Lecture 02: Basic Black-Box Techniques

Spring 2022
Delta Career Day

Date: 3 March 2022
Time: 11:00–16:00
Venue: University of Tartu Academic Sports Club (Ujula 4, Tartu)
Organisers: University of Tartu Institute of Computer Science, School of Economics and Business Administration, Institute of Mathematics and Statistics

Every year the Institute of Computer Science hosts the Career Day. The purpose of the event is to bring together IT students and practical training and career opportunities offered by companies in the field. Before the event and also throughout the year companies are welcome to add their internship offers into our internship database.

The event will take place as a fair and enables the organisations to present their internship and career opportunities, using information materials in various formats (banners, videos, brochures, etc.) or interactive activities to engage students. Each organisation has a booth to meet University of Tartu students. In addition, organisations can introduce themselves in the lounge area with a short presentation, which will also be live broadcasted.

Come to the event when you are entirely healthy and if in doubt, do a quick test first. Be prepared to show your COVID certificate and ID at the door and always wear a mask.

https://delta.ut.ee/en/careerday/
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 8 (07.04) – BBT adv.: GUI / Visual Testing, Usability Testing, A/B Testing
• Lecture 9 (14.04) – Security Testing of Mobile Applications
• Lecture 10 (21.04) – WBT adv.: Data-Flow Testing / Mutation Testing
• Lecture 11 (28.04) – WBT adv.: Symbolic Execution, Static Code Analysis, Review
• 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)
Structure of Lecture 2

- Black-Box vs. White-Box Testing
- Basic Black-Box Testing Techniques
  - Equivalence Class Partitioning (ECP)
  - Boundary Value Analysis (BVA)
- Lab 1 + Lab 2
Testing is difficult

Assume a ‘magic’ Function $M$

$M(x, y) \rightarrow z$
with $x, y$: int (32 bit)

Exhaustive testing:
How many test cases,
If only valid input ($\rightarrow$ int) used?
Testing is difficult

Assume a ‘magic’ Function $M$

$M(x, y) \rightarrow z$

with $x, y$: int (32 bit)

Exhaustive pos. testing:

$2^{32} \times 2^{32}$

$= 2^{64} \sim 1.8 \times 10^{19}$ test cases (input data + expected output)
Testing is difficult

Assume a ’magic’ Function M

\[ M(x, y) \rightarrow z = \text{SUM}(x, y) \]

with \( x, y: \text{int (32 bit)} \)

Exhaustive pos. testing:

\[ 2^{32} \times 2^{32} \]

\[ = 2^{64} \approx 1.8 \times 10^{19} \text{ test cases (input data + expected output)} \]
Testing is difficult

Assume a ’magic’ Function M

\[ M(x, y) \rightarrow z = \text{SUM}(x, y) \]
with \(x, y: \text{int (32 bit)}\)

Possible approaches:

- ???

White Box

```c
... 
if ( x - 100 <= 0 ) {
    if ( y - 100 <= 0 ) {
        if ( x + y - 200 == 0 ) {
            z = x / (y - 100);
        }
    }
} 
} 
} 
z = x + y; ...
```

Malicious code!
Testing is difficult

Assume a ’magic’ Function $M$

$M(x, y) \rightarrow z = \text{SUM}(x, y)$

with $x, y: \text{int (32 bit)}$

Possible approaches:

- Execute each statement
- Read (review) code

```java
... 
if ( x - 100 <= 0 ) {
    if ( y - 100 <= 0 ) {
        if ( x + y - 200 == 0 ) {
            z = x / (y - 100);
        }
    }
}
} z = x + y; ...
```

How?
Testing is difficult

Assume a 'magic' Function $M$

$M(x, y) \rightarrow z = \text{SUM}(x, y)$

with $x, y$: int (32 bit)

1st if = true: $x \leq 100$
2nd if = true: $y \leq 100$
3rd if = true: $x + y = 200$

$M(100, 100) \rightarrow \text{crash}$

White Box

```plaintext
... 

if (x - 100 <= 0) {
    if (y - 100 <= 0) {
        if (x + y - 200 == 0) {
            z = x / (y - 100);
        }
    }
}

} z = x + y; ...
```
Black-Box vs. White-Box

External/user view:
- Check conformance with specification -> function coverage

Abstraction from details:
- Source code not needed

Scales up:
- Different techniques at different levels of granularity

USE

Internal/developer view:
- Allows tester to be confident about code coverage

Based on control and data flow:
- Easier debugging

Does not scale up:
- Most useful at unit & integration testing levels, as well as regression testing

BOTH!
Black-Box vs. White-Box

Gray-Box Testing

Combines black-box and white-box testing; typically, the focus is on input/output testing (black-box view) which is informed by structural information of the code (white-box view).

Example: The tester knows that certain constraints on the input are checked by the unit under test.

Application, e.g., in regression testing: apply (or update) black-box test cases only where code has been changed;

Different techniques at different levels of granularity

Most useful at unit & integration testing levels, as well as regression testing

USE BOTH!
Black-Box vs. White-Box

System

Specification

Implementation
Goal of BBT: Tries to check whether specified functionality is available and working correctly.
Black-Box vs. White-Box

Specification-based Testing:
Test against specification

System

Specification

Implementation

Goal of BBT: Tries to check whether specified functionality is available and working correctly

Unexpected functionality: Cannot be (directly) revealed by black-box techniques
Black-Box vs. White-Box

System

Specification

Implementation

Structural Testing: Test against implementation

Goal of WBT: Tries to check, whether the Implementation is working correctly (there is no dead code, it’s maintainable, etc.); useful for debugging;
Black-Box vs. White-Box

System

Specification

Implementation

Structural Testing: Test against implementation

Goal of WBT: Tries to check, whether the Implementation is working correctly (there is no dead code, it’s maintainable, etc.); useful for debugging;

Missing functionality: Cannot be (directly) revealed by white-box techniques
Black-Box vs. White-Box

Specification-based Testing: Test against specification

System

Specification

Implementation

Structural Testing: Test against implementation

Missing functionality: Cannot be (directly) revealed by white-box techniques

Unexpected functionality: Cannot be (directly) revealed by black-box techniques
How do Black-Box and White-Box Testing relate to one another?

1. Develop an initial Test suite using BB techniques
2. Analyze the parts of the code uncovered by BB test suite
3. Enhance the Test suite using WB techniques
4. Apply WB coverage criteria to enhance it
5. Apply BB coverage criteria to enhance it
Structure of Lecture 2

• Black-Box vs. White-Box Testing
• Basic Black-Box Testing Techniques
  • Equivalence Class Partitioning (ECP)
  • Boundary Value Analysis (BVA)
• Lab 1 + Lab 2
Basic Black-Box Testing Techniques

Following are two techniques that can be used for designing black box tests

- **Equivalence Class Partitioning**: It is a software test design technique “that divides the input data of a software unit into partitions of equivalent data from which test cases can be derived. In principle, test cases are designed to cover each partition at least once. (…) Equivalence partitioning is typically applied to the inputs of a tested component, but may be applied to the outputs in rare cases. The equivalence partitions are usually derived from the requirements specification for input attributes that influence the processing of the test object.” (Source: Wikipedia)

- **Boundary Value Analysis**: It is a software test design technique that involves determination of boundaries for input values and selecting values that are at the boundaries and just inside/outside of the boundaries as test data.
Black-Box Testing Techniques

- Equivalence class partitioning (ECP)
- Boundary value analysis (BVA)
- Cause-effect graphing
- Combinatorial testing
- State transition testing (State-based testing)
- Exploratory testing
- Usability testing
- A/B testing (UX)
Equivalence Class Partitioning (ECP)

- Split input space into classes which the software handles equivalently with regards to the output produced.

- Select test cases to cover each class.

*green area = valid
white area = invalid*
public static boolean adultFunction(int age) {
    boolean adult;
    if (age >= 18)
        adult = true;
    else
        adult = false;
    return adult;
}
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

What are the ECs?

green area = valid
white area = invalid
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

Note that this spec is rather vague:
• it is unclear at what age one is an adult
• It is unclear what happens, if invalid input is entered
• It is unclear whether certain plausibility checks about feasible ages are made, e.g.:
  • Can a person be older than 150 years?
ECP – Simple Example

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  • Can a person be older than 150 years?

Use own domain knowledge (adult age starts with 18)
Talk to developers and ask for clarification
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

Output 1 = ‘adult’ $\Rightarrow$ age $\geq$ 18
Output 2 = ‘not adult’ $\Rightarrow$ age $<$ 18

green area = valid
white area = invalid
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

Output 1 = ‘adult’ ➔ age in [18, 150]
Output 2 = ‘not adult’ ➔ age in [0, 18)
Output 3 = ‘invalid input’ ➔ age not in [0, 150]

green area = valid
white area = invalid

[18, 150]
[0, 18)
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

Output 1 = ‘adult’ \(\Rightarrow\) age in \([18, 150]\)
Output 2 = ‘not adult’ \(\Rightarrow\) age in \([0, 18)\)
Output 3 = ‘invalid input’ \(\Rightarrow\) age not in \([0, 150]\)

\[
\begin{align*}
green\ area &= \text{valid} \\
\text{white area} &= \text{invalid}
\end{align*}
\]

Could be refined into:
age < 0
age > 150
age not an int
ECP – Simple Example

Look at specification:

Based on the age of a person, the program decides whether the person is an adult or not.

Output 1 = ‘adult’ $\Rightarrow$ age in $[18, 150)$
Output 2 = ‘not adult’ $\Rightarrow$ age in $[0, 18)$
Output 3 = ‘invalid input’ $\Rightarrow$ age not in $[0, 150]$ 

Output 3 was not mentioned in the specification but it’s good practice to think about this possibility (programmers hopefully do!).
Also the maximum age was not mentioned in the spec; the tester would have to talk to the developers to find out whether there is an age limit implemented (e.g., as plausibility check).
ECP – Simple Example

Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in [0, 18)
EC2: integer in [18, 150]
EC3: integer not in [0, 150] or not an integer

Output variable ‘adult’:
EC4: true
EC5: false

Output variable ‘error’:
EC6: ‘invalid input’

This is a variable derived based on reasoning of the tester
ECP – Simple Example

Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in [0, 18)
EC2: integer in [18, 150]
EC3: integer not in [0, 150] or not an integer

Output variable ‘adult’:
EC4: true
EC5: false
EC6: <empty>

Output variable ‘error’:
EC7: <empty>
EC8: ‘invalid input’

These are ECs derived based on reasoning of the tester
ECP – Simple Example

Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in [0, 18)
EC2: integer in [18, 150]
EC3: integer not in [0, 150] or not an integer

Output variable ‘adult’:
EC4: true
EC5: false
EC6: <empty>

Output variable ‘error’:
EC7: <empty>
EC8: ‘invalid input’

Test cases (minimum):

TC1: age = 10; adult = false; error = <empty>
TC2: age = 20; adult = true; error = <empty>
TC3: age = ‘x’; adult = <empty>;
    error = ‘invalid input’
ECP – Simple Example

Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in [0, 18)
EC2: integer in [18, 150]
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EC5: false
EC6: <empty>

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Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in \([0, 18)\)
EC2: integer in \([18, 150]\)
EC3: integer not in \([0, 150]\) or not an integer

Output variable ‘adult’:
EC4: true
EC5: false
EC6: <empty>

Output variable ‘error’:
EC7: <empty>
EC8: ‘invalid input’

Coverage of ECs:

<table>
<thead>
<tr>
<th></th>
<th>EC1</th>
<th>EC2</th>
<th>EC3</th>
<th>EC4</th>
<th>EC5</th>
<th>EC6</th>
<th>EC7</th>
<th>EC8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC2</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>TC3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
ECP – Simple Example

Summary of Equivalence Classes (ECs):

Input variable ‘age’:
EC1: integer in \([0, 18)\)
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Output variable ‘adult’:
EC4: true
EC5: false
EC6: <empty>

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EC7: <empty>
EC8: ‘invalid input’

Coverage of ECs:

<table>
<thead>
<tr>
<th></th>
<th>EC1</th>
<th>EC2</th>
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<th>EC4</th>
<th>EC5</th>
<th>EC6</th>
<th>EC7</th>
<th>EC8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC2</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>TC3</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
ECP Guidelines

Possible inputs/outputs must be known from specification or derived from exploration of the system.

If input is a range or an ordered list of values
→ one in-range/list and two out-of-range/list classes are defined
→ Example: \( x \in [0, 9] \rightarrow EC1: [0, 9], EC2: (-\infty, 0), EC3: (9, +\infty) \)

If input is a set or a “must be” condition (boolean)
→ one in-set and one out-of-set class are defined;
→ Example: EC1: \{car\}, EC2: empty (or: \{horse\})

If analysis of spec indicates that elements of input classes result in specific output classes (i.e., are treated equivalently) then additional classes may be defined.
→ Example: vehicle is in \{car, motorcycle, truck\} \rightarrow EC1: \{car\}, EC2: \{motorcycle\}, EC3: \{truck\}, EC4: empty or anything not in the set.

If there is anything else (e.g., invalid inputs) \rightarrow partition further
ECP Guidelines

Possible inputs/outputs must be known from specification or derived from exploration of the system.

If input is a range or an ordered list of values
→ one in-range/list and two out-of-range/list classes are defined
→ Example: x in [0, 9] → EC1: [0, 9], EC2: (-infinity, 0), EC3: (9, +infinity)

If input s a set or a “must be” condition (boolean)
→ one in-set and one out-of-set class are defined;
→ Example: EC1: {car}, EC2: empty (or: {horse})

If analysis of spec indicates that elements of input classes result in specific output classes (i.e., are treated equivalently) then additional classes may be defined.
→ Example: vehicle is in {car, motorcycle, truck} → EC1: {car}, EC2: {motorcycle}, EC3: {truck}, EC4: empty or anything not in the set.

If there is anything else (e.g., invalid inputs) → partition further

Union set of all ECs should cover complete input/output space. ECs must not overlap !!!
ECP in case of more than one input

This figure is a metaphor for the union set of ECs of all input variables.
From ECP to Test Cases
From ECP to Test Cases

Remember:
We must cover all ECs with Test Cases (TCs). We try to do this with as few TCs as possible!
From ECP to Test Cases

Step 1: Number each EC

Step 2: Apply the following rules ->

• Rule 1 – valid ECs: Combine as many valid ECs in one test case as possible

• Rule 2 – invalid ECs: Pick one invalid input EC and take a value from it; then combine it exclusively with values from valid input ECs
  • Reason: for each invalid EC there should be some dedicated error handling; this must be checked!

Remember:
We must cover all ECs with Test Cases (TCs). We try to do this with as few TCs as possible!
In-Class Exercise
Exercise: ECP

Assume a ’magic’ Function M

Spec:
The program accepts integers x, y
The program calculates sum = x + y
The program displays the result ‘sum’

M (x, y) → sum = x + y
with x, y: int (32 bit)

Exhaustive (positive) testing: ?
Exercise: ECP

Assume a ’magic’ Function $M$

Spec:
The program accepts integers $x$, $y$
The program calculates $\text{sum} = x + y$
The program displays the result ‘sum’

$M (x, y) \rightarrow \text{sum} = x + y$
with $x, y: \text{int (32 bit)}$

Exhaustive (positive) testing:
$2^{32} \times 2^{32}$
$= 2^{64} \sim 1.8 \times 10^{19}$ test cases (input data + expected output)
Exercise: ECP

Input: x & y | Output: sum

Classes

C1: InputX: ?
C2: InputY: ?
C3: OutputSum: ?

Note:
To save space, I use in this example ‘C” instead of ‘EC’ as abbreviation for ‘Equivalence Class’
Exercise: ECP

Input: x & y | Output: sum

Classes

C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]
Exercise: ECP

Input: x & y | Output: sum

Classes

C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]

Is that all?
Exercise: ECP

Input: \( x \) & \( y \) | Output: sum

Classes

C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]

C4: InputX: notInt
C5: InputY: notInt
C6: OutputSum: exception

Black Box

\[
\text{Input } x: \\
\text{Input } y: \\
\text{Output sum:}
\]
Exercise: ECP

Input: x & y | Output: sum

Classes
C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]
C4: InputX: notInt
C5: InputY: notInt
C6: OutputSum: exception

Test Cases
Data: x, y, sum
TC1: 0, 0 -> 0
TC2: notInt, 0 -> WrongInputException
TC3: 0, notInt -> WrongInputException

If we consider output=exception to be an error message caused by invalid input (notInt), then it’s good practice to check for the effect of each invalid input class independently.

minimal,
TCs cover all classes
Exercise: ECP

Input: x & y | Output: sum

Test Cases

Data: x, y, sum

TC1: 0, 0 -> 0  
TC2: notInt, 0 -> WrongInputException  
TC3: 0, notInt -> WrongInputException

Classes covered:

C1, C2, C3  
C4, C2, C6  
C1, C5, C6

minimal, 
TCs cover all classes
Exercise: ECP + BVA

Input: x & y | Output: sum

Classes

C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]

C4: InputX: notInt
C5: InputY: notInt
C6: OutputSum: exception

Test Cases

Data: x, y, sum

TC1: 0, 0 -> 0
TC2: notInt, 0 -> WrongInputException
TC3: 0, notInt -> WrongInputException

TC4: MinInt, MinInt -> ArithmeticException
TC5: MaxInt, MaxInt -> ArithmeticException
TC6: MaxInt/2, MaxInt/2 -> MaxInt
TC7: MinInt/2, MinInt/2 -> MinInt
Exercise: ECP

Input: x & y | Output: sum

Classes

C1: InputX: [MinInt, MaxInt]
C2: InputY: [MinInt, MaxInt]
C3: OutputSum: [MinInt, MaxInt]

C4: InputX: notInt
C5: InputY: notInt
C6: OutputSum: exception

There could be constraints on inputs. In this exercise:
InputX+InputY <= MaxInt
InputX-InputY >= MinInt
Example – Insurance System

Specification Statement:

• System shall reject over-age insurance applicants

Specification Item:

• Reject male insurance applicants, if over the age of 80 years on day of application
• Reject female insurance applicants, if over the age of 85 years on day of application
Example – Insurance System

Basic ECs:

Var age: accept == true ➔ [18, 80] or [18, 85]
   to avoid overlap ➔ [18, 80] or (80, 85] ➔ EC1, EC2
accept == false ➔ not in [18, 85] ➔ EC3

Var gender: accept == true ➔ male or female ➔ EC4, EC5
   accept == false ➔ not in {male, female} ➔ EC6

Var accept: true or false ➔ EC7, EC8
Example (cont.)
Input: Gender & Age | Output: accept/reject

UI – Case A

| Age:       | in [18, 80] ? O |
|           | in (80, 85] ? O |
|           | in (85, 99] ? O |
|           | other ? O      |

| Gender:   | male O       |
|           | female O    |

Enter

Result: <text>
Message: <text>

Result text in {<empty>, accept, reject}
Message text in {<empty>, missing input}

UI – Case B

Please enter gender (m, f):
<Message text>
Please enter age (integer>0):
<Message text>
Result: <text>

Message text in {
<empty>,
invalid input – retry or quit with Ctrl^D}
Result text in {
accept,
reject}
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: ???

...
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: ???

What do you say about this?

<table>
<thead>
<tr>
<th>Age</th>
<th>gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>in [18, 80]</td>
<td>male</td>
</tr>
<tr>
<td>in (80, 85]</td>
<td>male</td>
</tr>
<tr>
<td>in (85, 99]</td>
<td>female</td>
</tr>
<tr>
<td>other</td>
<td>female</td>
</tr>
</tbody>
</table>

Result: <text>
Message: <text>

Result text in {<empty>, accept, reject}
Message text in {<empty>, missing input}
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: InputAge: [18, 80]
C2: InputAge: (80, 85]
C3: InputAge: (85, 99]
C4: InputAge: other
C5: InputAge: <empty>
C6: InputGender: Male
C7: InputGender: Female
C8: InputGender: <empty>
C9: OutputResult: <empty>
C10: OutputResult: ‘accept’
C11: OutputResult: ‘reject’
C12: OutputMsg: <empty>
C13: OutputMsg: ’missing input’

Age: in [18, 80] ? O
     in (80, 85] ? O
     in (85, 99] ? O
     other ? O

Gender: male O
        female O

What do you say about C5?
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: InputAge: [18, 80]
C2: InputAge: (80, 85]
C3: InputAge: (85, 99]
C4: InputAge: other
C5: InputAge: <empty>
C6: InputGender: Male
C7: InputGender: Female
C8: InputGender: <empty>

Test Cases

Data: age, gender, result, message

How many test cases to cover all classes?

C9: OutputResult: <empty>
C10: OutputResult: ‘accept’
C11: OutputResult: ‘reject’
C12: OutputMsg: <empty>
C13: OutputMsg: ’missing input’
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: InputAge: [18, 80]
C2: InputAge: (80, 85]
C3: InputAge: (85, 99]
C4: InputAge: other
C5: InputAge: <empty>
C6: InputGender: Male
C7: InputGender: Female
C8: InputGender: <empty>
C9: OutputResult: <empty>
C10: OutputResult: ‘accept’
C11: OutputResult: ‘reject’
C12: OutputMsg: <empty>
C13: OutputMsg: ’missing input’

Test Cases

Data: age, gender, result, message

TC1: <empty>, <empty>, <empty>, ’missing input’
TC2: 56, male, ’accept’, <empty>
TC3: 83, male, ’reject’, <empty>
TC4: 88, female, ’reject’, <empty>
TC5: other, female, ’reject’, <empty>

minimal, TCs cover all classes
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: InputAge: [18, 80]
C2: InputAge: (80, 85]
C3: InputAge: (85, 99]
C4: InputAge: other
C5: InputAge: <empty>
C6: InputGender: Male
C7: InputGender: Female
C8: InputGender: <empty>
C9: OutputResult: <empty>
C10: OutputResult: ‘accept’
C11: OutputResult: ‘reject’
C12: OutputMsg: <empty>
C13: OutputMsg: ’missing input’

Test Cases

TC1: <empty>, male, <empty>, ’missing input’
TC2: other, <empty>, <empty>, ’missing input’
TC3: 56, male, ’accept’, <empty>
TC4: 83, male, ’reject’, <empty>
TC5: 88, female, ’reject’, <empty>
TC6: other, female, ’reject’, <empty>

If we consider ’missing input’ to be an error message caused by invalid input (<empty>), then it’s good practice to check for the effect of each invalid input class independently
Example – UI Case A
Input: Gender & Age | Output: accept/reject

<table>
<thead>
<tr>
<th>Input</th>
<th>Valid EC</th>
<th>Invalid EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>C1: [18, 80]</td>
<td>C5: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C2: (80, 85)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3: (85, 99)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4: other</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>C6: Male</td>
<td>C8: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C7: Female</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>em</td>
<td>oth</td>
<td>56</td>
<td>83</td>
<td>88</td>
<td>oth</td>
</tr>
<tr>
<td>Gend.</td>
<td>M</td>
<td>em</td>
<td>M</td>
<td>M</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>tests</td>
<td>C5</td>
<td>C4</td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
<td>C4</td>
</tr>
</tbody>
</table>

UNIVERSITY OF TARTU
INSTITUTE OF COMPUTER SCIENCE
Example – UI Case A
Input: Gender & Age | Output: accept/reject

<table>
<thead>
<tr>
<th>Input</th>
<th>Valid EC</th>
<th>Invalid EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>C1: [18, 80]</td>
<td>C5: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C2: (80, 85]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3: (85, 99]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4: other</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>C6: Male</td>
<td>C7: Female</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C8: &lt;empty&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Gend.</td>
<td>em M</td>
<td>oth em</td>
<td>56 M</td>
<td>83 M</td>
<td>88 F</td>
<td>oth F</td>
</tr>
<tr>
<td>tests</td>
<td>C5 C6</td>
<td>C4 C8</td>
<td>C1 C6</td>
<td>C2 C6</td>
<td>C3 C7</td>
<td>C4 C7</td>
</tr>
</tbody>
</table>

What is missing?
Example – UI Case A
Input: Gender & Age | Output: accept/reject

<table>
<thead>
<tr>
<th>Input</th>
<th>Valid EC</th>
<th>Invalid EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>C1: [18, 80]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2: (80, 85]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3: (85, 99]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4: other</td>
<td>C5: &lt;empty&gt;</td>
</tr>
<tr>
<td>Gender</td>
<td>C6: Male</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C7: Female</td>
<td>C8: &lt;empty&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Gend.</td>
<td>em</td>
<td>other</td>
<td>56</td>
<td>83</td>
<td>88</td>
<td>other</td>
</tr>
<tr>
<td>Tests</td>
<td>C5</td>
<td>C6</td>
<td>C4</td>
<td>C8</td>
<td>C1</td>
<td>C6</td>
</tr>
</tbody>
</table>

Must also check coverage of output ECs!
Example – UI Case A
Input: Gender & Age | Output: accept/reject

<table>
<thead>
<tr>
<th>In/Out</th>
<th>Valid EC</th>
<th>Invalid EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>C1: [18, 80]</td>
<td>C5: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C2: (80, 85]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3: (85, 99]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4: other</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>C6: Male</td>
<td>C8: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C7: Female</td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>C10: ’acc’</td>
<td>C9: &lt;empty&gt;</td>
</tr>
<tr>
<td></td>
<td>C11: ‘reject’</td>
<td></td>
</tr>
<tr>
<td>Message</td>
<td>C12: &lt;emp&gt;</td>
<td>C13: &lt;miss. In&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>em</td>
<td>M</td>
<td>em</td>
<td>M</td>
<td>83</td>
<td>F</td>
</tr>
<tr>
<td>Gend.</td>
<td>Male</td>
<td>other</td>
<td>Male</td>
<td>other</td>
<td>F</td>
<td>other</td>
</tr>
<tr>
<td>Result</td>
<td>emb</td>
<td>mem</td>
<td>mis</td>
<td>mem</td>
<td>mis</td>
<td>mis</td>
</tr>
<tr>
<td>Mess.</td>
<td>em</td>
<td>mem</td>
<td>mis</td>
<td>mem</td>
<td>mis</td>
<td>mis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Covers</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
</tr>
<tr>
<td>C6</td>
</tr>
<tr>
<td>C8</td>
</tr>
<tr>
<td>C9</td>
</tr>
<tr>
<td>C10</td>
</tr>
<tr>
<td>C11</td>
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<tr>
<td>C12</td>
</tr>
<tr>
<td>C13</td>
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<tr>
<td>C4</td>
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<tr>
<td>C7</td>
</tr>
<tr>
<td>C11</td>
</tr>
<tr>
<td>C11</td>
</tr>
<tr>
<td>C12</td>
</tr>
</tbody>
</table>
Example – UI Case A

Input: Gender & Age | Output: accept/reject

Classes

C1: InputAge: [18, 80]
C2: InputAge: (80, 85]
C3: InputAge: (85, 99]
C4: InputAge: other
C5: InputAge: <empty>
C6: InputGender: Male
C7: InputGender: Female
C8: InputGender: <empty>
C9: OutputResult: <empty>
C10: OutputResult: ‘accept’
C11: OutputResult: ‘reject’
C12: OutputMsg: <empty>
C13: OutputMsg: ’missing input’

Test Cases

TC1: <empty>, male, <empty>, ’missing input’
TC2: other, <empty>, <empty>, ’missing input’
TC3: 56, male, ’accept’, <empty>
TC4: 83, male, ’reject’, <empty>
TC4*: 83, female, ’accept’, <empty>
TC5: 88, female, ’reject’, <empty>
TC6: other, female, ’reject’, <empty>

With TC4* we have covered all cause-effect relationships (-> Cause-Effect Graphing)
Example – UI Case B

Input: Gender & Age | Output: accept/reject

Classes

C1: ???

Please enter gender (m, f):
<Message text>
Please enter age (integer>0):
<Message text>
Result: <text>

Message text in {
<empty>,
invalid input –
retry or quit with Ctrl^D}

Result text in {
accept,
reject}
Example – UI Case B

Input: Gender & Age | Output: accept/reject

Classes

C1: InputGender: m
C2: InputGender: f
C3: InputGender: not(m, f)
C4: InputGender: Ctrl^D
C5: InputAge: integer in [18, 80]
C6: InputAge: integer in (80, 85]
C7: InputAge: integer <18
C8: InputAge: integer >85
C9: InputAge: Ctrl^D
C10: InputAge: other than C5-C9
C11: OutputMsg: <empty>
C12: OutputMsg: ’invalid input ...’
C13: OutputResult: accept
C14: OutputResult: reject

Please enter gender (m, f):
<Message text>
Please enter age (integer>0):
<Message text>
Result: <text>

Message text in {
<empty>,
invalid input – retry or quit with Ctrl^D}
Result text in {
accept,
reject}
Example – UI Case B

Input: Gender & Age | Output: accept/reject

Classes

C1: InputGender: m
C2: InputGender: f
C3: InputGender: not(m, f)
C4: InputGender: Ctrl^D
C5: InputAge: integer in [18, 80]
C6: InputAge: integer in (80, 85]
C7: InputAge: integer <18
C8: InputAge: integer >85
C9: InputAge: Ctrl^D
C10: InputAge: other than C5-C9
C11: OutputMsg: <empty>
C12: OutputMsg: ’invalid input …’
C13: OutputResult: accept
C14: OutputResult: reject

Test Cases

TC1: Ctrl^D
TC2: not(m, f), ’invalid’, Ctrl^D
TC3: m, <empty>, Ctrl^D
TC4: m, <empty>, other, ’invalid’, Ctrl^D
TC5: m, <empty>, [18, 80], <empty>, accept
TC6: m, <empty>, (80, 85], <empty>, reject
TC7: f, <empty>, <18, <empty>, reject
TC8: f, <empty>, >85, <empty>, reject

...
Example – UI Case B
Input: Gender & Age | Output: accept/reject

Classes

C1: InputGender: m
C2: InputGender: f
C3: InputGender: not(m, f)
C4: InputGender: Ctrl^D
C5: InputAge: integer in [18, 80]
C6: InputAge: integer in (80, 85]
C7: InputAge: integer <18
C8: InputAge: integer >85
C9: InputAge: Ctrl^D
C10: InputAge: other than C5-C9
C11: OutputMsg: <empty>
C12: OutputMsg: ’invalid input ...’
C13: OutputResult: accept
C14: OutputResult: reject

Test Cases

TC1: Ctrl^D
TC2: g, ’invalid’, Ctrl^D
TC3: m, <empty>, Ctrl^D
TC4: m, <empty>, 3.5, ’invalid’, Ctrl^D
TC5: m, <empty>, 56, <empty>, accept
TC6: m, <empty>, 83, <empty>, reject
TC7: f, <empty>, 5, <empty>, reject
TC8: f, <empty>, 103, <empty>, reject
...
Example – UI Case B

Input: Gender & Age | Output: accept/reject

Classes

C1: InputGender: m
C2: InputGender: f
C3: InputGender: not(m, f)
C4: InputGender: Ctrl^D
C5: InputAge: integer in [18, 80]
C6: InputAge: integer in (80, 85]
C7: InputAge: integer <18
C8: InputAge: integer >85
C9: InputAge: Ctrl^D
C10: InputAge: other than C5-C9
C11: OutputMsg: <empty>
C12: OutputMsg: 'invalid input ...'
C13: OutputResult: accept
C14: OutputResult: reject

Test Cases

Every path from the root to a leaf (STOP) is (at least) one test case
Boundary Value Analysis

- Adds to the equivalence partitioning method
- Select test cases to represent each side of the class boundaries
Boundary Value Analysis Guidelines

• Range $a..b \Rightarrow a, b, \text{just above } a, \text{just below } b$

• List of ordinal values $\Rightarrow \text{max, min, just below min, just above max}$

• Boundaries of externally visible data structures shall be checked (e.g. ordered sets, arrays)

• Output bounds should be checked
Example – UI Case B

Input: Gender & Age | Output: accept/reject

Classes

C1: InputGender: m
C2: InputGender: f
C3: InputGender: not(m, f)
C4: InputGender: Ctrl^D
C5: InputAge: integer in [18, 80]
C6: InputAge: integer in (80, 85]
C7: InputAge: integer <18
C8: InputAge: integer >85
C9: InputAge: Ctrl^D
C10: InputAge: other than C5-C9
C11: OutputMsg: <empty>
C12: OutputMsg: 'invalid input ...'
C13: OutputResult: accept
C14: OutputResult: reject

Test Cases

TC1: Ctrl^D
TC2: g, 'invalid’, Ctrl^D
TC3: m, <empty>, Ctrl^D
TC4: m, <empty>, 3.5, 'invalid’, Ctrl^D
TC5: m, <empty>, 56, <empty>, accept
TC5L: m, <empty>, 18, <empty>, accept
TC5U: m, <empty>, 80, <empty>, accept
TC6: m, <empty>, 83, <empty>, reject
... 
TC7: f, <empty>, 5, <empty>, reject
TC8: f, <empty>, 103, <empty>, reject
...
Combinatorial Designs

- ECP and BVA define test cases per equivalence class.
- In ECP testing, each EC needs to be covered once.
- In Combinatorial Testing all possible combinations of ECs of the input variables need to be covered.
BBT – Advantages & Disadvantages

Advantages
• Tests are done from a user’s point of view and will help in exposing discrepancies in the specifications.
• Tester need not know programming languages or how the software has been implemented.
• Tests can be conducted by a body independent from the developers, allowing for an objective perspective and the avoidance of developer-bias.
• Test cases can be designed as soon as the specifications are complete.

Disadvantages
• Only a small number of possible inputs can be tested and many program paths will be left untested.
• Without clear specifications, which is the situation in many projects, test cases will be difficult to design.
• Tests can be redundant if the software designer/developer has already run a test case.
• Ever wondered why a soothsayer closes the eyes when foretelling events? So is almost the case in Black Box Testing.
Structure of Lecture 2

• Black-Box vs. White-Box Testing
• Basic Black-Box Testing Techniques
  • Equivalence Class Partitioning (ECP)
  • Boundary Value Analysis (BVA)
• Lab 1 + Lab 2
Due to the still unstable COVID-19 situation, the February lectures will be conducted fully online. You will find the instructions in Moodle (use the BBB link). Currently, we still plan to conduct the practice sessions physically in the classroom.

Here you find the lecture slides and any other materials handed out during a lecture or related to a lecture and associated lab sessions. The detailed lab instructions can be found under the tab Labs.

Disclaimer: The following schedule might be updated as needed.

**SW Testing Lectures:**

- Lecture 1 (10.02) - Introduction to Software Testing - [Online (Link in Moodle)]
  - This lecture is related to Quiz 1 and HW 1
  - Slides-2022 (all parts)
  - Videos:
    - Video-2021-Part1 (36:18 min) - Introduction & Motivation (Relevant for Quiz 1)
    - Video-2022-Part2 - (27:58 min) Course Information (updated to 2022)
    - Video-2021-Part3 (36:49 min) - Basic Vocabulary (Relevant for Quiz 1)
    - Video-2021-Part4 (34:41 min) - Lab 1 (Relevant for homework assignment HW 1)
  - Link to an introductory tutorial on testing: Guru99
  - Link to an introductory survey of testing concepts: SoftwareTestingFundamentals
  - The "Heartbleed Bug" explained: [link] - Think about a test case that would have found this bug!
  - A recent book on debugging by Andreas Zeller: [link]
HW 1: Black-Box Testing

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  - Link to an introductory survey of testing concepts: SoftwareTestingFundamentals
  - The "Heartbleed Bug" explained: (link) - Think about a test case that would have found this bug!
  - A recent book on debugging by Andreas Zeller: (link)
HW 2: Black-Box Testing

Lab 2 (week 27: Mar 01 & 02) – Black-Box Testing (9 pts)

BBT Instructions
BBT Documentation
BBT Application

Submission Deadlines:
- Tuesday Labs: Monday, 07 Mar, 23:59
- Wednesday Labs: Tuesday, 08 Mar, 23:59
- Penalties apply for late delivery: 50% penalty, if submitted up to 24 hours late; 100 penalty, if submitted more than 24 hours late
HW 2: Black-Box Testing
– Triangle Program

Inputs:
- Triangle side-1
- Triangle side-2
- Triangle side-3

Outputs:
- Triangle perimeter
- Triangle area
- Triangle type

At least 15 ECs
At least 20 test cases covering all defined ECs
HW 2: Black-Box Testing (cont’d)

Test Cases:
Input & Exp. Output
1 3 4 → triangle type x, area, perimeter
2 5 5 → triangle type y, ...
0 1 2 → no triangle, ...
...

Test Report:
TC1 → pass
TC2 → pass
TC3 → pass
TC4 → fail → defect
...

Strategies:
- Equivalence Class Partitioning
- Boundary Value Analysis
To Do & Next Weeks

• Quiz 2 (in Moodle!):
  – Opens after today’s lecture – closes on Monday at 17:30am!

• Lab 1: go to Lab session! Watch Part4 video of Lect. 1!

• Lab 2:
  – Basic Black-Box-Testing  Week after next Week!

• Lecture 3:
  – Black-Box Testing (advanced): Combinatorial Testing