Objectives

- Software testing issue: when have I tested enough?
- Coverage criteria

Review

- What is *unit testing*?
- What are the benefits of unit testing?
- What are the characteristics of good unit tests?
- What are the steps in a JUnit Test Case?

Review: Example Test Cases for Calculator Program

- Basic Functionality
  - Addition
  - Subtraction
  - Multiplication
  - Division
  - Order of operations
- Invalid Input
  - Letters, not-operation characters (&,$, …)
- "Tricky" Cases
  - Divide by 0
  - Negative Numbers
  - Long sequences of operands, operators
  - VERY large, VERY small numbers

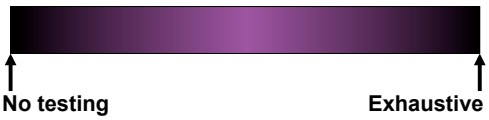
Software Testing Issues

- How do we know if the calculator program is correct?
  - How do we know that we've exposed all the faults?
  - How confident are we in its correctness?
- How do we know if we've tested enough?
  - Our customers want this product soon but we need product to be correct
    - Harder to fix after it has been released

Software Testing Issues

- How do we know if the calculator program is correct?
  - How do we know that we've exposed all the faults?
  - How confident are we in its correctness?
- How do we know if we've tested enough?
  - Time? It's been a couple hours/days/…
  - Number of test cases executed? A lot!
  - I asked my brother and he's really smart and he says that it's enough

Testing Continuum

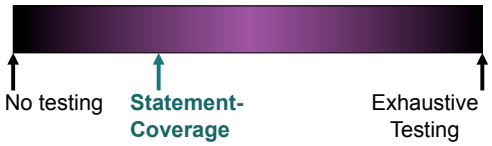


No testing — **Exhaustive Testing**

- Give to customer immediately
- Likely buggy!
- Very little confidence in program's quality

- Test *every possible* input
- Costly, impractical
- Need to release application to customers *sometime!*

Testing Continuum



- Need to execute **all code**
- Cover (i.e., execute) all **statements** in the program

Statement Coverage

- Cover all statements in the program

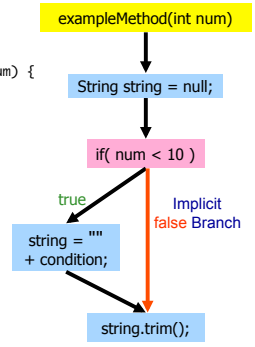
Test Suite:
num=5

```
public String exampleMethod(int num) {
    String string = null;
    if (num < 10) {
        string = "" + condition;
    }
    // remove the leading & trailing whitespace
    return string.trim();
}
```

Is this method bug-free?

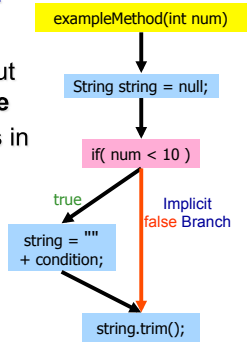
Program Flow

```
public String exampleMethod(int num) {
    String string = null;
    if (num < 10) {
        string = "" + condition;
    }
    return string.trim();
}
```



What Went Wrong?

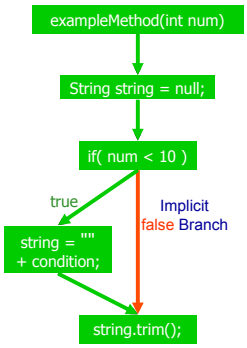
- Test suite had 100% statement coverage but missed a **branch/edge**
- Try covering all **edges** in program's flow
  - Also covers all **nodes**
  - Called **Branch Coverage**



Branch Coverage

- Cover all **branches** in the program

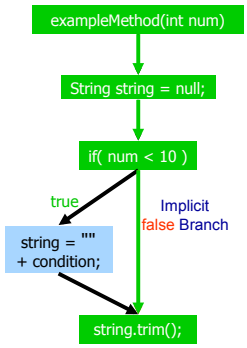
Test Suite:
num=5,
num=10



Branch Coverage

- Cover all **branches** in the program

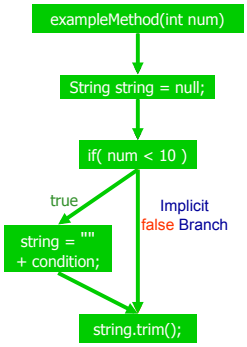
Test Suite:
num=5,
num=10



Branch Coverage

- Cover all **branches** in the program

Test Suite:
num=5,
num=10



INTERLUDE: ECLIPSE DEBUGGER

Interlude: Eclipse Debugger

1. Set breakpoint
   - Near and BEFORE point of failure
2. Run program in debug mode
3. Inspect variables
4. Step through program, inspecting variables
   - Step into, over, and return

BACK TO COVERAGE…

Example 2

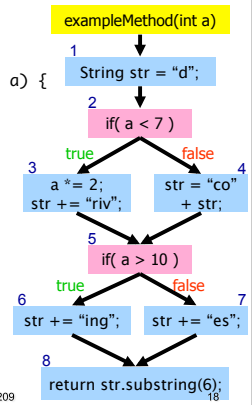
```
public String exampleMethod(int a) {
   String str = "d";
   if ( a < 7 ) {
      a *= 2;
      str += "riv";
   } else {
      str = "co" + str;
   }

   if( a > 10 ) {
      str += "ing";
   } else {
      str += "es";
   }
   return str.substring(6);
}
```


Example 2

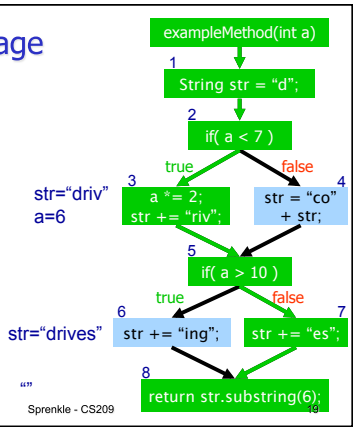
```
public String exampleMethod(int a) {
   String str = "d";
   if ( a < 7 ) {
      a *= 2;
      str += "riv";
   } else {
      str = "co" + str;
   }

   if( a > 10 ) {
      str += "ing";
   } else {
      str += "es";
   }
   return str.substring(6);
}
```



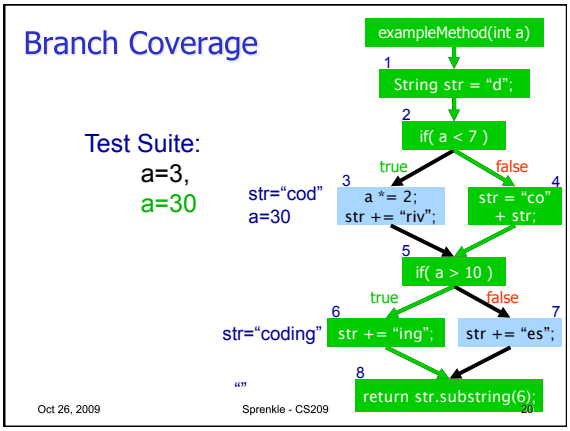
Branch Coverage

Test Suite:
a=3,
a=30



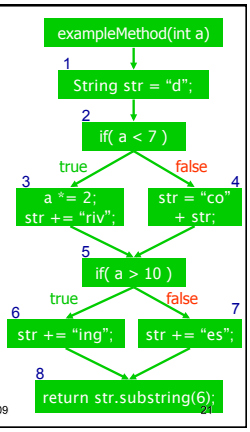
Branch Coverage

Test Suite:
a=3,
a=30



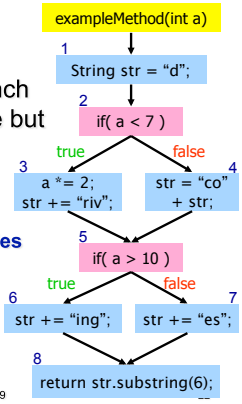
Branch Coverage

Test Suite:
a=3,
a=30



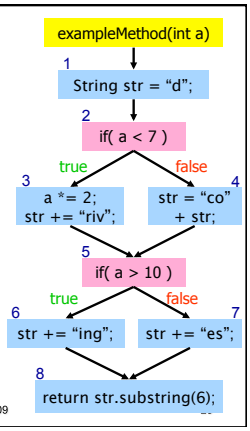
What Went Wrong?

- Test suite had 100% branch (and statement) coverage but missed a **path**
- Try to cover all **paths** in program's flow
  - Also gets all **branches**, **nodes**
  - Called **Path Coverage**



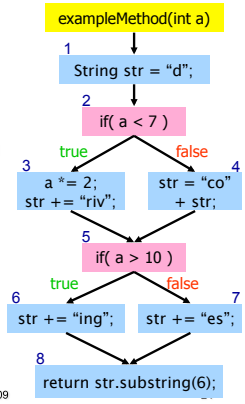
Path Coverage

- Cover all **paths** in program's flow
- How many paths through this method?



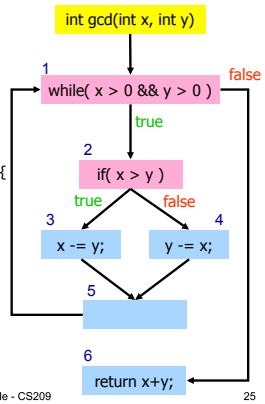
Path Coverage

- Cover all **paths** in program's flow
- How many paths through this method?
  - 1-2-**3**-5-**6**-8
  - 1-2-**3**-5-**7**-8
  - 1-2-**4**-5-**6**-8
  - 1-2-**4**-5-**7**-8
- What test cases would give us path coverage?



Example 3

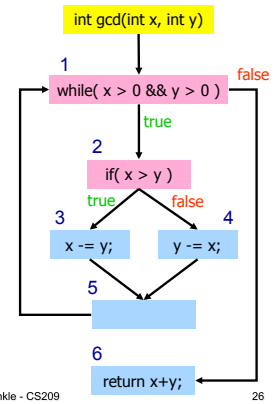
```
/**
 * Euclid's algorithm to
 * calculate greatest
 * common divisor
 */
public int gcd( int x, int y ) {
    while ( x > 0 && y > 0 ) {
        if( x > y ) {
            x -=y ;
        } else {
            y -=x;
        }
    }
    return  x+y;
}
```



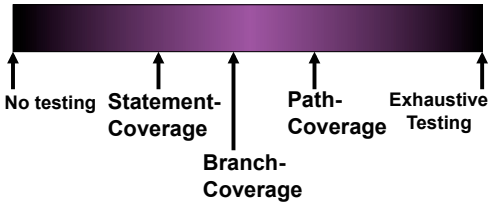
Path Coverage

- How many paths through this method?
  - Too many to count, test them all!

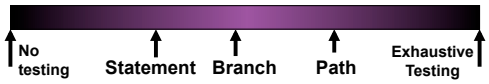
1-6
1-2-3-5-1-6
1-2-4-5-1-6
1-2-3-5-1-2-3-5-1-6
1-2-4-5-1-2-4-5-1-6
1-[2-(3|4)-5-1]*-6



Testing Continuum



Comparison of Coverage



Coverage Criterion	Advantages	Disadvantages
Statement		
Branch		
Path		

Comparison of Coverage

Coverage Criterion	Advantages	Disadvantages
Statement	Practical	Weak, may miss many faults
Branch	Practical, Stronger than Statement	Weaker than Path
Path	Strongest	Infeasible, too many paths to be practical

Uses of Coverage Criteria

- "Stopping" rule → sufficient testing
  - Avoid unnecessary, redundant tests
- Measure test quality
  - Dependability estimate
  - Confidence in estimate
- Specify test cases
  - Describe additional test cases needed

Coverage Criteria Discussion

- Is it always possible for a test suite to cover all the statements in a given program?
  - No. Could be infeasible statements
    - Unreachable code
    - Legacy code
    - Configuration that is not on site
- Do we need the test suite to cover 100% of statements/branches to believe it is adequate?
  - 100% coverage does not mean correct program
  - But < 100% coverage does mean testing inadequacy

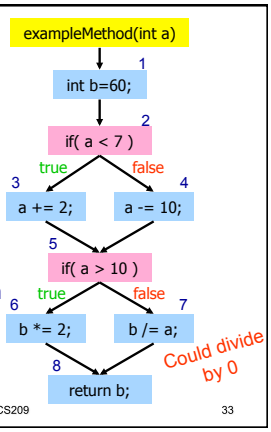
True/False Quiz

- A program that passes all test cases in a test suite with 100% path coverage is bug-free.
  - **False.**
  - The test suite may cover a faulty path with data values that don't expose the fault.
    - Towards Exhaustive Testing

Example

Test Suite:
- 3-7: a=3
- 4-6: a=30
- 3-6: a=6
- 4-7: a=9

But, error shows up with
- 3-7: a=0
- 4-7: a=10



True/False Quiz

- When you add test cases to a test suite that covers all statements so that it covers all branches, the new test suite is more likely to be better at exposing faults.
  - **True.**
  - You're adding test cases and covering new paths, which may have faults.

Which Test Suite Is Better?

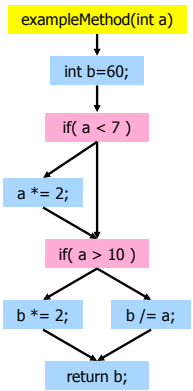
Statement-adequate Test Suite

Branch-adequate Test Suite

- Branch-adequate suite is not *necessarily* better than Statement-adequate suite
  - Statement-adequate suite could cover buggy paths that Branch-adequate suite doesn't

Example

- TS1 (Statement-Adequate):
  - a=0, 6
- TS2 (Branch-Adequate):
  - a=3, 30
- Statement-adequate will find fault but branch-adequate won't
  - Covers the path that exposes the fault



Software Testing: When is Enough Enough?

- Need to decide when tested enough
  - Balance goals of releasing application, high quality standards
- Can use program coverage as "stopping" rule
  - Also measure of confidence in test suite
  - Statement, Branch, Path and their tradeoffs
  - Use coverage tools to measure statement, branch coverage
- Still, need to use some other "smarts" besides program coverage for creating test cases

Planning Ahead

- Wednesday
  - Coverage tools
- Friday
  - Project 1 due