Software Engineering

Lecture 08: Testing and Debugging — Overview

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SS 2013

Literature

Essential Reading

- *Why Programs Fail: A Guide to Systematic Debugging*, A Zeller

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- *Why Programs Fail: A Guide to Systematic Debugging*, A Zeller
- *The Art of Software Testing*, 2nd Edition, G J Myers

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- *Why Programs Fail: A Guide to Systematic Debugging*, A Zeller
- *The Art of Software Testing*, 2nd Edition, G J Myers

Further Reading

- *Code Complete*, 2nd Edition, S McConnell

Cost of Software Errors

$ 60 billion

Cost of Software Errors

$ 60 billion

yearly cost of software errors for US economy [NIST 2002]

Cost of Software Errors

$ 180 billion

Cost of Software Errors

$ 180 billion

total sales of software in 2000

Cost of Software Errors

$ 180 billion

total sales of software in 2000

697,000 software engineers & 585,000 computer programmers

Cost of Software Errors

estimated

50%

Cost of Software Errors

estimated

50%

of each software project spent on testing

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estimated

50%

of each software project spent on testing

(spans from 30% to 80%)

Cost of Software Errors

very rough approximation

money spent on testing	$\approx$	cost of remaining errors

Cost of Software Errors

very rough approximation

money spent on testing	+	cost of remaining errors

=

Cost of Software Errors

very rough approximation

money spent on testing + cost of remaining errors

=

66% of size of software industry

A Quiz About Testing

A simple program

Input

Read three integer values from the command line.
The three values represent the lengths of the sides of a triangle.

Output

Tells whether the triangle is

Scalene:	no two sides are equal
Isosceles:	exactly two sides are equal
Equilateral:	all sides are equal

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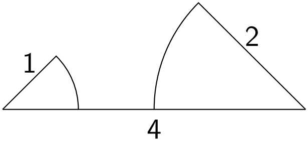
Task: Create a Set of Test Cases for this Program

Solution — 1 Point for each Correct Answer

Q 1: (4,1,2) a invalid triangle



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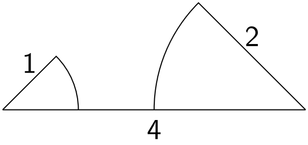

Why not a valid triangle?

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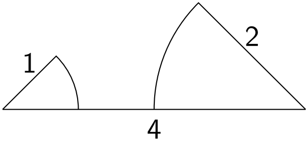

Why not a valid triangle? (a,b,c) with $a > b + c$

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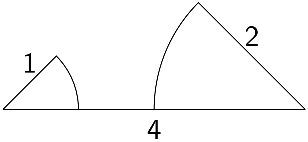

Why not a valid triangle? (a,b,c) with $a > b + c$

Define valid triangles: $a \leq b + c$

Solution — 1 Point for each Correct Answer

Q 2: some permutations of previous (1,2,4), (2,1,4)

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Fulfill above definition, but are still invalid.

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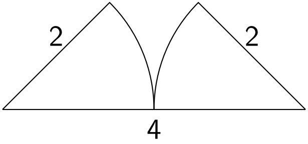
Fulfill above definition, but are still invalid.

Patch definition of valid triangles:

$a \leq b + c$ and $b \leq a + c$ and $c \leq a + b$

Solution — 1 Point for each Correct Answer

Q 3: (4,2,2) a invalid triangle with equal sum



Solution — 1 Point for each Correct Answer

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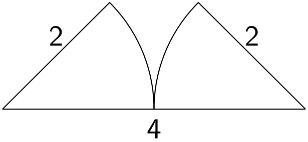

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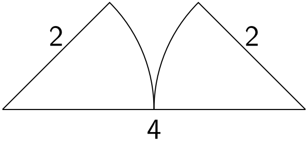


Fulfills above definition, but is invalid (depending on what we want!).

Patch definition of valid triangles:

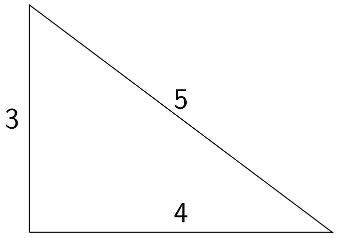
$a < b + c$ and $b < a + c$ and $c < a + b$

Solution — 1 Point for each Correct Answer

Q 4: some permutations of previous (2,2,4), (2,4,2)

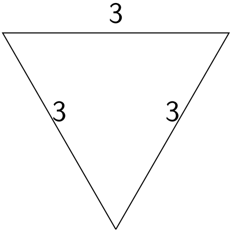
Solution — 1 Point for each Correct Answer

Q 5: (3,4,5) a valid scalene triangle



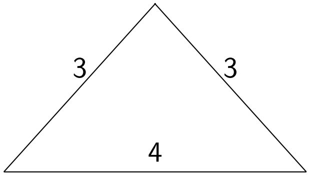
Solution — 1 Point for each Correct Answer

Q 6: (3,3,3) an equilateral triangle



Solution — 1 Point for each Correct Answer

Q 7: (3,4,3) valid isosceles t.



Solution — 1 Point for each Correct Answer

Q 8: all permutations of valid isosceles triangle:

(3,4,3), (3,3,4), (4,3,3)

Solution — 1 Point for each Correct Answer

Q 9: one side with zero value (0,4,3)

Solution — 1 Point for each Correct Answer

Q 10: one side with negative value (-1,4,3)

Solution — 1 Point for each Correct Answer

Q 11: all sides zero (0,0,0)

Solution — 1 Point for each Correct Answer

Q 12: at least one value is non-integer (1,3,2.5)

Solution — 1 Point for each Correct Answer

Q 13: wrong number of arguments (2,4) or (1,2,3,3)

Solution — 1 Point for each Correct Answer

Q 14 (the most important one):

Did you specify the expected output in each case?

About the Quiz

- Q 1–13 correspond to failures that have actually occurred in implementations of the program
- How many questions did you answer?
  < 5? $5 - 7$? $8 - 10$? > 10? All?

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- Q 1–13 correspond to failures that have actually occurred in implementations of the program
- How many questions did you answer?
  < 5? $5 - 7$? $8 - 10$? > 10? All?
- Highly qualified, experienced programmers score 7.8 on average

First Conclusions

- Finding good and sufficiently many test cases is difficult
- Even a good set of test cases cannot exclude more failures
- A specification is required to identify failures

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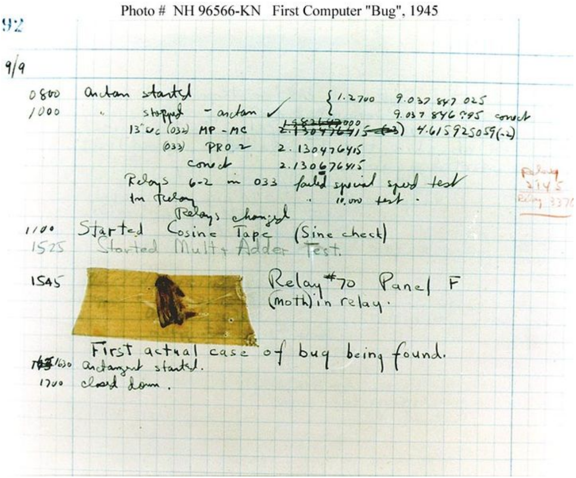
The discipline of Testing is all about Test Cases

Remark: At Ericsson: 35% of code is test cases!

What is a Bug?



Harvard University, Mark II Aiken Relay Calculator

What is a Bug? Basic Terminology

Bug-Related Terminology

1. Defect (aka bug, fault) introduced to code by programmer (not always programmer's fault, if, e.g., requirements changed)

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Bug-Related Terminology

1. Defect (aka bug, fault) introduced to code by programmer (not always programmer's fault, if, e.g., requirements changed)
2. Defect may cause infection of program state during execution (not all defects cause infection)
3. Infected state propagates during execution (infected parts of states may be overwritten or corrected)
4. Infection may cause a failure: an externally observable error (including, e.g., non-termination)

Defect — Infection — Propagation — Failure

Failure and Specification

Some failures are obvious

- obviously wrong output/behaviour
- non-termination
- crash
- freeze

... but most are not!

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Failure and Specification

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Correctness is a relative notion

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Every program is correct with respect to SOME specification

— myself, today

Specification: Intro

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Economist:
The cows in Scotland are brown

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No, there are cows in Scotland of which one at least is brown!

Specification: Intro

Economist:
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Logician:
No, there are cows in Scotland of which one at least is brown!

Computer Scientist:
No, there is at least one cow in Scotland, which is brown on one side!!

Specification: Putting it into Practice

Example

A Sorting Program:

```
public static Integer[] sort(Integer[] a) { ...
    }
```

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- $\texttt{sort}(\{3,2,5\}) == \{2,3,5\}$ ✔

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public static Integer[] sort(Integer[] a) { ...
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Testing `sort()`:

- sort({3, 2, 5}) == {2, 3, 5} ✔
- sort({}) == {} ✔

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Example

A Sorting Program:

```
public static Integer[] sort(Integer[] a) { ...
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Testing `sort()`:

- sort($\{3,2,5\}$) == $\{2,3,5\}$ ✔
- sort($\{\}$) == $\{\}$ ✔
- sort($\{17\}$) == $\{17\}$ ✔

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- $\texttt{sort}(\{3, 2, 5\}) == \{2, 3, 5\}$ ✔
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Specification?

Specification: Putting it into Practice

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Specification

Requires: `a` *is an array of integers*
Ensures: *returns the sorted argument array* `a`

Example Cont'd

Example

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public static Integer[] sort(Integer[] a) { ...
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Specification

Requires: a *is an array of integers*
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Is this a good specification?

Example Cont'd

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Specification

Requires: `a` *is an array of integers*
Ensures: *returns the sorted argument array* `a`
Is this a good specification?

$\mathrm{sort}(\{2,1,2\}) == \{1,2,2,17\}$ ✘

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ...
    }
```

Specification

Requires: `a` *is an array of integers*
Ensures: *returns a sorted array with only elements from* `a`

Example Cont'd

Example

```java
public static Integer[] sort(Integer[] a) { ... }
```

Specification

Requires: `a` *is an array of integers*

Ensures: *returns a sorted array with only elements from* `a`

$\mathtt{sort}(\{2, 1, 2\}) == \{1, 1, 2\}$ ✘

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ...
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Specification

Requires: a *is an array of integers*
Ensures: *returns a permutation of* a *that is sorted*

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ... }
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Specification

Requires: `a` *is an array of integers*
Ensures: *returns a permutation of* `a` *that is sorted*

`sort(null)` throws `NullPointerException` ✘

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ... }
```

Specification

Requires: `a` *is a non-null array of integers*
Ensures: *returns a permutation of* `a` *that is sorted*

Example Cont'd

Example

```
public static Integer[] sort(Integer[] a) { ... }
```

Specification

Requires: `a` *is a non-null array of integers*

Ensures: *returns the unchanged reference* `a` *containing a permutation of the old contents of* `a` *that is sorted*

The Contract Metaphor

Contract is preferred specification metaphor for procedural and OO PLs

first propagated by B. Meyer, *Computer* 25(10)40–51, 1992

Same Principles as Legal Contract between a Client and Supplier

- **Supplier** aka Implementer, in JAVA, a class or method
- **Client** Mostly a caller object, or human user for `main()`
- **Contract** One or more pairs of ensures/requires clauses defining mutual benefits and obligations of client and implementer

The Meaning of a Contract

Specification (of method `C::m()`)

Requires: *Precondition*
Ensures: *Postcondition*

"If a caller of `C::m()` fulfills the required Precondition, then the class `C` ensures that the Postcondition holds after `m()` finishes."

The Meaning of a Contract

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"If a caller of `C::m()` fulfills the required Precondition, then the class `C` ensures that the Postcondition holds after `m()` finishes."

Often the following wrong interpretations of contracts are seen:

Wrong!

"Any caller of `C::m()` must fulfill the required Precondition."

Wrong!

"Whenever the required Precondition holds, then `C::m()` is executed."

Failure

Definition: failure

A method fails if it is called in a state fulfilling the required precondition of its contract and does not terminate in a state fulfilling the postcondition.

Non-termination, abnormal termination considered as failures here

Notions of Correctness

Definition: partial correctness

A method is partially correct if whenever it is started in a state fulfilling the required precondition and it terminates, then its final state fulfills the postcondition.

This amounts to proving Absence of Failures!

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Definition: total correctness

A method is totally correct if whenever it is started in a state fulfilling the required precondition, then it terminates and its final state fulfills the postcondition.

Total correctness implies termination!

Invariant

Objects with non-trivial state

often maintain a class invariant.

Example: a class for dates

```
public class Date {
  public int day;
  public int month;
  public int year;
}
```

Invariant:

```
1 <= day <= 31 /\ 1 <= month <= 12 /\
(month in {4, 6, 9, 11} => day <= 30) /\
(month == 2 => day <= 29) /\
(month == 2 /\ (year % 4 != 0 \/ (year % 100 == 0 /\ year %
       => day <= 28)
```

Invariant II

- All public methods of a class must preserve the class invariant.
- Class invariants can be incorporated into pre- and postconditions.

Specification (of a method)

Requires: *Precondition and Invariant*
Ensures: *Postcondition and Invariant*

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Specification (of a method)

Requires: *Precondition and Invariant*
Ensures: *Postcondition and Invariant*

Specification (of a constructor)

Requires: *Precondition*
Ensures: *Invariant*

Further Elements of a Contract

Type signature (minimal contract)

Exceptions raised

Temporal properties

- the capacity of the table does not change over time
- a set that is only supposed to grow

Testing vs. Verification

TESTING

Goal: find evidence for presence of failures

Testing: execute a program with the intent of detecting failure

Testing cannot guarantee correctness, i.e., absence of failures

Related techniques: code reviews, program inspections

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VERIFICATION

Goal: find evidence for absence of failures

Verification guarantees correctness

Related techniques: code generation, program synthesis (from spec)

Debugging: from Failures to Defects

- Both, testing and verification attempts exhibit new failures
- Debugging is a systematic process that finds and eliminates the defect that led to an observed failure
- Programs without known failures may still contain defects:
  - if they have not been verified
  - if they have been verified,
    but the failure is not covered by the specification

Where Formalization Comes In

Testing is very expensive, even with tool support

30–80% of development time goes into testing

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Test cases

↓

Code under test

↑

Code checking success

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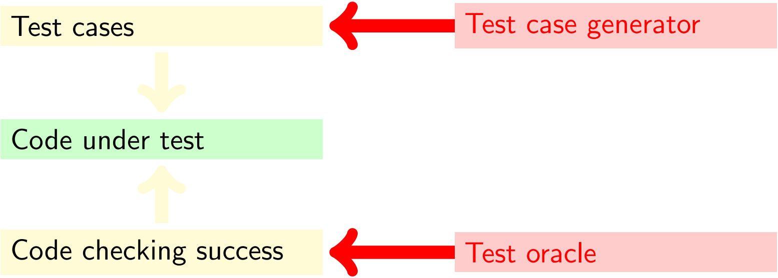

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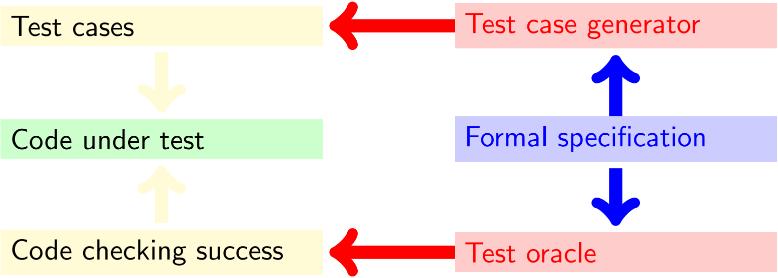
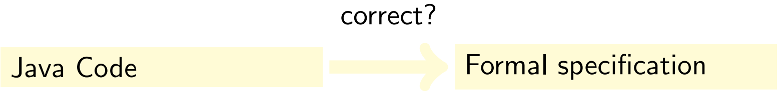


Formal Verification of Program Correctness

Java Code

Formal specification

Formal Verification of Program Correctness



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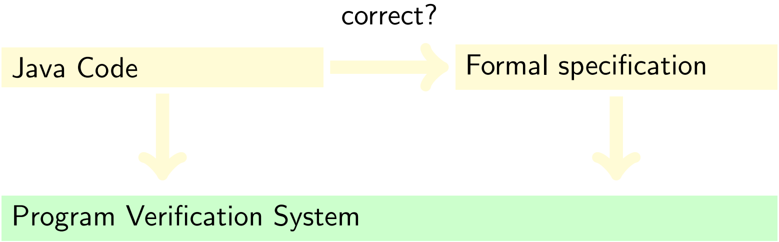

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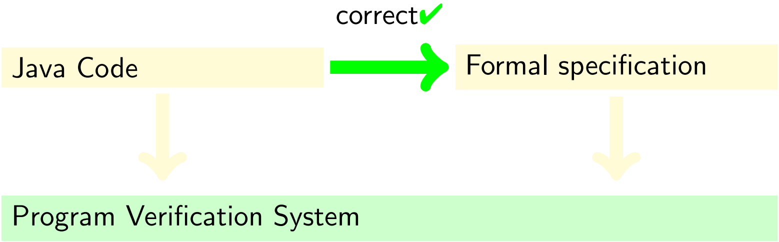

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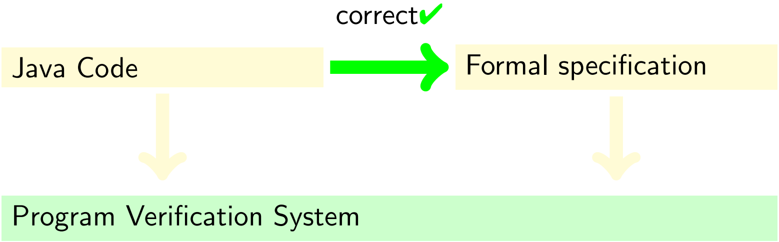

Computer support essential for verification of real programs

`synchronized java.lang.StringBuffer append(char c)`

- ca. 15.000 proof steps
- ca. 200 case distinctions
- Two human interactions, ca. 1 minute computing time

Tool Support is Essential

Some Reasons for Using Tools

- Automate repetitive tasks
- Avoid typos, etc.
- Cope with large programs

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Tools Used

- Automated running of tests: JUnit
- Debugging: Eclipse debugger