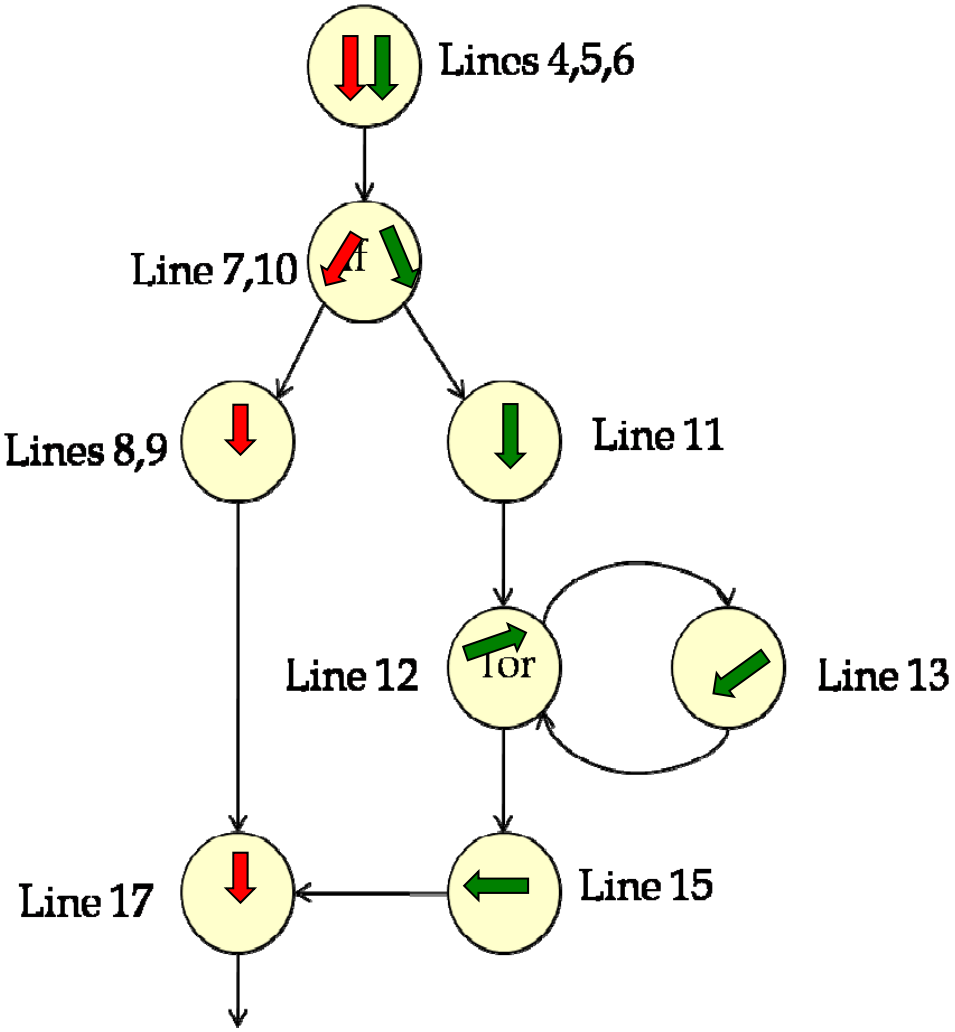
- Concept: executable statements are basis for test design selection
- Test derivation: identify test data to force execution of all statements
- Coverage criteria: number of statements executed / total number of statements
- Bug hypothesis: defects may exist in executable statements even though control flow is correct

Example: Statement Coverage

```
1 #include <stdio.h>
 2 main()
 3 {
 4   int i, n, f;
 5   printf("n = ");
 6   scanf("%d", &n);
 7   if (n < 0) {
 8     printf("Invalid: %d\n", n);
 9     n = -1;
10   } else {
11     f = 1;
12     for (i = 1; i <= n; i++) {
13       f *= i;
14     }
15     printf("%d! = %d\n", n, f);
16   }
17   return n;
18 }
```

Test value: **n < 0**

n > 0



Decision Coverage

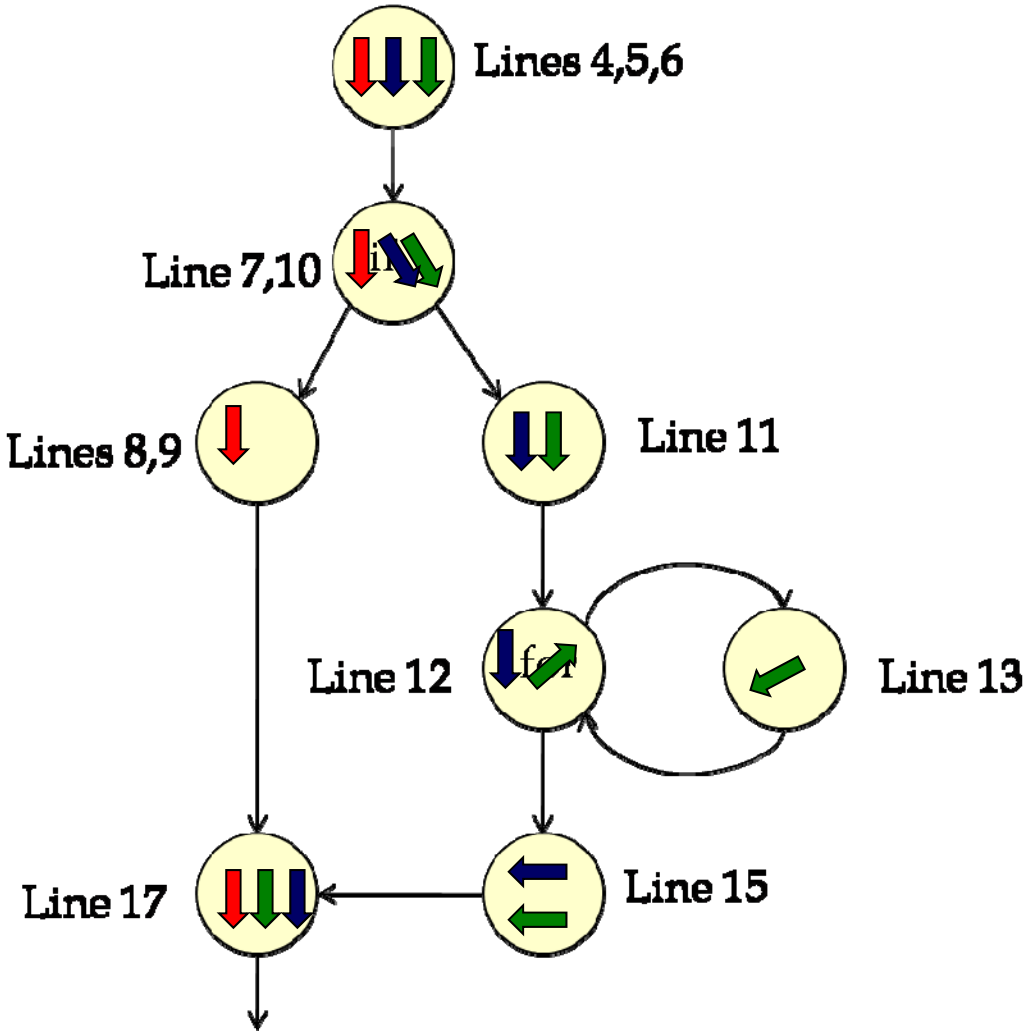
- Concept: control decisions are basis for test design selection
- Test derivation: identify data to force execution of each decision both ways (TRUE/FALSE)
- Coverage criteria: number of decision outcomes executed divided by total number of decision outcomes
- Bug hypothesis: defects may exist in untested decisions or branches
- 100% decision coverage gives 100% statement coverage

Example: Decision Coverage

```
1 #include <stdio.h>
 2 main()
 3 {
 4   int i, n, f;
 5   printf("n = ");
 6   scanf("%d", &n);
 7   if (n < 0) {
 8     printf("Invalid: %d\n", n);
 9     n = -1;
10   } else {
11     f = 1;
12     for (i = 1; i <= n; i++) {
13       f *= i;
14     }
15     printf("%d! = %d\n", n, f);
16   }
17   return n;
18  }
```

Statement coverage: We tested (**n < 0**) and (**n > 0**)

To get decision coverage, we still need (**n == 0**)



Loop Coverage

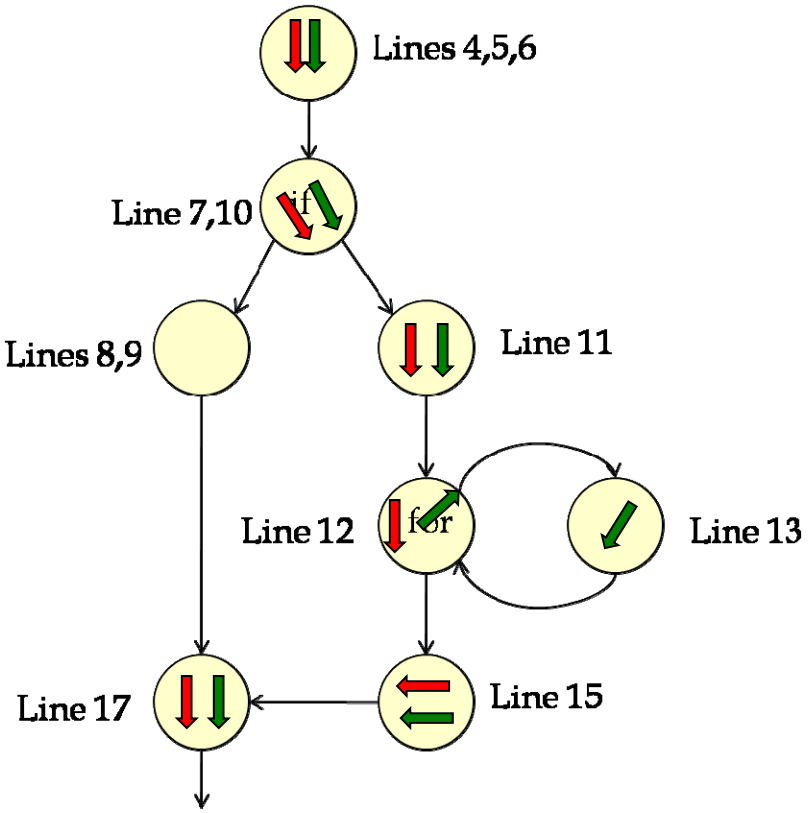
- Concept: because the number of paths when there is a loop may be close to infinite, we want to test a representative number of times through the loop
- Test Derivation: identify data that causes system to loop a finite number of different times
- Coverage criteria: tests such that the system loops 0 times, 1 time, n times where n equals the expected max number of loops (if possible)
- Bug hypothesis: failing to loop (or looping too often) may cause failures

Example: Loop Coverage (0, 1 Loops)

```
1 #include <stdio.h>
 2 main()
 3 {
 4   int i, n, f;
 5   printf("n = ");
 6   scanf("%d", &n);
 7   if (n < 0) {
 8     printf("Invalid: %d\n", n);
 9     n = -1;
10   } else {
11     f = 1;
12     for (i = 1; i <= n; i++) {
13       f *= i;
14     }
15     printf("%d! = %d\n", n, f);
16   }
17   return n;
18 }
```

Loop 0 times by testing **(n=0)**

Loop 1 time by testing **(n = 1)**



Condition Coverage

- Concept: each atomic condition must be evaluated in tests both ways (T/F)
- Test Derivation: identify data to force execution of each atomic condition both ways
- Coverage criteria: number of Boolean operand values executed divided by the total number of Boolean operand values
- Bug hypothesis: defects may exist in untested atomic conditions
- Atomic condition: the simplest form of code that can result in a TRUE or FALSE outcome *--Bath & McKay*

Atomic Conditions

- A decision is made up of one or more atomic conditions
- Examples:

x → TRUE

-- There is one atomic condition

D && F → FALSE

-- There are 2 atomic conditions

(A || B) && (C == D) → TRUE

-- There are 3 atomic conditions [**A, B, (C==D)**]

(a>b)||(x+y==-1)&&((d)!=TRUE) → TRUE

-- There are 3 atomic conditions

- In each case, there is still only one decision for the whole expression

Condition Testing

- The rule of condition testing is to ensure that each atomic condition has been evaluated to both TRUE and FALSE in testing
- In the previous slide:

x, D, F, A and B must all be tested TRUE and FALSE

(C == D) must be tested both TRUE and FALSE

(a > b) must be tested both TRUE and FALSE

(x+y==-1) must be tested both TRUE and FALSE

((d)!=TRUE) must be tested both TRUE and FALSE

Decision/Condition Coverage

- Concept: each atomic condition must be evaluated in a test both ways (T/F) **AND** decision coverage must also be satisfied
- Test derivation: identify data to force execution of each atomic condition both ways and add tests to ensure decision coverage
- Coverage criteria: must include both condition and decision coverage
- Bug hypothesis: testing all conditions alone may not be sufficient

Example: Decision/Condition Coverage

- Consider the following code snippet:

  if (a AND b) then…

- Condition coverage is satisfied with

  a==FALSE, b==TRUE → FALSE
  a==TRUE, b==FALSE→ FALSE

- Decision/Condition coverage is satisfied by adding

  a==TRUE, b==TRUE → TRUE

- Is that sufficient testing?

Modified Condition/Decision Coverage

- Concept: each atomic condition must be evaluated in a test both ways (T/F) **AND** decision coverage must also be satisfied **AND** each condition must affect the outcome decision independently
- Test derivation: identify data to force execution of each atomic condition both ways **AND** add tests to ensure decision coverage **AND** ensure each condition affects the decision outcome independently
- Coverage criteria: see next slide
- Bug hypothesis: testing all decisions and conditions alone may not be sufficient

MC/DC Coverage

- MC/DC is achieved when:
  1. Each decision tries every possible outcome
  2. Each condition in a decision takes on every possible outcome
  3. Each entry and exit point is invoked
  4. Each condition in a decision is shown to independently affect the outcome of the decision while holding fixed all other possible conditions
- When the programming language uses short circuits decision making, testing MC/DC is problematic

  if (a | | b) {} → if **a** is TRUE, **b** is never evaluated

Achieving MC/DC Coverage

- Given that definition, how do we achieve MC/DC coverage?
- Consider the following code snippet:

  if ((a OR b) AND c) then…

- Decision/Condition coverage can be achieved with

  a==TRUE, b==TRUE, c==TRUE → TRUE

  a==FALSE, b==FALSE, c==FALSE → FALSE

- Notice that b never independently affects the outcome of the decision

Achieving MC/DC Coverage

- The following test set will achieve the MC/DC coverage
  1. **a==TRUE, b==FALSE, c==TRUE → TRUE**
  2. **a==FALSE, b==TRUE, c==TRUE → TRUE**
  3. **a==TRUE, b==TRUE, c==FALSE → FALSE**
- Note that the decision would be reversed:
  - In test 1, if **a** changed with b and c held constant
  - In test 2, if **b** changed with a and c held constant
  - In test 3, if **c** changed with a and b held constant

Multiple Condition Coverage

- Concept: exhaustively test every single combination of conditions that can affect an outcome
- Test derivation: use Boolean truth table to generate all possible combinations of values that must be tested
- Coverage criteria: number of Boolean operand value combinations executed / total number of Boolean operand value combinations
- Bug hypothesis: bugs could be anywhere!

Conclusion

- In this webinar, we've seen how to apply code coverage to understand what's been tested…and what hasn't
- In our previous webinars, we looked at various test techniques, including behavior-based
- Code coverage can allow us to measure the degree to which these tests exercise the code
- Thus, code coverage can build confidence in your tests

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