L10: Software Specifications

Software Analysis

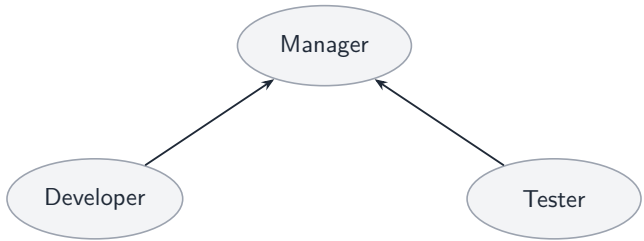
IIT Guwahati · 18 August 2026

What Is a Specification?

A **specification** is a high-level description of the software's *intended* behaviour.

Naik, *Software Specifications*, CIS 5470, Penn

Software Development Scenario



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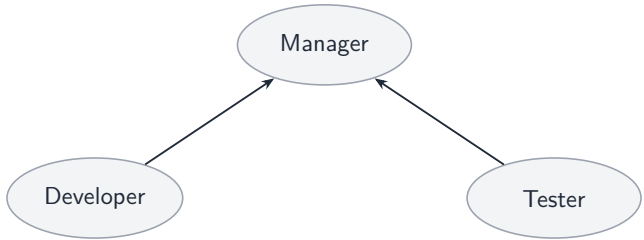

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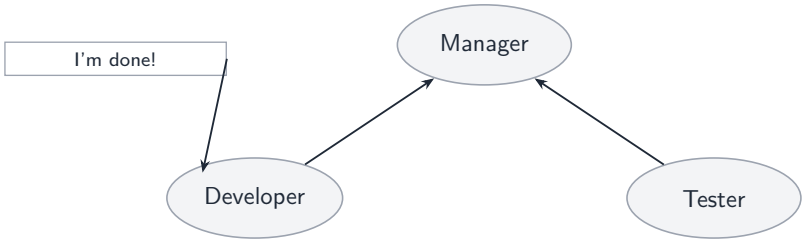

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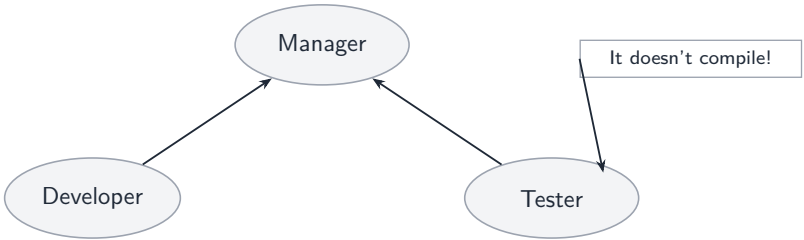

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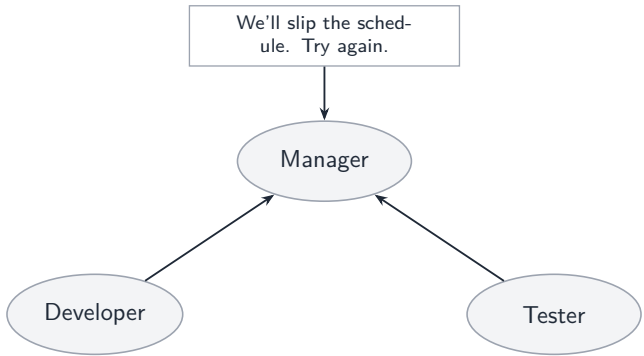

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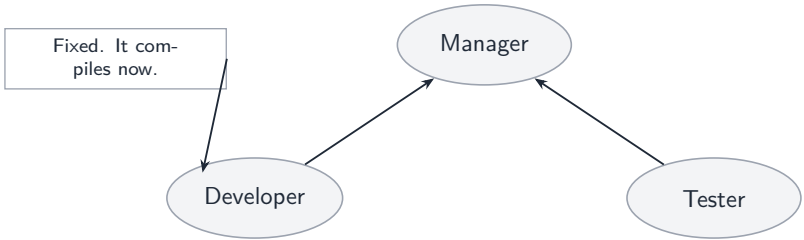

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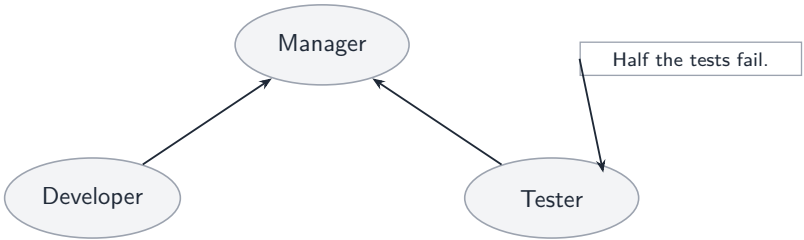

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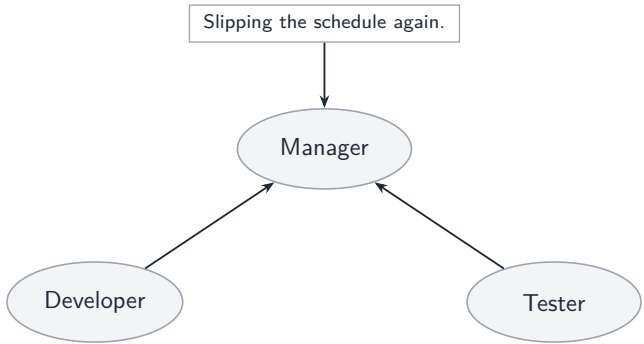

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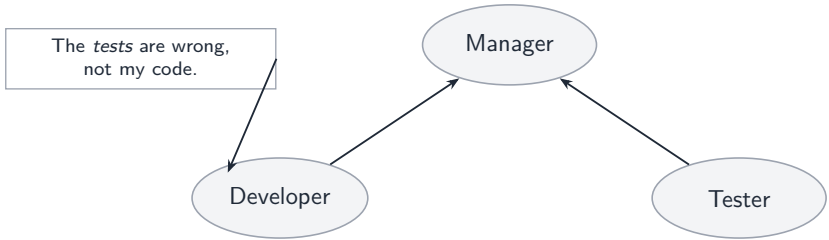

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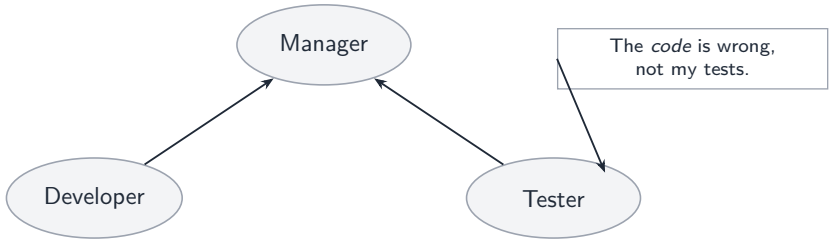

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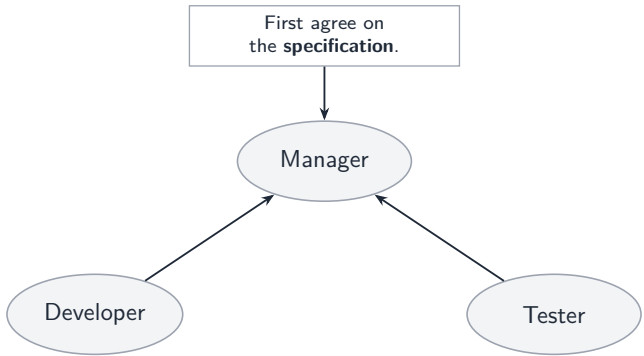

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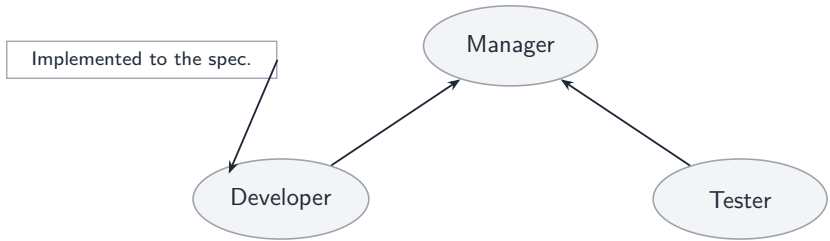

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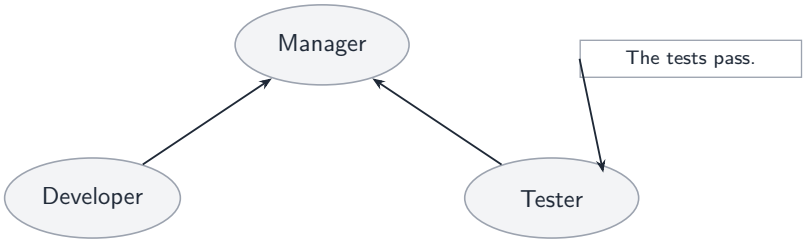

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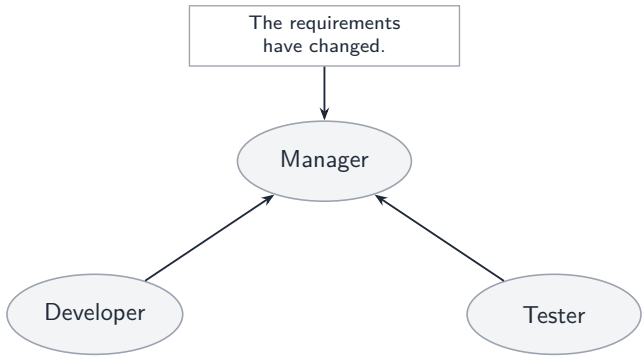

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- Both artifacts may be wrong, and the check still succeeds

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- A specification remains useful even when written by the developer
- A specification describes a **specific facet** of behaviour and is usually much simpler than the implementation

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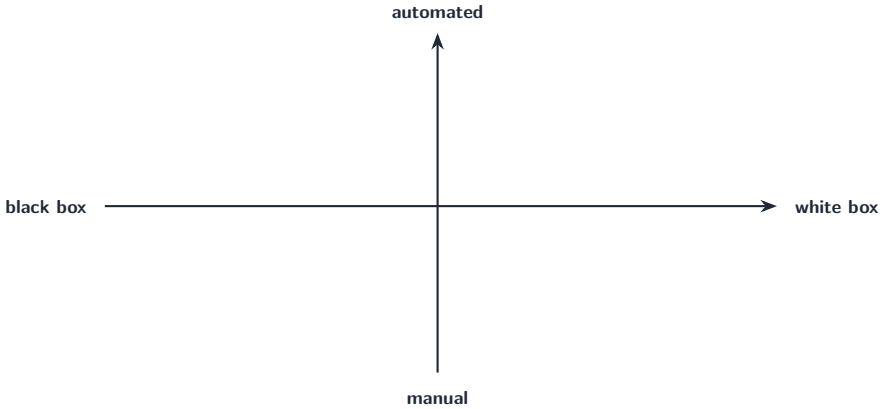
- **Specifications evolve**: a test suite valid today need not stay valid
- Testing is necessary, ongoing and resource-intensive, which motivates **automated testing**

Classification of Testing Approaches



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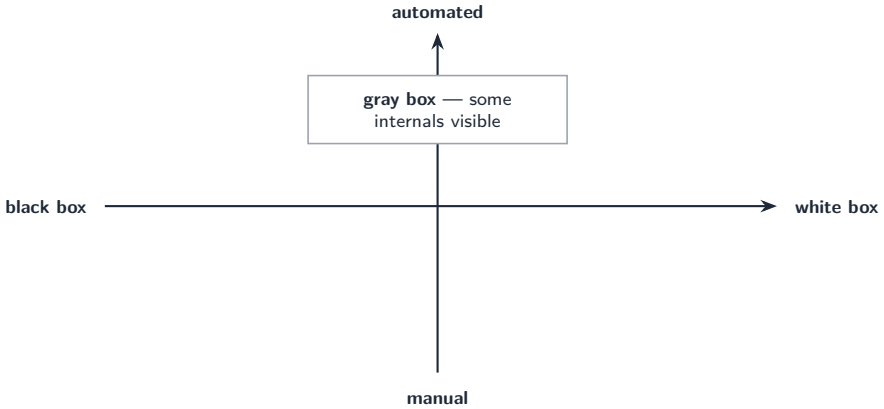
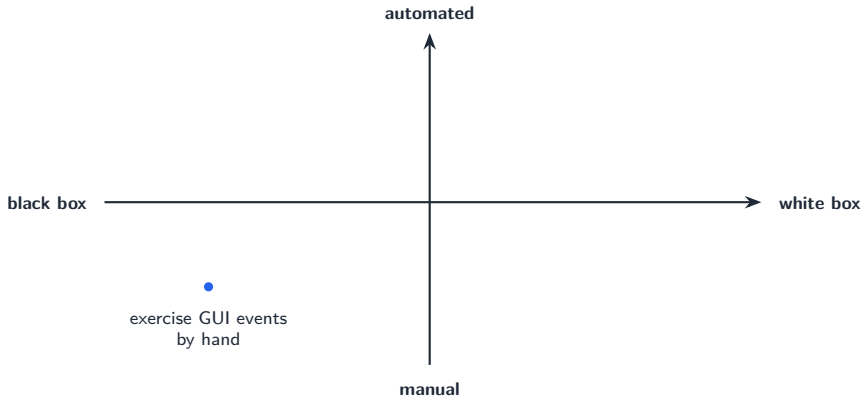


Both axes are continua, not discrete categories.

Example: Testing an Android Application



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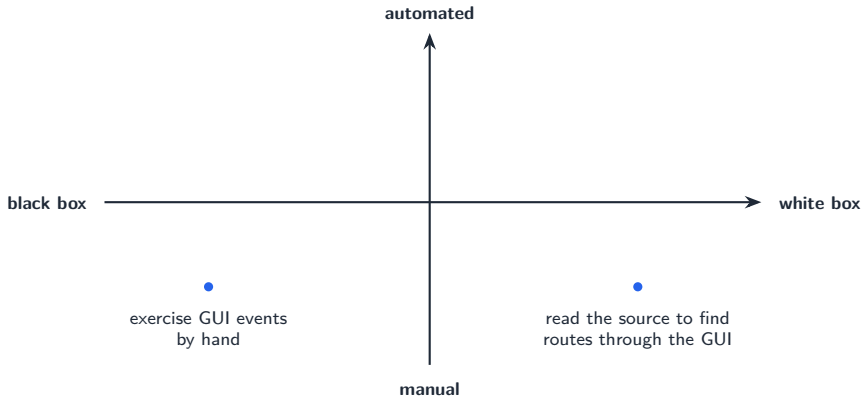

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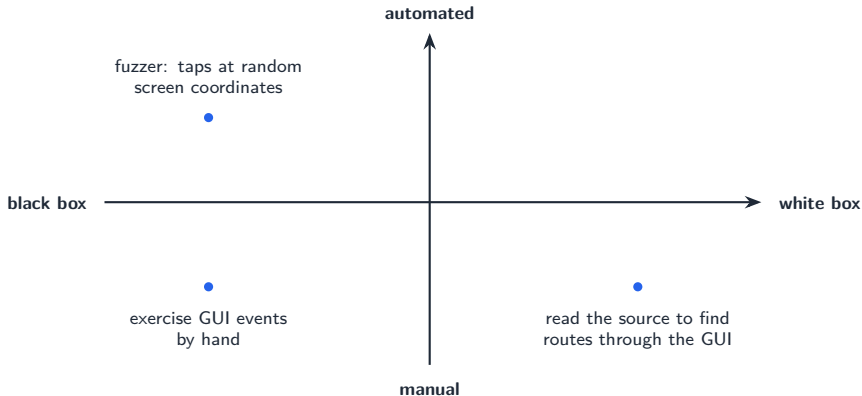

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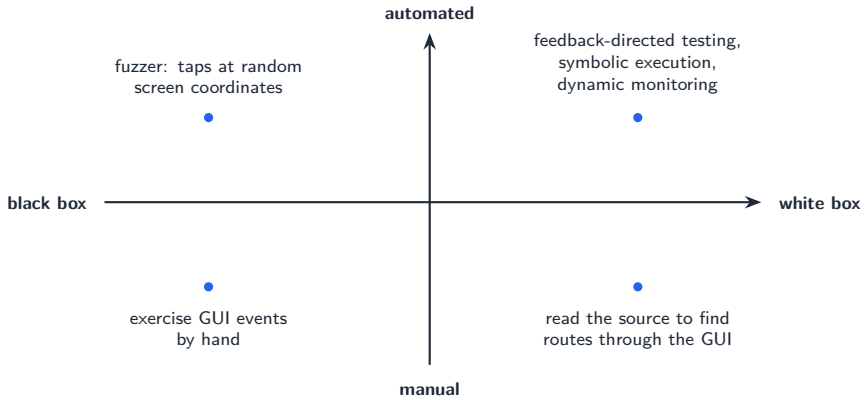

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A **semi-automated** approach combines the two: the human supplies the grammar of valid inputs, the machine generates within it.

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Does not require modifying the code

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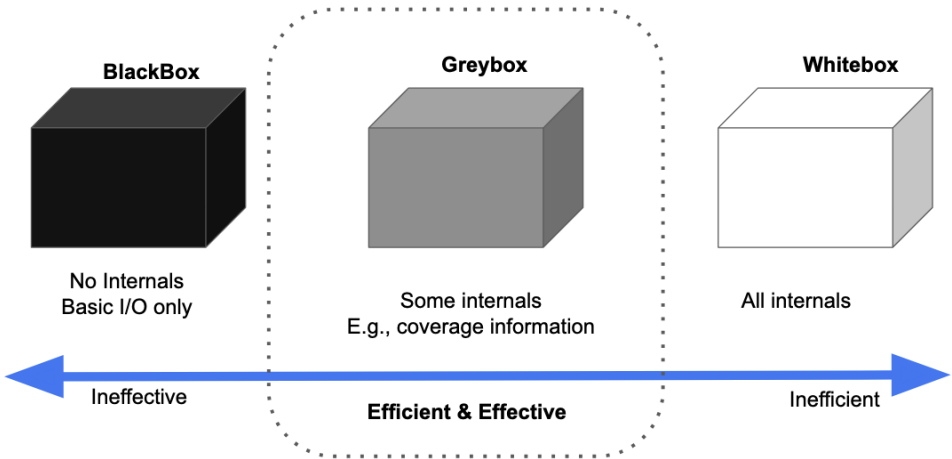

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White box

Inspect the source or binary code, revealing the call that opens that connection.

The Automated Testing Problem

```
void f(int a[30]) {
    if (a[0]) { ... } else { ... }
    if (a[1]) { ... } else { ... }
    ...                                    // 30 branch points
    if (a[29]) { ... } else { ... }
}
```

$2^{30} > 10^9$ execution paths; with a loop, the number of paths may be unbounded.

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- Automated testing of programs is hard
- Probably impossible for entire systems
- Certainly impossible without specifications

Kinds of Specifications

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- **Pre- and post-conditions**

  `double sqrt(double x)`

For `sqrt`: pre-condition `x >= 0`; post-condition: the return value `ret` satisfies `ret * ret == x`.

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  `double sqrt(double x)`

- **Loop and class invariants**

For `sqrt`: pre-condition `x >= 0`; post-condition: the return value `ret` satisfies `ret * ret == x`.

Types

Adding the specification to the implementation allows the implementation to be checked against the specification.

```
int x;                      // specification:  x is an integer
x = read();
printf("%d", x + 1);        // implementation:  x is used as an integer
```

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Types: Dynamically Typed Languages

Explicit type specifications are missing in dynamically typed or untyped programming languages.

```
function getPass(clearTextPass) {           // JavaScript
    if (clearTextPass) return "PASS";
    return "****";
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let pass = getPass('false');                // "PASS"
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```
function getPass(clearTextPass : boolean) : string {   // TypeScript
    if (clearTextPass) return "PASS";
    return "****";
}
let pass = getPass('false');                // compile-time error
```

The Checker Framework

The Checker Framework extends Java's type system: developers add annotations that statically eliminate entire classes of runtime error, such as null pointer dereferences.

```
@NonNull   Object o;     // specification:  never null
@Nullable  String s;     // specification:  may be null

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- Further checkers: taint checking, GUI effects, and developer-defined checkers
- Used at Amazon, Uber and Google; the nullness checker is part of Google's standard build

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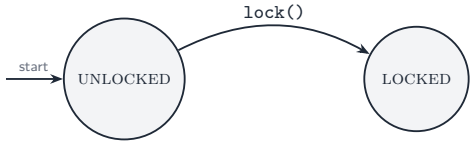
- Also called **temporal safety properties**

Example Property 1: Locking

Calls to `lock()` and `unlock()` must alternate. Re-acquiring an acquired lock, or releasing a released lock, is an error.



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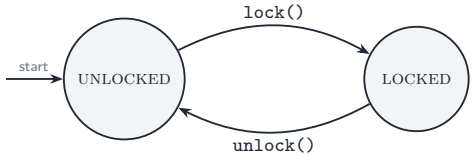

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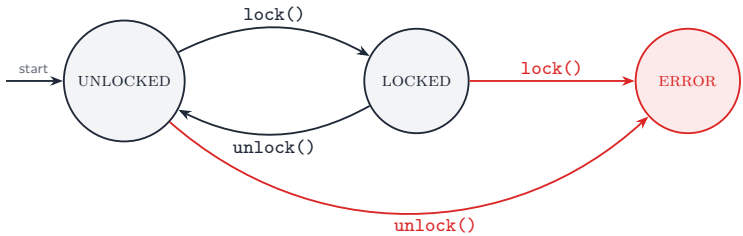

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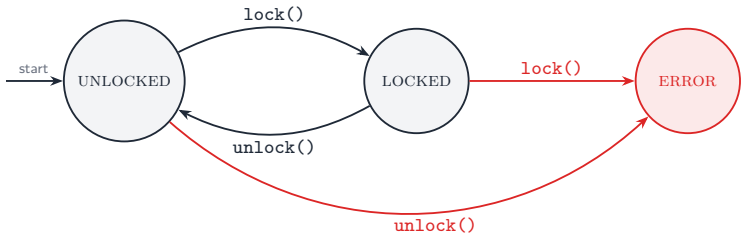

This models `pthread_mutex_lock()` and `pthread_mutex_unlock()` in pthreads.

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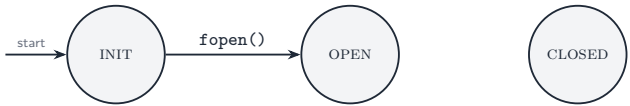

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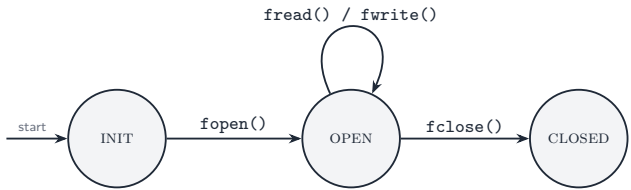

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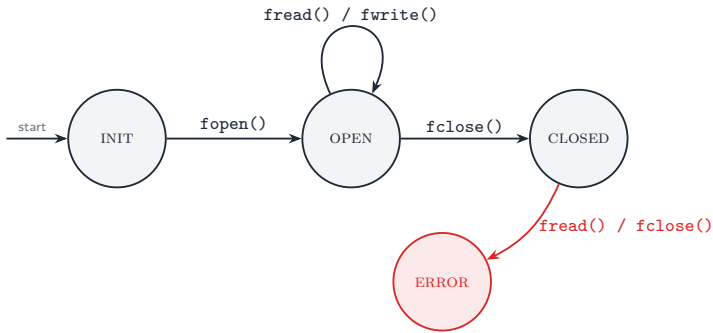

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- Written as comments here; we will later see machine-checkable annotations

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- Written as comments here; we will later see machine-checkable annotations
- The post-condition says nothing about the remaining $n - 1$ elements

Pre- and Post-Conditions

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  written in the programming language itself, using a testing framework or an assertion

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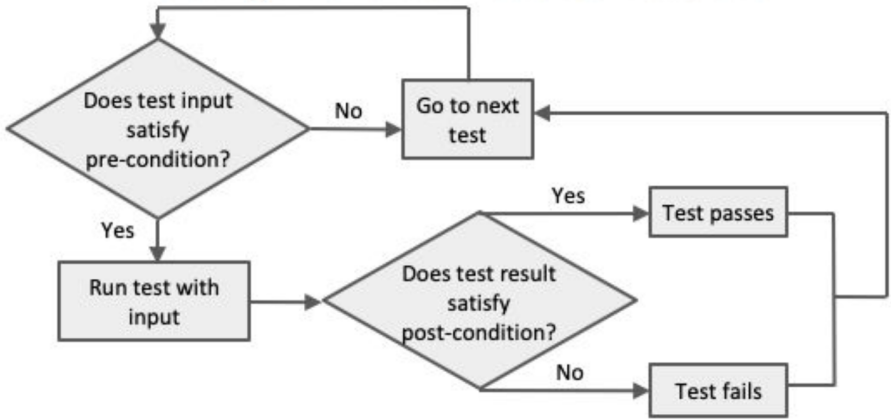
- They **need not be precise**

  a precise condition may be more complex than the code it specifies; partial conditions trade precision for tractability

Using Pre- and Post-Conditions



Contracts in Testing and in Verification

$$\{P\}\ C\ \{Q\}$$

Naik, *Software Specifications*, CIS 5470, Penn

Contracts in Testing and in Verification

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Contracts in Testing and in Verification

$$\{P\}\ C\ \{Q\}$$

- **Testing**: check P, execute C on one input, check Q
- **Verification**: assume P, reason over all inputs, prove Q

Contracts in Testing and Verification

$$\{\, x \geq 0 \,\} \qquad C:\ y = x + 1 \qquad \{\, y > 0 \,\}$$

Testing

Verification

Contracts in Testing and Verification

$$\{\, x \geq 0 \,\} \qquad C: \; y = x + 1 \qquad \{\, y > 0 \,\}$$

Testing

- Choose an input: $x = 5$

Verification

Contracts in Testing and Verification

$$\{\, x \geq 0 \,\} \qquad C: \; y = x + 1 \qquad \{\, y > 0 \,\}$$

Testing

- Choose an input: $x = 5$
- Check pre-condition: $5 \geq 0$ ✓

Verification

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$$\{\, x \geq 0 \,\} \qquad C:\ y = x + 1 \qquad \{\, y > 0 \,\}$$

Testing

- Choose an input: $x = 5$
- Check pre-condition: $5 \geq 0$ ✓
- Execute: $y = 6$

Verification

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$$\{\, x \geq 0 \,\} \qquad C:\ y = x + 1 \qquad \{\, y > 0 \,\}$$

Testing

- Choose an input: $x = 5$
- Check pre-condition: $5 \geq 0$ ✓
- Execute: $y = 6$
- Check post-condition: $6 > 0$ ✓

Test passes

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- Execute symbolically: $y = x + 1$

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- Check pre-condition: $5 \geq 0$ ✓
- Execute: $y = 6$
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Test passes

Verification

- Assume $x \geq 0$
- Execute symbolically: $y = x + 1$
- Prove:

$$x \geq 0 \Rightarrow x + 1 > 0$$

Property proved

Weakest Pre-Condition

$$\{P\} \quad C \quad \{Q\}$$

A condition P such that:

If P is true before C, then Q is guaranteed after C

The **weakest pre-condition** is the *least restrictive* condition that guarantees Q after executing C.

Quiz: Pre-Conditions

Write the weakest pre-condition that prevents any out-of-bounds or null-pointer access in the following function.

```
int foo(int *A, int lenA, int *B, int lenB) {
    int r = 0;
    for (int i = 0; i < lenA; i++)
        r += A[i] * B[i];
    return r;
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The *weakest* pre-condition admits the largest set of inputs while still excluding every failing execution.

Solution: Pre-Conditions

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A != nullptr && B != nullptr && lenA <= lenB
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```
A != nullptr && B != nullptr && lenA <= lenB
```

- Both pointers are dereferenced, so neither may be null
- For every cell of `A` the corresponding cell of `B` is read, so `B` must be at least as long as `A`

Quiz: Post-Conditions

A sorting function takes a non-null integer array `A`, places its elements in sorted order in an integer array `B`, and returns `B`. Which statements form the strongest post-condition that does not improperly reject a correctly sorted array?

1. `B` is non-null
2. `B` has the same length as `A`
3. the elements of `B` contain no duplicates
4. the elements of `B` are a permutation of the elements of `A`
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6. the elements of `A` are in sorted order
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These four conditions constitute the entire specification of the output of a sorting function.

Writing the Post-Condition in Code

```
int[] B = sort(A);

assert B != null;
assert B.length == A.length;
for (int i = 0; i < B.length - 1; i++)
    assert B[i] <= B[i+1];
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