More on Software Testing

CSE 403 Software Engineering
Winter 2026

Lectures this week

Today: Software testing

- White box testing: code coverage
- Integration testing

Wednesday: Industry guest Tanvi Tiwari, Meta

- Question on your takeaway from the talk due Wed

Friday: In-class exercise: code coverage

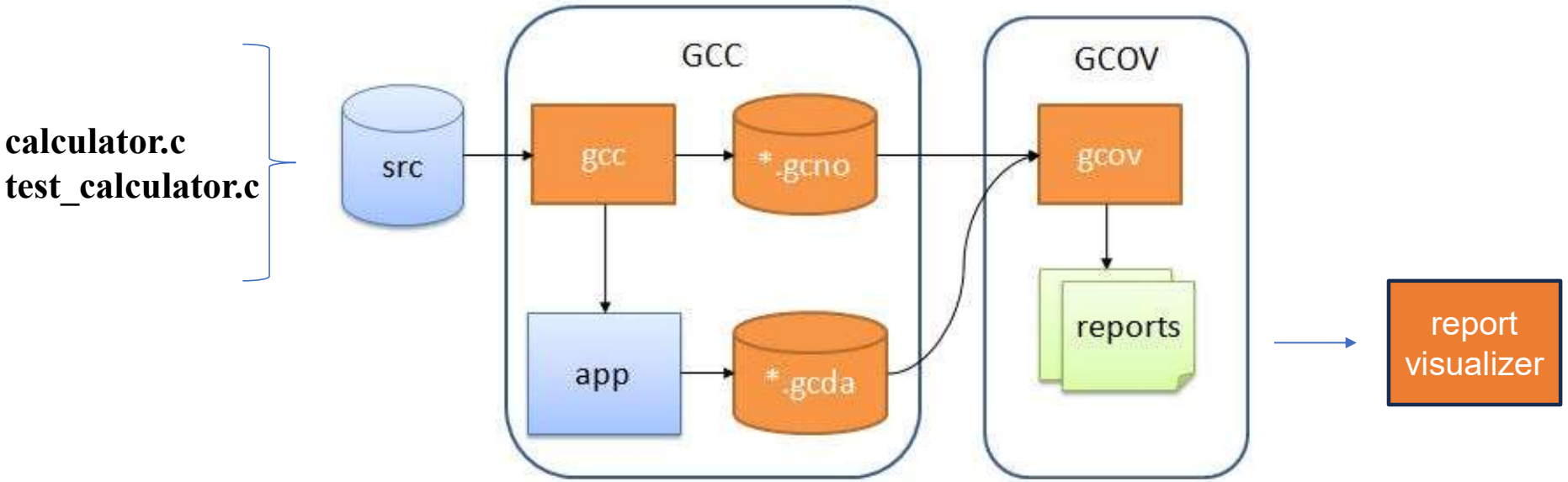
- Assignment due Fri

Motivating example – calculator module

Scenario

- You've inherited responsibility for some code
- There is a test suite! Woohoo!
- But you don't know how well the tests cover the code / how adequate they are
- So you'll run **coverage** analysis to provide some insights

GNU's gcov is an available option



Intro to gcov demo

Link a code coverage tool into your CI automation

Consult the results as part of your testing process and code reviews

Back to basics: code coverage metrics

Code coverage testing: examines what fraction of the code under test is reached by existing unit tests

Structural code coverage metrics include:

- Statement coverage (what we looked at with gcov)
- Condition coverage
- Decision coverage
- Modified condition/decision coverage

Which type of coverage requires the most tests?

Code coverage: the basics

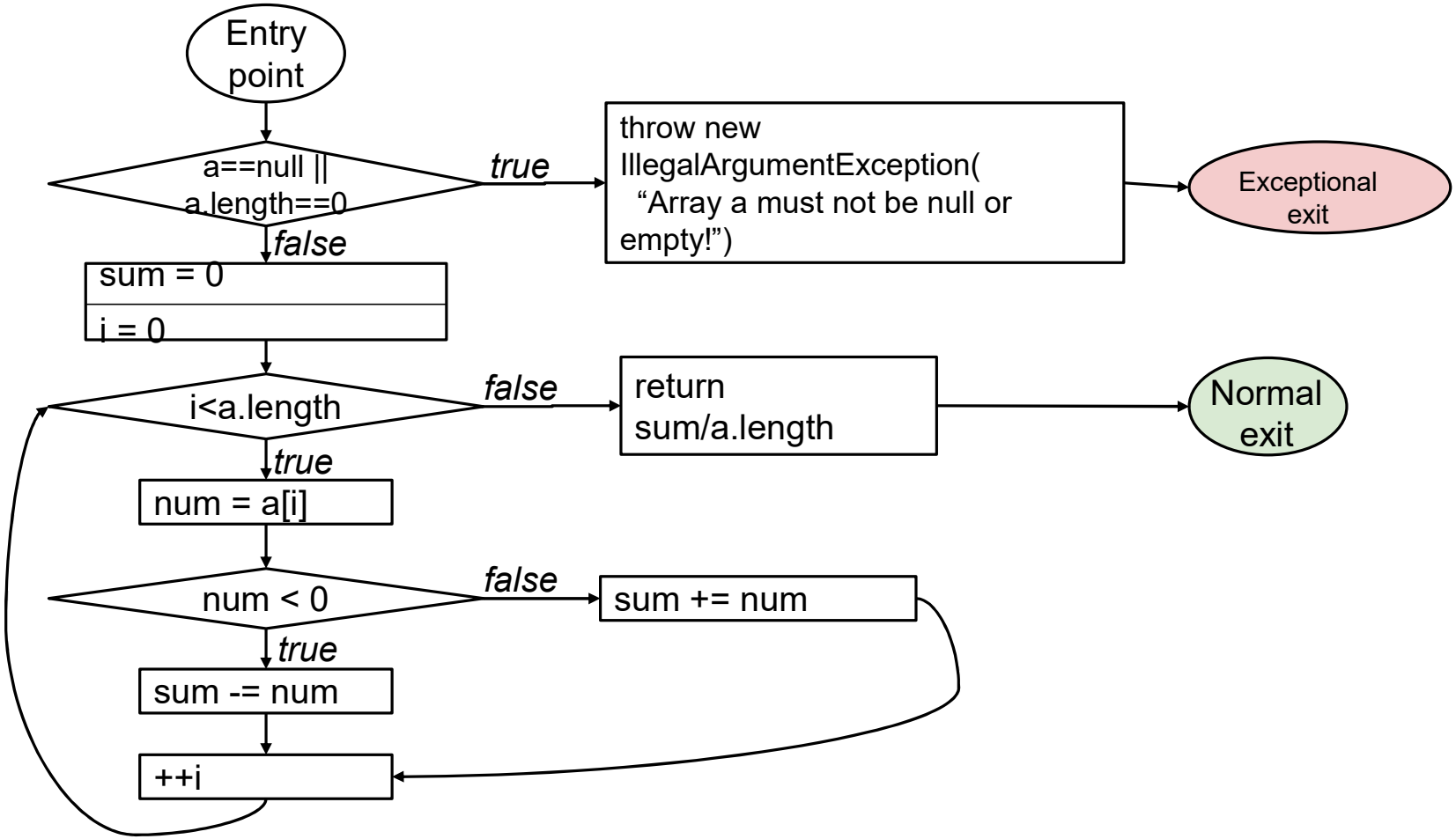
Average of the absolute values of an array of doubles

```
public double avgAbs(double ... numbers) {

  // We expect the array to be non-null and non-empty
  if (numbers == null || numbers.length == 0) {
    throw new IllegalArgumentException(“Nums cannot be null or empty!");
  }

  double sum = 0;
  for (int i=0; i<numbers.length; ++i) {
    double d = numbers[i];
    if (d < 0) {
      sum -= d;
    } else {
      sum += d;
    }
  }
  return sum/numbers.length;
}
```

Create the control flow graph



And align the two to help identify tests

```
public double avgAbs(double ... numbers) {

  // We expect the array to be non-null and non-empty
  if (numbers == null || numbers.length == 0) {
    throw new IllegalArgumentException("Numbers must not be null or empty!");
  }

  double sum = 0;
  for (int i=0; i<numbers.length; ++i) {
    double d = numbers[i];
    if (d < 0) {
      sum -= d;
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      sum += d;
    }
  }
  return sum/numbers.length;
}
```
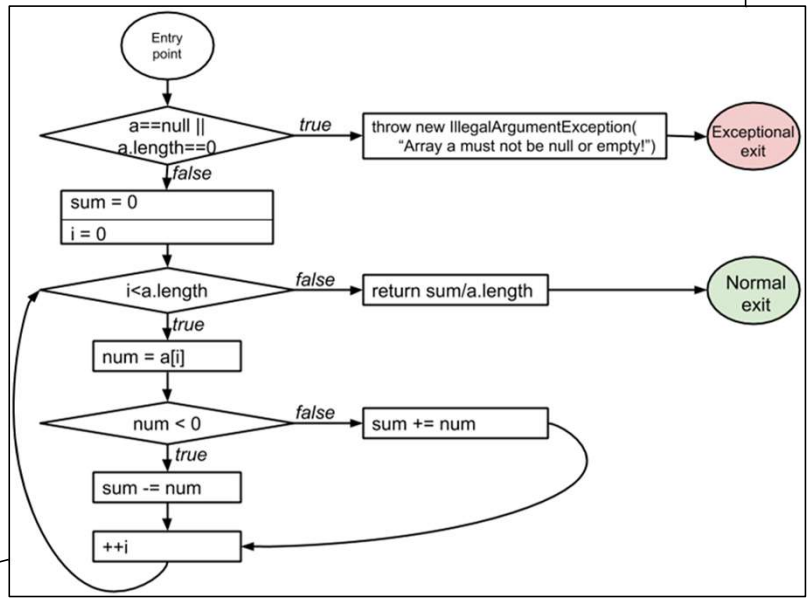
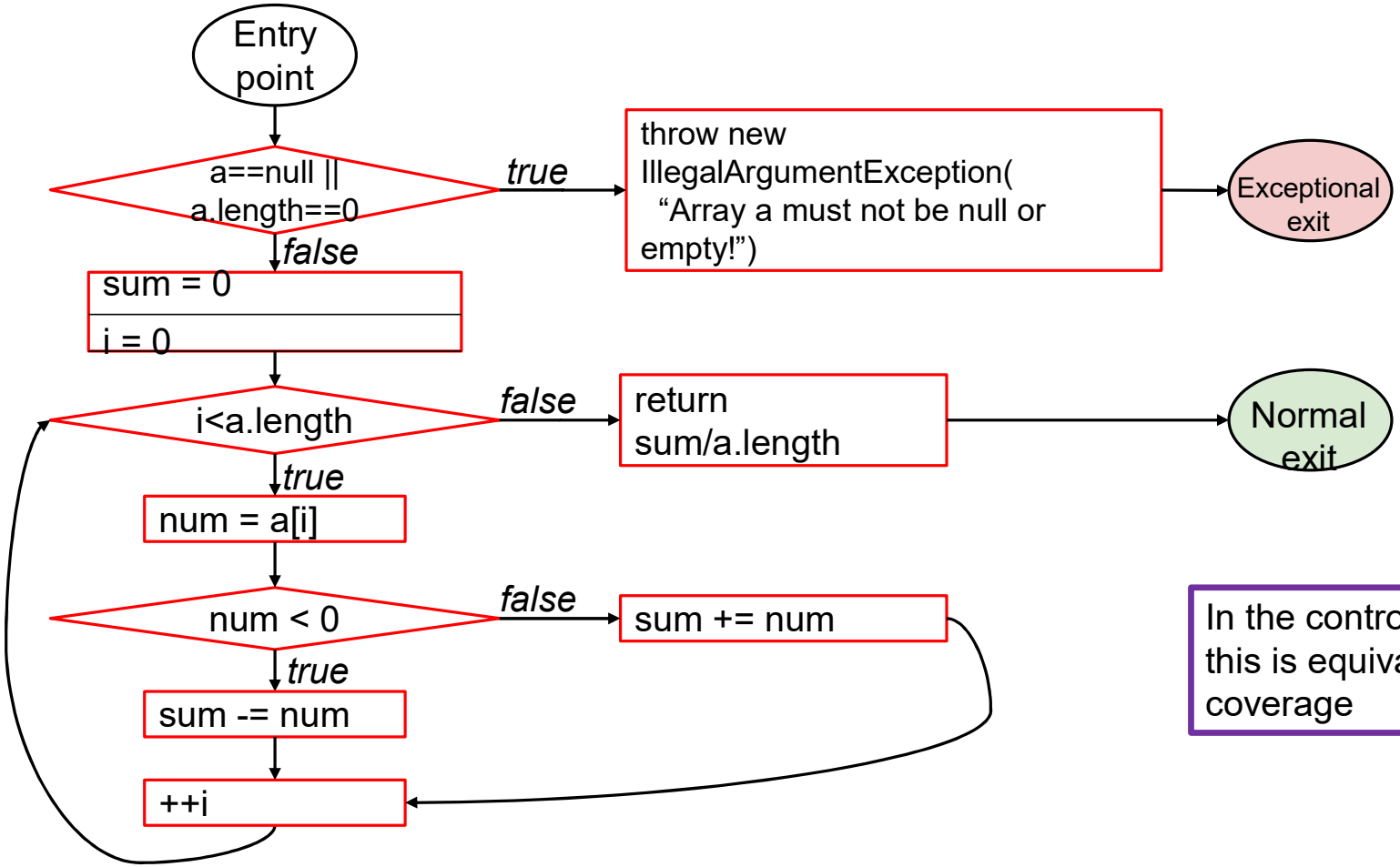



Statement coverage

Every statement in the program must be **executed at least once** by the tests

Statement coverage



In the control flow graph, this is equivalent to **node** coverage

Condition and decision coverage

Condition: a boolean expression that cannot be decomposed into simpler boolean expressions (e.g., an atomic boolean expression)

Decision: a boolean expression that is composed of conditions, using 0 or more logical connectors (a decision with 0 logical connectors is a condition)

Quiz:

```
If (a | b) { …}
```

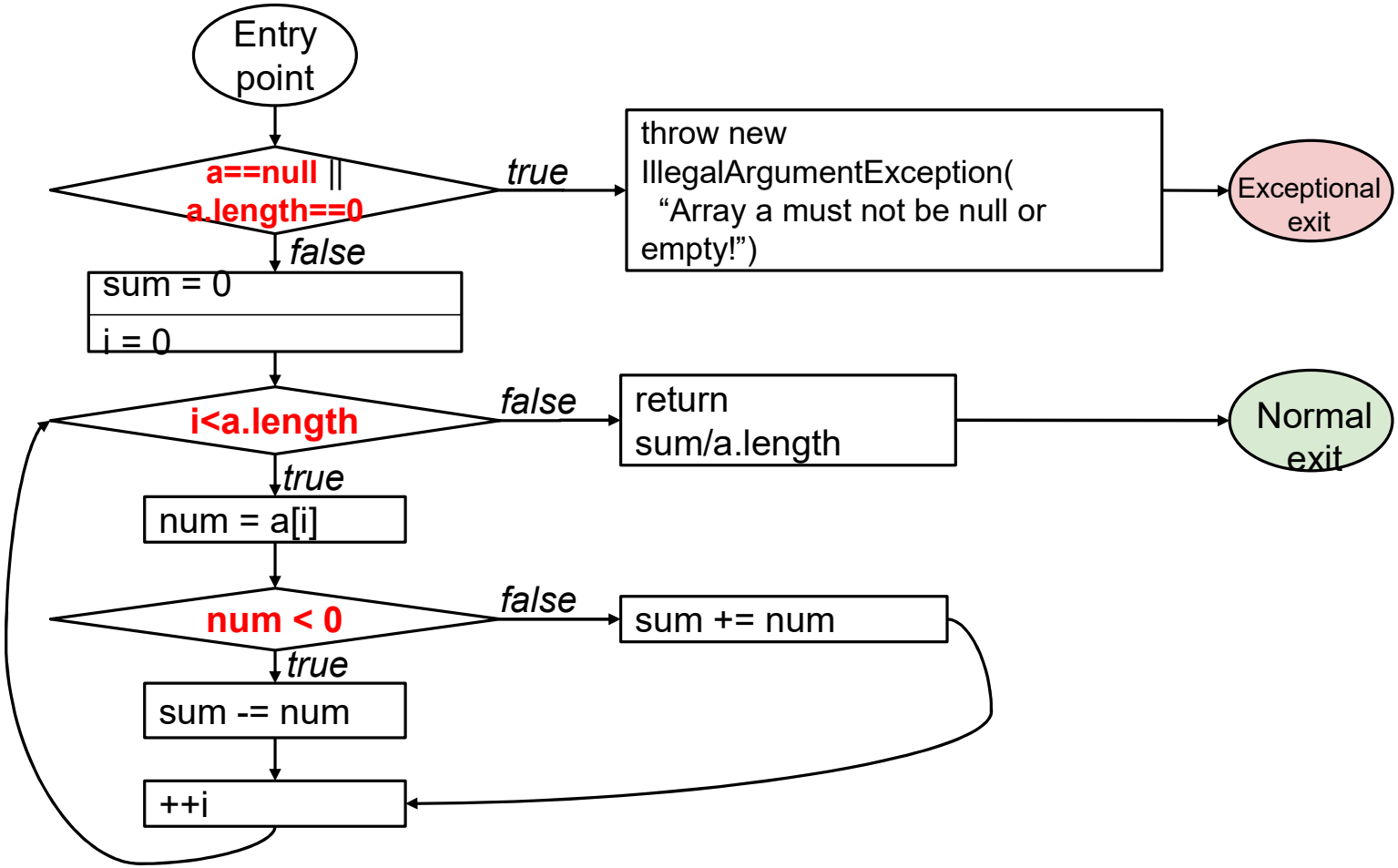
What are a and b?
What is the boolean expression (a | b)?

Condition coverage

Condition: a boolean expression that cannot be decomposed into simpler boolean expressions (atomic)

Condition coverage: every condition in the program must take on all possible **outcomes (true/false) at least once**

Condition coverage

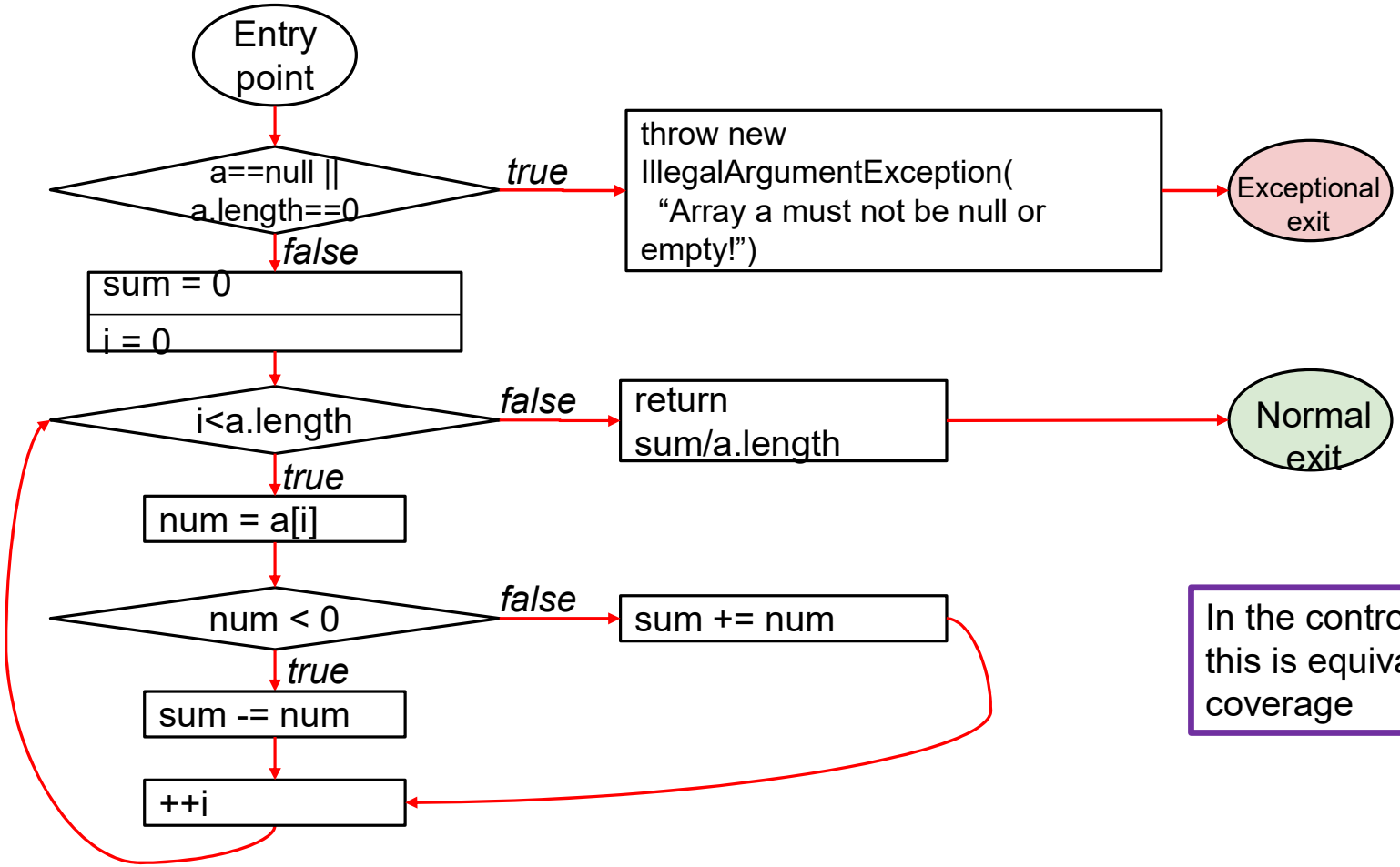


Decision coverage

Decision: a boolean expression that is composed of conditions, using 0 or more logical connectors

Decision coverage: every decision in the program must take on all possible **outcomes (true/false) at least once**

Decision coverage



In the control flow graph, this is equivalent to **edge** coverage

There is a concept of "subsumption"

Given two coverage metrics A and B,
A subsumes B if and only if **satisfying A implies satisfying B**

- Subsumption relationships (true or false):
  1. Does **statement** coverage subsume **decision** coverage?
  2. Does **decision** coverage subsume **statement** coverage?
  3. Does **decision** coverage subsume **condition** coverage?
  4. Does **condition** coverage subsume **decision** coverage?

https://pollev.com/cse403wi

Code Coverage - Do coverage types subsume each other

0 surveys completed

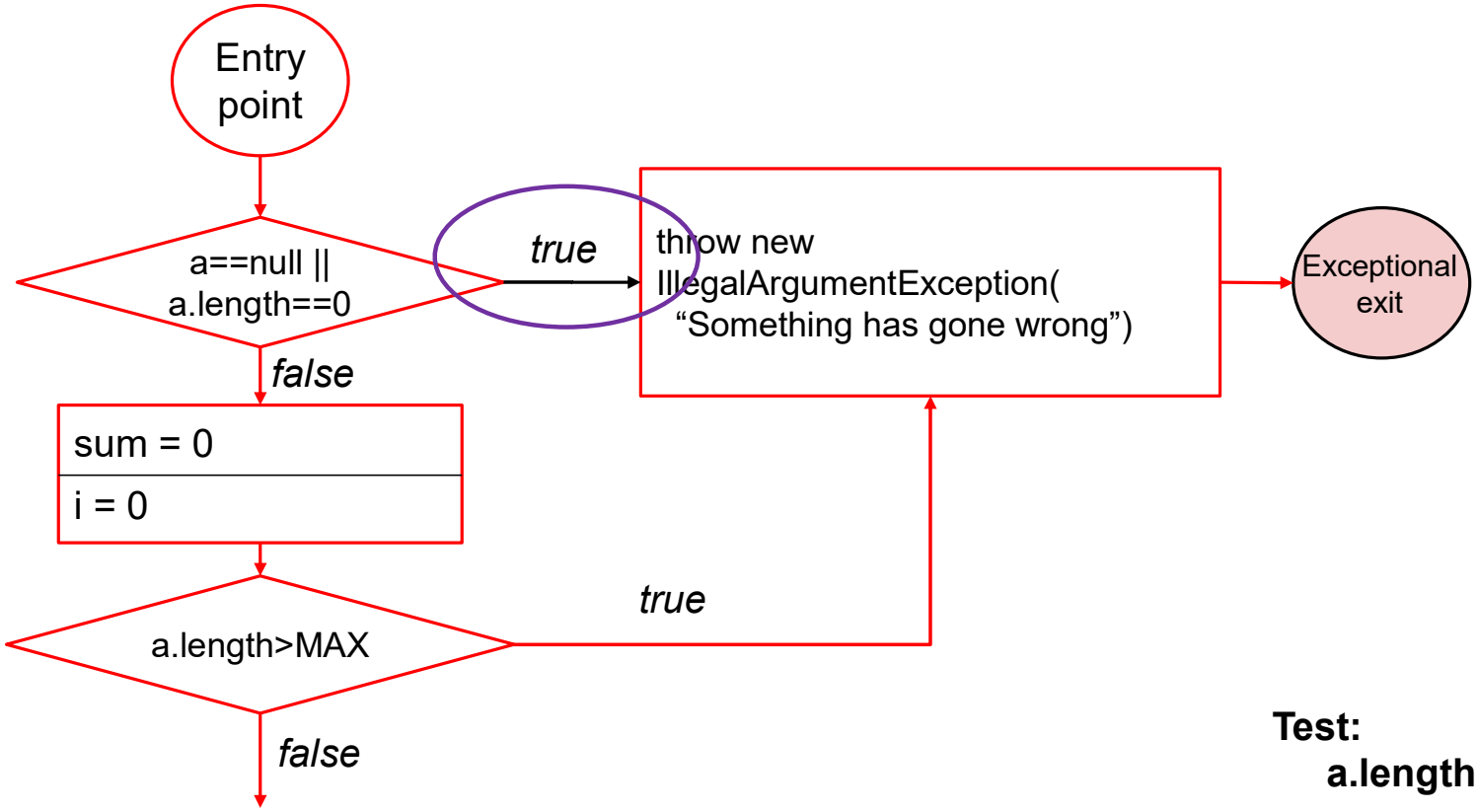
0 surveys underway

Does statement coverage subsume decision coverage?

Yes

No

Statement does not subsume Decision coverage



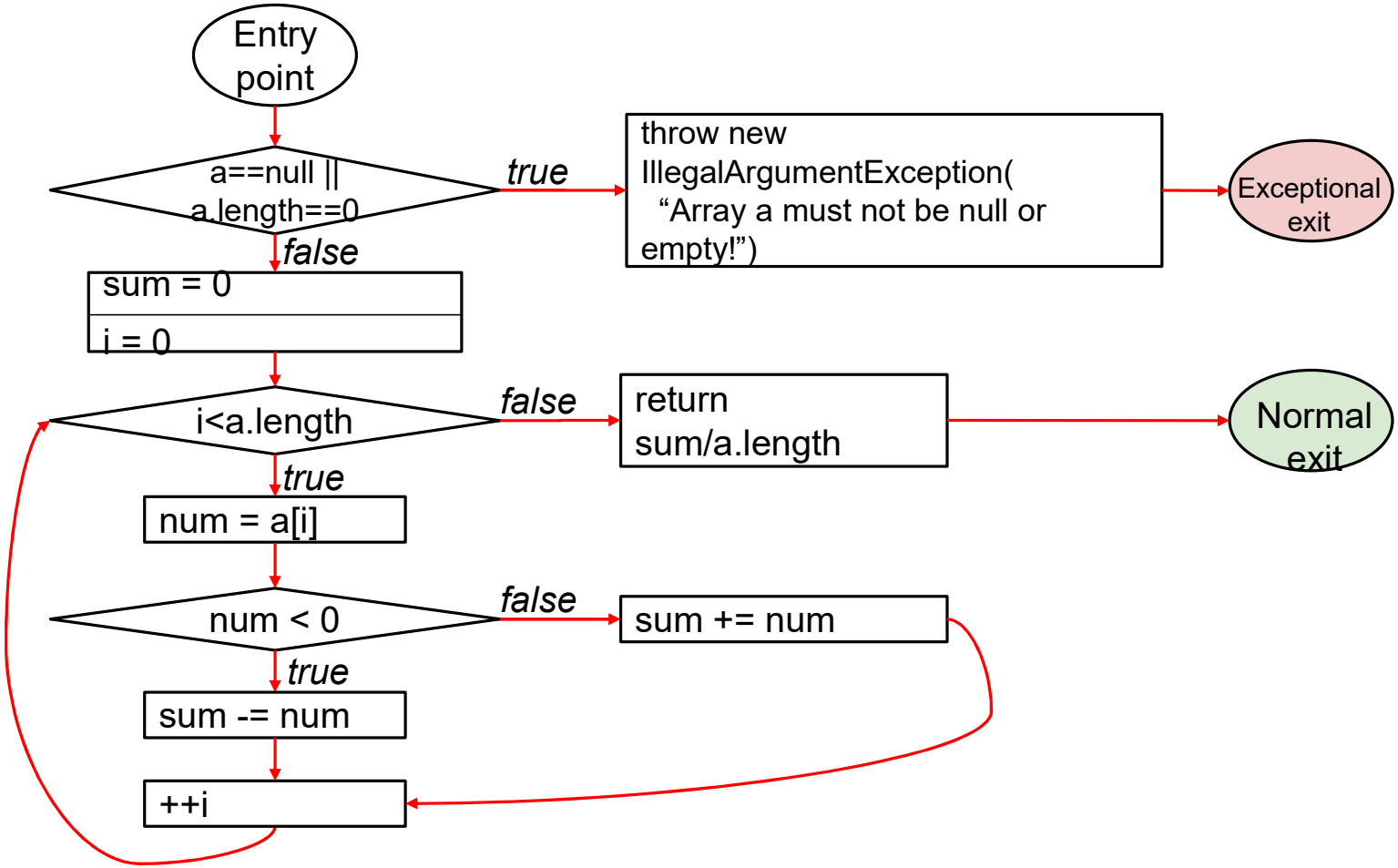
Test:
a.length = MAX+1

Does decision coverage subsume statement coverage?

Yes

No

Decision subsumes Statement coverage



Does decision coverage subsume condition coverage?

Yes

No

Does condition coverage subsume decision coverage?

Yes

No

Decision and Condition – neither subsumes the other

4 possible tests for the decision:

```
If (a | b) { …}
```

1. a = 0, b = 0
2. a = 0, b = 1
3. a = 1, b = 0
4. a = 1, b = 1

a	b	a | b
0	0	0
0	**1**	**1**
1	**0**	**1**
1	1	1

These two satisfy **condition coverage** but **not decision coverage**

a	b	a | b
0	**0**	**0**
0	**1**	**1**
1	0	1
1	1	1

These two satisfy **decision coverage** but **not condition coverage**

Summarizing

Given two coverage criteria A and B,
A subsumes B iff **satisfying A implies satisfying B**

- Subsumption relationships :
  1. **Statement** coverage **does not** subsume **decision** coverage
  2. **Decision coverage subsumes statement coverage**
  3. **Decision** coverage **does not** subsume **condition** coverage
  4. **Condition** coverage **does not** subsume **decision** coverage

Let's look at one more: MC/DC - Modified condition and decision coverage

- **Every decision** in the program must take on all possible outcomes (true/false) **at least once**
- **Every condition** in the program must take on all possible outcomes (true/false) **at least once**
- **Each condition** in a decision has been shown to **independently affect that decision's outcome**

  A condition is shown to independently affect a decision's outcome by varying just that condition while holding fixed all other possible conditions

Required for safety critical systems (DO-178B/C)

MC/DC: an example

```
if (a | b)
```

a	b	Outcome
0	0	0
0	1	1
1	0	1
1	1	1

MCDC

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

Which tests (combinations of a and b) satisfy MCDC?

MC/DC: an example

```
if (a | b)
```

a	b	Outcome
0	0	0
0	1	1
1	0	1
1	1	1

MCDC

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

Which tests (combinations of a and b) satisfy MCDC?

MC/DC: an example

```
if (a | b)
```

a	b	Outcome
0	**0**	**0**
0	**1**	**1**
1	**0**	**1**
1	1	1

MCDC

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

MCDC is usually cheaper than testing all possible combinations

MC/DC: coffee example

```
if( kettle && cup && beans ) {
  return cup_of_coffee;
}
else { return none; }
```

Kettle	Cup	Beans	Coffee!
1	1	1	1
1	1	0	0
1	0	1	0
1	0	0	0
0	1	1	0
0	1	0	0
0	0	1	0
0	0	0	0

Consider where each condition is shown to independently affect the outcome

MC/DC: coffee example

```
if( kettle && cup && beans ) {
  return cup_of_coffee;
}
else { return none; }
```

Kettle	Cup	Beans	Coffee!
1	1	1	1
1	1	0	0
1	0	1	0
1	0	0	0
0	1	1	0
0	1	0	0
0	0	1	0
0	0	0	0

Consider where each condition is shown to independently affect the outcome

MC/DC: coffee example

```
if( kettle && cup && beans ) {
  return cup_of_coffee;
}
else { return none; }
```

Kettle	Mug	Beans	Coffee!
1	1	1	1
1	1	0	0
1	0	1	0
1	0	0	0
0	1	1	0
0	1	0	0
0	0	1	0
0	0	0	0

Consider where each condition is shown to independently affect the outcome

MC/DC: coffee example

```
if( kettle && cup && beans ) {
  return cup_of_coffee;
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```

Kettle	Mug	Beans	Coffee!
1	1	1	1
1	1	0	0
1	0	1	0
1	0	0	0
0	1	1	0
0	1	0	0
0	0	1	0
0	0	0	0

MC/DC adequate test set

MC/DC: another example

```
if (a || b)
```

a	b	Outcome
0	0	0
0	1	1
1	0	1
1	1	1

MCDC

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

Why is this example different than (a | b)?

MC/DC: another example

```
if (a || b)
```

a	b	Outcome
0	0	0
0	1	1
1	--	1
1	--	1

MCDC

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

Short-circuiting operators may not evaluate all conditions

- Last two row values for b don't affect the outcome (so compiler/interpreter may short circuit execution such that they aren't evaluated if a is true)

Provide an MCDC-adequate test suite for: a | b | c

a	b	c	Outcome
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Provide an MCDC-adequate test suite for: a | b | c

a	b	c	Outcome
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Provide an MCDC-adequate test suite for: a | b | c

a	b	c	Outcome
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Provide an MCDC-adequate test suite for: a | b | c

a	b	c	Outcome
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

- **Decision** coverage
- **Condition** coverage
- **Each condition** shown to **independently affect outcome**

How much coverage is enough? 100%?

May be subject to the law of diminishing returns … shoot for 80%

Another resource on code coverage and code coverage tools:
https://www.atlassian.com/continuous-delivery/software-testing/code-coverage
And a good list of coverage tools:
https://www.browserstack.com/guide/code-coverage-tools

Code coverage takeaways

- Code coverage can provide valuable insights into your code and into your testing adequacy
- It is intuitive to interpret
- There are great tools available to help compute code coverage of your tests
- Code coverage itself is not sufficient to ensure correctness
- Code coverage is well known and used in industry

Last topic for today -

Integration testing

Do you get the expected results when the parts are put together?

Start with plain, “integration”

Integration: combining 2 or more software units and getting the expected results

Why do we care about integration?

- New problems will inevitably surface
  - Many modules are now together that have never been together before
- If done poorly, all problems will present themselves at once
  - This can be hard to diagnose, debug, fix
- There can be a cascade of interdependencies
  - Cannot find and solve problems one-at-a-time

What do you think of phased integration

Phased ("big-bang") integration:

- Design, code, test, debug each class/unit/subsystem separately
- Combine them all
- Hope for the best

In contrast to incremental integration

Incremental integration:

- Repeat
  - Design, code, test, debug a new component
  - Integrate this component with another (a larger part of the system)
  - Test the combination
- Can start with a functional "skeleton" system (e.g., zero feature release)
  - And incrementally “flesh it out”

Is it obvious which is more successful?

- **Incremental integration** benefits:
  - Errors easier to isolate, find, fix
    - reduces developer bug-fixing load
  - System is always in a (relatively) working state
    - good for customer, developer morale

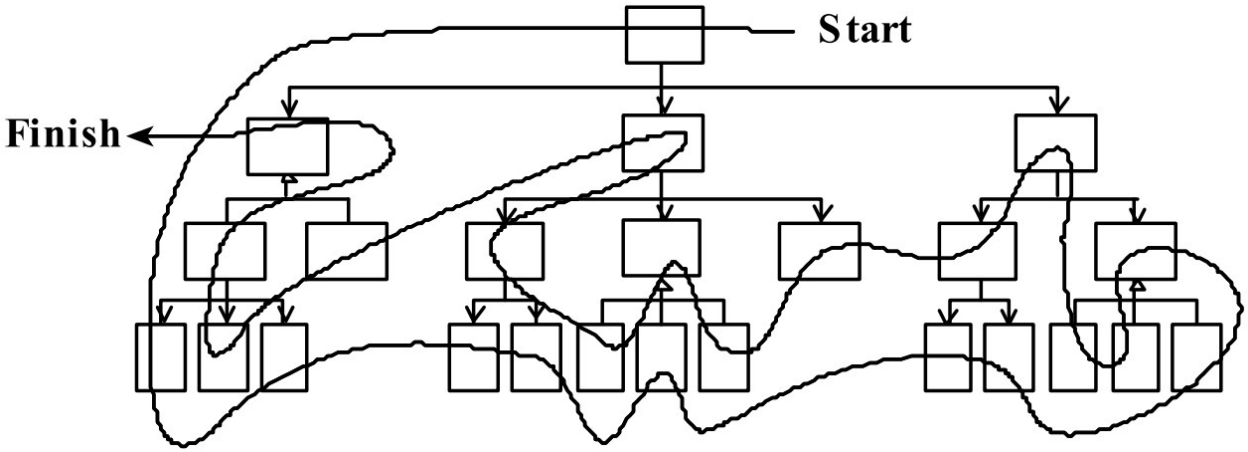
- But it isn't without challenges:
  - May need to create "**stub**" versions of some features that aren't yet available

Incrementally from the top, bottom or “sandwich"?

“Sandwich" integration by fleshing out a skeleton system

Connect top-level UI with crucial bottom-level components

- Add middle layers incrementally
- More common and agile approach



Milestone 05: Beta

Demo a skeleton implementation of your product showing the main components are integrated

Integration testing

Integration testing: verifying software quality by testing two or more dependent software modules as a group

Can be quite challenging as:

- Combined units can fail in more places and in more complicated ways
- May need to use stubs to "rig" behavior if not all pieces yet exist

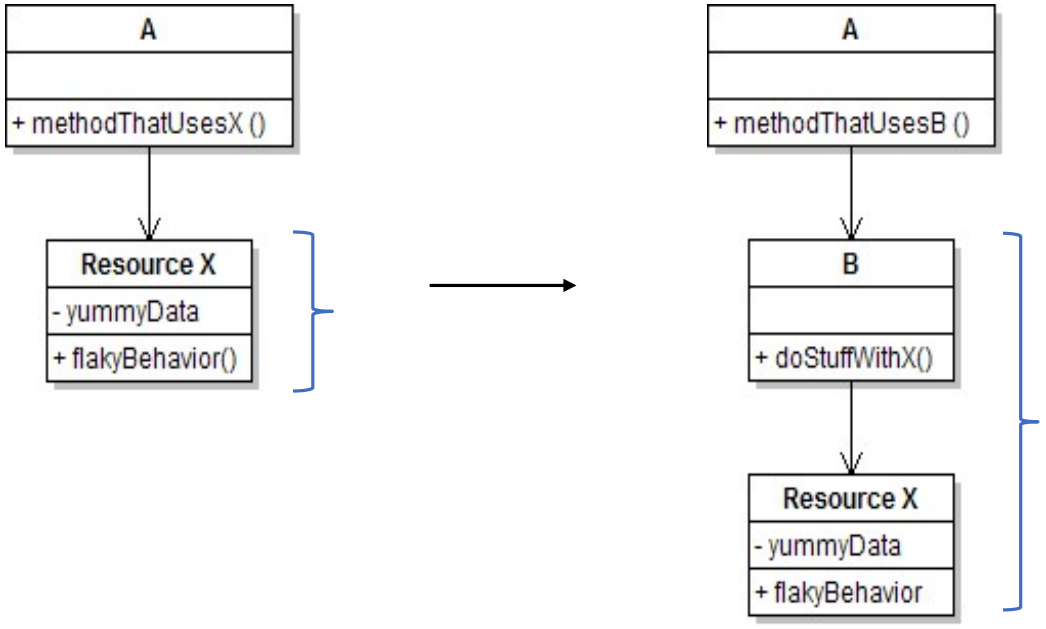
Testing takeaways

- Testing matters!!!
- Test early, test often
  - Bugs become well-hidden beyond the unit in which they occur
- Don't confuse volume with quality of test data
  - Can lose relevant cases in mass of irrelevant ones
  - Look for revealing subdomains (“characteristic tests”)
- Choose test data to cover:
  - Specification (black box testing)
  - Code (white box testing)
- Testing cannot prove the absence of bugs
  - But it can increase quality and confidence

Additional reference material on creating stubs to allow for integration testing before all code is written

How to create a stub, step 1

1. Identify the dependency
   a) This is either a resource or a class/object that is challenging or not yet written
   b) If it isn't an object, wrap it up into one



Goal: Test class A

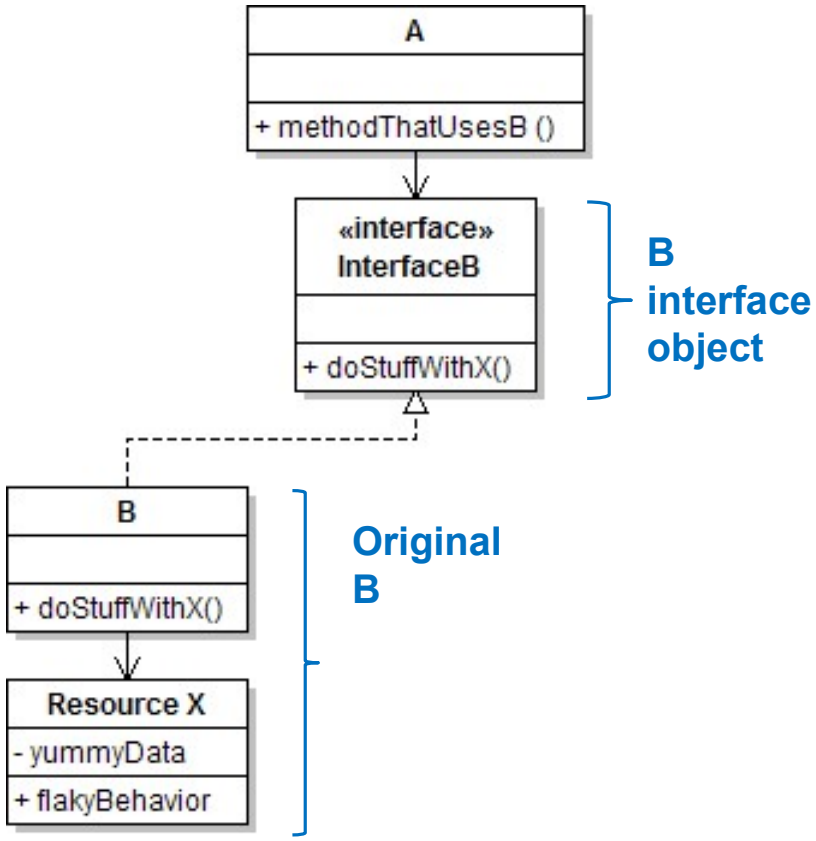
Create Class B to represent the challenging/missing dependency (as needed)

How to create a stub, step 2

2. Extract the core functionality of the object into an interface

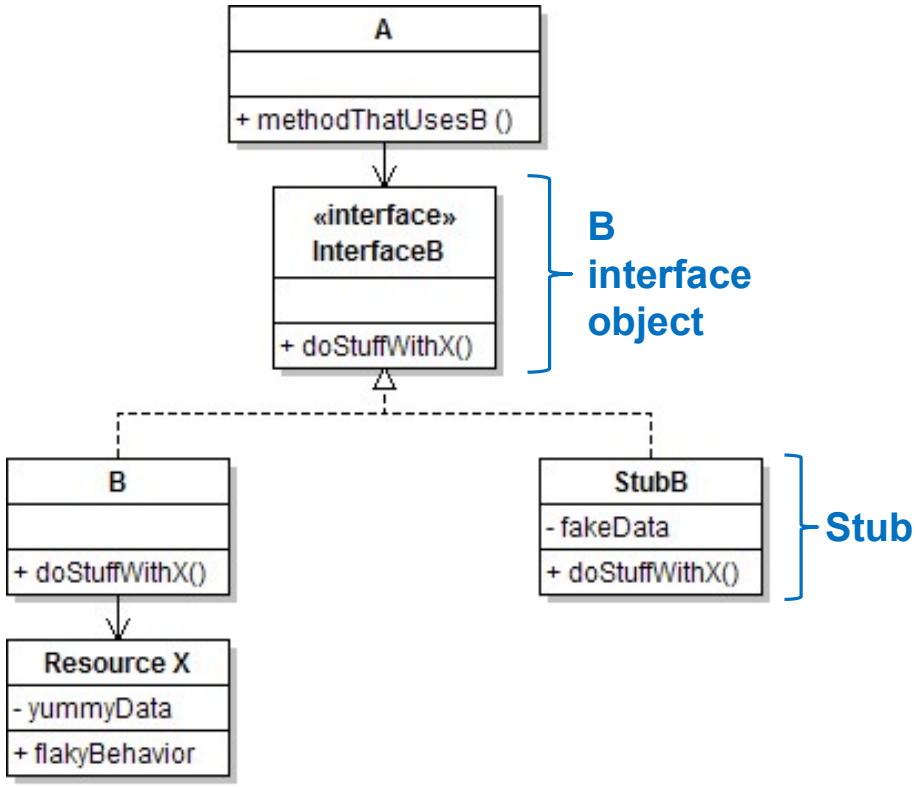
Create a **stub** InterfaceB based on B

Update A's code to work with type InterfaceB, not B



Create a stub, step 3

3. Write a second "stub" class that also implements the interface,
   but returns pre-determined fake data



Now A's dependency on B is dodged and can be tested easily

Can focus on how well A *integrates* with B's expected behavior

Inject the stub, step 4

So cool! Where inject the stub in the code so Class A will reference it?

- At construction
  apple = new A(**new StubB()**);
- Through a getter/setter method
  apple.setResource(**new StubB()**);
- Just before usage, as a parameter
  apple.methodThatUsesB(**new StubB()**);

Think about how to minimize code changes when you no longer depend on the stub