Software Engineering
Lecture 09: Testing and Debugging — Testing

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Recap

- Testing – detect the presence of bugs by observing failures
- Debugging – find the bug causing a certain failure
- In order to know when a program fails we must have a specification (except for obvious failure such as a program crash)
- A great deal of care is needed when writing specifications
- Finding a good set of test cases is often difficult
- Even with good test cases, absence of failures does not imply absence of bugs (the number of ways to use the program is huge or infinite)
- Program Verification is about making sure there are no bugs
- This seems preferable, but software verification is in most cases economically impossible
- On the other hand, testing is not just a way of finding bugs during the development – Making testing a part of the development makes claims about the software more credible
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Contents of Testing part
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  - How to write a test case
Contents of Testing part

- Specifications (informal)
- Test Cases
  - How to write a test case
  - How to come up with a good test suite (collection of test cases)
Specifications

- Program specifications tell what a piece of code should do
- But also what it requires to be able to do its job
- A specification can be seen as **contract** between the implementor and the user of the implemented code.
- A specification consists of two parts:
  - **Requires** (precondition) – what the user should fulfill before calling the code
  - **Ensures** (postcondition) – what the implementor promises about the result of the execution (provided requires were fulfilled)
1 public static int find_min(int[] a) { ... }
public static int find_min(int[] a) {
    ...
}
1. public static int find_min(int[] a) {
    ...
}

**Specification**

- **Requires:** a is non-null
- **Ensures:** Result is the minimum element in a
public static int find_min(int[] a) { ... }
public static int find_min(int[] a) { ... }

**Specification**

*Requires:* a is non-null

*Ensures:* Result is equal to the minimum element in a
public static int find_min(int[] a) { ... }

**Specification**

*Requires:* a is non-null

*Ensures:* Result is less than or equal to all elements in a
```java
1 public static int find_min(int[] a) {
   ... 
}
```

**Specification**

<table>
<thead>
<tr>
<th>Requires</th>
<th>Ensure主要内容</th>
</tr>
</thead>
<tbody>
<tr>
<td>a is non-null</td>
<td>Result is less than or equal to all elements in a</td>
</tr>
<tr>
<td></td>
<td>and equal to at least one element in a</td>
</tr>
</tbody>
</table>
1  public static int find_min(int[] a) {
2   int x, i;
3   x = a[0];
4   for (i = 1; i < a.length; i++) {
5     if (a[i] < x) x = a[i];
6   }
7   return x;
8 }

**Specification**

*Requires:*  a is non-null

*Ensures:*  Result is less than or equal to all elements in a and equal to at least one element in a
public static int find_min(int[] a) {
    int x, i;
    x = a[0];
    for (i = 1; i < a.length; i++) {
        if (a[i] < x) x = a[i];
    }
    return x;
}

**Specification**

**Requires:** 
*a* is non-null and contains at least one element

**Ensures:** 
Result is less than or equal to all elements in *a* and equal to at least one element in *a*.
What can be wrong about a specification?

- Badly stated – does not make sense
- Vague – unclear what is meant
- Imprecise – more can be said about the behaviour
- Postcondition is too weak
- Precondition is too strong
- Incorrect – too much is said
- Precondition is too weak
- Postcondition is too strong
What can be wrong about a specification?

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**Specification**

*Requires:* \( a \) is non-null

*Ensures:* Result is the minimum element in \( a \)
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Specification

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  - Precondition is too strong

**Specification**

*Requires:* a is non-null and contains exactly one element

*Ensures:* Result is less than or equal to all elements in a and equal to at least one element in a
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Specification

Requires: $a$ is non-null

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  - Postcondition is too strong

Specification

**Requires:** a is non-null and contains at least one element

**Ensures:** Result is less than or equal to all elements in a and equal to at least one element in a, and result is greater than 0
What can go wrong when writing specifications?

Are all these cases of “bad” specifications?

- It’s clear that we don’t want invalid or incorrect specifications.
- Vague specifications is a matter of whether they can be misunderstood.
- But imprecise specifications is not such a bad thing
What does this method do?

```java
public static int[] insert(int[] x, int n)
{
    int[] y = new int[x.length + 1];
    int i;
    for (i = 0; i < x.length; i++) {
        if (n >= x[i]) break;
        y[i] = x[i];
    }
    y[i] = n;
    for (; i < x.length; i++) {
        y[i+1] = x[i];
    }
    return y;
}
```
Example

What does this method do?

```java
public static int[] insert(int[] x, int n)
{
    ...
}
```

Specification

*Requires:*

*Ensures:*
Example, cont’d

Example

What does this method do?

1 public static int[] insert(int[] x, int n)
2 { ... }

Specification

Requires: x is non-null.
Ensures: Result is equal to x with n inserted in it.
Example

What does this method do?

```java
1    public static int[] insert(int[] x, int n)
2    { ... }
```

Specification

**Requires:**  
x is non-null.

**Ensures:**  
Result is equal to x with n inserted in it and result is sorted in ascending order.
Example, cont’d

Example

What does this method do?

1 public static int[] insert(int[] x, int n)
2 { ... }

Specification

Requires: $x$ is non-null and sorted in ascending order.

Ensures: Result is equal to $x$ with $n$ inserted in it and result is sorted in ascending order.
A class invariant is a condition about the state of each class instance that should be maintained throughout its existence. We will focus on weak invariants. It should hold between calls to methods of the class, but not during the execution of such methods.
Specification of a Class

Class invariant

- A class invariant is a condition about the state of each class instance that should be maintained throughout its existence.
- We will focus on weak invariants.
  - It should hold between calls to methods of the class,
  - but not during the execution of such methods.

Class specification consists of

- Class invariant
- Requires and ensures of the methods
Example, class invariant

```java
public class HashSet {
    private Object[] arr;
    int nobj;

    public void insert(Object o) { ... }

    ... 
}
```
Example, class invariant

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1  public class HashSet {
2      private Object[] arr;
3      int nobj;
4
5      public void insert(Object o) { ... }
6          ...
7  }
```

Class Invariant

- `nobj` should be equal to the number of non-null elements in `arr`.
- For each index `i` in range of `arr` such that `arr[i]` is non-null, `arr[i]`.hash and `i` are non-null, and there are no two non-null elements of `arr` that are equal.
Example, class invariant

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**Class Invariant**

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- there are no two non-null elements of `arr` that are equal
Testing
Software testing

What we look at here

- Systematic – general rules for how to write test cases
- Repeatable – be able to run tests over and over again
Software testing

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- Repeatable – be able to run tests over and over again

What we don’t look at here
- Running a program to see if anything goes wrong
- Letting a lot of people run the program to see if anything goes wrong (Beta-testing)
Testing on Different Levels

- **Unit Testing** – testing a small unit of a system
  Requires that the behaviour of the unit has been specified.
  In **Java** this often corresponds to testing a method or a class.
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- **Integration Testing** – testing the interaction between two or more units.
Testing on Different Levels

- **Unit Testing** – testing a small unit of a system. Requires that the behaviour of the unit has been specified. In *Java* this often corresponds to testing a method or a class.

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- **System Testing** – testing a whole system against the specification of its externally observable behaviour. System testing is mostly useful for convincing about the correctness. Less useful for finding bugs because the infection phase going from defect to failure is usually complex and difficult to unwind.
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  System testing is mostly useful for convincing about the correctness. Less useful for finding bugs because the infection phase going from defect to failure is usually complex and difficult to unwind.

The code that is being tested is called the IUT (implementation under test).
Testing Non-Functional Requirements
Not considered further

- Performance testing or load testing
- Stability testing
- Usability testing
- Security testing
The sooner a bug is found, the better.
So, testing should start early.
Extreme case: Test-driven program development
When Should Testing Take Place?

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So, testing should start early.
Extreme case: Test-driven program development

but

Testing early means a lot of unit testing which requires a lot of specifications.
But writing specifications for the units of a system is already needed for a large project when programming by contract.
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Testing early means a lot of unit testing which requires a lot of specifications.
But writing specifications for the units of a system is already needed for a large project when programming by contract.

Tested units may be replaced later on, making the tests useless.
On the other hand, writing and running tests often gives a deep understanding of the program. The need to replace the unit may have been realized during the testing activities.
Systematic testing

- Use precise methods to design correct tests
Systematic testing

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- Each individual test is called a test case
Systematic testing

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- Each individual test is called a test case
- Organize collections of related test cases in test suites
Systematic testing

- Use precise methods to design correct tests
- Each individual test is called a test case
- Organize collections of related test cases in test suites
- Use precise methods to make sure that a test suite has a good coverage of the different cases of usage
Repeatable testing

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- When a bug has been fixed, the tests can be rerun to check if the failure is gone
Repeatable testing

The basic idea is to write code that performs the tests.

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- Whenever the code is extended, all old test cases can be rerun to check that nothing is broken (regression testing)
Repeateable testing

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- When a bug has been fixed, the tests can be rerun to check if the failure is gone.
- Whenever the code is extended, all old test cases can be rerun to check that nothing is broken (regression testing).

JUnit is a small tool for writing and running test cases. It provides:

- Some functionality that is repeatedly needed when writing test cases.
- A way to annotate methods as being test cases.
- A way to run test cases automatically in a batch.
Apart the obvious – that testing should result in removal of bugs
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- When writing specifications and test cases for units, the responsibilities of the different parts become clearer, which promotes good OO programming style (low coupling)
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- When writing specifications and test cases for units, the responsibilities of the different parts become clearer, which promotes good OO programming style (low coupling)
- In order to be able to test programs automatically, separating the IO and functionality becomes important
What does a test case consist of?

- Initialisation (of class instance and input arguments)
- Call to the method of the IUT
- A test oracle which decides if the test succeeded or failed
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Test case

- Initialisation (of class instance and input arguments)
- Call to the method of the IUT
- A test oracle which decides if the test succeeded or failed

- The test oracle is vital to run tests automatically
Small demo showing basics of how to use JUnit
Summary

- Specifications (motivation, contracts, pre- and postconditions, what to think about)
- Testing (motivation, different kinds of testing, role in software development, JUnit)

What’s next?

- More examples of test cases, presenting aspects of writing test cases and features of JUnit
- How to write a good test case?
- How to construct a good collection of test cases (test suite)?