CS 520

Theory and Practice of Software Engineering
Fall 2018

Software testing

October 11, 2018

Today

Introduction to software testing

- Blackbox vs. whitebox testing
- Unit testing (vs. integration vs. system testing)
- Test adequacy
  - Structural code coverage
    - Statement coverage
    - Decision coverage
    - Condition coverage
  - Mutation analysis

Software testing

What can testing do, and what can't it do?

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?

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?

Our focus: unit testing

Unit testing

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

Software testing

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.

When should we stop testing if no (new) test fails?

Test effectiveness

Ratio of detected defects is the best effectiveness metric!

Problem
- The set of defects is unknowable

Solution
- Use a proxy metric, for example code coverage

Structural code coverage: live example

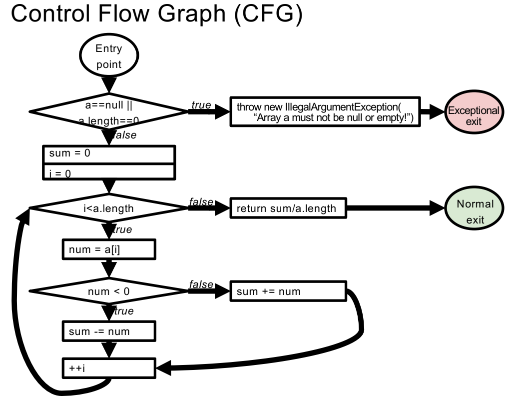
Average of the absolute values of an array of doubles

```
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("Array 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;
    } else {
      sum += d;
    }
  }

  return sum/numbers.length;
}
```

Control Flow Graph (CFG)



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

Structural code coverage: live example

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
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    double d = numbers[i];
    if (d < 0) {
      sum -= d;
    } else {
      sum += d;
    }
  }

  return sum/numbers.length;
}
```
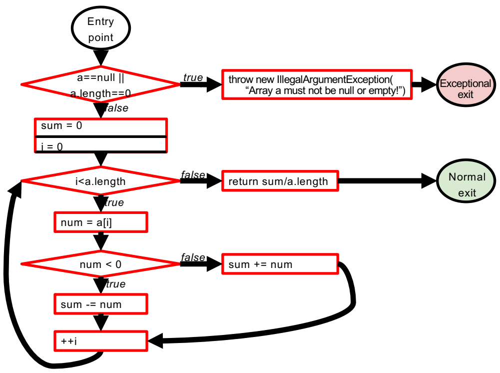

Structural code coverage: statement coverage



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 (a.k.a. branch coverage)

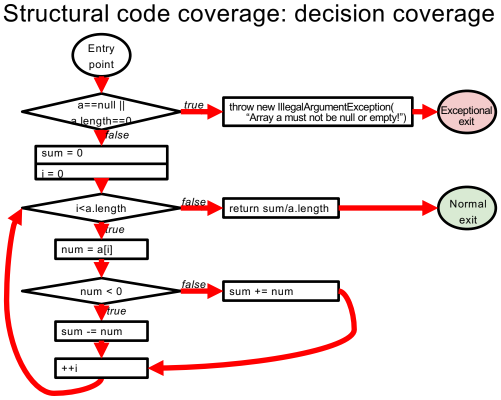
- **Every decision** in the program must take on **all possible outcomes** (true/false) **at least once**
- Given the CFG, this is equivalent to edge coverage
- Example: if (a>0 && b>0)
  - a=1, b=1
  - a=0, b=0

Structural code coverage: live example

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("Array 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;
    } else {
      sum += d;
    }
  }

  return sum/numbers.length;
}
```

Structural code coverage: decision 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=0
  - a=0, b=1

Structural code coverage: live example

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) {
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    double d = numbers[i];
    if (d < 0) {
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    } else {
      sum += d;
    }
  }

  return sum/numbers.length;
}
```
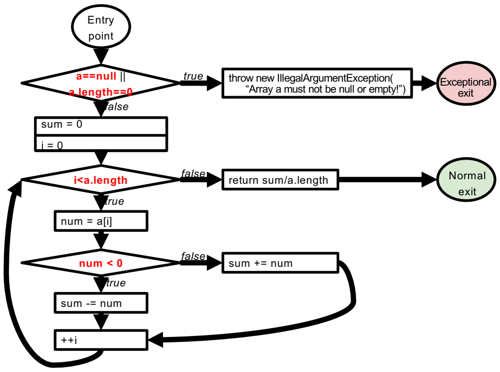

Structural code coverage: condition coverage



Structural code coverage: subsumption

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

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

Code coverage: advantages

Classes in this File	Line Coverage	Branch Coverage	Complexity
Avg	100% 10/10	100% 8/8	6

```
1     package avg;
2
3  4  public class Avg {
4
5         /*
6          * Compute the average of the absolute values of an array of doubles
7          */
8         public double avgAbs(double ... numbers) {
9             // We expect the array to be non-null and non-empty
10 4          if (numbers == null || numbers.length == 0) {
11 2              throw new IllegalArgumentException("Array numbers must not be null or empty!");
12            }
13
14 2          double sum = 0;
15 8          for (int i=0; i<numbers.length; ++i) {
16 6              double d = numbers[i];
17 6              if (d < 0) {
18 2                  sum -= d;
19                } else {
20 4                  sum += d;
21                }
22            }
23 2          return sum/numbers.length;
24        }
25    }
```

- Code coverage is easy to compute.
- Code coverage has an intuitive interpretation.

But, does coverage ensure effective testing?

Code coverage: drawbacks

Classes in this File	Line Coverage	Branch Coverage	Complexity
Avg	100% 10/10	100% 8/8	6

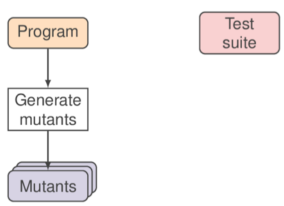
```
package avg;

public class Avg {

    /*
     * Compute the 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("Array 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;
            } else {
                sum += d;
            }
        }
        return sum/numbers.length;
    }
}
```

- Code coverage does not require test assertions.
- Not all statements etc. are equally important.
- Coverage is not the same as behavior.

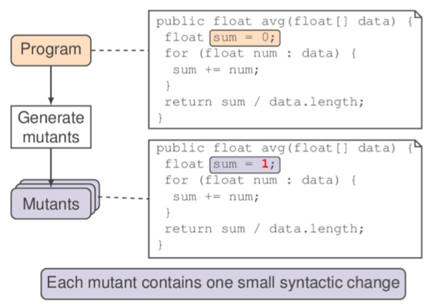
Are there any alternatives?

Mutation analysis: overview

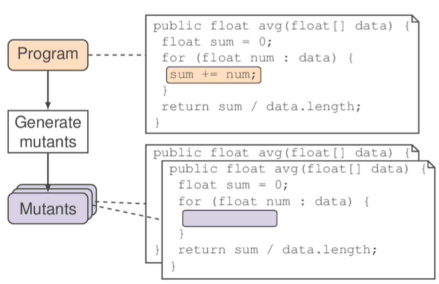
Mutation analysis: overview



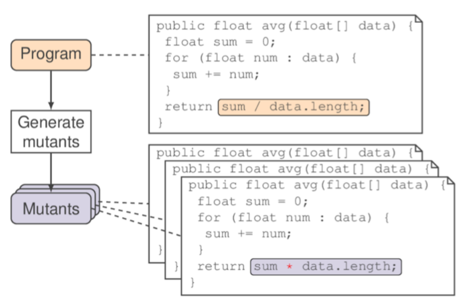
Mutation analysis: overview



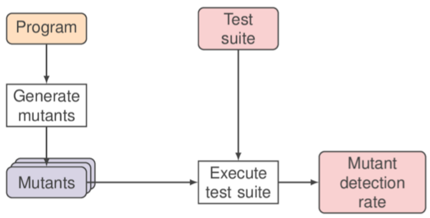
Mutation analysis: overview



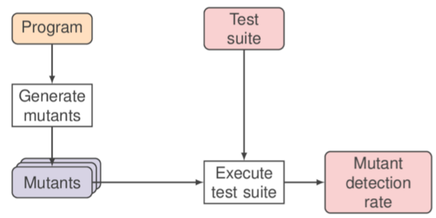
Mutation analysis: overview



Mutation analysis: overview



Mutation analysis: overview



Assumption: Mutant detection rate is a good proxy for fault detection rate.

What does it mean for a test to fail on a mutant program?

Mutation analysis: example

Find a test case that detects the following mutant
(i.e., passes on the original program but fails on the mutant)

Original program:

```
public int min(int a, int b) {
    return a < b ? a : b;
}
```

Mutant:

```
public int min(int a, int b) {
    return a;
}
```

a	*b*	Original	Mutant
1	2	1	1
1	1	1	1
2	**1**	**1**	**2**

Mutation analysis: another example

Find a test case that detects the following mutant (i.e., passes on the original program but fails on the mutant)

Original program:

```
public int min(int a, int b) {
    return a < b ? a : b;
}
```

Mutant:

```
public int min(int a, int b) {
    return a <= b ? a : b;
}
```

There is no such test that can detect the mutant...

The mutant is **undetectable** because it is **equivalent** to the **original program!**

Summary

- Testing is an important way to measure code quality
- Black-box testing
- White-box testing
- Coverage metrics
  - Statement
  - Condition
  - Decision
- Mutation-based metric

For more, read:
"Are mutants a valid substitute for real faults in software testing?" in FSE 2014