CSE 503

Software Engineering

Winter 2021

Software Testing

January 22, 2021

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

```
double avg(double[] nums) {
 int n = nums.length;
 double sum = 0;

 int i = 0;
 while (i<n) {
   sum = sum + nums[i];
   i = i + 1;
 }

 double avg = sum * n;
 return avg;
}
```

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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FAIL

```
testAvg failed: 2.0 != 18.0
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Software testing vs. software debugging

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FAIL

```
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

```java
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

Average of the absolute values of an array of doubles

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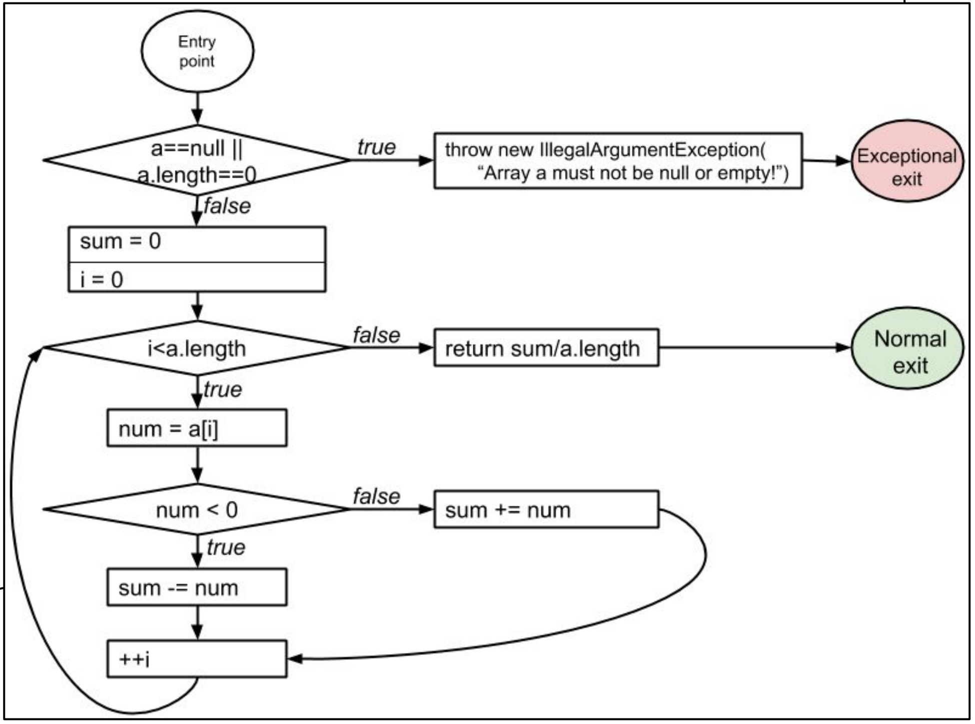
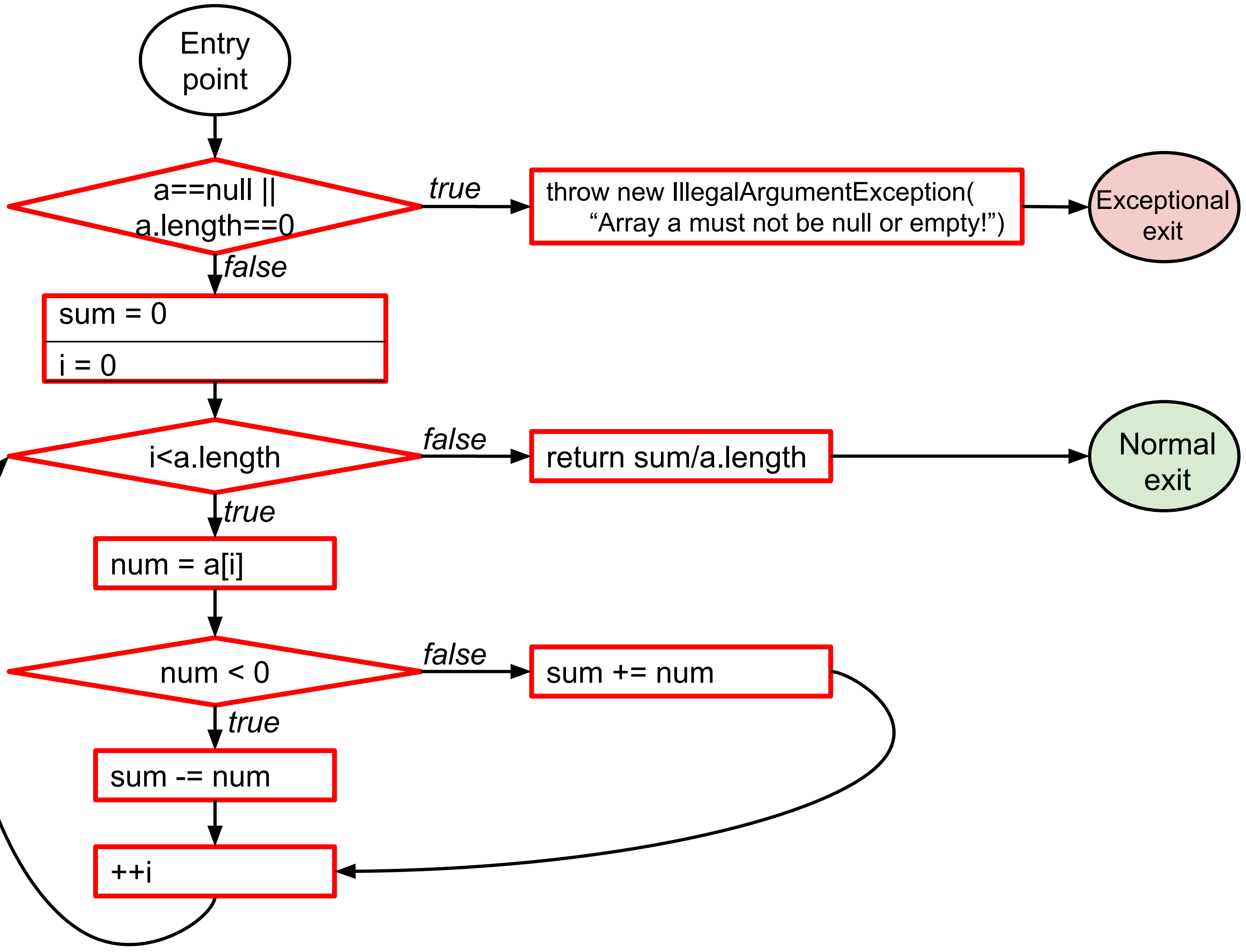


Statement coverage

- **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

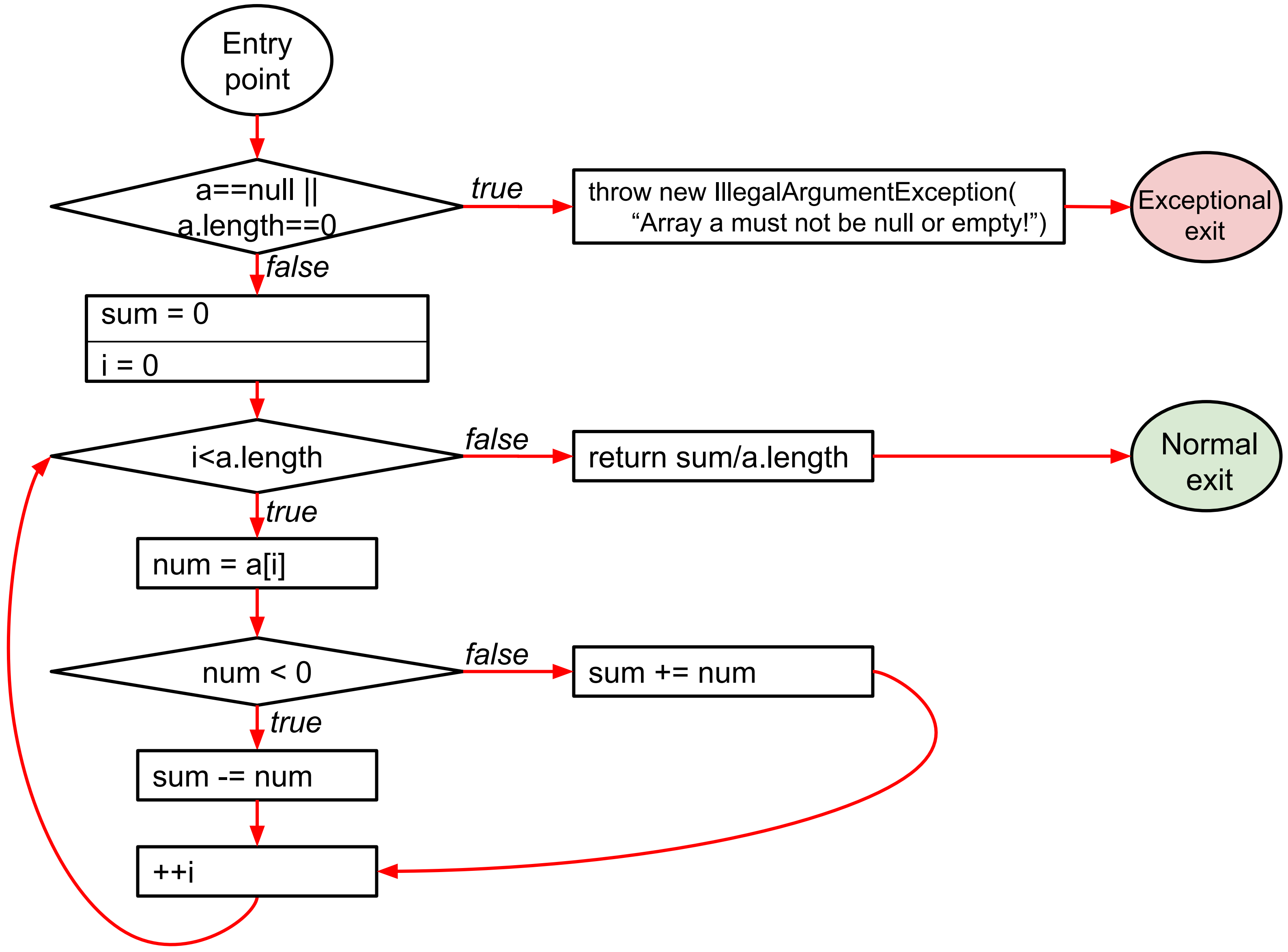
Terminology

- **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

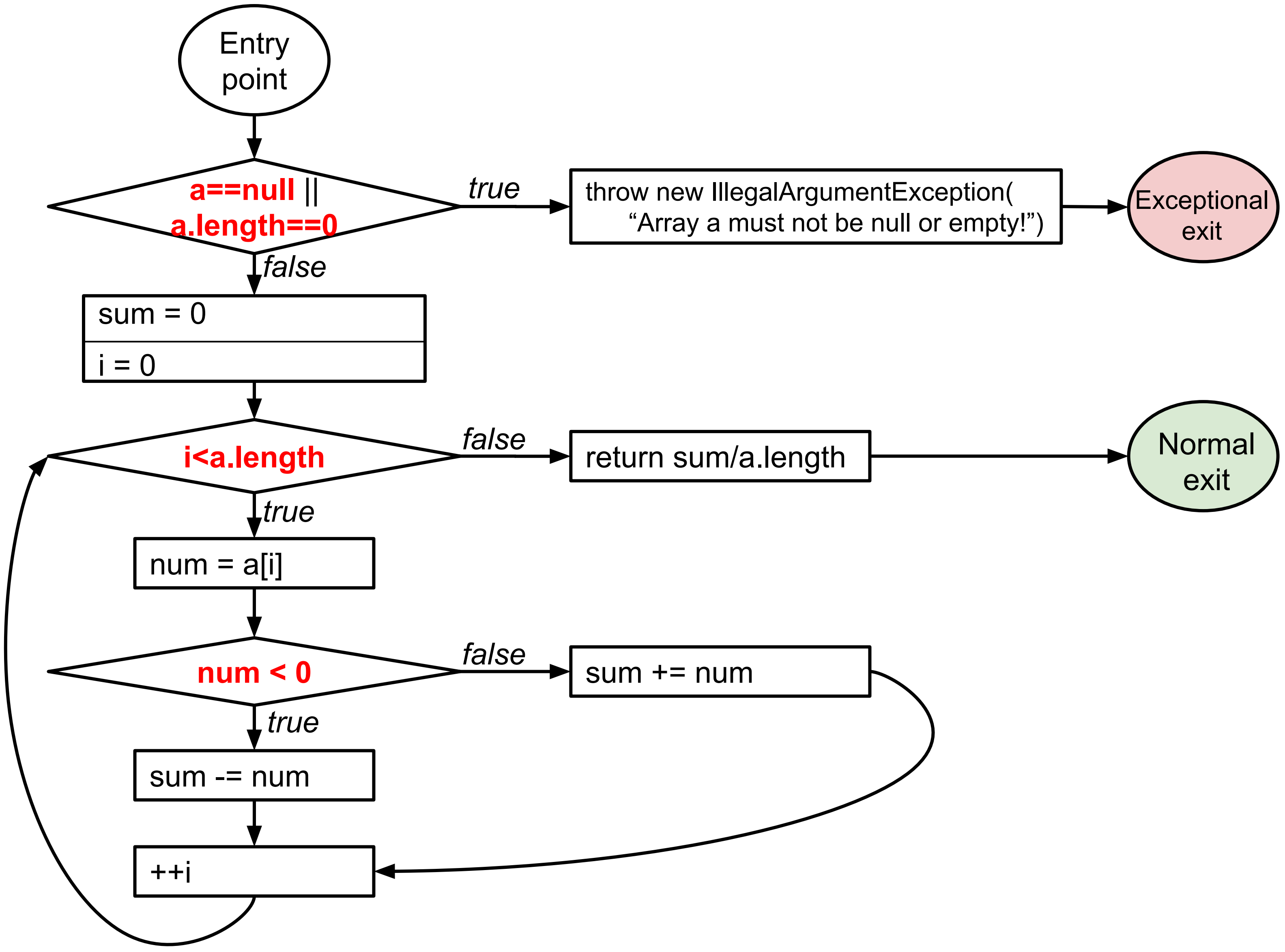
Decision coverage (aka branch coverage)



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

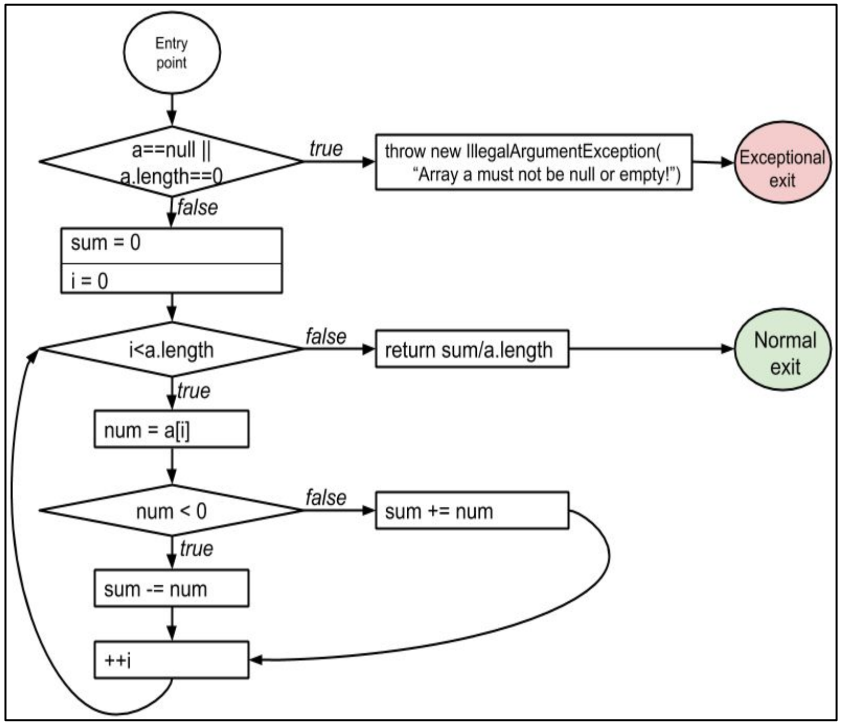


Structural code coverage: subsumption

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* | *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

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

a	*b*	*a* | *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!

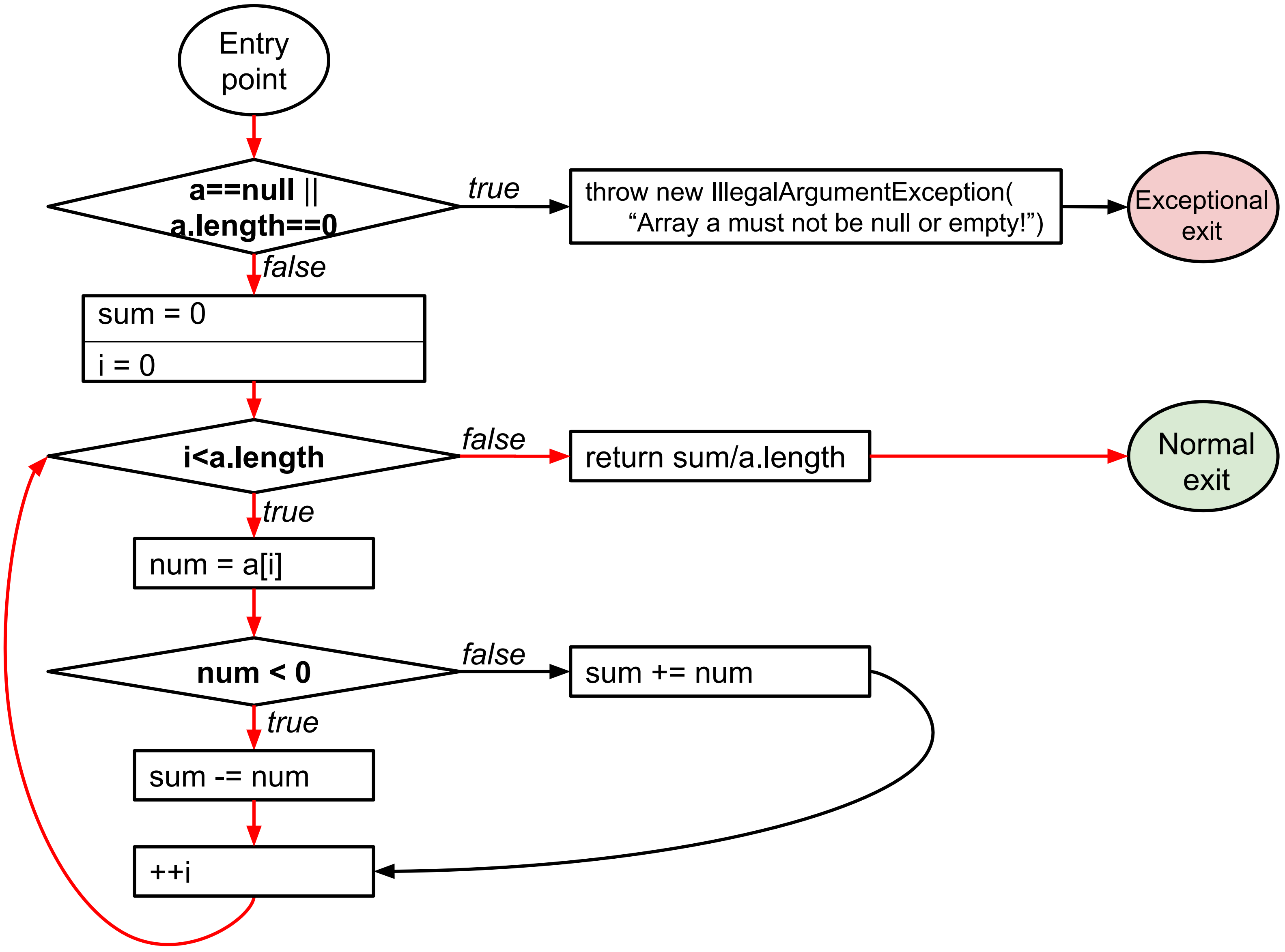
Structural code coverage: subsumption

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



DART: Directed Automated Random Testing

Reading questions

1. A test case consists of two parts: test input(s) and a test oracle. Briefly explain for each of the two parts how to derive it and whether this process can be (easily) automated.
2. DART executes a program both concretely and symbolically. Briefly explain the difference of these two types of executions in DART and why both are necessary.
3. What are path constraints? Give one example for path constraints that DART can solve and one example for path constraints that it cannot. Briefly explain why.
4. Give an example for a test oracle that test cases generated by DART use. Give one example for a test oracle that DART cannot automatically generate and briefly explain why.