Code Coverage Metrics

And How to Use Them

```
int main(int argc, char* argv[])
{
        long int i, n=0;
        ubcd pp, p, c;

        if (argc > 1) {
                n = atol(argv[1]);
        } else {
                cout << "Enter element count: ";
                cin >> n;
        }

        if (n < 0) {
                cout << "No " << n << " series!\n";
                n = -1;
        } else {
                cout << "{ ";
                pp = 0;
                p = 1;
                for (i=0; i < n; i++) {
                        c = pp + p;
                        cout << c.csrep() << ' ';
                        pp = p;
                        p = c;
                }
                cout << "} \n";
        }

        return n;
}
```


A Hands-on Demonstration

Introduction

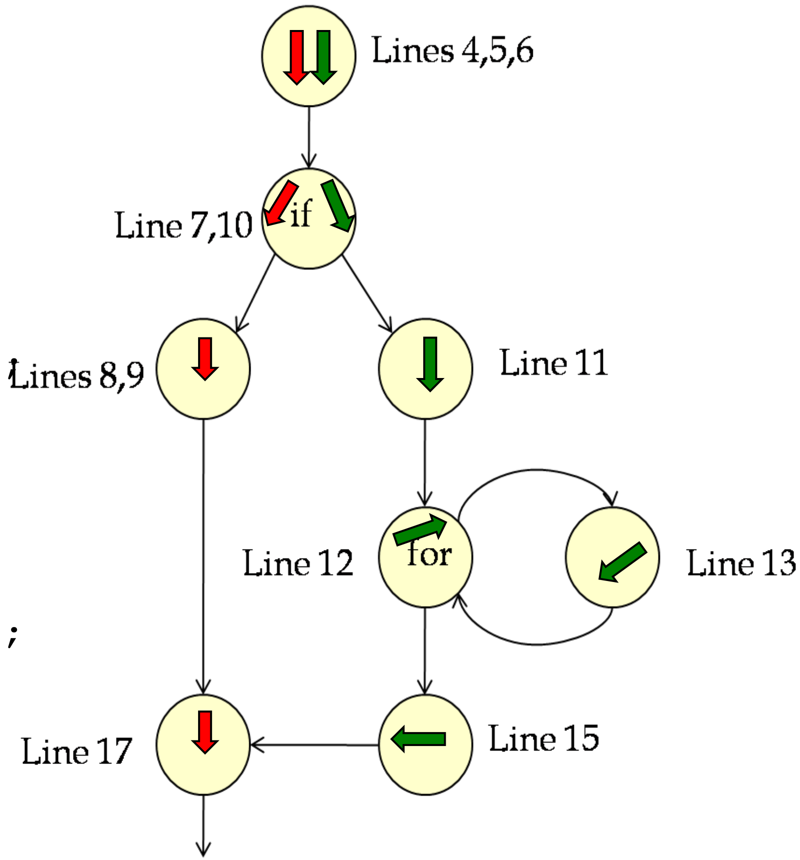
- More and more testers and programmers use tools that provide code coverage metrics
  - How do these tools work?
  - What do these metrics tell us?
- Some testers and programmers use tools that measure code maintainability
  - How do these tools work?
  - What do these metrics tell us?
- Let's look at three examples to examine these questions
  - Statement and branch coverage metrics
  - McCabe Cyclomatic complexity and basis path coverage
- I'll illustrate with a real program, along with open source tools, using a Virtual Box environment

Statement Coverage Testing

- Concept: executable statements are basis for test design and selection
- Test derivation: identify test data to force execution of all statements
- Coverage criterion: (number of statements executed / total number of statements) = 100%
- 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 values: **n < 0, n > 0**

Decision Coverage

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

What is a Decision?

- The ability to decide to take one path rather than another is the real power of a computer
- The decision may be a simple Boolean expression

  a > b

- Or, it might be arbitrarily complex

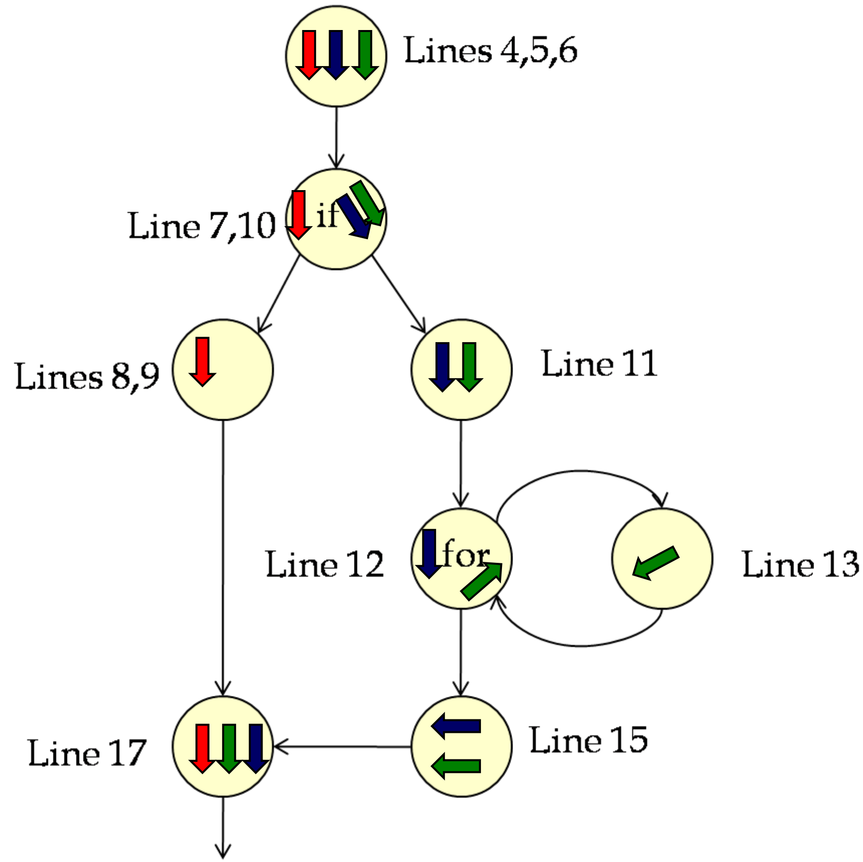
  (a>b) || (x+y==-1) && ((d) != TRUE)

- Different programming languages have different constructs for making decisions
  - if then (else)
  - while
  - until do
  - for
  - switch/case
  - and lots more…

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 }
```

Test values: **n < 0**, **n > 0**, **n == 0**



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Demo: Control Flow Coverage

- Compile WordTree with code coverage enabled

  g++ -Wall -fprofile-arcs -ftest-coverage -o wordtree wordtree.cpp driver.cpp

- Run tests designed to achieve 100% equivalence partition and boundary value coverage

- Let's see if we obtain complete statement and decision coverage

  gcov wordtree.cpp | less

  less wordtree.cpp.gcov

McCabe Cyclomatic Complexity

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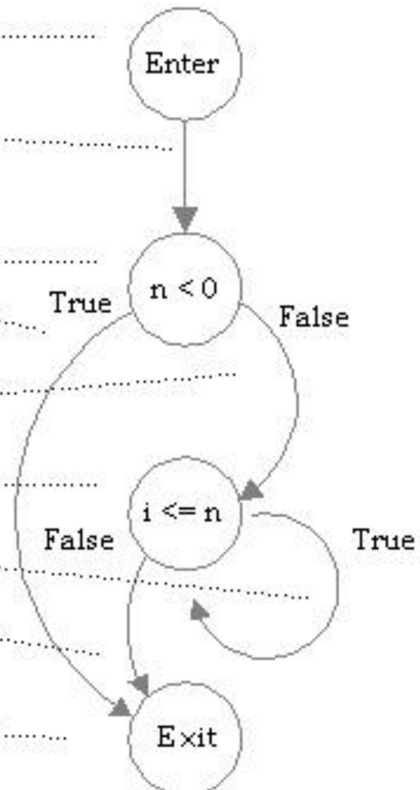
- McCabe's Cyclomatic Complexity measures control flow complexity
  - Measured by drawing a directed graph
  - Nodes represent entries, exits, decisions
  - Edges represent non-branching statements
- It has some useful testing implications
  - High-complexity modules are inherently buggy and regression-prone
  - The complexity is approximately equal to the number of tests you'll need to run to get decision coverage
- Let's see how…

Cyclomatic Complexity for Factorial

Program

```
main()
{
 int i, n, f;
 printf("n = ");
 scanf("%d", &n);
 if (n < 0) {
  printf("Invalid: %d\n", n);
  n = -1;
 } else {
  f = 1;
  for (i = 1; i <= n; i++) {
   f *= i;
  }
  printf("%d! = %d.\n", n, f);
 }
 return n;
}
```

Flow Diagram



Cyclomatic Complexity

C = #R + 1 =
2 + 1 = 3

or

C = #E - #N + 2 =
5 - 4 + 2 = 3

Complexity Rule of Thumb

- Calculating the Cyclomatic Complexity graphically can be tedious and error prone
- A useful rule of thumb: Count the branching and looping constructs and add 1
  - For if/else, use 1 for each if (ignore else)
  - For switch/case, count the case blocks (ignore default)
- This rule of thumb has proven accurate for me, but there might be a situation where it doesn't give the exact answer (but it'll be close)

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Demo: Cyclomatic Complexity

- Use the pmccabe program to calculate the Cyclomatic Complexity for each of the member functions in the Tnode and WordTree classes

  pmccabe -v wordtree.cpp

- Use the pmccabe program to calculate the Cyclomatic Complexity for the triangle program

  pmccabe -v triangle.c

- Check to see if the calculations are correct using the rule of thumb

Conclusion

- Code coverage can tell us what we've tested, and what we haven't tested
- We won't find all the bugs in the code we have tested, but we can't find bugs in any of the code we haven't tested
- Complexity can give us an idea of how hard it will be to maintain our code
- As with code coverage, not perfect, but useful
- I hope you find these techniques useful tools in your work as a tester or programmer

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