CSE 503

Software Engineering

Software Testing

Today

- Course projects
- Introduction to software testing
  - Blackbox vs. whitebox testing
  - Unit testing (vs. integration vs. system testing)
  - Test adequacy: code coverage
    - Statement coverage
    - Decision coverage (Branch coverage)
    - Condition coverage
    - Path coverage
- Discussion of DART: Directed Automated Random Testing

Software Testing 101

Software testing vs. software debugging

```
1  double avg(double[] nums) {
2    int n = nums.length;
3    double sum = 0;
4
5    int i = 0;
6    while (i<n) {
7      sum = sum + nums[i];
8      i = i + 1;
9    }
10
11   double avg = sum * n;
12   return avg;
13 }
```

Testing: is there a bug?

```
@Test
public void testAvg() {
  double nums =
      new double[]{1.0, 2.0, 3.0});
  double actual = Math.avg(nums);
  double expected = 2.0;
  assertEquals(expected,actual,EPS);
}
```

Software testing vs. software debugging

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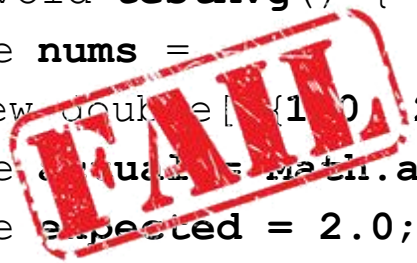


```
testAvg failed: 2.0 != 18.0
```

Software testing vs. software debugging

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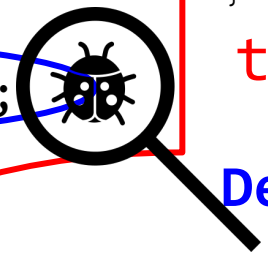

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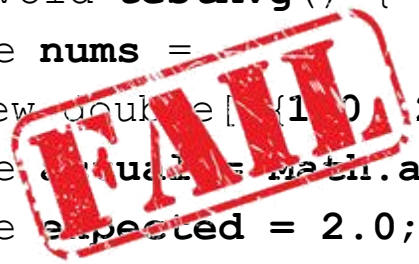


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testAvg failed: 2.0 != 18.0
```

Debugging: where is the bug?

how to fix the bug?

Two strategies: black box vs. white box

Black box testing

- The system is a black box (can’t see inside).
- No knowledge about the internals of a system.
- Create tests solely based on the specification (e.g., input/output behavior).

White box testing

- Knowledge about the internals of a system.
- Create tests based on these internals (e.g., exercise a particular part or path of the system).

Unit testing, integration testing, system testing

Unit testing

- Does each unit work as specified?

Integration testing

- Do the units work when put together?

System testing

- Does the system work as a whole?

Unit testing

- A **unit** is the **smallest testable part** of the software system (e.g., a method in a Java class).
- **Goal**: Verify that each software unit performs as specified.
- **Focus**:
  - Individual units (not the interactions between units).
  - Usually input/output relationships.

Test effectiveness

Software **testing** can **show** the **presence of defects**, but **never** show their **absence**! (Edsger W. Dijkstra)

- A good test is one that fails because of a defect.

How do we come up with good tests?

Test effectiveness

Ratio of detected defects is the best effectiveness metric!

Problem

- The set of defects is unknowable.

Solution

- Use a proxy metric (e.g., code coverage or mutation analysis).

Structural code coverage: example

Average of the absolute values of an array of doubles

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

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

  double sum = 0;
  for (int i=0; i<a.length; ++i) {
    double num = a[i];
    if (num < 0) {
      sum -= num;
    } else {
      sum += num;
    }
  }

  return sum/a.length;
}
```

What's the CFG for this method?

Structural code coverage: example

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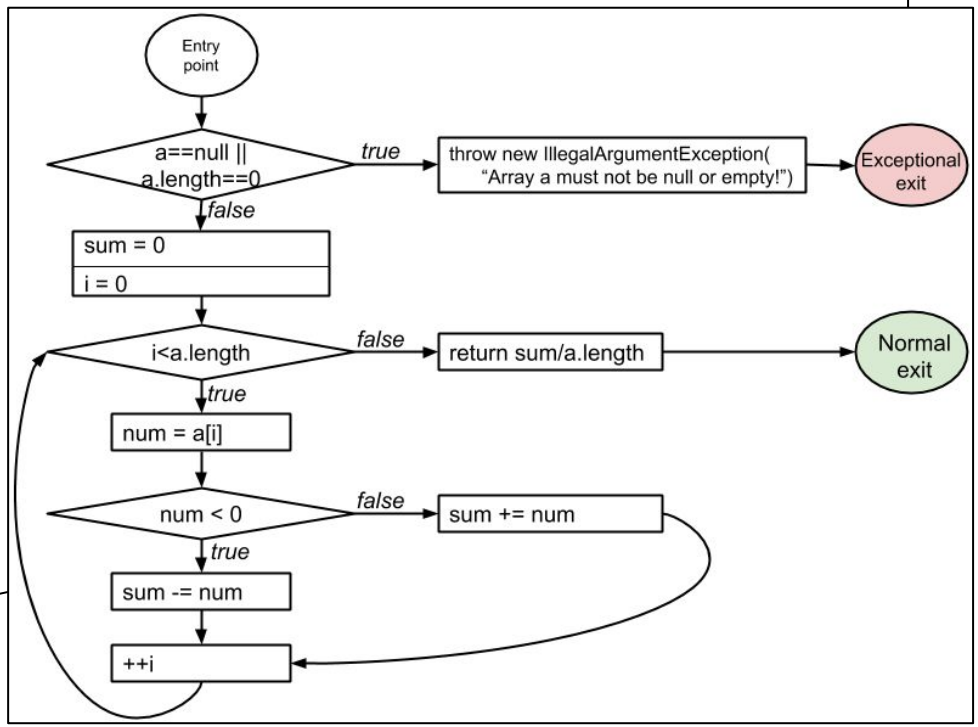
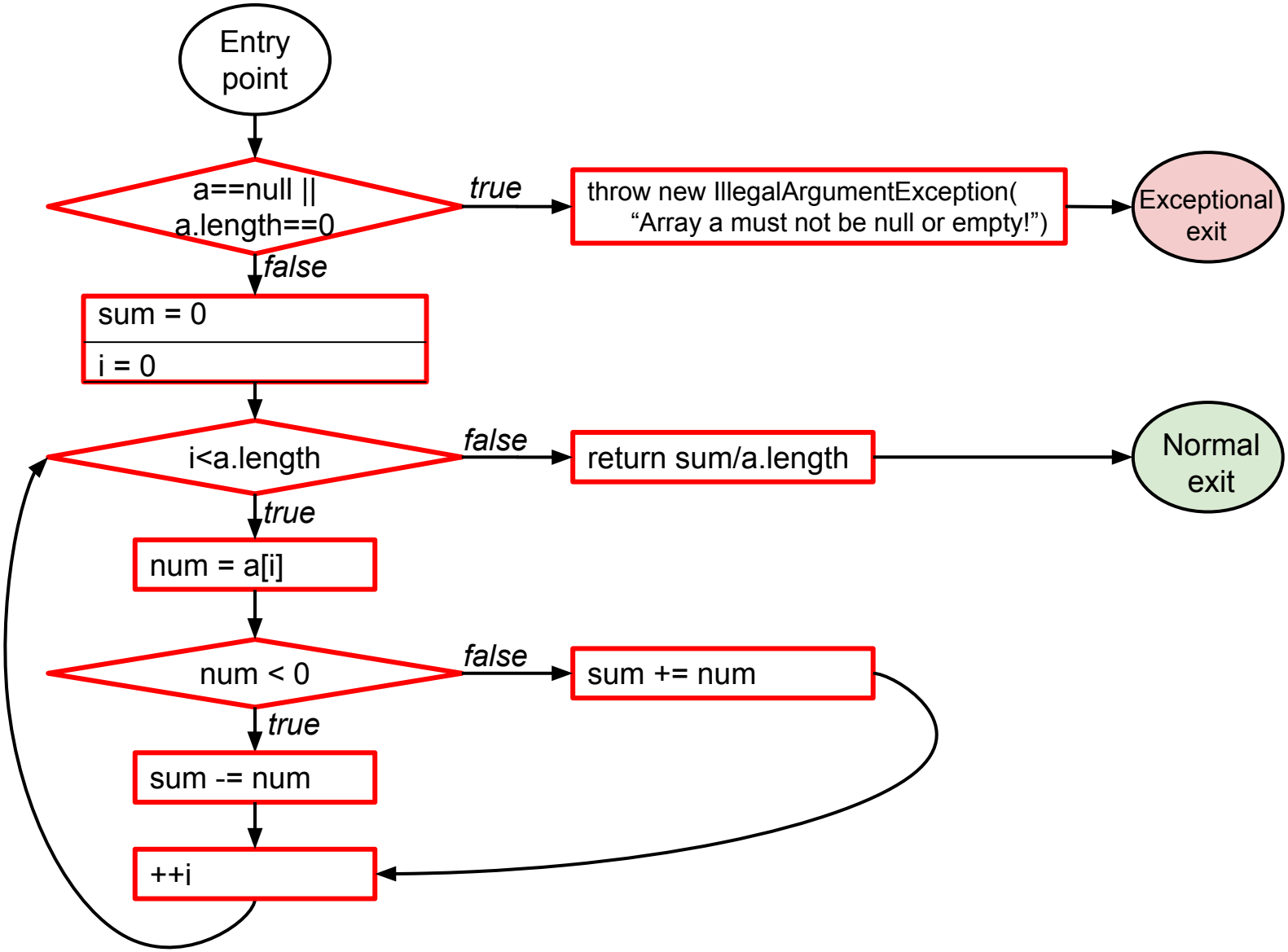


Statement coverage

- **Every statement** in the program must be **executed at least once.**
- Given the control-flow graph (CFG), this is equivalent to node coverage.

Statement coverage



Condition coverage vs. decision coverage

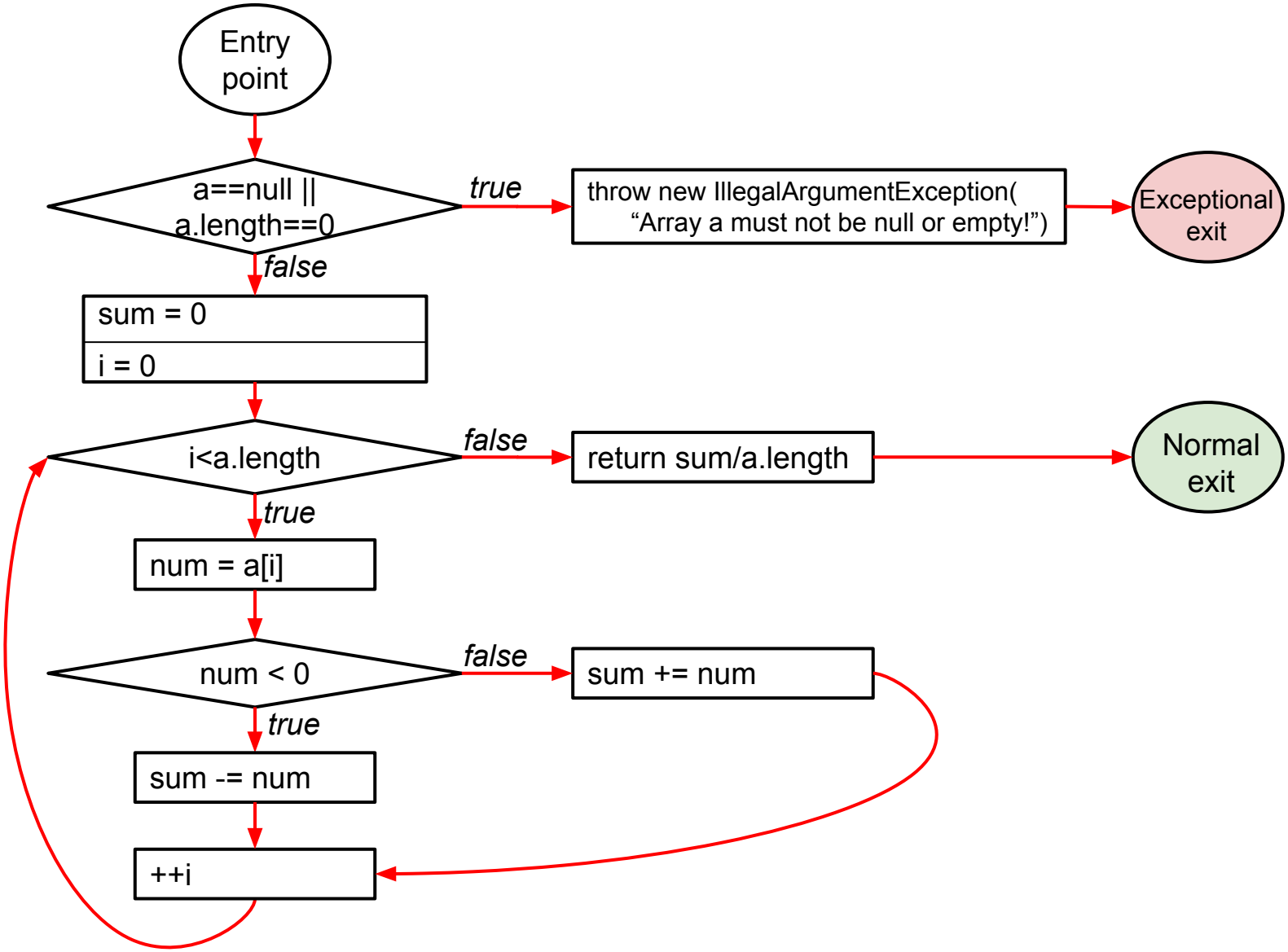
Terminology

- **Condition**: a boolean expression that cannot be decomposed into simpler boolean expressions.
- **Decision**: a boolean expression that is composed of conditions, using 0 or more logical connectors (a decision with 0 logical connectors is a condition).
- **Example:** if (*a* & *b*) { … }
  - *a* and *b* are *conditions.*
  - The boolean expression *a & b* is a *decision.*

Decision coverage (aka branch coverage)

- **Every decision** in the program must take on **all possible outcomes** (true/false) **at least once**
- Given the CFG, this is equivalent to edge coverage
- Example: (a>0 & b>0)
  - a=1, b=1
  - a=0, b=0

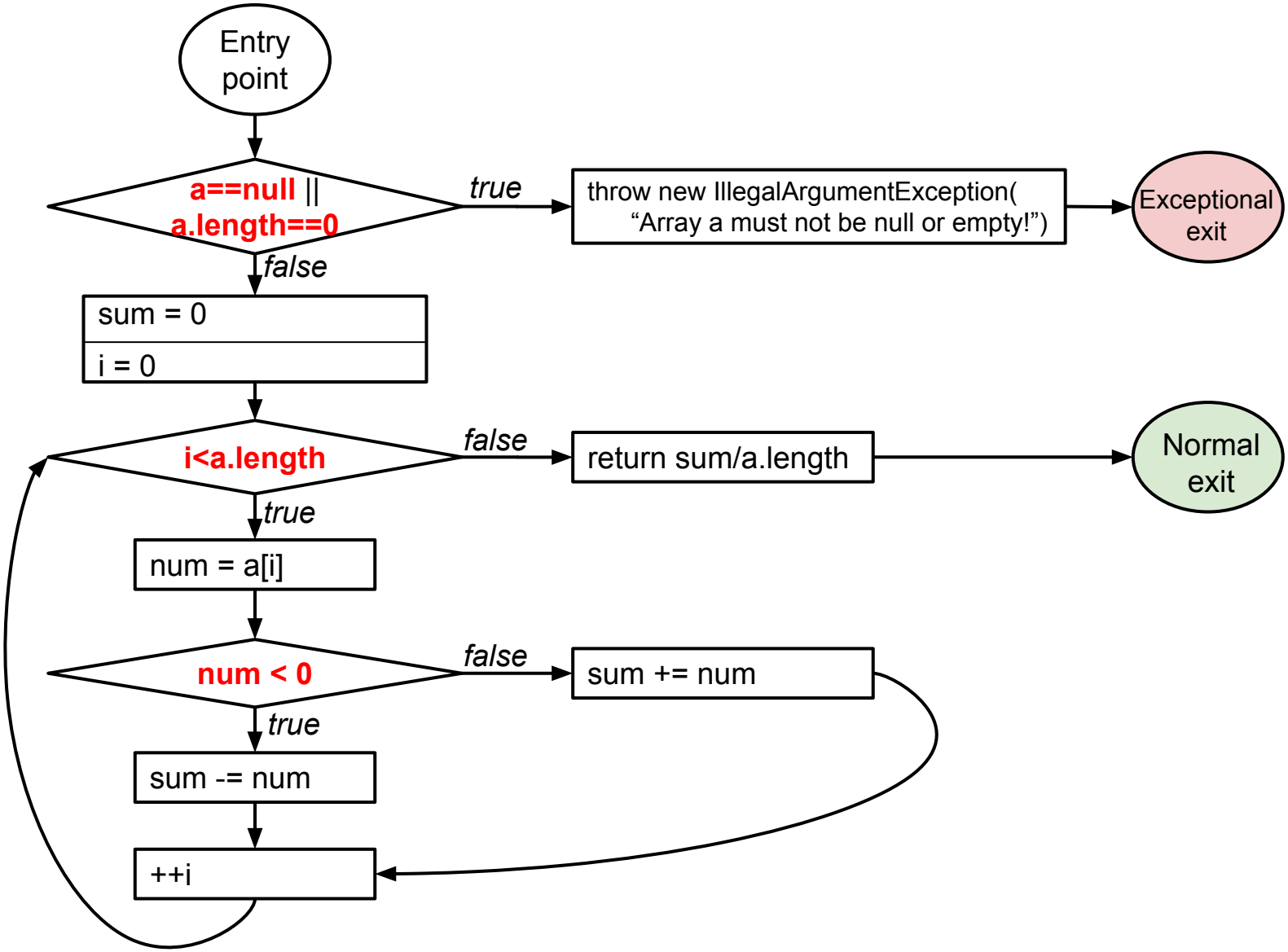
Decision coverage (aka branch coverage)



Condition coverage

- **Every condition** in the program must take on **all possible outcomes** (true/false) **at least once**
- Example: (a>0 & b>0)
  - a=1, b=1
  - a=0, b=0

Condition coverage

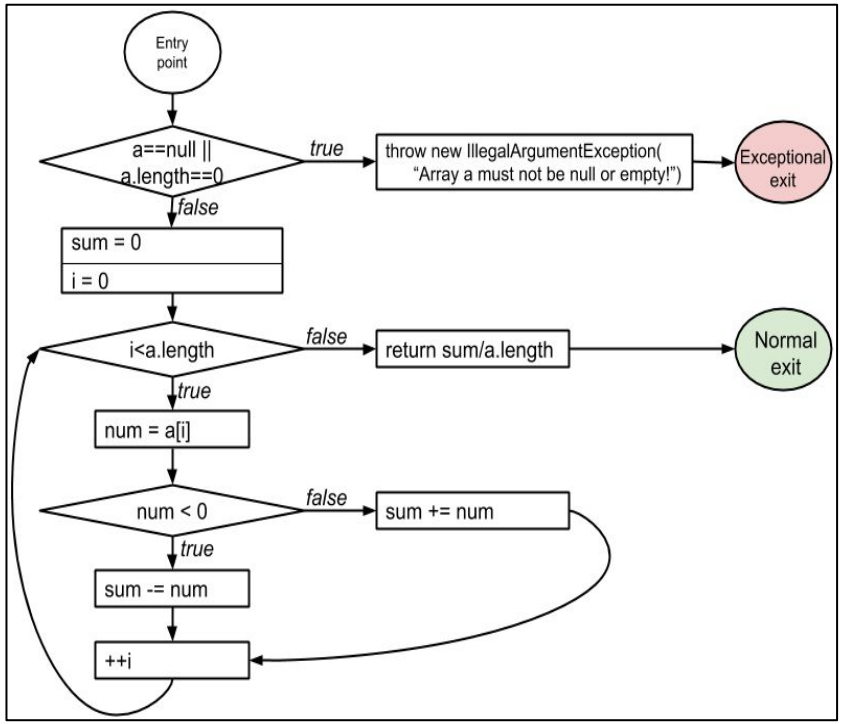


Structural code coverage: subsumption

Given two coverage criteria A and B,

A subsumes B iff satisfying A implies satisfying B

- Subsumption relationships:
  - Does **statement** coverage **subsume decision** coverage?
  - Does **decision** coverage **subsume statement** coverage?
  - Does **decision** coverage **subsume condition** coverage?
  - Does **condition** coverage **subsume decision** coverage?



Decision coverage vs. condition coverage

4 possible tests for the decision $a \mid b$:

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

a	b	$a \mid b$
0	0	0
0	**1**	**1**
1	**0**	**1**
1	1	1

Satisfies **condition coverage** but not **decision coverage**

a	b	$a \mid b$
0	**0**	**0**
0	**1**	**1**
1	0	1
1	1	1

Does not satisfy **condition coverage** but **decision coverage**

Neither coverage criterion subsumes the other!

Structural code coverage: subsumption

Given two coverage criteria A and B,

A subsumes B iff satisfying A implies satisfying B

- Subsumption relationships:
  - **Statement** coverage **does not subsume decision** coverage
  - **Decision** coverage **subsumes statement** coverage
  - **Decision** coverage **does not subsume condition** coverage
  - **Condition** coverage **does not subsume decision** coverage

Path coverage