Software Architecture

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Lecture 10: Testing Object-Oriented Software

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Introduction (1)

(Geoffrey James –*The Zen of Programming*, 1988)

"Thus spoke the master: "Any program, no matter how small, contains bugs."

The novice did not believe the master's words. "What if the program were so small that it performed a single function?" he asked.

"Such a program would have no meaning," said the master, "but if such a one existed, the operating system would fail eventually, producing a bug."

But the novice was not satisfied. "What if the operating system did not fail?" he asked.

Introduction (2)

"There is no operating system that does not fail," said the master, "but if such a one existed, the hardware would fail eventually, producing a bug."

The novice still was not satisfied. "What if the hardware did not fail?" he asked.

The master gave a great sigh. "There is no hardware that does not fail", he said, "but if such a one existed, the user would want the program to do something different, and this too is a bug."

A program without bugs would be an absurdity, a nonesuch. If there were a program without any bugs then the world would cease to exist."

Agenda for today

- What testing is and what it is not
- Terminology
  - bugs
  - types of tests
  - components of a test
- Partition testing
- Black-box vs white-box testing
- Measuring test quality
  - code coverage
  - mutation testing
- Testing strategy
- Test-driven development
- Test automation
- Contract-based testing

Assignment 3: Testing

- http://se.inf.ethz.ch/teaching/ss2006/0050/exercises/exercise3.pdf
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A definition

"Software testing is the execution of code using combinations of input and state selected to reveal bugs."

"Software testing […] is the design and implementation of a special kind of software system: one that exercises another software system with the intent of finding bugs."

R. V. Binder, *Testing Object-Oriented Systems: Models, Patterns, and Tools* (1999)

What does testing involve?

- Determine the parts of the system to be tested
- Find input values which should bring significant information
- Run the software on the input values
- Compare the produced results to the expected ones
- (Measure execution characteristics: time, memory used, etc)

Some more insight into the situation

"Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence."

E. Dijkstra, *Structured Programming* (1972)

What testing can do: find bugs

What testing cannot do: prove the absence of bugs

What testing is not

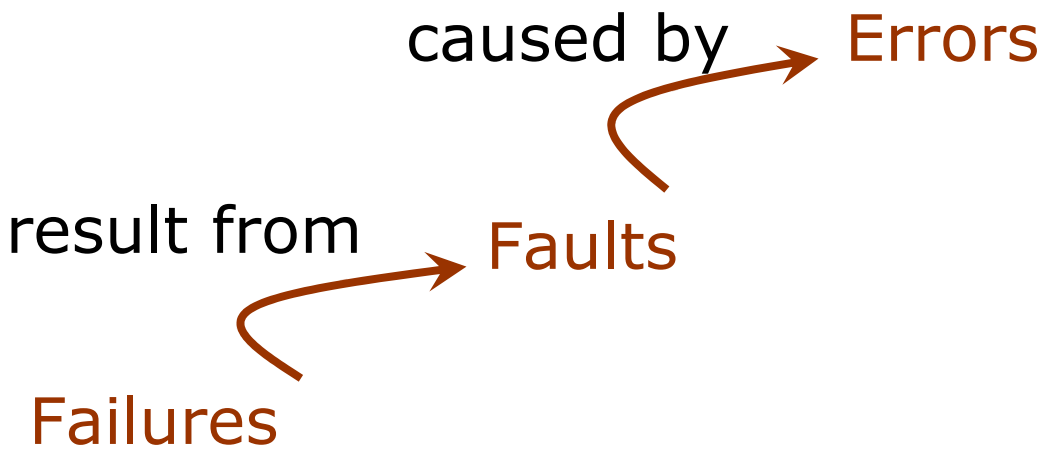
- Testing ≠ debugging
  - When testing uncovers an error, debugging is the process of removing that error
- Testing ≠ program proving
  - Formal correctness proofs are mathematical proofs of the equivalence between the specification and the program

Common abbreviations

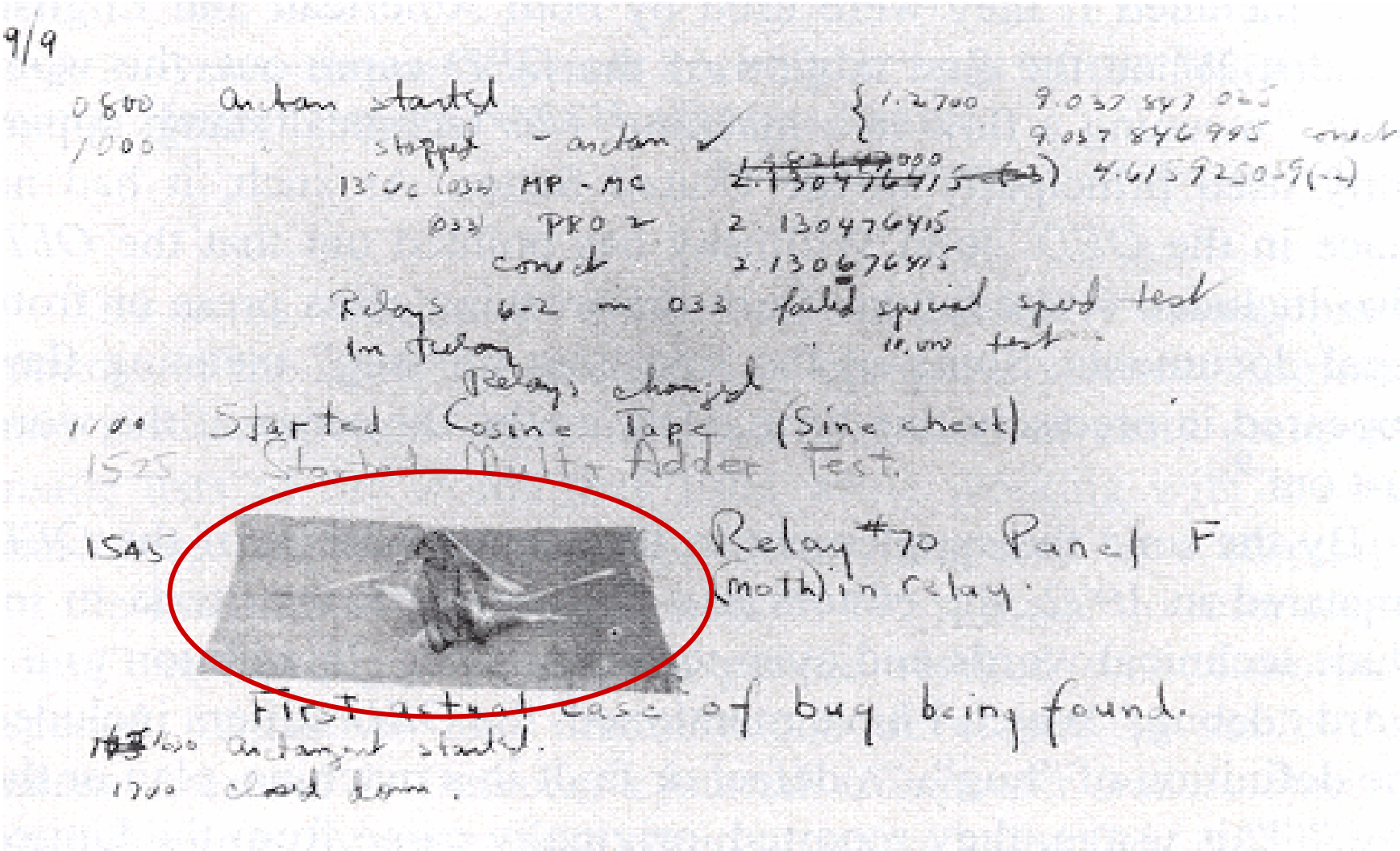
- IUT – implementation under test
- MUT – method under test
- OUT – object under test
- CUT – class/component under test
- SUT – system under test

Bug-related terminology

- Failure – manifested inability of the IUT to perform a required function; evidenced by:
  - Incorrect output
  - Abnormal termination
  - Unmet time or space constraints
- Fault – incorrect or missing code
  - Execution may result in a failure
- Error – human action that produces a software fault
- Bug – error or fault



Hopper's bug


9/9
0800 Arctan started
1000 " stopped - arctan ✓
1300 MP - MC
033 PRO 2
cond
Relays 6-2 in 033 failed special speed test
In relay
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Multy Adder Test.
1545
Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1700 closed down.

Dijkstra's criticism of the word "bug"

We could, for instance, begin with cleaning up our language by no longer calling a bug "a bug" but by calling it an error. It is much more honest because it squarely puts the blame where it belongs, with the programmer who made the error. The animistic metaphor of the bug that maliciously sneaked in while the programmer was not looking is intellectually dishonest as it is a disguise that the error is the programmer's own creation. The nice thing about this simple change of vocabulary is that it has such a profound effect. While, before, a program with only one bug used to be "almost correct", afterwards a program with an error is just "wrong"…

E. Dijkstra, *On the cruelty of really teaching computer science* (December 1989)

Testing scope

- Unit test – typically a relatively small executable
- Integration test – a complete system or subsystem of software and hardware units
  - Exercises interfaces between units to demonstrate that they are collectively operable
- System test – a complete integrated application
  - Focuses on characteristics that are present only at the level of the entire system
  - Categories: functional, performance, stress or load

Intent (1)

- Fault-directed testing – reveal faults through failures
  - Unit and integration testing
- Conformance-directed testing – to demonstrate conformance to required capabilities
  - System testing
- Acceptance testing – enable a user/customer to decide whether to accept a software product

Intent (2)

- Regression testing – retesting a previously tested program following modification to ensure that faults have not been introduced or uncovered as a result of the changes made
- Mutation testing – purposely introducing faults in the software in order to estimate the quality of the tests

Components of a test

- Test case – specifies:
  - The state of the IUT and its environment before test execution
  - The test inputs
  - The expected result
- Expected results – what the IUT should produce:
  - Returned values
  - Messages
  - Exceptions
  - Resultant state of the IUT and its environment
- Oracle – produces the results expected for a test case
  - Can also make a pass/no pass evaluation

Test execution

- Test suite – collection of test cases
- Test driver – class or utility program that applies test cases to an IUT
- Stub – partial, temporary implementation of a component
  - May serve as a placeholder for an incomplete component or implement testing support code
- Test harness – a system of test drivers and other tools to support test execution

Partition testing

- Partition – divides the input space into groups which hopefully have the property that any value in the group will produce a failure if a bug exists in the code related to that partition
- Examples of partition testing:
  - Equivalence class – a set of input values so that if any value in the set is processed correctly (incorrectly) then any other value in the set will be processed correctly (incorrectly)
  - Boundary value analysis
  - Special values testing

Choosing values

- Each Choice (EC): A value from each set for each input parameter must be used in at least one test case.

- All Combinations (AC): A value from each set for each input parameter must be used with a value from every set for every other input parameter.

Partition testing: conclusions

- Applicable to all levels of testing – unit, class, integration, system, etc.
- Divides the input space of the program into partitions, based on the specification and/or on the implementation
- It's probably what you're doing unconsciously anyway

Black box vs white box testing (1)

Black box testing	White box testing
Uses no knowledge of the internals of the SUT	Uses knowledge of the internal structure and implementation of the SUT
Also known as responsibility-based testing and functional testing	Also known as implementation-based testing or structural testing
Goal: to test how well the SUT conforms to its requirements (Cover all the requirements)	Goal: to test that all paths in the code run correctly (Cover all the code)

Black box vs white box testing (2)

Black box testing	White box testing
Uses no knowledge of the program except its specification	Relies on source code analysis to design test cases
Typically used in integration and system testing	Typically used in unit testing
Can also be done by user	Typically done by programmer

White box testing

- Allows you to look inside the box
- Some people prefer “glass box” or “clear box” testing

Measures of test quality

- Code coverage
- Data coverage
- Specification coverage
- Mutation testing

Coverage

- General notion expressing a percentage of elements (defined by a test strategy) exercised by a test suite
- A certain coverage measure is achieved by a test suite if 100% of the required elements have been exercised
  - e.g.: "*This test suite achieves statement coverage for method* `m`"

    $\Rightarrow$ every statement in method `m` is executed by at least one test case in the test suite

Code coverage

- Code coverage - how much of your code is exercised by your tests

- Code coverage analysis = the process of:
  - Computing a measure of coverage (which is a measure of test suite quality)
  - Finding sections of code not exercised by test cases
  - Creating additional test cases to increase coverage

Code coverage analyzer

- Tool that automatically computes the coverage achieved by a test suite

- Steps involved:
  1. Source code is instrumented by inserting trace statements.
  2. When the instrumented code is run, the trace statements produce a trace file.
  3. The analyzer parses the trace file and produces a coverage report (example).

Basic measures of code coverage

- Statement coverage – reports whether each executable statement is encountered
  - Disadvantage: insensitive to some control structures
- Decision coverage – reports whether boolean expressions tested in control structures evaluate to both true and false
  - Also known as branch coverage
- Condition coverage – reports whether each boolean sub-expression (separated by logical-and or logical-or) evaluates to both true and false
- Path coverage – reports whether each of the possible paths in each function has been tested
  - Path = unique sequence of branches from the function entry to the exit point

Mutation testing

- Idea: make small changes to the program source code (so that the modified versions still compile) and see if your test cases fail for the modified versions

- Purpose: estimate the quality of your test suite

Terminology

- Faulty versions of the program = mutants
  - We only consider mutants that are not equivalent to the original program!
- A mutant is said to be killed if at least one test case detects the fault injected into the mutant
- A mutant is said to be alive if no test case detects the injected fault
- A mutation score (MS) is associated to the test set to measure its effectiveness
- A test set is relatively adequate if it distinguishes the original program from all its non-equivalent mutants

Mutation operators

- Mutation operator = a rule that specifies a syntactic variation of the program text so that the modified program still compiles
- Mutant = the result of an application of a mutation operator
- The quality of the mutation operators determines the quality of the mutation testing process.
- Mutation operator coverage (MOC): For each mutation operator, create a mutant using that mutation operator.

Examples of mutants

Original program:

```
if (a < b)
        b := b – a;
else
        b := 0;
```

Mutants:

```
if (a < b)
if (a <= b)
if (a > b)
if (c < b)
        b := b – a;
        b := b + a;
        b := x – a;
else
        b := 0;
        b := 1;
        a := 0;
```

System test quality (STQ)

- S - system composed of n components denoted C_i, $i \in [1..n]$
- d_i - number of killed mutants after applying the unit test sequence to C_i
- m_i - total number of mutants of C_i
- the mutation score MS for C_i being given a unit test sequence T_i:

$$MS(C_i, T_i) = d_i / m_i$$

- $STQ(S) = \dfrac{\sum_{i=1,n} d_i}{\sum_{i=1,n} m_i}$

- STQ is a combined measure of test suite quality and contract quality

Testing strategy

How to plan and structure the testing of a large program:

- Who is testing?
  - Developers / special testing teams / customer
  - It is hard to test your own code
- What test levels are needed?
  - Unit, integration, system, acceptance, regression test
- How is it done in practice?
  - Manual testing
  - Testing tools
  - Automatic testing

Tom Van Vleck, *ACM SIGSOFT Software Engineering Notes*, 14/5, July 1989

Testing and bug prevention

"*Three questions about each bug you find*" (Van Vleck):

- "*Is this mistake somewhere else also?*"
- "*What next bug is hidden behind this one?*"
- "*What should I do to prevent bugs like this?*"

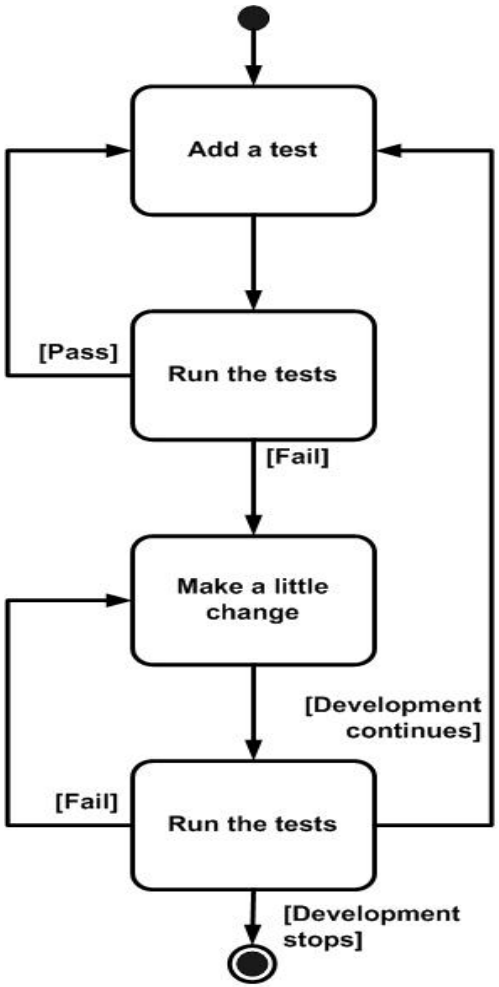
Test-driven development (TDD)

- Software development methodology
- One of the core practices of extreme programming (XP)
- Steps:
  1. Write a small test.
  2. Write enough code to make the test succeed.
  3. Clean up the code.
  4. Repeat.
- The testing in TDD is unit testing + acceptance testing
- Always used together with xunit

Test-driven development (TDD)

- Evolutionary approach to development
- Combines
  - Test-first development
  - Refactoring
- Primarily a method of software design
  - Not just method of testing

TDD 1: test-first development (TFD)



TDD 2: refactoring

A change to the system that leaves its behavior unchanged, but enhances some non-functional qualities:

- Simplicity
- Understandability
- Performance

Refactoring does not fix bugs or add new functionality.

TDD & traditional testing

TDD is a programming technique that ensures that source code is thoroughly unit tested

Need remains for:

- Functional testing
- User acceptance testing
- System integration testing

XP suggests these tests should also occur early

xunit

- The generic name for any test automation framework for unit testing
  - Test automation framework – provides all the mechanisms needed to run tests so that only the test-specific logic needs to be provided by the test writer
- Implemented in all the major programming languages:
  - JUnit – for Java
  - cppunit – for C++
  - SUnit – for Smalltalk (the first one)
  - PyUnit – for Python
  - vbUnit – for Visual Basic

JUnit: Overview

- Provides a framework for running test cases
- Test cases
  - Written manually
  - Normal classes, with annotated methods
- Input values and expected results defined by the tester
- Execution is the only automated step

JUnit: Resources

- Unit testing framework for Java
- Written by Erich Gamma and Kent Beck
- Open source (CPL 1.0), hosted on SourceForge
- Current version: 4.0
- Available at: www.junit.org
- Very good introduction for JUnit 3.8: Erich Gamma, Kent Beck, *JUnit Test Infected: Programmers Love Writing Tests*, available at http://junit.sourceforge.net/doc/testinfected/testing.htm
- For JUnit 4.0: Erich Gamma, Kent Beck, *JUnit Cookbook*, available at http://junit.sourceforge.net/doc/cookbook/cookbook.htm

Push-button testing

- Never write a test case, a test suite, a test oracle, or a test driver
- Automatically generate
  - Objects
  - Feature calls
  - Evaluation and saving of results
- The user must only specify the SUT and the tool does the rest (test generation, execution and result evaluation)

Design by Contract™ and testing

"*Design by Contract implemented with assertions is a straightforward and effective approach to built-in test. Not only does this strategy make testing more efficient, but it is also a powerful bug prevention technique.*"

R. V. Binder, *Testing Object-Oriented Systems: Models, Patterns, and Tools* (1999)

Run-time contract monitoring

A contract violation always signals a bug:

- Precondition violation: bug in client
- Postcondition violation: bug in routine

Assertions as built-in test (BIT)

- Must be executable
- An executable assertion has 3 parts:
  - A predicate expression
    In Eiffel: boolean expression + **`old`** notation
  - An action
    Executed when an assertion violation occurs
  - An enable/disable mechanism

Benefits and limitations of assertions as BIT

- Advantages:
  - BIT can evaluate the internal state of an object without breaking encapsulation
  - Contracts written before or together with implementation
- Limitations inherent to assertions
  - Frame problem

- The quality of the test is only as good as the quality of the assertions

Errors in the testing system

- Bugs in test design
- Bugs in oracle (faulty contracts)
  - Unsatisfiable contracts
  - Omissions in contracts
  - Incorrect translation of the specification into contracts
- Bugs in test driver

Reference texts for testing (1)

- OO testing "bible":

  Robert V. Binder: *Testing Object-Oriented Systems: Models, Patterns, and Tools*, 1999
- Glenford J. Myers: *The Art of Software Testing*, Wiley, 1979
- Paul Ammann and Jeff Offutt, *Introduction to Software Testing*, in preparation
- Writing unit tests with JUnit:

  Erich Gamma and Kent Beck: *Test Infected: Programmers Love Writing Tests*
  http://junit.sourceforge.net/doc/testinfected/testing.htm
- Code coverage:

  http://www.bullseye.com/coverage.html
- Mutation testing:

  Jezequel, J. M., Deveaux, D. and Le Traon, Y. *Reliable Objects: a Lightweight Approach Applied to Java*. In IEEE Software, 18, 4, (July/August 2001) 76-83

Reference texts for testing (2)

- Test-driven development:
  - Kent Beck: *Agile software development : principles, patterns, and practices*, Addison-Wesley, 2003
  - Astels: *Test Driven Development: A Practical Guide*, Prentice Hall, 2003
  - Kent Beck: *Extreme Programming Explained*, Addison-Wesley, 2000
  - Bertrand Meyer: *Practice to perfect: the quality first model*, IEEE Computer, 30, 5, pages 102-103, 105-106, 1997

Testing tools references

- JUnit: http://www.junit.org/index.htm
- Gobo Eiffel Test: http://www.gobosoft.com/eiffel/gobo/getest/
- AutoTest: http://se.inf.ethz.ch/people/leitner/auto_test/

End of lecture 10

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