Code Coverage Metrics
And How to Use Them

```c
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
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: \( \frac{\text{number of statements executed}}{\text{total number of statements}} = 100\% \)
- Bug hypothesis: defects may exist in executable statements even though control flow is correct
Example: Statement Coverage

```c
#include <stdio.h>

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

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: \((\text{number of decision outcomes executed/total number of decision outcomes}) = 100\%\)
- 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: \((a > b) \land (x + y = -1) \land ((d) \neq \text{TRUE})\)
- Different programming languages have different constructs for making decisions:
  - `if` then `(else)`
  - `while`
  - `until` do
  - `for`
  - `switch/case`
  - and lots more…
Example: Decision Coverage

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

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

- 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

```c
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).
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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