Lecture 01: Introduction to Software Testing

Dietmar Pfahl
email: dietmar.pfahl@ut.ee

Spring 2022
Structure of Lecture 1

• Introduction and Motivation
• Course Information
• Basic Vocabulary
• Lab 1
2012: Knight Capital loses 440M USD

- August 12th: New Trading Software installed
- Administrator forgets to deploy on one out of eighth server nodes
- New code repurposed a flag previously used for testing scenarios
- On that one server node, old trading algorithm interprets flag differently and starts buying and selling 100 different stocks randomly without human verification
- NYSE has to suspend trade of several stocks
- Knight Capital loses 440 Mio USD in only 30 minutes, until system is suspended
- Investors have to raise 400 Mio USD in order to rescue the company
Uber’s car fatal car crash in Arizona, 2018

“The fatal crash that killed pedestrian Elaine Herzberg in Tempe, Arizona, in March occurred because of a software bug in Uber's self-driving car technology (...). According to two anonymous sources (...), Uber's sensors did, in fact, detect Herzberg as she crossed the street with her bicycle. Unfortunately, the software classified her as a "false positive" and decided it didn't need to stop for her.

Distinguishing between real objects and illusory ones is one of the most basic challenges of developing self-driving car software. Software needs to detect objects like cars, pedestrians, and large rocks in its path and stop or swerve to avoid them. However, there may be other objects—like a plastic bag in the road or a trash can on the sidewalk—that a car can safely ignore. Sensor anomalies may also cause software to detect apparent objects where no objects actually exist.

Software designers face a basic tradeoff here. If the software is programmed to be too cautious, the ride will be slow and jerky, as the car constantly slows down for objects that pose no threat to the car or aren't there at all. Tuning the software in the opposite direction will produce a smooth ride most of the time—but at the risk that the software will occasionally ignore a real object.”

List of SW Problems from Guru99 /1

Source: https://www.guru99.com/software-testing-introduction-importance.html

- In April 2015, Bloomberg terminal in London crashed due to software glitch affected more than 300,000 traders on financial markets. It forced the government to postpone a 3bn pound debt sale.

- Nissan cars have to recall over 1 million cars from the market due to software failure in the airbag sensory detectors. There has been reported two accident due to this software failure.

- Starbucks was forced to close about 60 percent of stores in the U.S and Canada due to software failure in its POS system. At one point store served coffee for free as they were unable to process the transaction.
List of SW Problems from Guru99 /2

Source: https://www.guru99.com/software-testing-introduction-importance.html

- Some of the Amazon’s third party retailers saw their product price is reduced to 1p due to a software glitch. They were left with heavy losses.

- Vulnerability in Window 10. This bug enables users to escape from security sandboxes through a flaw in the win32k system.

- In 2015, fighter plane F-35 fell victim to a software bug, making it unable to detect targets correctly.

- In may of 1996, a software bug caused the bank accounts of 823 customers of a major U.S. bank to be credited with 920 million US dollars.
List of SW Problems from Guru99 /3

Source: https://www.guru99.com/software-testing-introduction-importance.html

- In April of 1999, a software bug caused the failure of a $1.2 billion military satellite launch, the costliest accident in history.
- China Airlines Airbus A300 crashed due to a software bug on April 26, 1994, killing 264 persons.
- In 1985, Canada's Therac-25 radiation therapy machine malfunctioned due to software bug and delivered lethal radiation doses to patients, leaving 3 people dead and critically injuring 3 others.
Heartbleed Vulnerability – 2014

• The Heartbleed bug was a serious flaw in OpenSSL, an encryption software that powers a lot of secure communications on the web. It was announced by computer security researchers on April 7, 2014.
  – The protocol is widely used in applications such as email, instant messaging, and voice over IP, but its use in securing HTTPS remains the most publicly visible.
  – Secure Sockets Layer (SSL) has been replaced by Transport Layer Security (TLS)

• Companies affected by the vulnerability:
  – Tumblr, Google, Yahoo, Intuit, Dropbox, Netflix, and Facebook …

Source: https://www.vox.com/2014/6/19/18076318/heartbleed
Heartbleed Vulnerability – What is it?

The SSL standard includes a "heartbeat" option, which provides a way for a computer at one end of the SSL connection to double-check that there's still someone at the other end of the line (so the router does not drop the connection for being idle too long).

![Diagram showing the heartbeat process between a user and a server. The user asks, "Are you there? The magic word is "banana," which is 6 characters long." The server responds, "Yes I'm here. Your magic word was "banana.""

Source: [https://www.vox.com/2014/6/19/18076318/heartbleed](https://www.vox.com/2014/6/19/18076318/heartbleed)
Heartbleed Vulnerability – What is it?

• What problem could arise?

• How could the potential problem have been found by proper testing?
Heartbleed Vulnerability – What is it?

Obviously, the word "giraffe" isn't 100 characters long. But the server doesn't bother to check before sending back its response, so it sends back 100 characters. Specifically, it sends back the 7-character word "giraffe" followed by whichever 93 characters happen to be stored after the word "giraffe" in the server's memory.

Source: https://www.vox.com/2014/6/19/18076318/heartbleed
Heartbleed Vulnerability – How to fix it?

• The server just needs to be less trusting. Rather than blindly sending back as much data as is requested, the server needs to check that it's not being asked to send back more characters than it received in the first place.
  – That's exactly what OpenSSL's fix for the Heartbleed Bug does. See here: https://github.com.openssl/openssl/commit/96db9023b881d7cd9f379b0c154650d6c108e9a3#diff-2

• NB: A simple test that checks whether the parameters <word> and <length> match or whether the returned string has the same length as the sent word would have detected the problem.
What is Software Testing?
What is Software Testing? (Static & Dynamic)

Confirm quality (pass-test) vs.
Find defects (fail-test)
Cost of Testing / Cost of not Testing

2014 industrial survey of 1543 executives from 25 countries:
• Testing and quality assurance of software-intensive systems accounts for roughly 26% of IT budgets [1]

2013 study by researchers at the University of Cambridge:
• Global cost of locating and removing bugs from software has risen to $312 billion annually and it makes up half of the development time of the average project [2].

Sources:
Recall Exercise: A Pen

• Quality?

• Testing?
Software Quality – Definition

- **Software quality is the degree of conformance to explicit or implicit requirements and expectations**

Explanation:
- *Explicit*: clearly defined and documented
- *Implicit*: not clearly defined and documented but indirectly suggested
- *Requirements*: business/product/software requirements
- *Expectations*: mainly end-user expectations
Software Product Quality Model
– ISO 25010 Standard

Safety?
Software Product Quality Model
– ISO 25010 Standard
Software Quality Assurance (SQA)

versus

Software Quality Control (SQC)
Software Quality Assurance (SQA)

• **SQA is a set of activities for ensuring quality in software engineering processes (that ultimately result in quality in software products).**

   It includes the following activities:
   • Process definition
   • Process implementation
   • Auditing
   • Training

   Processes could be:
   - Software Development Methodology
   - Project Management
   - Configuration Management
   - Requirements Development/Management
   - Estimation
   - Software Design
   - Testing
   - ...
Software Quality Control (SQC)

- SQC is a set of activities for ensuring quality in software products.

It includes the following activities:
- Reviews
  - Requirement Review
  - Design Review
  - Code Review
  - Deployment Plan Review
  - Test Plan Review
  - Test Cases Review
- (Dynamic) Testing:
  - Unit Testing
  - Integration Testing
  - System Testing
  - Acceptance Testing
Verification versus Validation
Validation versus Verification

Requirements Backlog
(e.g., User Stories)

Work Product
Work Product
...

Development Process

End Product
(i.e., the Software that is delivered/deployed)
Validation versus Verification

Requirements Backlog
(e.g., User Stories)

Work Product

Work Product

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Development Process

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(i.e., the Software that is delivered/deployed)
Validation versus Verification

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Work Product

Work Product

Work Product

Development Process

End Product
(i.e., the Software that is delivered/deployed)


**Verification vs. Validation**

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**Legend**

- Executable Work Products
- Tests

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**Source:**
SEI at CMU, Donald Firesmith

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## Verification

### Definition
- The process of evaluating work-products (not the actual final product) of a development phase to determine whether they meet the specified requirements for that phase.

### Objective
- To ensure that the product is being built according to the requirements and design specifications. In other words, to ensure that work products meet their specified requirements.

### Question
- Are we building the product *right*?

<table>
<thead>
<tr>
<th>Evaluation Items:</th>
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<tbody>
<tr>
<td>- Plans, System requirement specs, Design Specs, Code, Test Cases</td>
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<table>
<thead>
<tr>
<th>Activities:</th>
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</thead>
<tbody>
<tr>
<td>- All kinds of reviews and testing with exception of user requirements review and acceptance testing</td>
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</table>
Validation

Definition
• The process of evaluating software during or at the end of the development process to determine whether it satisfies specified (or implicit) business requirements.

Objective
• To ensure that the product actually meets the user’s needs, and that the requirements were correct in the first place. In other words, to demonstrate that the product fulfills its intended use when placed in its intended environment.

Question
• Are we building the **right** product?

Evaluation Items:
- User requirements, Final product/software

Activities:
- Requirements review, Acceptance testing
Example:

- 30 variables, 2 levels
- Test all combinations

How long does it take to test, if 5 tests/sec can be executed automatically?

Answer choices:

1. Less than 10 sec
2. Less than 1 min
3. Less than 1 hour
4. Less than 1 day
5. Less than 1 year
6. More than 1 year
Test Complexity

Example:

- 30 variables, 2 levels
  -> $2^{30} \approx 10^9$ combinations to test
- 5 tests/second
  -> 2,147,483,648.8 sec or 6.8 years of testing!
How to test when correct SW output is unknown?

- Scientific calculations
- Artificial intelligence
- Simulation and modelling
How to test when correct SW output is unknown?

Idea: Metamorphic Testing
Example of Metamorphic Testing: Google Maps Navigator
Structure of Lecture 1

• Introduction and Motivation
• Course Information
• Basic Vocabulary
• Lab 1
Course Information/Overview

• Level: Course at bachelor's level (in English), 2\textsuperscript{nd} year
• Credits: 6 ECTS
• Prerequisite:
  – Compulsory: MTAT.03.094/LTAT.05.003 Software Engineering (6 ECTS)
  – Recommended: MTAT.03.130 Object-oriented Programming (6 ECTS)
• Work load:
  – Lectures (incl. practical work): 64 person-hours – incl. lab and exam sessions
  – Independent work (outside classroom): 92 person-hours
• Assessment:
  – 10 Homework Assignments (work in pairs) – 60\% of grade (~5 ph per lab = 55 ph)
  – 10 Quizzes (individual) – 10\% of grade (~10 ph)
  – Exam (written) – 30\% of grade (~27 ph)
• Grade scale: A (90\%+), B(80\%+), C(70\%+), D(60\%+), E(50\%+), F
Letter Grades

- **A** - An excellent performance, clearly outstanding. The candidate demonstrates excellent judgement and a high degree of independent thinking.

- **B** - A very good performance. The candidate demonstrates sound judgement and a very good degree of independent thinking.

- **C** - A good performance in most areas. The candidate demonstrates a reasonable degree of judgement and independent thinking in the most important areas.

- **D** - A satisfactory performance, but with significant shortcomings. The candidate demonstrates a limited degree of judgement and independent thinking.

- **E** - A performance that meets the minimum criteria, but no more. The candidate demonstrates a very limited degree of judgement and independent thinking.

- **F** - A performance that does not meet the minimum academic criteria. The candidate demonstrates an absence of both judgement and independent thinking.

ECTS recommended distribution:

A: 10%  B: 25%  C: 30%  D: 25%  E: 10%

ECTS = European Credit Transfer and Accumulation System
Lectures

- Lecture 1 (10.02) – Introduction to Software Testing
- Lecture 2 (17.02) – Basic Black-Box Testing Techniques: Boundary Value Analysis & Equivalence Class Partitioning
- Lecture 3 (03.03) – BBT advanced: Combinatorial Testing
- Lecture 4 (10.03) – Basic White-Box Testing Techniques: Control-Flow Coverage
- Lecture 5 (17.03) – BBT adv.: State-Transition, Metamorphic, Random Testing
- Lecture 6 (24.03) – Test Levels, Test Tools, Test Automation
- Lecture 7 (31.03) – BBT adv.: Exploratory Testing, Behaviour Testing
- Lecture 9 (14.04) – Security Testing of Mobile Applications
- Lecture 10 (21.04) – WBT adv.: Data-Flow Testing / Mutation Testing
- Lecture 12 (05.05) – Defect Estimation / Test Documentation, Organisation and Process Improvement (Test Maturity Model)
- Lecture 13 (12.05) – Exam Preparation
- Lecture 14 (19.05) – Advanced Topics (optional)
### Lectures / Labs (HW) / Quiz Schedule

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<tr>
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<td>Q 9</td>
<td>Q 10</td>
<td>Q 11</td>
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Lab Assignments (HW) to be submitted via course wiki
(1 week time / strict deadlines / 24 h grace period with penalty – afterwards 0 points / 10 best count)

Quizzes to be done in Moodle
(2 attempts / 15 min each / Thu 11:45 am – Mon 17:30 am / 10 best count)
Lab Sessions (Delta -... various rooms)

Preparation, Execution, Report – Work in Pairs

Lab 1 (week 26: Feb 22 & 23) - Debugging (9 marks)
Lab 2 (week 27: Mar 01 & 02) - Basic Black-Box-Testing (9 marks)
Lab 3 (week 28: Mar 08 & 09) - Combinatorial Testing (9 marks)
Lab 4 (week 29: Mar 15 & 16) - Basic White-Box Testing (9 marks)
Lab 5 (week 30: Mar 22 & 23) - Random Testing (9 marks)
Lab 6 (week 31: Mar 29 & 30) - Automated Web-App Testing (9 marks)

==========================================

Lab 7 (week 33: Apr 12 & 13) - Automated GUI || Visual Testing (9 marks)
Lab 8 (week 34: Apr 19 & 20) - Security Testing (9 marks)
Lab 9 (week 35: Apr 26 & 27) - Mutation Testing (9 marks)
Lab 10 (week 36: May 03 & 04) - Static Code Analysis (9 marks)
Lab 11 (week 37: May 10 & 11) - Doc Inspection and Defect Prediction (9 marks)

Send reports via submission button on course wiki before your next lab starts. Only PDF files will be accepted.
Attend Labs !!!!!

(if you don’t, you might not fully understand the HW assignment)
Final Exam

Written exam (30%)
• Based on textbook, lectures and lab sessions
• Open book & open laptop
• Any kind of communication with another person and/or copying from another person is considered cheating

Dates:
• Exam 1: Thursday, 19-May-2022 at 10:15-11:55 – room 1021 (via Moodle)
• Exam 2: Thursday, 26-May-2022, 16:15-17:55 – room 1021 (via Moodle)
• Retake Exam (resit): Monday, 13-June-2022 at 16:15-17:55, in room r1022 via Moodle
Books on SW Testing

Software Testing: From Theory to Practice
• By: Maurício Aniche and Arie van Deursen (TU Delft, The Netherlands)
  https://www.effective-software-testing.com

The Fuzzing Book - Tools and Techniques for Generating Software Tests
• By: Andreas Zeller, Rahul Gopinath, Marcel Böhme, Gordon Fraser, and Christian Holler
  Link: https://www.fuzzingbook.org

Introduction to Software Testing
• By: P. Ammann and J. Offutt
• Year 2017 (2nd ed.)
Software Testing 2021/22 spring

Software Testing

Course Responsible / Lecturer:
- Dietmar Pfahl (dietmar.pfahl at ut dot ee) - room: 3007 (Delta)

Additional Lecturer:
- Kristiina Rahnema

Lab Supervisors (TAs):
- Ezequiel Scott (ezequiel dot scott at ut dot ee) -- coordinator of labs (not teaching)
- Alejandra Duque Torres
- Karoline Holter
- Anna Talas
- Vimal Kumar Dwivedi
- Hina Anwar (back-up and coordinator of labs together with Ezequiel)
- Baseer Ahmad Baheer (back-up)

Lectures (begin in week 24 of the academic year, on 10-Feb-2022):
- Thursday 10:15 - 12:00, Narva mnt 18 - r1021 (Delta building)

Labs (practice learning; begin in week 26, on 22/23-Feb-2022):
- Group 1: Tuesday 10.15 - 11.45, Delta r2010 - TA: Alejandra Duque Torres
- Group 2: Tuesday 10.15 - 11.45, Delta r2034 - TA: Vimal Kumar Dwivedi
- Group 3: Tuesday 12.15 - 13.45, Delta r2010 - TA: Anna Talas
- Group 4: Tuesday 12.15 - 13.45, Delta r2034 - TA: Vimal Kumar Dwivedi
SIGN UP TO MESSAGE BOARD (Slack)

(if you don’t, you will miss up to date info)
Sign-Up Link for Slack

• Before the first labs start next week, please sign up to the course Slack channel. You will get your homework feedback exclusively via Slack from the lab supervisors.

Here is the sign-up link:

• <see link in email of Monday, Feb 7>
Handling of Plagiarism and Cheating

Since 60% of the final grade depends on the homework assignments, it is important that you solve the homework problems independently (in pairs). If we have a suspicion that complete solutions of homework assignments have been passed on to other students and then largely copied, then we inform you and allow you to clarify the issue in writing and in a follow-up face-to-face meeting.

If you have passed on your work to course mates or you copied from your course mates' work, you will get a penalty. In addition, you will be reported to the Vice Dean Academic Affairs. This procedure applies also in the case of cheating during the final exam.

If you feel that you have been unfairly treated then you have the right to submit an official appeal to the Vice Dean's office.

The official university rules can be found at the following link:
https://ut.ee/en/content/academic-fraud
Structure of Lecture 1

• Introduction and Motivation
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• Lab 1
Recall SE Lecture 9
Test Case

• A **Test Case** is a set of conditions or variables under which a tester will determine whether a system under test satisfies requirements or works correctly.

• Templates and examples of formal test case documentation can be found here:

  http://softwaretestingfundamentals.com/test-case/
Test Case

A **Test Case** consists of:
- A set of inputs + expected outputs
- Execution conditions

Example of ‘execution condition’:
When pressing the ‘save’ button of a word processor, what happens depends on what you did previously (e.g., what you typed in or deleted)

<table>
<thead>
<tr>
<th>Test Suite</th>
<th>set of Test Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Data</td>
<td>input to a Test Case</td>
</tr>
<tr>
<td>Test Oracle</td>
<td>condition that determines whether a test case passed or failed (-&gt; fail happens if actual output is different from expected output)</td>
</tr>
<tr>
<td>Test Verdict</td>
<td>decision of whether a test passed or failed</td>
</tr>
</tbody>
</table>
Test Case – Recommendations

• As far as possible, write test cases in such a way that you test only one thing at a time. Do not overlap or complicate test cases. Attempt to make your test cases ‘atomic’.

• Ensure that all positive scenarios and negative scenarios are covered.

• Language:
  • Write in simple and easy to understand language.
  • Use active voice: Do this, do that.
  • Use exact and consistent names (of forms, fields, etc).

• Characteristics of a good test case:
  • Accurate: Exacts the purpose.
  • Economical: No unnecessary steps or words.
  • Traceable: Capable of being traced to requirements.
  • Repeable: Can be used to perform the test over and over.
  • Reusable: Can be reused if necessary.
Test Script

- A **Test Script** is a set of instructions (written using a scripting/programming language) that is performed on a system under test to verify that the system performs as expected.
  - Test scripts are used in automated testing.

- Examples of Test Frameworks supporting test scripting:
  - JUnit, Selenium, Sikuli, …
Test Script – Examples

JUnit

```java
@Test
public void shortRegularRental() {
    Customer customer = new Customer("Cust");
    Movie movie = new Movie("Groundhog Day", REGULAR);
    Rental rental = new Rental(movie, 2); // 2 days rental = short
    customer.addRental(rental);

    String expected = "Rental Record for Cust\n";
    expected += "\tGroundhog Day\t2.0\n";
    expected += "Amount owed is 2.0\n";
    expected += "You earned 1 frequent renter points";

    Assert.assertEquals(expected, customer.statement());
}
```

Sikuli

```python
def sample_test_script(self):
    type ("TextA")
    click (ImageButtonA)
    assertExist (ImageResultA)
```

Input

<table>
<thead>
<tr>
<th>Input</th>
<th>Expected Output</th>
<th>Oracle</th>
<th>Actual Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

Oracle

<table>
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<tr>
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Actual Output

<table>
<thead>
<tr>
<th>Actual Output</th>
<th>Oracle</th>
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What is a ‘Bug’ in SE?
First ‘Computer Bug’ in 1947

The term "bug" was used in an account by computer pioneer Grace Hopper, who publicized the cause of a malfunction in an early electromechanical computer. (Harvard’s Mark II relay computer)

Source: https://en.wikipedia.org/wiki/Software_bug
What is a Bug in SE?

Error?

Fault?

if amountOf(baby) > 1
  answer = "Twins";
if equals(baby, baby1)
  answer = "Twins";
print(answer);
Definition 1: Error – Fault – Failure (according to IEEE Standard)

- **Failure** is an event caused by a **fault**, and a **fault** is an anomaly of the software caused by an **error**
  - **Error** – mistake made by human (e.g., programmer)
  - **Fault** – wrong/missing statement in the software (code)
  - **Failure** – inability to perform the program’s required functions (correctly)
  - Defect? – Bug?

- **Debugging** / Fault localization – localizing, repairing, re-testing.
Origins and Impact of Faults

Fault sources
- Lack of skills/training
- Oversight
- Poor communication
- ‘Lost in translation’
- Immature process

Fault context

Impact on / of software program

Errors → Faults → Failures

User’s point of view
- Poor quality software
- User dissatisfaction

Source:
Fig 3.1 in I. Burnstein: Practical Software Testing
Definition 2: Error – Fault – Failure
(as it is often used in IDEs/tools)

- **Failure** is an event caused by an **error**, **error** is a state of the program caused by a **fault** in the code
- **Fault** – wrong/missing statement in code (resulting in error)
- **Error** – incorrect program state (may result in a failure)
- **Failure** – inability to perform its required functions (correctly)
- Defect? – Bug?

- **Debugging** / Fault localization – localizing, repairing, re-testing.
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs: Correct (=Expected) result?
x = [2,7,0] Actual result?
x = [0,7,2] Fault? Error? Failure?

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

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public static int numZero (int[] x) {
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        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs: Correct (=Expected) result? 1
x = [2,7,0] Actual result? ?

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

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    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs:

<table>
<thead>
<tr>
<th>Correct (=Expected) result?</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x = [2,7,0]</td>
<td></td>
</tr>
<tr>
<td>Actual result?</td>
<td>1</td>
</tr>
</tbody>
</table>

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs:
- Correct (=Expected) result? 1
- Actual result? 1

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs:
- Correct (=Expected) result? 1
- x = [2,7,0] Actual result? 1
- Fault? Error? Failure? Yes / ? / No

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

**Example:**

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

**Inputs:**
- **Correct (=Expected) result?** 1
- **Actual result?** 1
- **Fault? Error? Failure?** Yes / Yes / No

**Program state:** x, i, count, PC
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    // else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs:

- Correct (=Expected) result?
- Actual result?

Values:

- x = [0,7,2]
- Fault? Error? Failure?

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs:

- Correct (=Expected) result? 1
- Actual result? 0

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the number of occurrences of 0 in x
    int count = 0;
    for (int i = 1; i < x.length; i++) {
        if (x[i] == 0) {
            count++;
        }
    }
    return count;
}
```

Inputs: Correct (=Expected) result? 1
        Actual result? 0
        x = [0,7,2] Fault? Error? Failure? Yes / Yes / Yes

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

We have seen ...

Fault = Yes
Error = Yes
------------------
Failure = No
or
Failure = Yes
Definition 2: Error – Fault – Failure

Could any of this happen?

Fault = No
Error = No
----------
Failure = No
or
Failure = Yes

Fault = No
Error = Yes
----------
Failure = No
or
Failure = Yes

Fault = Yes
Error = No
----------
Failure = No
or
Failure = Yes
### Definition 2: Error – Fault – Failure

Could any of this happen?

<table>
<thead>
<tr>
<th>Fault</th>
<th>Error</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Definition 2: Error – Fault – Failure

New Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the index of the 1st occurrence of 0 in x
    for (int i = 0; i < x.length-1; i++) {
        if (x[i] == 0) {
            return i;
        }
    }
    return -1;
}
```

Inputs:

Correct (=Expected) result?  
Actual result?  

x = [0,7,2]  
Fault? Error? Failure?  

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

New Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the index of the 1st occurrence of 0 in x

    for (int i = 0; i < x.length-1; i++) {
        if (x[i] == 0) {
            return i;
        }
    }
    return -1;
}
```

Inputs: Correct (=Expected) result? 0
        Actual result? 0

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

New Example:

```java
public static int numZero (int[] x) {
    // Effects: if x==null throw NullPointerException
    //          else return the index of the 1st occurrence of 0 in x
    for (int i = 0; i < x.length-1; i++) {
        if (x[i] == 0) {
            return i;
        }
    }
    return -1;
}
```

Inputs: Correct (=Expected) result? 0
Actual result? 0

x = [0,7,2] Fault? Error? Failure? Yes / No / No

Program state: x, i, count, PC
Definition 2: Error – Fault – Failure

Summary of the four possible situations:

Fault = No  
Error = No  
-----------------  
Failure = No

Fault = Yes  
Error = No  
-----------------  
Failure = No

Fault = Yes  
Error = Yes  
-----------------  
Failure = Yes

or

Fault = Yes  
Error = Yes  
-----------------  
Failure = No
Definition 2: Error – Fault – Failure

Summary of the four possible situations:

Fault = No  
Error = No  
Failure = No

Fault = Yes  
Error = No  
Failure = No

Fault = Yes  
Error = Yes  
Failure = No or Failure = No
Definition 2: Error – Fault – Failure

Summary of the four possible situations:

Fault = No  
Error = No  
Failure = No

Fault = Yes  
Error = No  
Failure = No

Fault = Yes  
Error = Yes  
Failure = Yes

Fault = Yes  
Error = Yes  
Failure = No

No failure when testing does not imply no fault or error!
Structure of Lecture 1

• Introduction and Motivation
• Course Information
• Basic Vocabulary
• Lab 1
HW 1 – Debugging

System 1
- Issue 1
- Issue 2
- Issue 3

System 2
- Issue 1
- Issue 2

Faults?
Faults?
Faults?
Faults?

Localization steps & heuristics for each fault

Use IntelliJ Debugger

Submission:
At 23:59 on day before next lab
HW 1 – Debugging

- Thought process for setting breakpoints and deciding where to step in next to see the program state.
Starting Point: Issue Report

- Example Report
  - Admin Data
  - Short Description
  - Reproduction Steps (input)
  - Expected vs Actual Result
  - Additional Information (screen shots, stack traces, etc.)
  - Comments / Discussion
Issue Report – Sys_1: HeapSort

- **Issue report 1:**
  
  **Description:**
  The program should heapify any given list of positive integers but the resulting tree (and list) does not meet the max binary heap structure.

  **Input:**
  heapifying a list of integers - [1, 2, 5, 7, 6, 8, 11, 10, 3, 4, 9, 1, 0]

  **Input code:**
  ```java
  System.out.println(heapList);
  Heap heap = new Heap(heapList);
  System.out.println("After heapifying: ");
  heap.printAsList();
  heap.printAsTree();
  ```

  **Expected output:**
  List before heapifying:
  [1, 2, 5, 7, 6, 8, 11, 10, 3, 4, 9, 1, 0]
  After heapifying:
  [11, 10, 8, 7, 9, 1, 5, 2, 3, 4, 6, 1, 0]

  **Actual output:**
  List before heapifying:
  [1, 2, 5, 7, 6, 8, 11, 10, 3, 4, 9, 1, 0]
  After heapifying:
  [11, 9, 5, 3, 9, 7, 1, 6, 3, 4, 2, 1, 0]
## System 1: HeapSort – Build the Heap

<table>
<thead>
<tr>
<th>Heap</th>
<th>New element</th>
<th>Swap elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>null</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6, 5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6, 5, 3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6, 5, 3, 1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>6, 5, 3, 1, 8</td>
<td>5, 8</td>
<td></td>
</tr>
<tr>
<td>6, 8, 3, 1, 5</td>
<td>6, 8</td>
<td></td>
</tr>
<tr>
<td>8, 6, 3, 1, 5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8, 6, 3, 1, 5, 7</td>
<td>7, 3</td>
<td></td>
</tr>
<tr>
<td>8, 6, 7, 1, 5, 3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>8, 6, 7, 1, 5, 3, 2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>8, 6, 7, 1, 5, 3, 2, 4</td>
<td>1, 4</td>
<td></td>
</tr>
<tr>
<td>8, 6, 7, 4, 5, 3, 2, 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

List to be sorted in ascending order:

\[ \{ 6, 5, 3, 1, 8, 7, 2, 4 \} \]

Heapified list:

\[ \{ 8, 6, 7, 4, 5, 3, 2, 1 \} \]
# System 1: HeapSort – Sorting /1

<table>
<thead>
<tr>
<th>Heap</th>
<th>Swap elements</th>
<th>Delete element</th>
<th>Sorted array</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>8, 6, 7, 4, 5, 3, 2, 1</td>
<td>8, 1</td>
<td></td>
<td></td>
<td>Swap 8 and 1 to delete 8 from heap</td>
</tr>
<tr>
<td>1, 6, 7, 4, 5, 3, 2, 8</td>
<td>8</td>
<td></td>
<td></td>
<td>Delete 8 from heap &amp; add to sorted array</td>
</tr>
<tr>
<td>1, 6, 7, 4, 5, 3, 2</td>
<td>1, 7</td>
<td></td>
<td>8</td>
<td>Swap 1 and 7 as they are not in order</td>
</tr>
<tr>
<td>7, 6, 1, 4, 5, 3, 2</td>
<td>1, 3</td>
<td></td>
<td>8</td>
<td>Swap 1 and 3 as they are not in order</td>
</tr>
<tr>
<td>7, 6, 3, 4, 5, 1, 2</td>
<td>7, 2</td>
<td></td>
<td>8</td>
<td>Swap 7 and 2 to delete 7 from heap</td>
</tr>
<tr>
<td>2, 6, 3, 4, 5, 1, 7</td>
<td>7</td>
<td></td>
<td>8</td>
<td>Delete 7 from heap &amp; add to sorted array</td>
</tr>
<tr>
<td>2, 6, 3, 4, 5, 1</td>
<td>2, 6</td>
<td></td>
<td>7, 8</td>
<td>Swap 2 and 6 as they are not in order</td>
</tr>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
</tbody>
</table>

*Note:* The table continues with similar operations, demonstrating the process of sorting an array using HeapSort.
## System 1: HeapSort – Sorting /2

<table>
<thead>
<tr>
<th>Heap</th>
<th>Swap elements</th>
<th>Delete element</th>
<th>Sorted array</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>3, 2, 1</td>
<td>3, 1</td>
<td></td>
<td>4, 5, 6, 7, 8</td>
<td>Swap 3 and 1 to delete 3 from heap</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td></td>
<td>3</td>
<td>4, 5, 6, 7, 8</td>
<td>Delete 3 from heap &amp; add to sorted array</td>
</tr>
<tr>
<td>1, 2</td>
<td>1, 2</td>
<td></td>
<td>3, 4, 5, 6, 7, 8</td>
<td>Swap 1 and 2 as they are not in order</td>
</tr>
<tr>
<td>2, 1</td>
<td>2, 1</td>
<td></td>
<td>3, 4, 5, 6, 7, 8</td>
<td>Swap 2 and 1 to delete 2 from heap</td>
</tr>
<tr>
<td>1, 2</td>
<td></td>
<td>2</td>
<td>3, 4, 5, 6, 7, 8</td>
<td>Delete 2 from heap &amp; add to sorted array</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td>2, 3, 4, 5, 6, 7, 8</td>
<td>Delete 1 from heap &amp; add to sorted array</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
<td>completed</td>
</tr>
</tbody>
</table>

https://en.wikipedia.org/wiki/Heapsort
Issue Report 1– Sys_2: 8-Queens Problem

- Issue report 1 (Hint: corresponds to 3 bugs)
  Description:
  When running the program, it should return a list of generations and the correct solution
  that it found. Instead, it throws an exception after 1000 generations.
  Input:
  Running the code with the population size of 100.
  Input code:
  ```
  Population pop = new Population(100);
  runAlgorithm(pop);
  ```
  Expected output:
  Generation: 1  Current highest fitness: <?>
  Generation: 2  Current highest fitness: <?>
  ...
  Found suitable board state on generation <?>: <[x1,x2,x3,x4,x5,x6,x7,x8]>
  Here is the found solution as a board where . marks an empty spot and, X marks a queen
  <printout of 1 correct solution of 92 possible>
  Actual output:
  Generation: 1  Current highest fitness: 22
  Generation: 2  Current highest fitness: 22
  Generation: 3  Current highest fitness: 26
  ...
  Generation: 1000  Current highest fitness: 38
Issue Report 1– Sys_2: 8-Queens Problem

• Issue report 1 (Hint: corresponds to 3 bugs)
  Description:
  When running the program, it should return a list of generations and the correct solution
  that it found. Instead, it throws an exception after 1000 generations.
  Input:
  Running the code with the population size of 100.
  Input code:
  ```java
  Population pop = new Population(100);
  runAlgorithm(pop);
  ```
  Expected output:
  Generation: 1  Current highest fitness: <?
  Generation: 2  Current highest fitness: <?
  ...
  Found suitable board state on generation <?>: <[x1,x2,x3]
  Here is the found solution as a board where . marks an e:
  <printout of 1 correct solution of 92 possible>
  Actual output:
  Generation: 1  Current highest fitness: 22
  Generation: 2  Current highest fitness: 22
  Generation: 3  Current highest fitness: 26
  ...
  Generation: 1000  Current highest fitness: 38

Exception in thread "main" java.lang.Exception: Didn't find solution in 1000 generations
  at Algorithm.generation(Algorithm.java:119)
  at Algorithm.generation(Algorithm.java:129)

Comments:
This issue might not be reproducible line-to-line due to randomness in the algorithm,
meaning the current highest fitness can vary. But the core of the issue is reproducible
(exception).

Hints:
1. There are 3 bugs that correspond to this issue
2. You can consider this issue fixed only when all 3 bugs have been fixed. In order to be
   sure that you have fixed the correct bugs, run the program multiple times. The expected
   output may sometimes be seen because of the randomness of the data, make sure that
   the correct output appears every time you run the program.
3. While you have not yet fixed all the bugs, depending on the order in which you find and
   fix them, you might see any of the following output:
   o The described exception is thrown.
   o The program outputs a board state that it claims to be correct. However, the
     board state is not correct as all the queens are positioned in one single diagonal
     on the board.
   o The program outputs a board state that it claims to be correct. However, the
     board state is not correct as there is at least one clash visible on the board.
Issue Report 2– Sys_2: 8-Queens Problem

• Issue report 2 (Hint: corresponds to 1 bug) (This issue appears after Issue 1 has been fixed)

Description:
Based on past projects using genetic algorithms, the average amount of generations should be less than 87 and the program should produce the correct output in less than 100 generations on at least 75% of the runs. However, the performance is much worse, the average amount of generations is over 100 and it only gets the solution in under 100 generations in less than 62% of the time. On very few runs, the program throws an exception of not finding a solution in under 1000 generations.

Input:
Calculated average amount of generations and percentage of runs where solution was found in under 100 generations with population size 100 and 1000 runs.

Input code:
```java
public static List<Integer> generationCounts = new ArrayList<>();
public static void main(String[] args) throws Exception {
    for (int i = 0; i<1000; i++) {
        pop = new Population(100);
        generation(pop);
        generationCounts.add(counter+1);
        counter = 0;
    }
    System.out.println(calculateAverage(generationCounts));
    System.out.println(calculatePercent(generationCounts));
    generationCounts.removeAll(generationCounts);
}
```
Issue Report 2– Sys_2: 8-Queens Problem

- Issue report 2 (Hint: corresponds to 1 bug) (This issue appears after Issue 1 has been fixed)

Description:
Based on past projects using genetic algorithms, the average amount of generations should be less than 87 and the program should produce the correct output in less than 100 generations on at least 75% of the runs. However, the performance is much worse, the average amount of generations is over 100 and it only gets the solution in under 100 generations in less than 62% of the time. On very few runs, the program throws an exception of not finding a solution in under 1000 generations.

Input:
Calculated average amount of generations and percent in under 100 generations with population size 100

Input code:
```java
public static List<Integer> generationCounts = new ArrayList<>();
public static void main(String[] args) throws Exception {
    for (int i = 0; i<1000; i++) {
        pop = new Population(100);
        generation(pop);
        generationCounts.add(counter+1);
        counter = 0;
    }
    System.out.println(calculateAverage(generationCounts));
    System.out.println(calculatePercent(generationCounts));
    generationCounts.remove(0);
}
```

Expected output:
```
. . . . . . . .
. X . . . . . .
X . . . . . . .
. . . . . . . X
. . . . . . . X
. . . . . . . X
. . . . . . . X
X . . . . . . .
```

Expected output:
```
Average generation count < 87
P(generation count<=100) > 75%

Actual output generalized and specific:
Average generation count > 87
P(generation count<=100) < 75%
Average generation count: 109.916
P(generation count <100): 57.7%

Comments and hints:
As performance can be affected by many things, the issue reporter has provided their own insight as a hint. You may use this, but don’t have to.

a) Genetic algorithms and their performance are strongly based on evaluations of states and fitness calculations.

b) It is important to check that the code does what the developer has intended it to do. To know what is intended, use Appendix A and helpful methods in the program (main class, the run<method_name>() methods)
Representation of Chess Board

5th row, 8th position
8th position = index 7

[ 2 4 1 6 7 0 2 3 ]

Queen
Genetic Algorithm

1. Start
2. Input: size of Population
3. Generate Population
4. Calculate fitness
5. Is there an Individual with fitness 0?
   - False: 7. Generate new Population
   - True: 6. End, print that Individual
Genetic Algorithm

Size = 4

Fitness of first individual?
+1 in the fitness function per each queen per each clash
**Genetic Algorithm**

Generate new population:
- Sort by fitness value
- Take upper half
- Then generate new board allocations based on allocation pairs in the upper half
Genetic Algorithm

Generate new population:

Size = 4
To Do & Next Week

• Quiz 1 (in Moodle!):
  – Opens after lecture – closes on Monday at 17:30!

• Lab/HW 1:
  – Debugging  In 2 Weeks! Tue/Wed

• Lecture 2:
  – Basic Black-Box and White-Box Testing Techniques (intro)