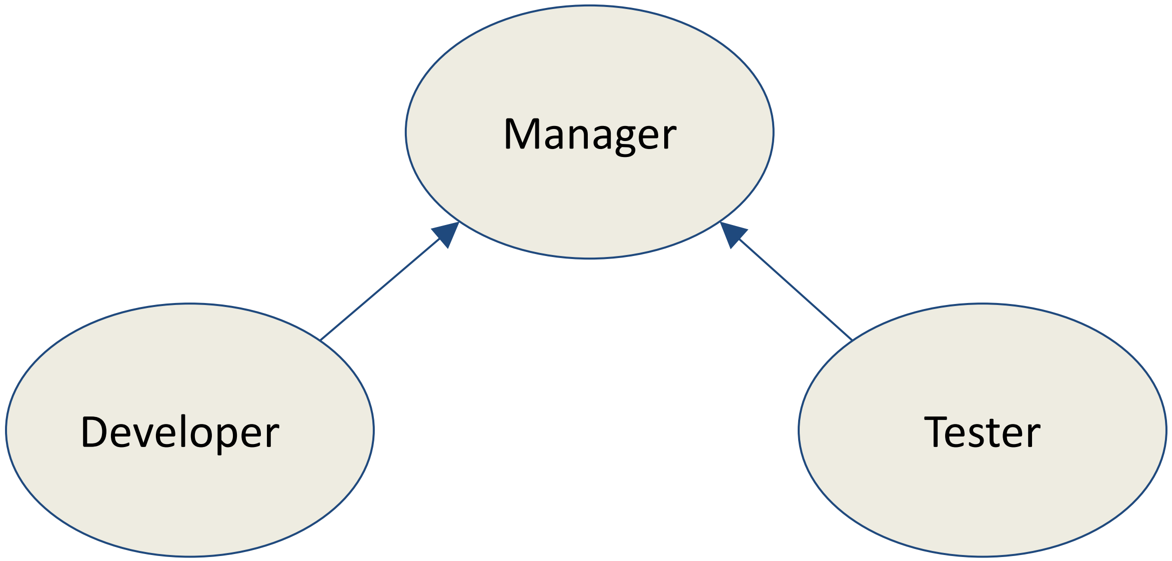
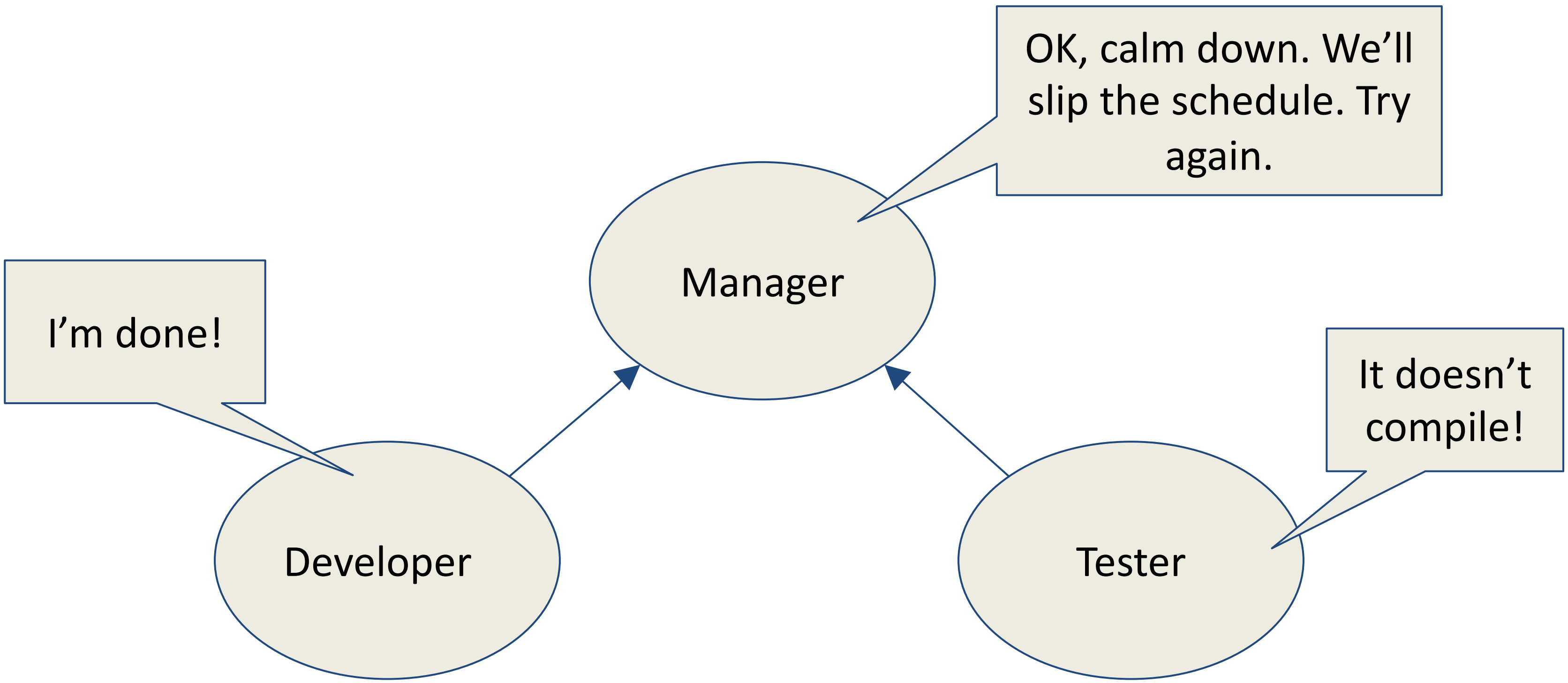
Introduction to Testing

CS 6340

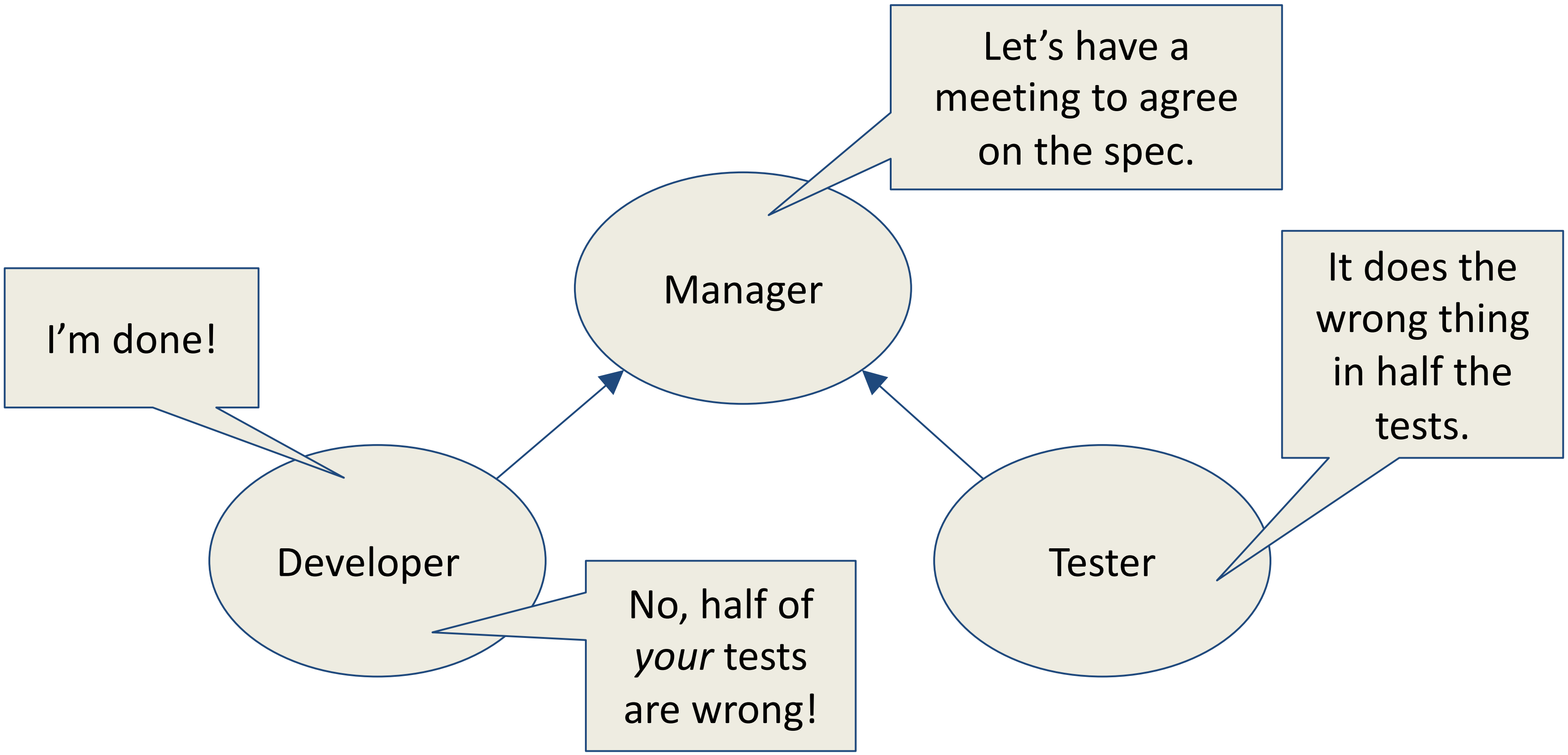
Software Development Today



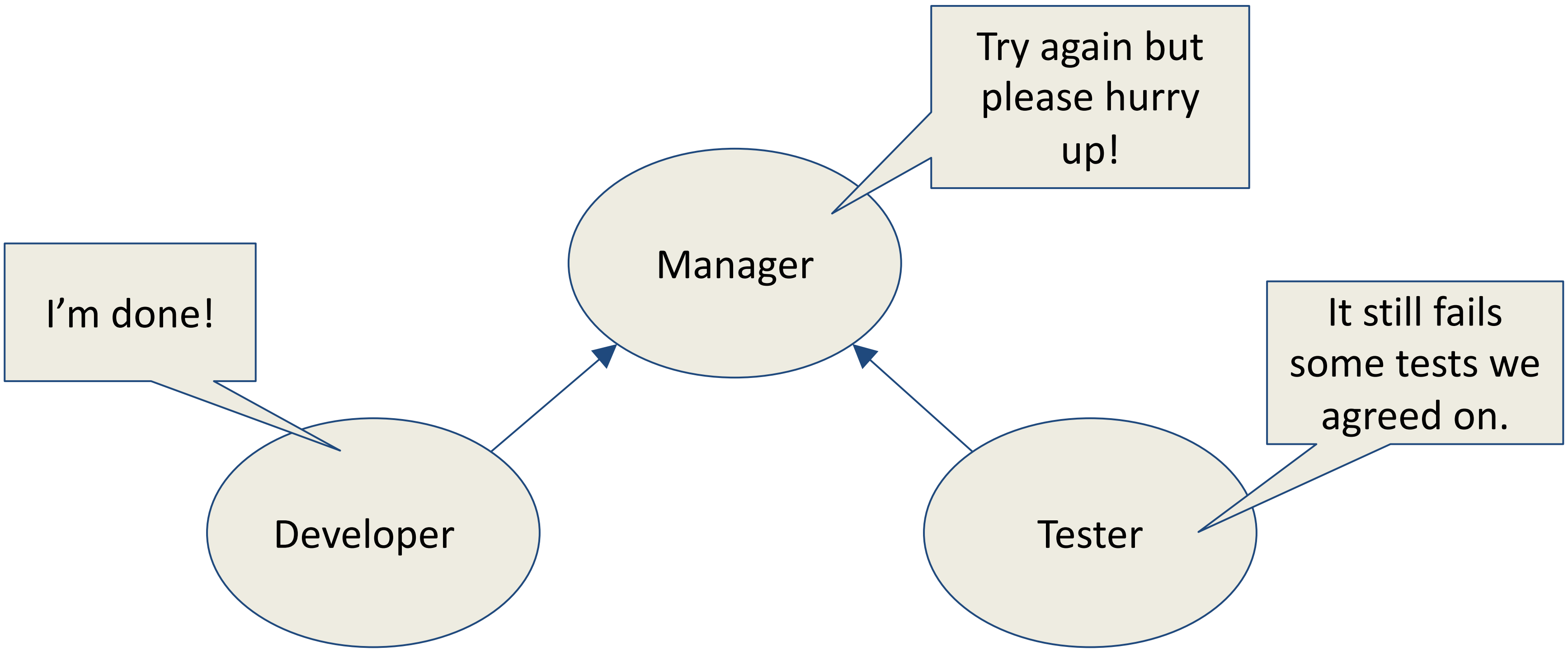
A Typical Scenario



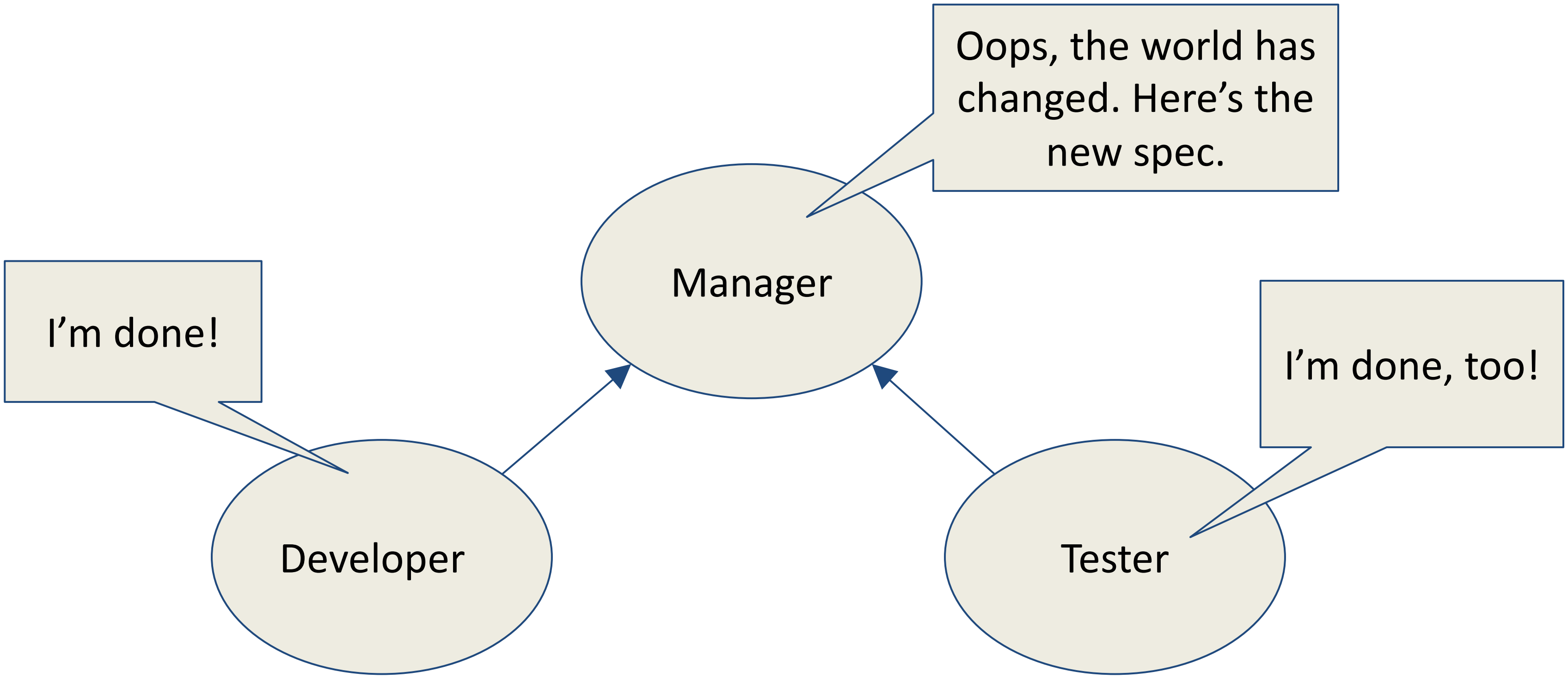
A Typical Scenario



A Typical Scenario



A Typical Scenario



Key Observations

- Specifications must be explicit
- Independent development and testing
- Resources are finite
- Specifications evolve over time

The Need for Specifications

- Testing checks whether program implementation agrees with program specification
- Without a specification, there is nothing to test!
- Testing a form of consistency checking between implementation and specification
  - Recurring theme for software quality checking approaches
  - What if both implementation and specification are wrong?

Developer != Tester

- Developer writes implementation, tester writes specification

- Unlikely that both will independently make the same mistake

- Specifications useful even if written by developer itself
  - Much simpler than implementation
  - => specification unlikely to have same mistake as implementation

Other Observations

- Resources are finite

  => Limit how many tests are written

- Specifications evolve over time

  => Tests must be updated over time

- An Idea: Automated Testing

  => No need for testers!?

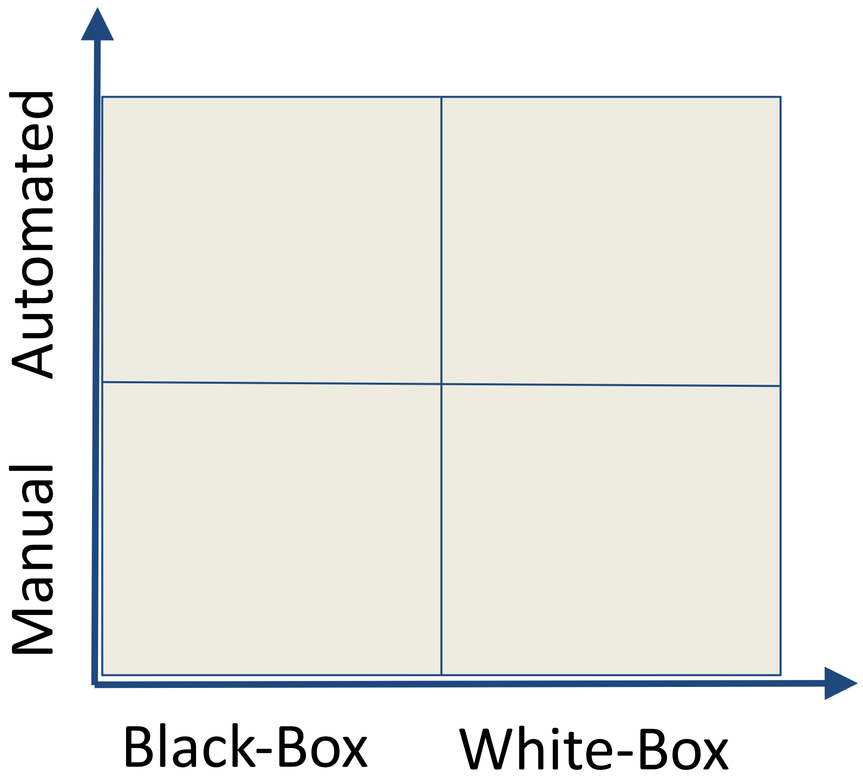
Outline of This Lesson

- Landscape of Testing

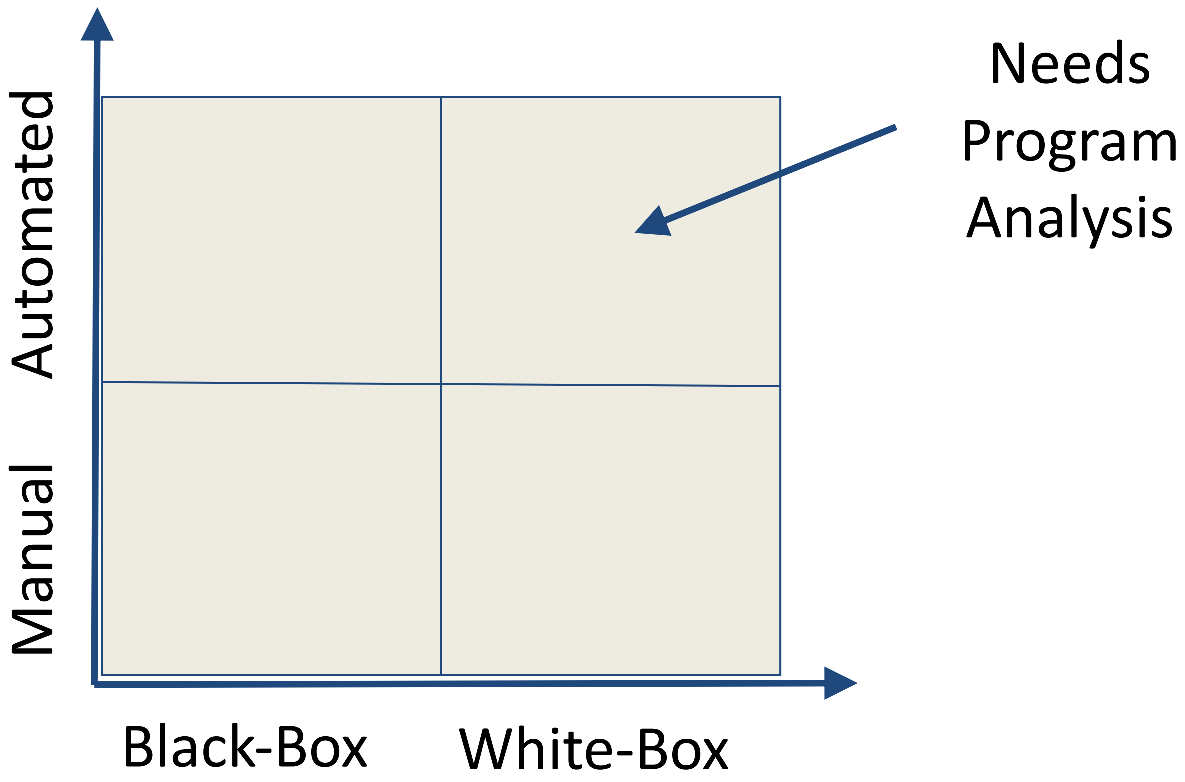
- Specifications
  - Pre- and Post- Conditions

- Measuring Test Suite Quality
  - Coverage Metrics
  - Mutation Analysis

Classification of Testing Approaches



Classification of Testing Approaches



Automated vs. Manual Testing

- Automated Testing:
  - Find bugs more quickly
  - No need to write tests
  - If software changes, no need to maintain tests

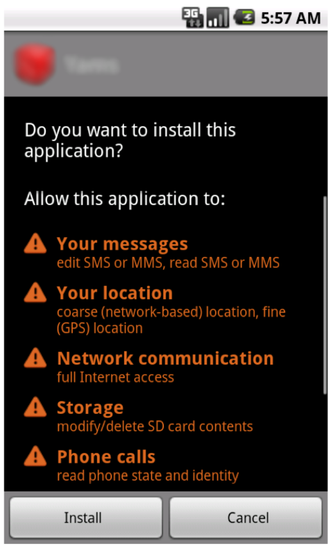
- Manual Testing:
  - Efficient test suite
  - Potentially better coverage

Black-Box vs. White-Box Testing

- Black-Box Testing:
  - Can work with code that cannot be modified
  - Does not need to analyze or study code
  - Code can be in any format (managed, binary, obfuscated)

- White-Box Testing:
  - Efficient test suite
  - Potentially better coverage

An Example: Mobile App Security




```
HttpPost localHttpPost = new HttpPost(...);
(new DefaultHttpClient()).execute(localHttpPost);
```

http://[...]search.gongfu-android.com:8511/[...]

The Automated Testing Problem

- Automated testing is hard to do
- Probably impossible for entire systems
- Certainly impossible without specifications

Pre- and Post-Conditions

- A pre-condition is a predicate
  - Assumed to hold before a function executes
- A post-condition is a predicate
  - Expected to hold after a function executes, whenever the pre-condition also holds

Example

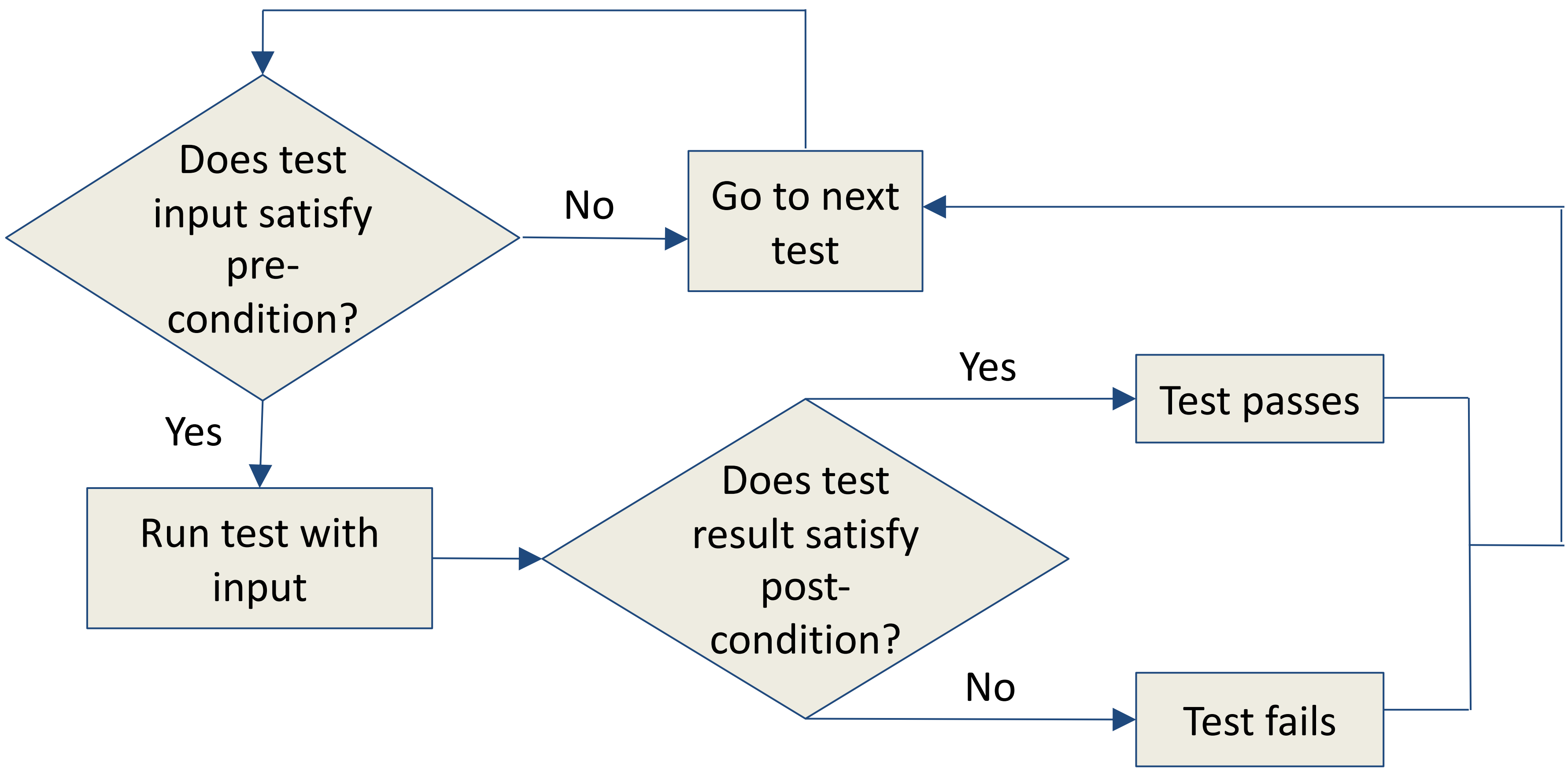
```
class Stack<T> {
   T[] array;
   int size;

   Pre: s.size() > 0
   T pop() { return array[--size]; }
   Post: s’.size() == s.size() - 1

   int size() { return size; }
}
```

More on Pre- and Post-Conditions

- Most useful if they are executable
  - Written in the programming language itself
  - A special case of assertions

- Need not be precise
  - May become more complex than the code!
  - But useful even if they do not cover every situation

Using Pre- and Post-Conditions



Doesn't help write tests, but helps run them

QUIZ: Pre-Conditions

Write the weakest possible pre-condition that prevents any in-built exceptions from being thrown in the following Java function.

```
Pre:

int foo(int[] A, int[] B) {
    int r = 0;
    for (int i = 0; i < A.length; i++) {
        r += A[i] * B[i];
    }
    return r;
}
```

QUIZ: Pre-Conditions

Write the weakest possible pre-condition that prevents any in-built exceptions from being thrown in the following Java function.

Pre: `A != null && B != null && A.length <= B.length`

```
int foo(int[] A, int[] B) {
    int r = 0;
    for (int i = 0; i < A.length; i++) {
        r += A[i] * B[i];
    }
    return r;
}
```

QUIZ: Post-Conditions

Consider a sorting function in Java which takes a non-null integer array A and returns an integer array B. Check all items that specify the strongest possible post-condition.

- [ ] B is non-null
- [ ] B has the same length as A
- [ ] The elements of B do not contain any duplicates
- [ ] The elements of B are a permutation of the elements of A
- [ ] The elements of B are in sorted order
- [ ] The elements of A are in sorted order
- [ ] The elements of A do not contain any duplicates

QUIZ: Post-Conditions

Consider a sorting function in Java which takes a non-null integer array A and returns an integer array B. Check all items that specify the strongest possible post-condition.

- [ ] B is non-null
- [ ] B has the same length as A
- [ ] The elements of B do not contain any duplicates
- [ ] The elements of B are a permutation of the elements of A
- [ ] The elements of B are in sorted order
- [ ] The elements of A are in sorted order
- [ ] The elements of A do not contain any duplicates

Executable Post-Condition

- B is non-null

```
B != null;
```

- B has the same length as A

```
B.length == A.length;
```

- The elements of B are in sorted order

```
for (int i = 0; i < B.length-1; i++)
    B[i] <= B[i+1];
```

- The elements of B are a permutation of the elements of A

```
// count number of occurrences of
// each number in each array and
// then compare these counts
```

How Good Is Your Test Suite?

- How do we know that our test suite is good?
  - Too few tests: may miss bugs
  - Too many tests: costly to run, bloat and redundancy, harder to maintain

How Good Is Your Test Suite?

- How do we know that our test suite is good?
  - Too few tests: may miss bugs
  - Too many tests: costly to run, bloat and redundancy, harder to maintain

- Two approaches:
  - Code coverage metrics
  - Mutation analysis (or mutation testing)

Code Coverage

- Metric to quantify extent to which a program's code is tested by a given test suite
- Given as percentage of some aspect of the program executed in the tests
- 100% coverage rare in practice: e.g., inaccessible code
  - Often required for safety-critical applications

Types of Code Coverage

- Function coverage: which functions were called?
- Statement coverage: which statements were executed?
- Branch coverage: which branches were taken?
- Many others: line coverage, condition coverage, basic block coverage, path coverage, …

QUIZ: Code Coverage Metrics

Test Suite:

`foo(1, 0)`

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Statement Coverage: [ ] %

Branch Coverage: [ ] %

Give arguments for another call to foo(x,y) to add to the test suite to increase both coverages to 100%.

x = [ ] y = [ ]

QUIZ: Code Coverage Metrics

Test Suite:

```
foo(1, 0)
```

Statement Coverage: 80 %

Branch Coverage: 50 %

Give arguments for another call to foo(x,y) to add to the test suite to increase both coverages to 100%.

x = 1 y = 1

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Mutation Analysis

- Founded on "competent programmer assumption":

  The program is close to right to begin with
- Key idea: Test variations (mutants) of the program
  - Replace $x > 0$ by $x < 0$
  - Replace w by $w + 1$, $w - 1$
- If test suite is good, should report failed tests in the mutants
- Find set of test cases to distinguish original program from its mutants

QUIZ: Mutation Analysis - Part 1

Check the boxes indicating a passed test.	Test 1 assert: `foo(0,1)==0`	Test 2 assert: `foo(0,0)==0`
Mutant 1 x <= y → x > y	☐	☐
Mutant 2 x <= y → x != y	☐	☐

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Is the test suite adequate with respect to both mutants?

○ Yes   No ○

QUIZ: Mutation Analysis - Part 1

Check the boxes indicating a passed test.	Test 1 assert: `foo(0,1)==0`	Test 2 assert: `foo(0,0)==0`
Mutant 1 x <= y → x > y	☐	☐
Mutant 2 x <= y → x != y	☐	☐

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Is the test suite adequate with respect to both mutants?

○ Yes   No ○

QUIZ: Mutation Analysis - Part 2

Check the boxes indicating a passed test.	Test 1 assert: `foo(0,1)==0`	Test 2 assert: `foo(0,0)==0`
Mutant 1 x <= y → x > y	☐	☐
Mutant 2 x <= y → x != y	☐	☐

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Give a test case which Mutant 2 fails but the original code passes.

assert:
foo(☐, ☐) == ☐

QUIZ: Mutation Analysis - Part 2

Check the boxes indicating a passed test.	Test 1 assert: `foo(0,1)==0`	Test 2 assert: `foo(0,0)==0`
Mutant 1 x <= y → x > y	☐	☐
Mutant 2 x <= y → x != y	☐	☐

```
int foo(int x, int y) {
    int z = 0;
    if (x <= y) {
        z = x;
    } else {
        z = y;
    }
    return z;
}
```

Give a test case which Mutant 2 fails but the original code passes.

assert: foo(1 , 0) == 0

A Problem

- What if a mutant is equivalent to the original?
- Then no test will kill it
- In practice, this is a real problem
  - Not easily solved
  - Try to prove program equivalence automatically
  - Often requires manual intervention

What Have We Learned?

- Landscape of Testing
  - Automated vs. Manual
  - Black-Box vs. White-Box

- Specifications: Pre- and Post- Conditions

- Measuring Test Suite Quality
  - Coverage Metrics
  - Mutation Analysis

Reality

- Many proposals for improving software quality
- But the world tests
  - > 50% of the cost of software development
- Conclusion: Testing is important