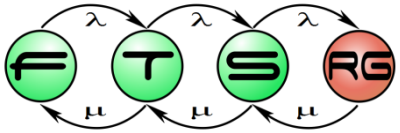
Testing and Profiling



Goals of Testing

- Understand system quality
- Provide information for decisions
  - E.g. release-readiness
- Bug finding/preventing
  - Beware: Testing shows the **presence**, not the absence of bugs. (Dijkstra)

7 Testing Principles

7 Testing Principles

1. Only presence of bugs can be shown
2. Exhaustive testing practically impossible
3. Test in the early development phases
4. Defect clustering
   - Most defects relate to a small number of components
5. Pesticide paradox
   - Efficiency of testing decreases when re-executed
   - Every methodology misses some problems
6. Testing is context-dependent
7. Absence-of-errors fallacy
   - Error-free test execution does not mean error-free program

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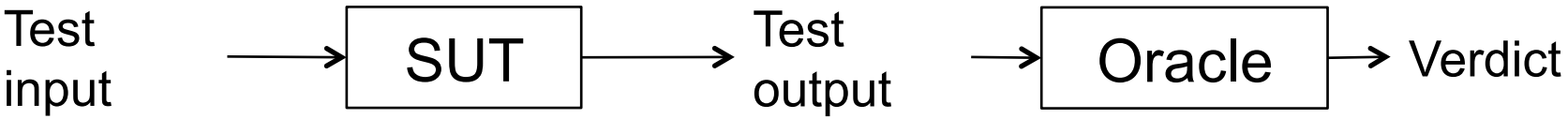
Basics



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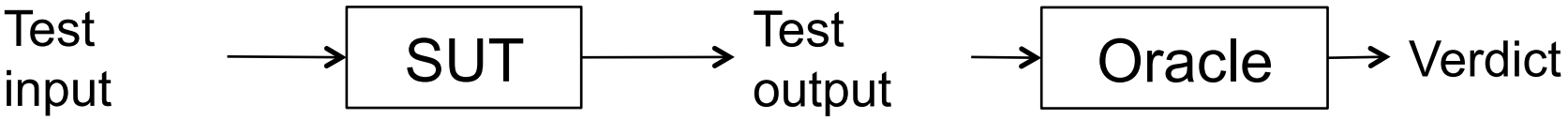
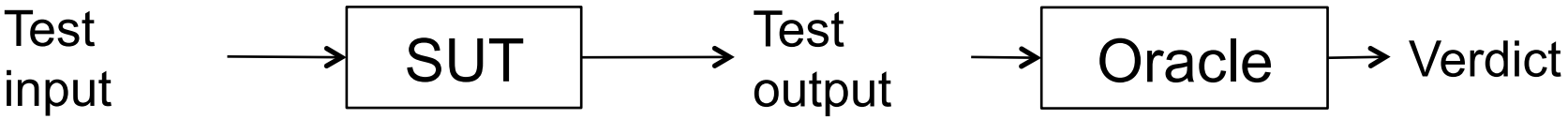


- Test case
  - Input values, preconditions, expected results and postconditions
- Test suite
- Oracle
  - Compares real and expected outputs
- Verdict
  - Pass, Fail, Inconclusive, Error
- Testing != debugging

Basics



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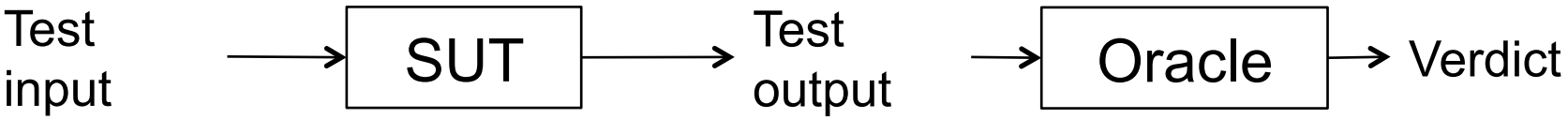

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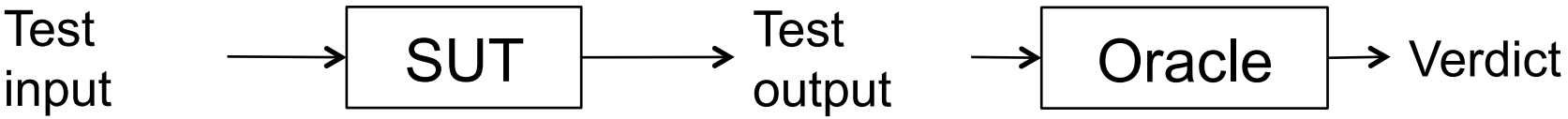

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Problems, Challenges

- Test selection
  - How to select test inputs
- Exit criteria
  - When is testing finished
- Oracle
  - How to define a good test oracle
- Testability
  - How easy is to test the system?
    - Observability
    - Controllability

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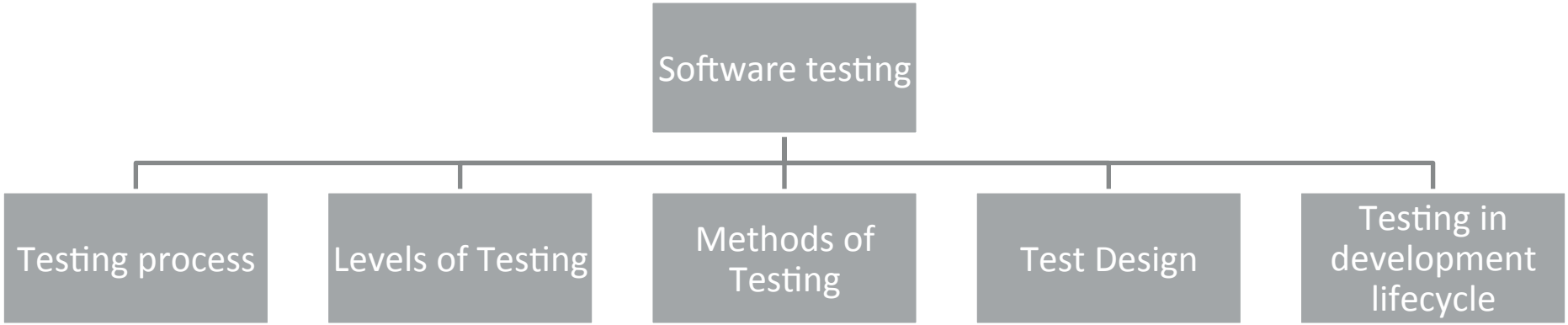
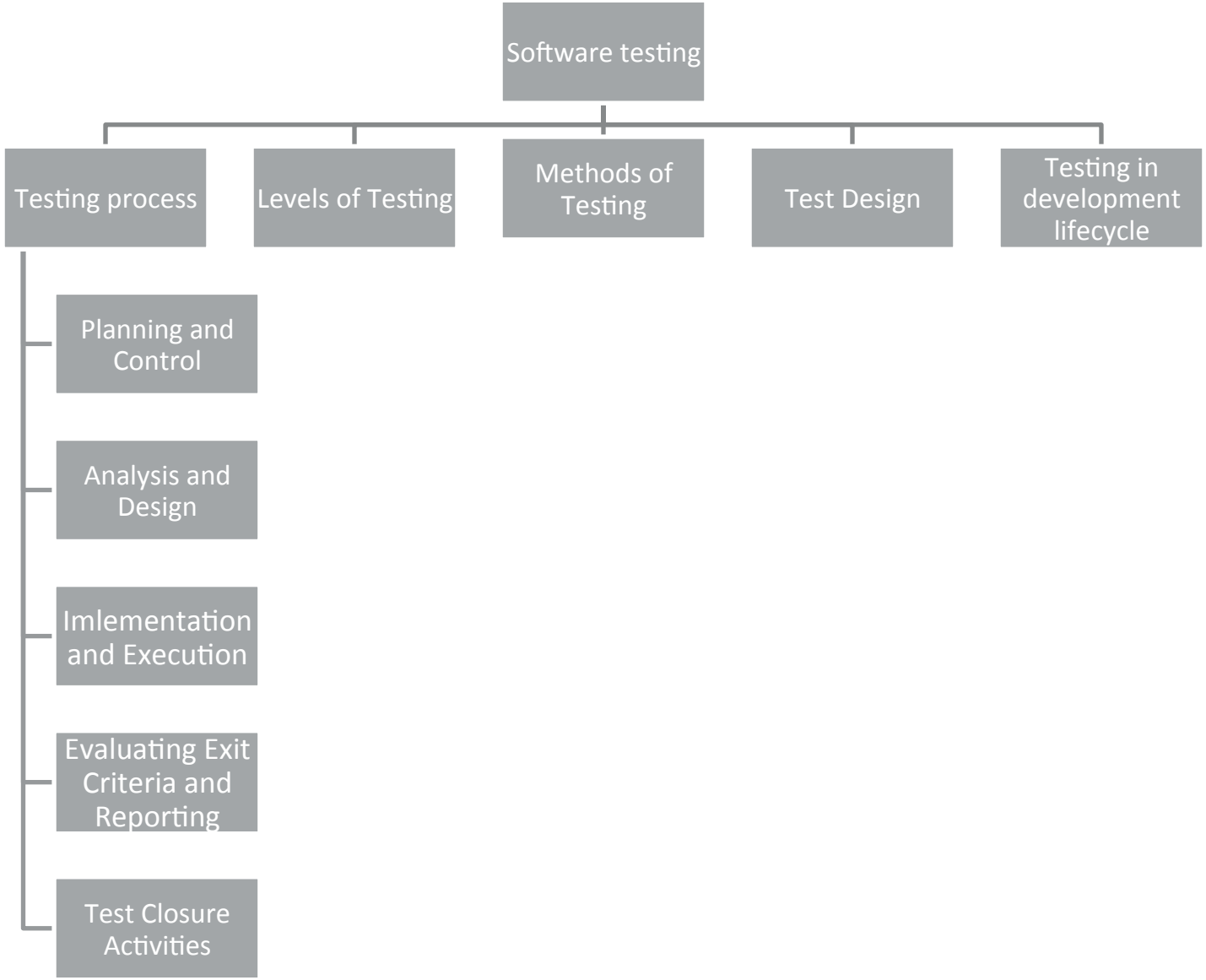

Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle


Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
Planning and Control
Analysis and Design
Imlementation and Execution
Evaluating Exit Criteria and Reporting
Test Closure Activities

Testing Strategy

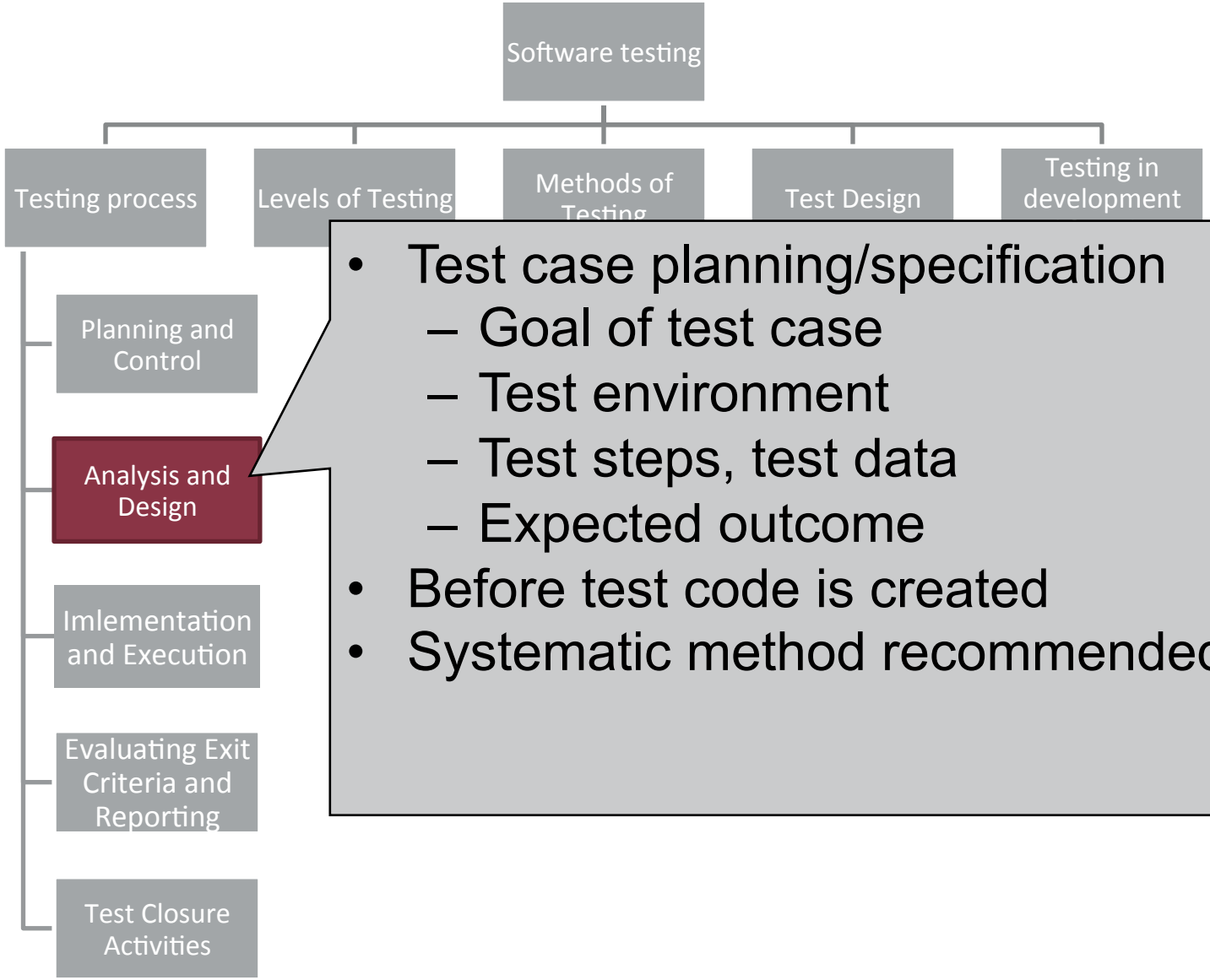
- General policies
  - Methodology
  - Test types
  - Test tools
  - Who tests
  - Exit criteria
  - Testing documentation
  - …

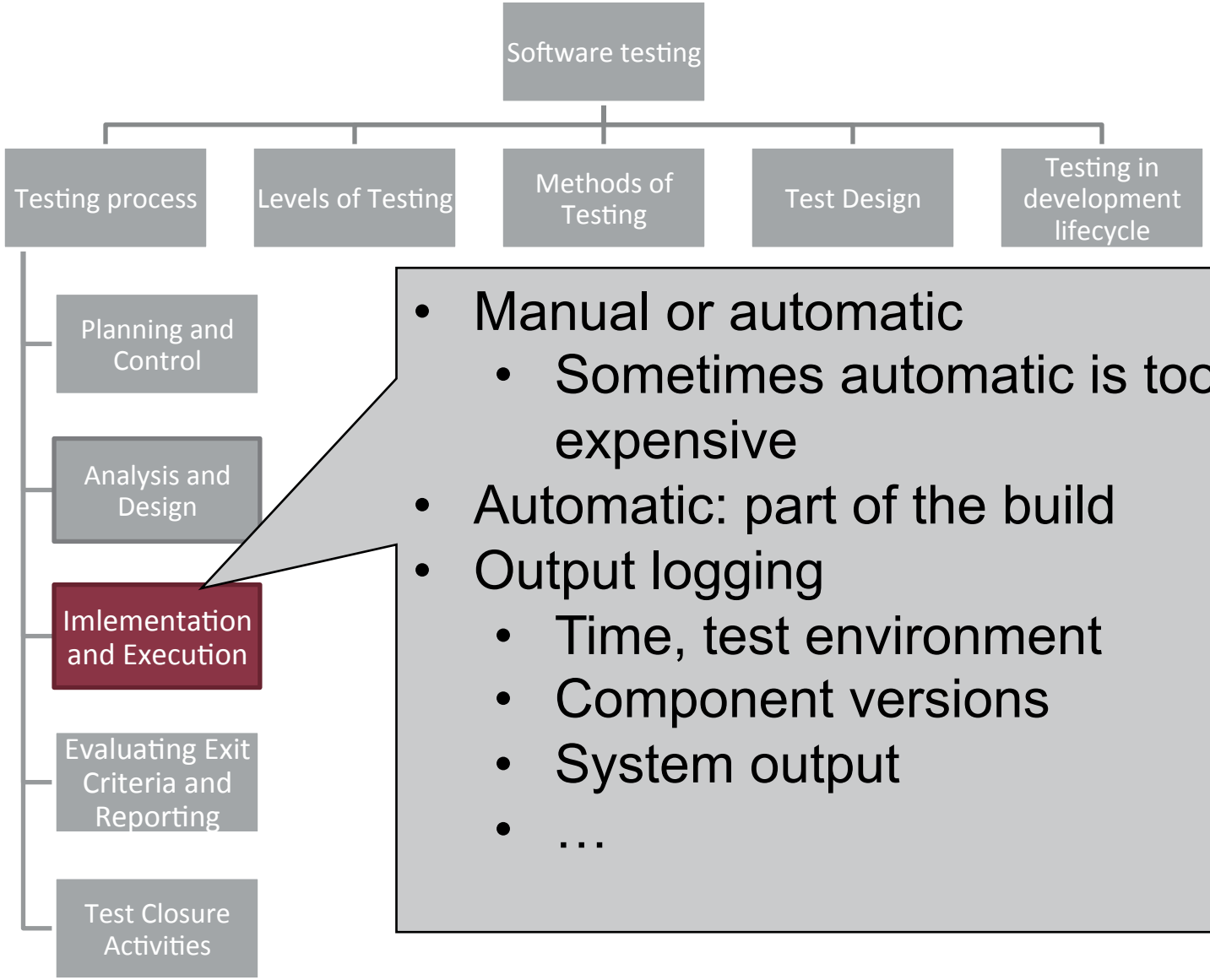
Testing Strategy

- General policies
  - Methodology
  - Test types
  - Test tools
  - Who tests
  - Exit criteria
  - Testing documentation
  - …
- E.g.:
  - Extreme programming
  - Module & system
  - JUnit & GUI Tester
  - Developers and test team
  - 90% code coverage & 100% use case coveragy

Test Suite Evaluation

- Coverage
  - Code
  - Specification
- Output distribution
- Cost!


Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development
Planning and Control
Analysis and Design
Imlementation and Execution
Evaluating Exit Criteria and Reporting
Test Closure Activities
• Test case planning/specification
– Goal of test case
– Test environment
– Test steps, test data
– Expected outcome
• Before test code is created
• Systematic method recommended


Software testing
Testing process
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Test Design
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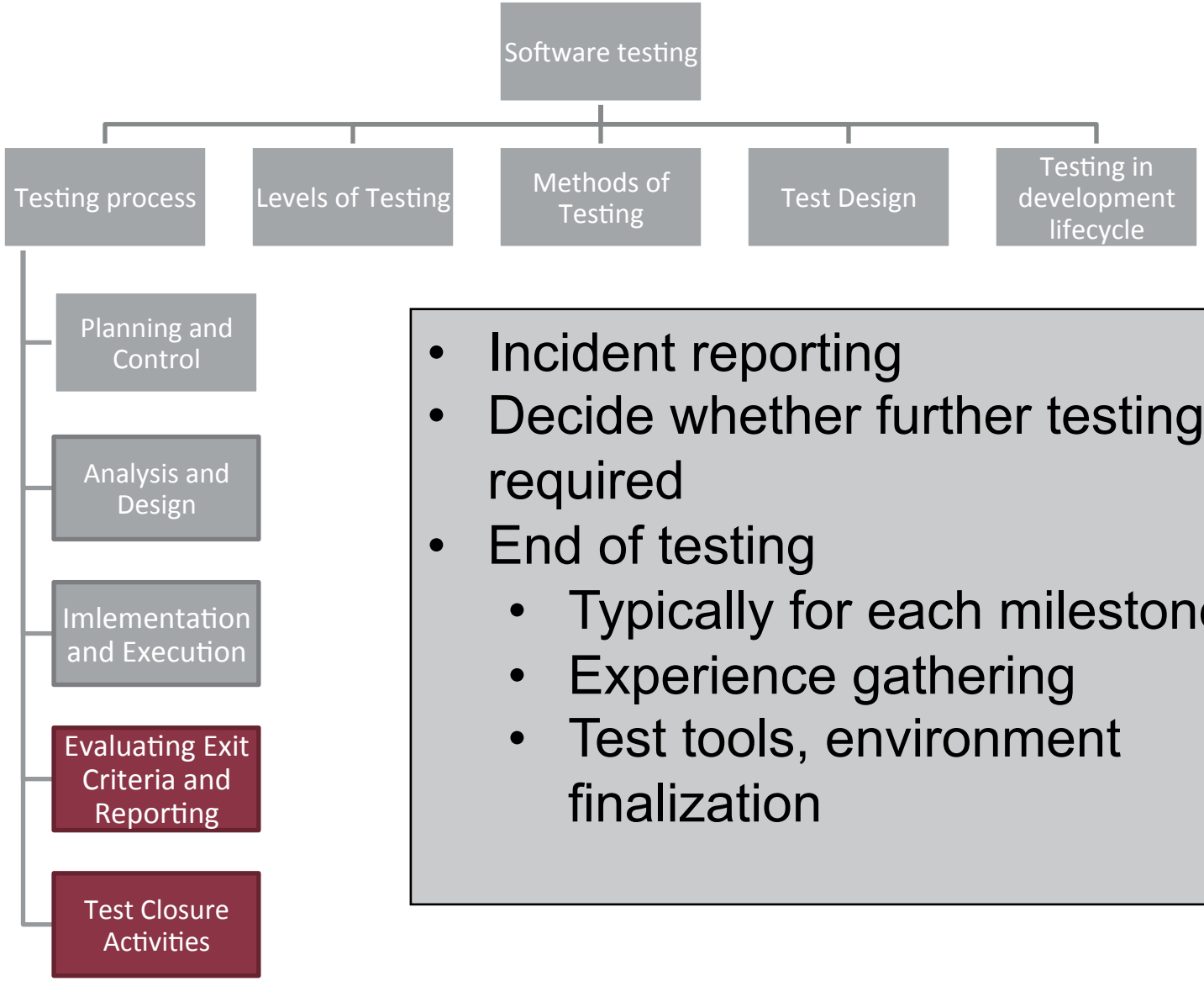
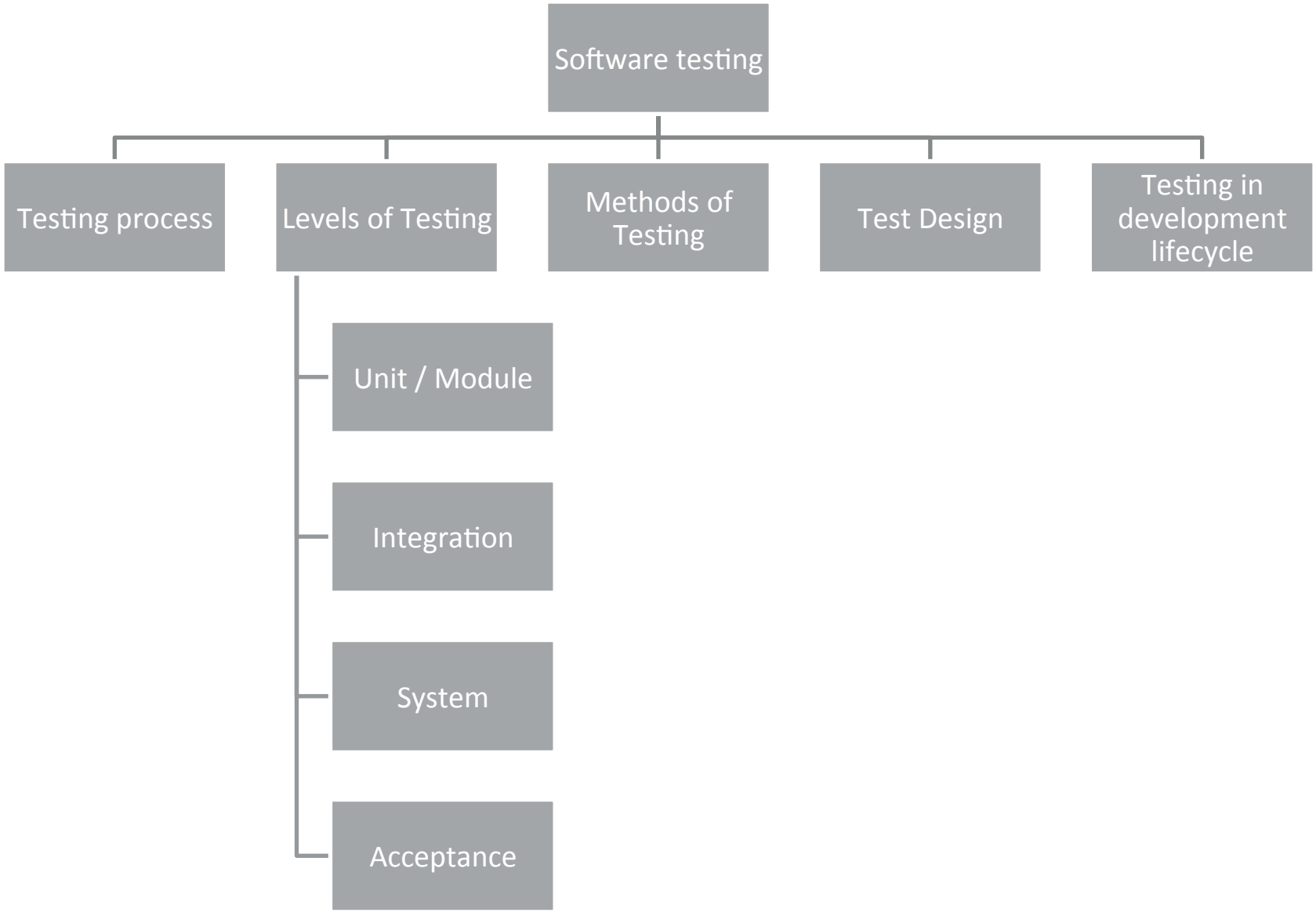
Test Closure Activities
• Manual or automatic
• Sometimes automatic is too expensive
• Automatic: part of the build
• Output logging
• Time, test environment
• Component versions
• System output
• …



- Incident reporting
- Decide whether further testing required
- End of testing
  - Typically for each milestone
  - Experience gathering
  - Test tools, environment finalization


Software testing
Testing process
Levels of Testing
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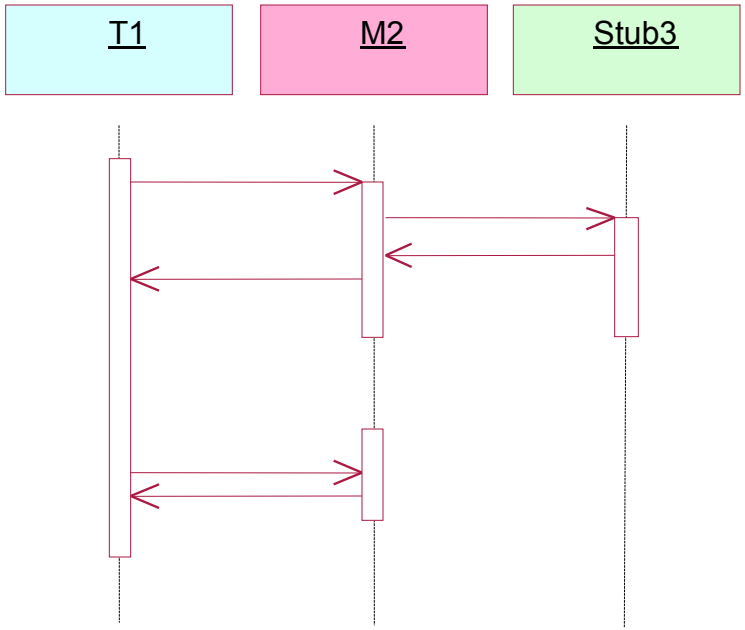
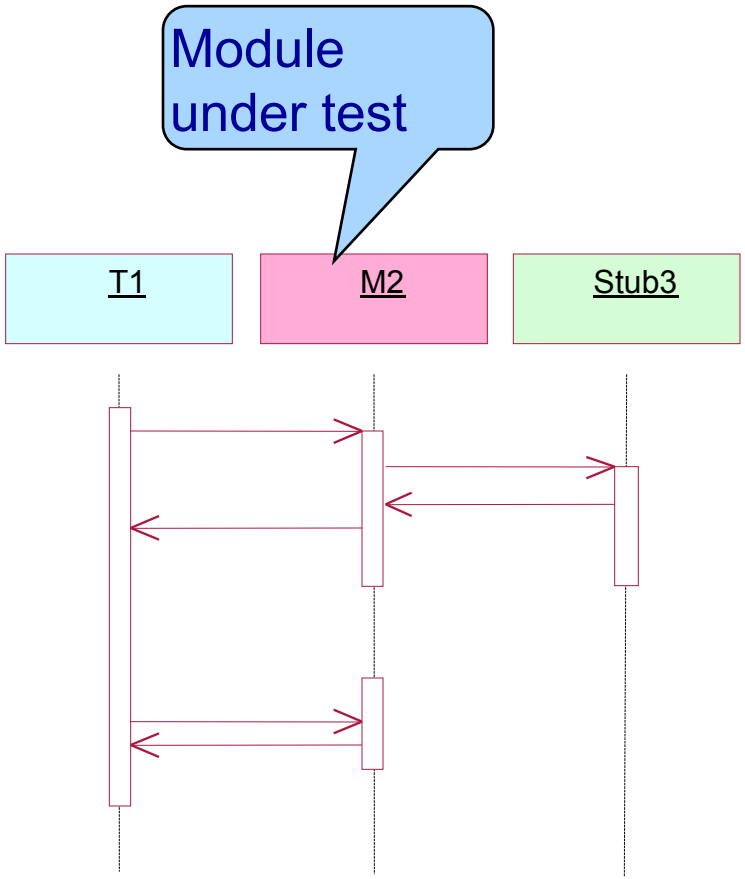
Test Design
Testing in development lifecycle
Unit / Module
Integration
System
Acceptance

Module Testing



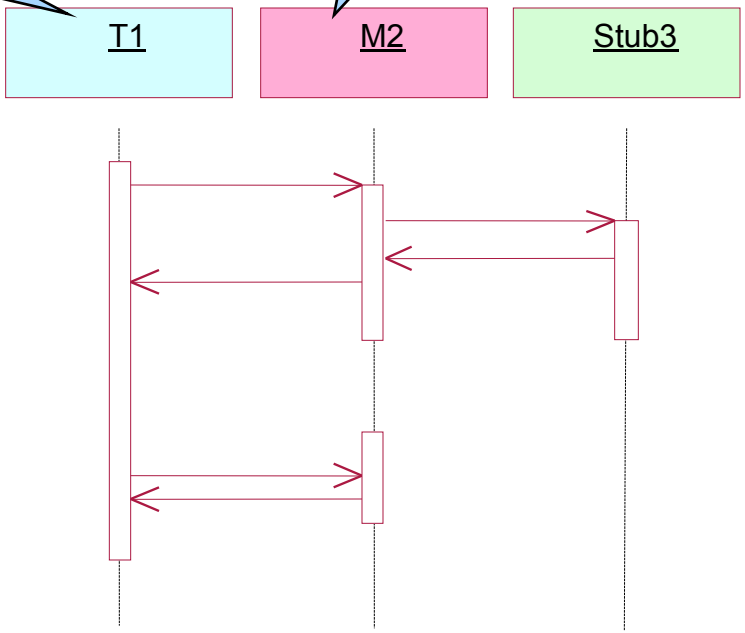
Module Testing



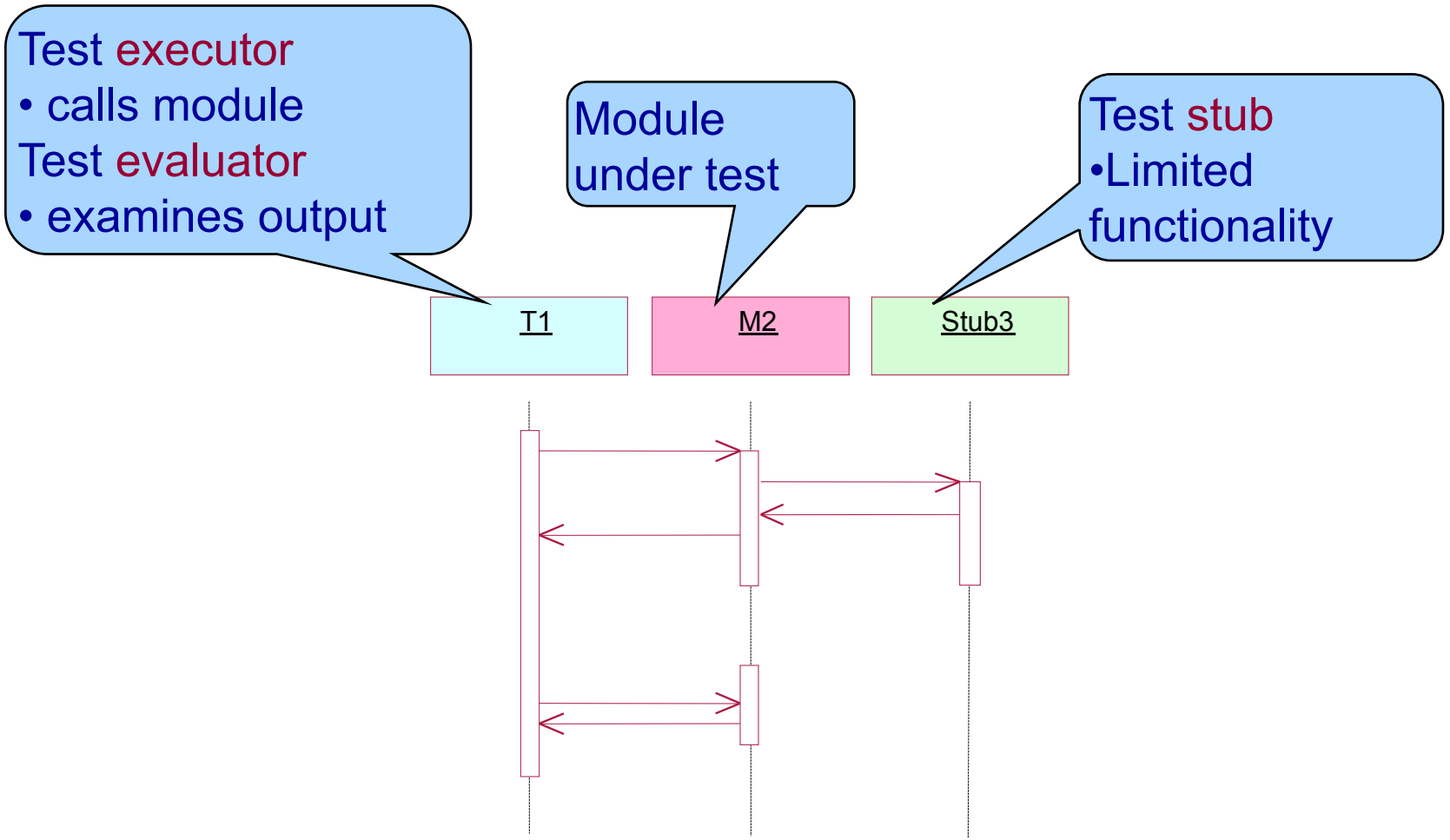
Module Testing

Test executor
• calls module
Test evaluator
• examines output

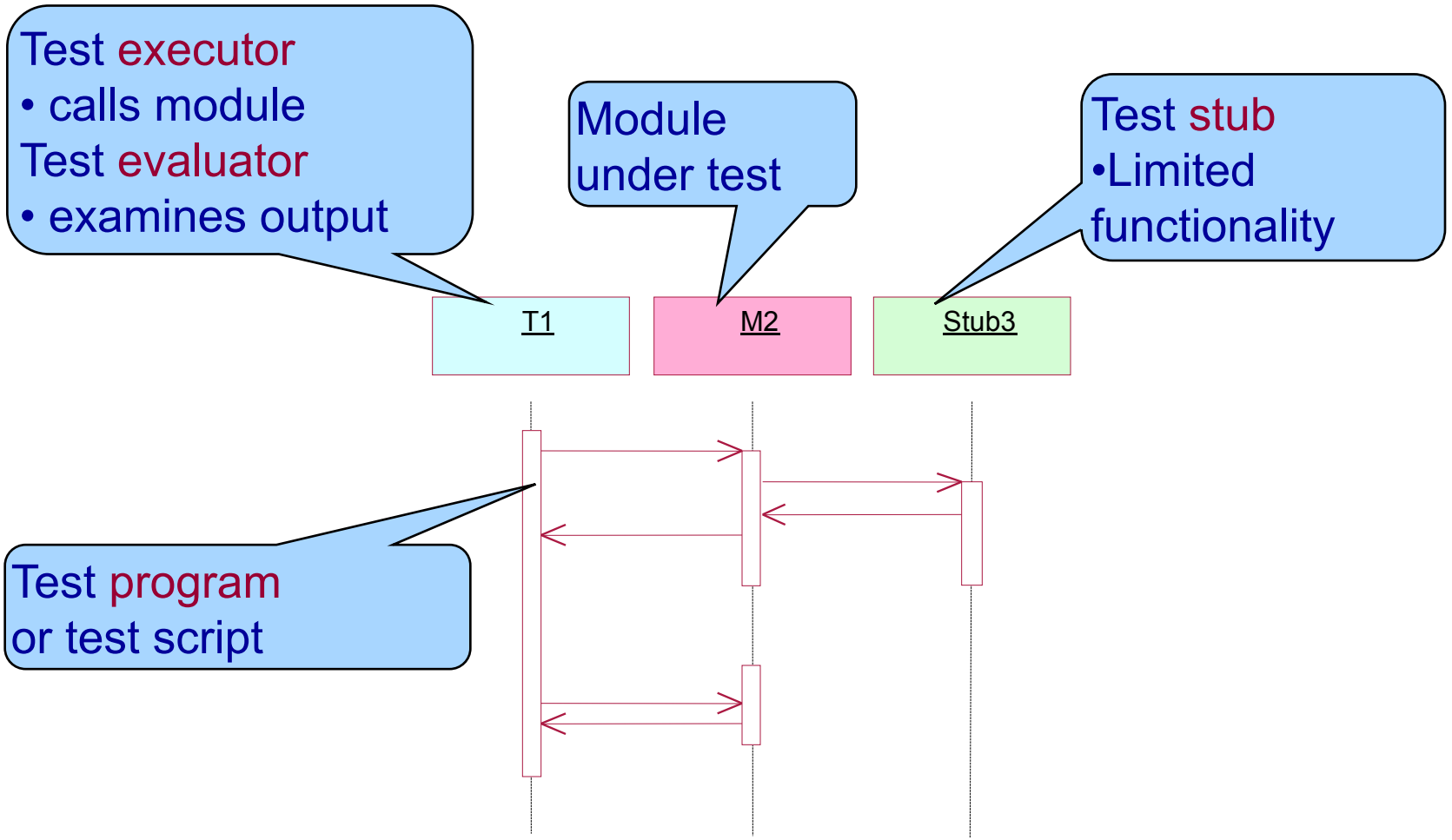
Module under test



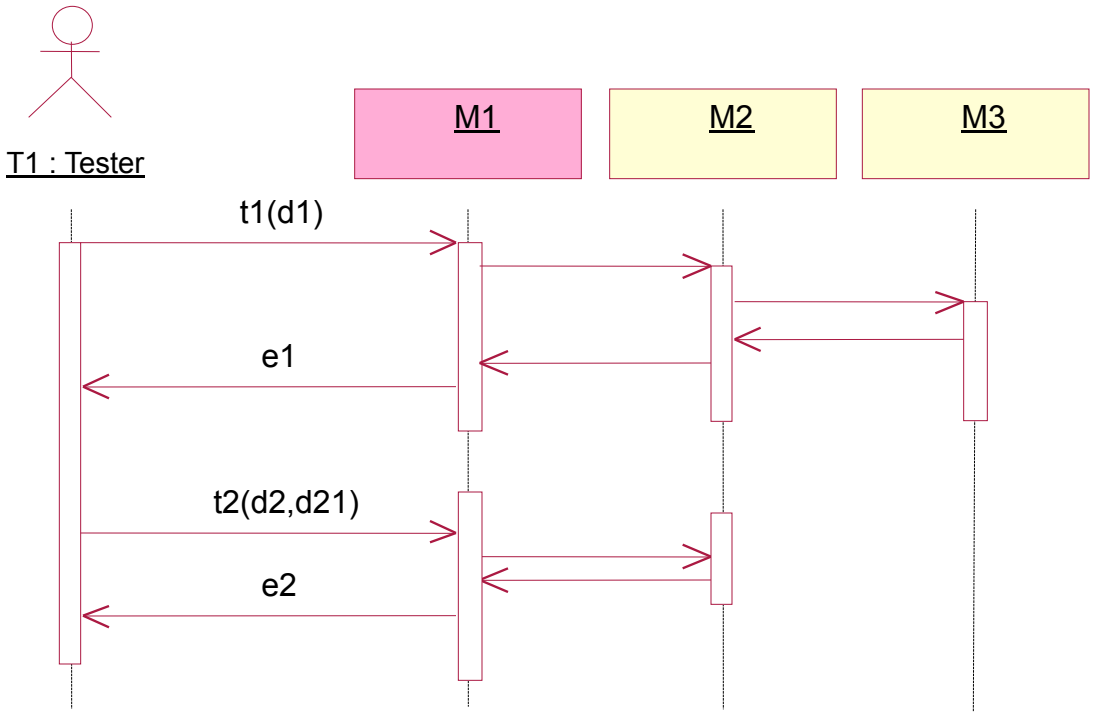
Module Testing



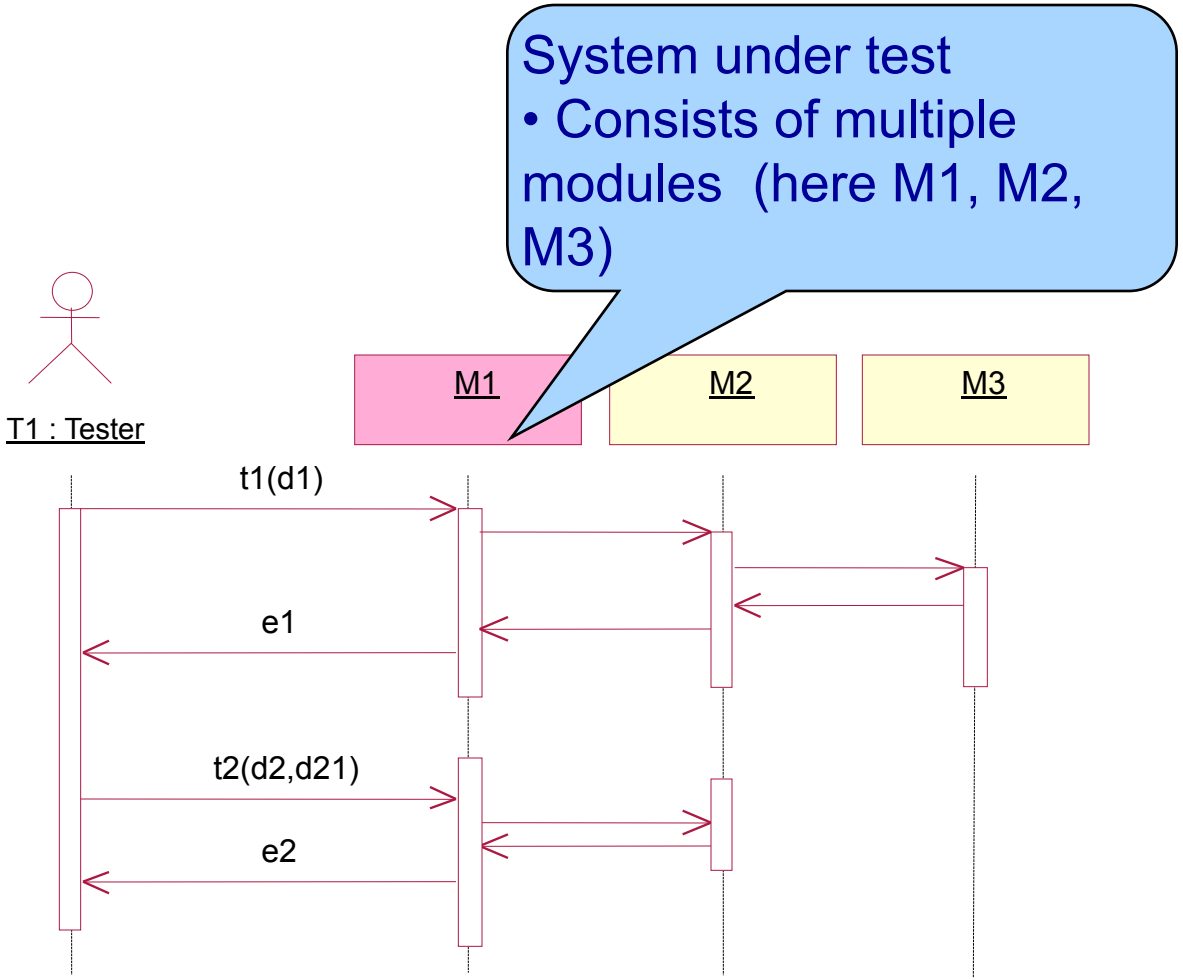
Module Testing



Integration Testing



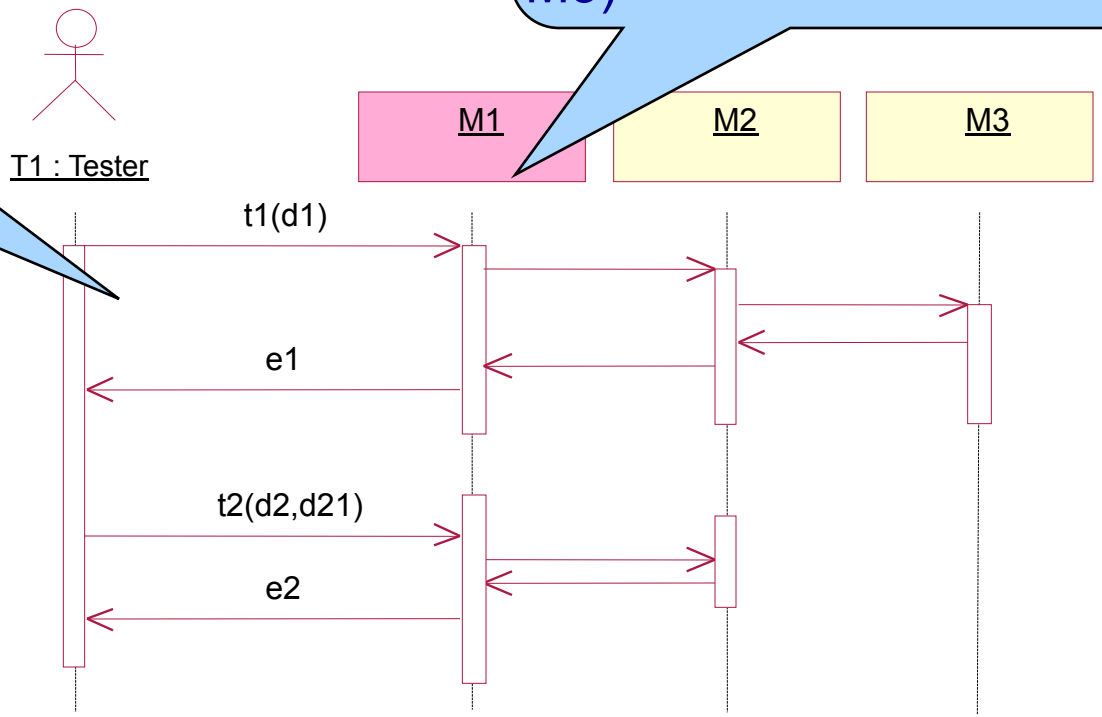
Integration Testing



Integration Testing

System under test
• Consists of multiple modules (here M1, M2, M3)

Test 1
• test input
• expected output



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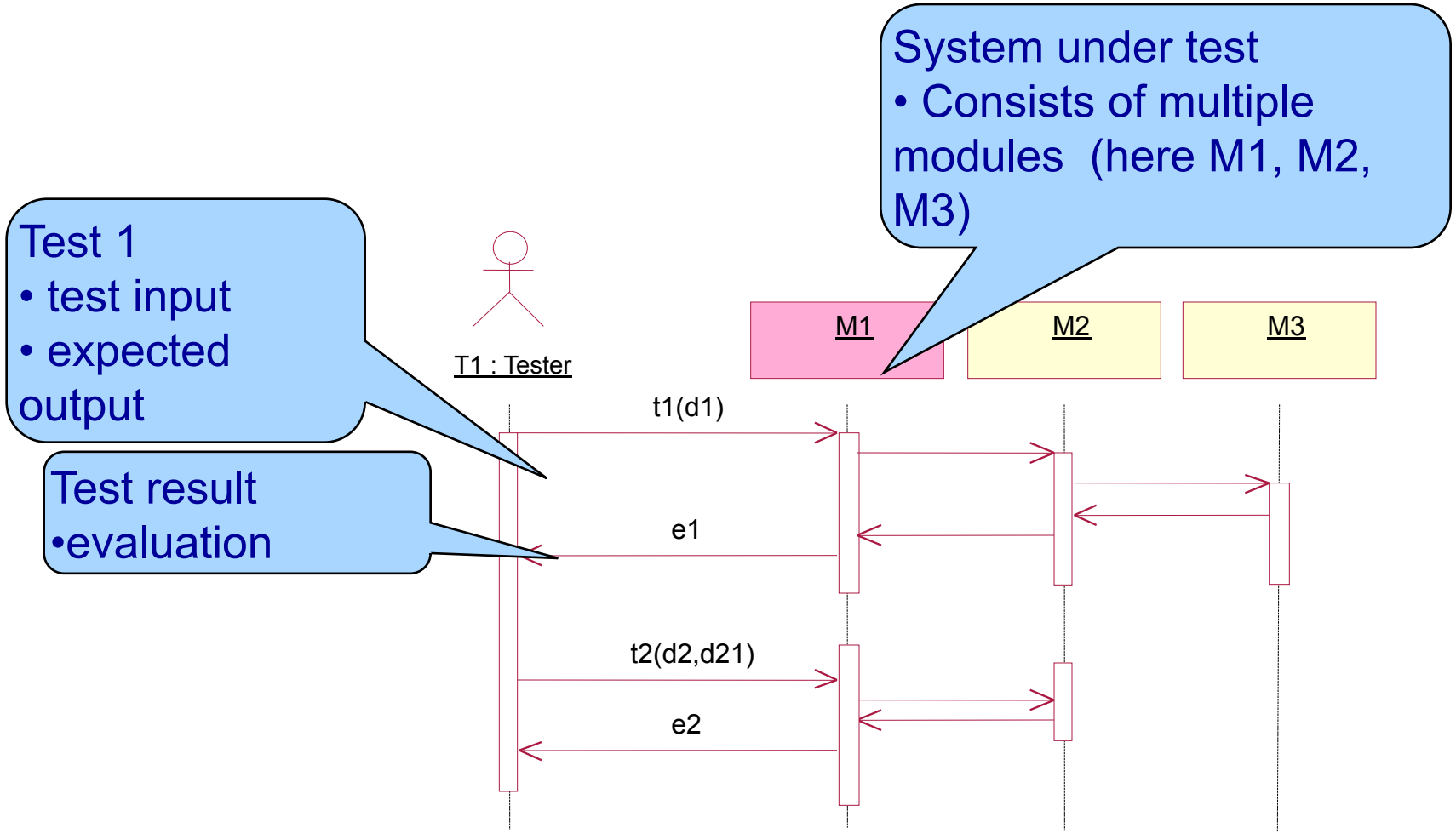

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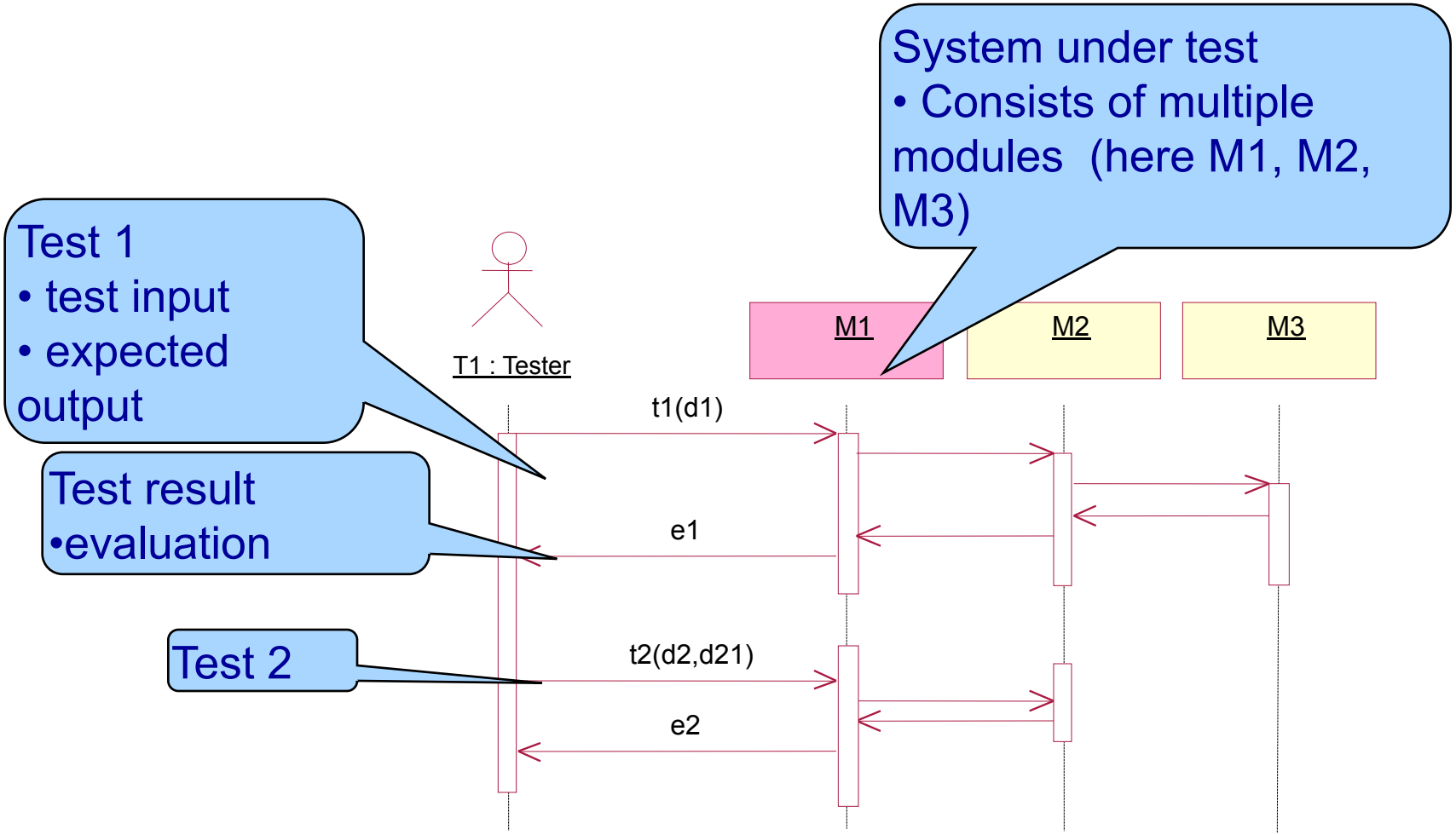
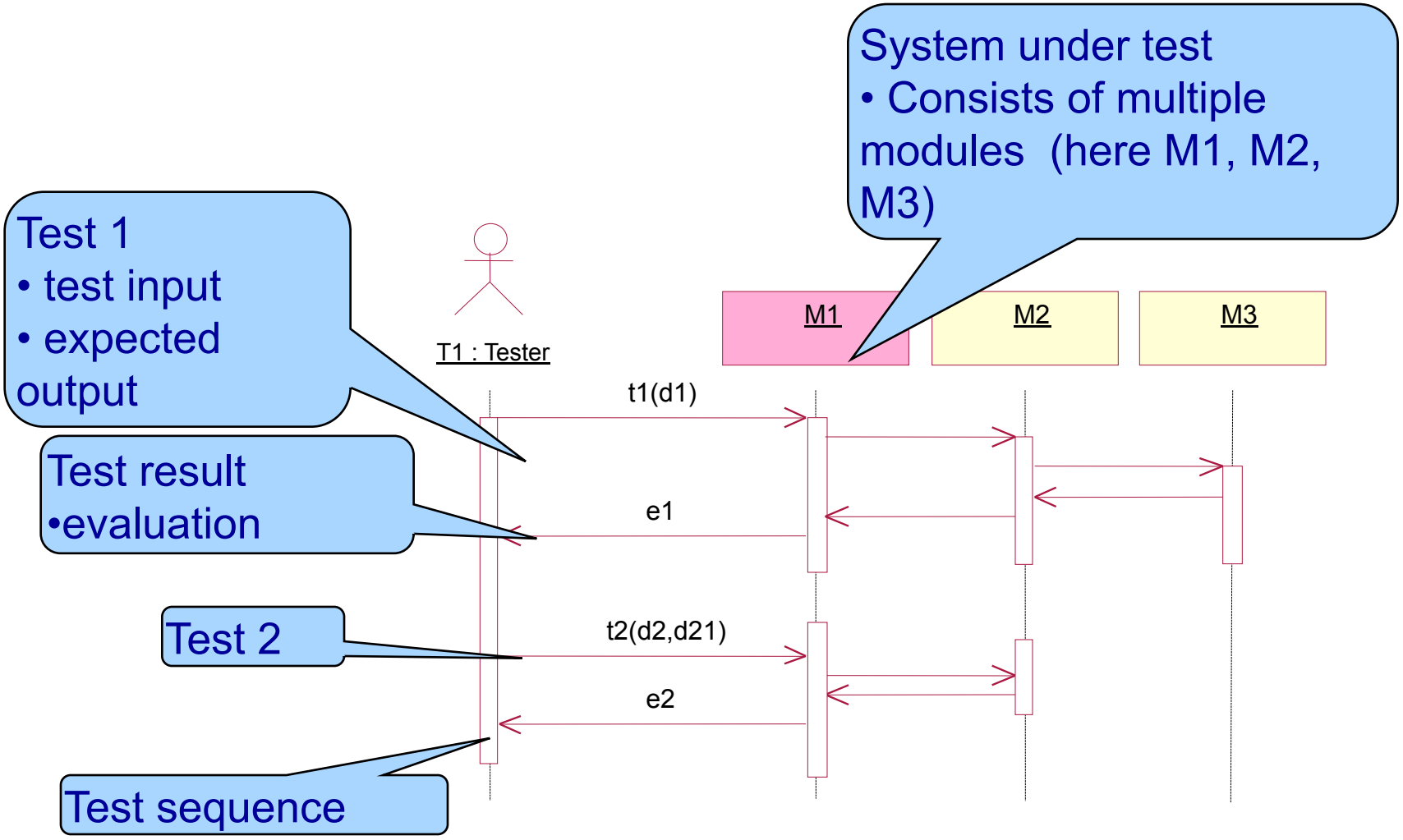
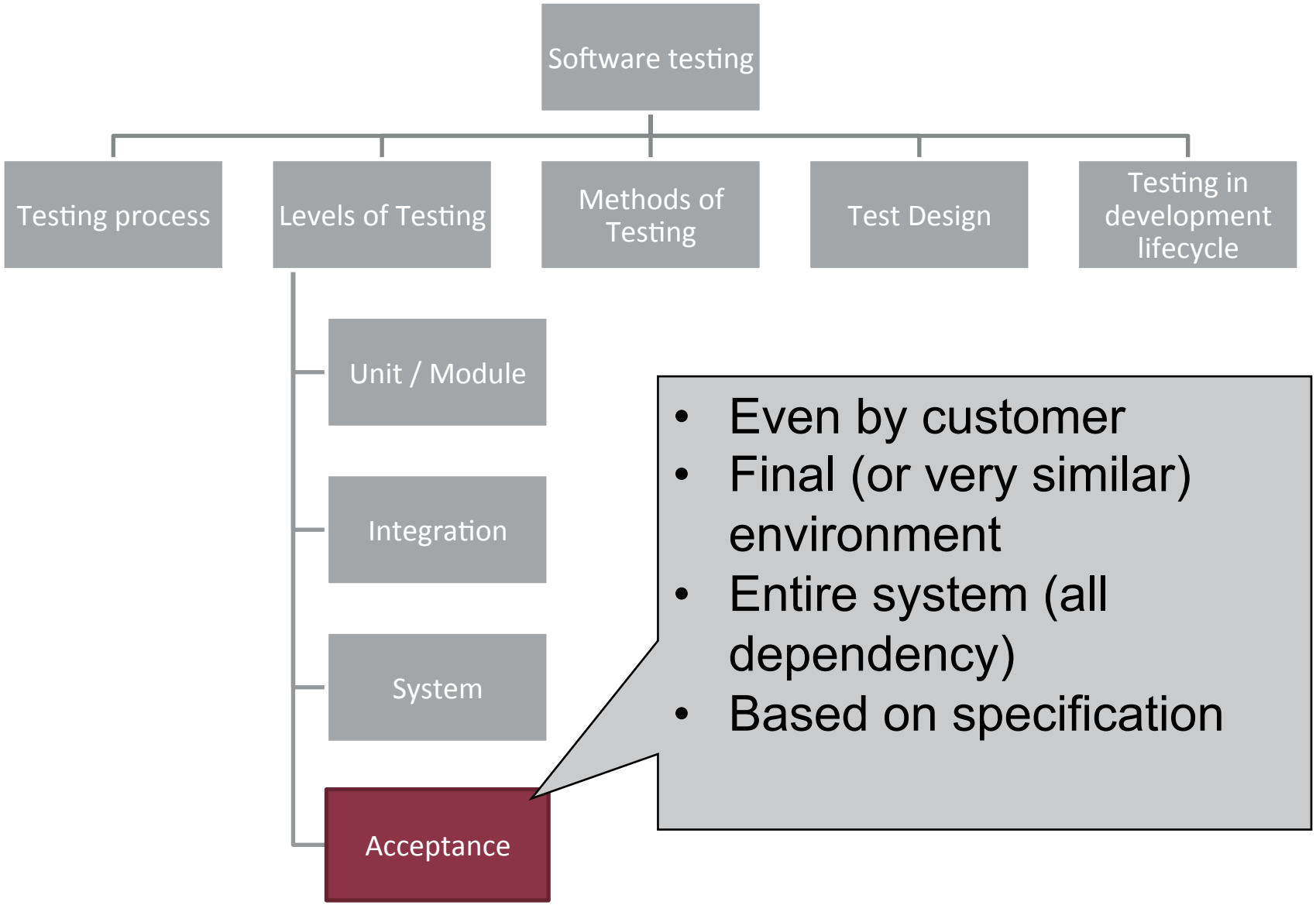
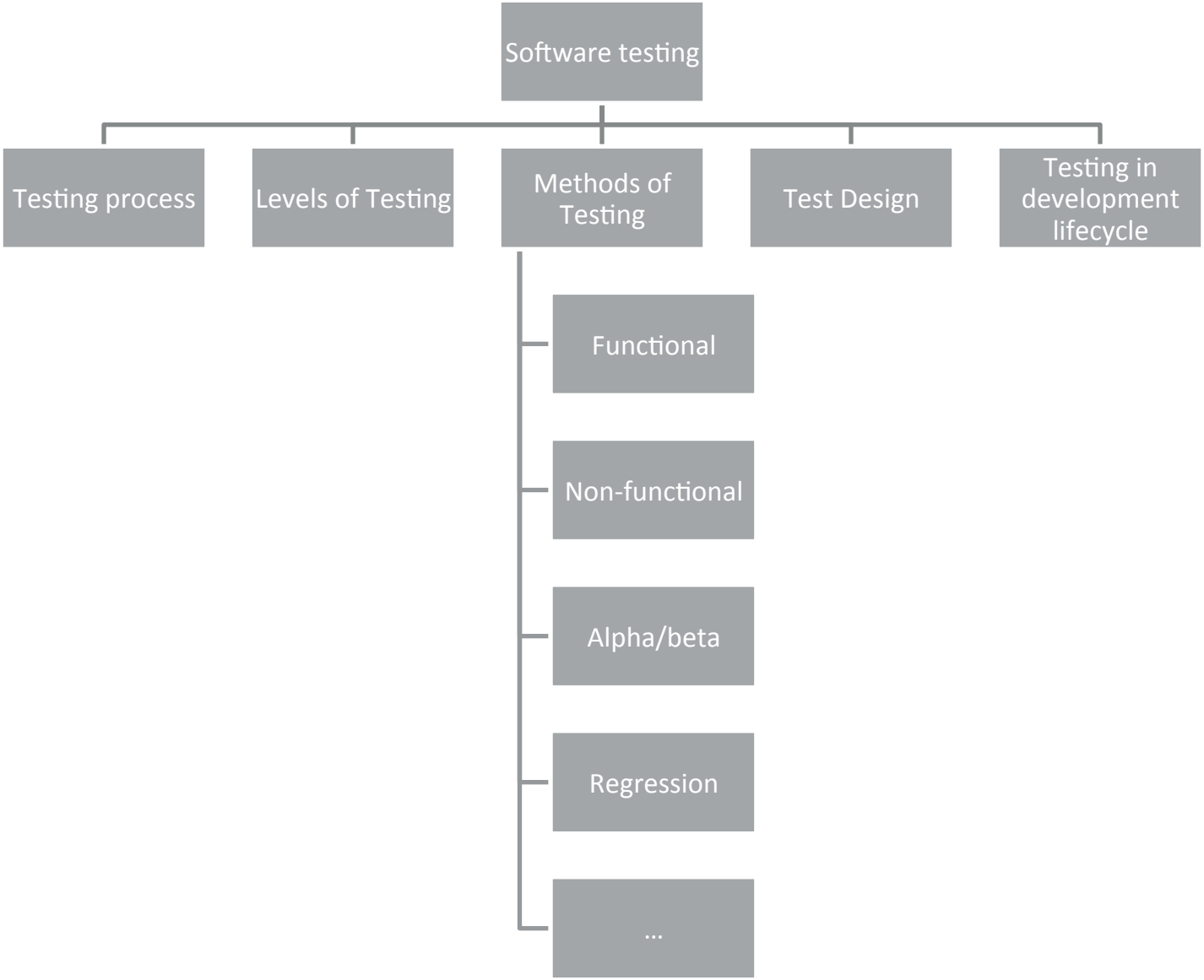


Integration Testing




Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
Unit / Module
Integration
System
Acceptance
• Even by customer
• Final (or very similar) environment
• Entire system (all dependency)
• Based on specification


Software testing
Testing process
Levels of Testing
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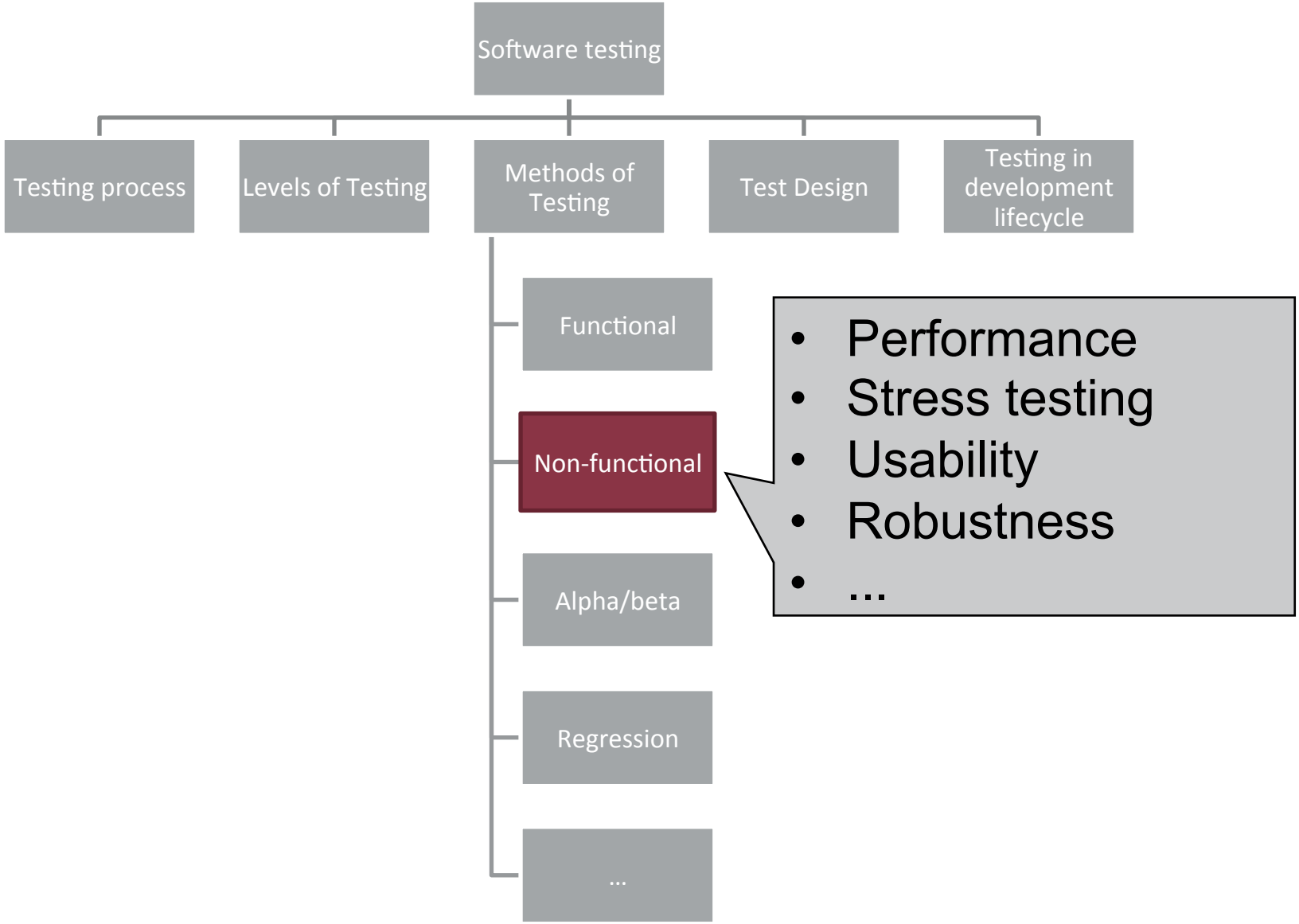
Test Design
Testing in development lifecycle
Functional
Non-functional
Alpha/beta
Regression
...


Software testing
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Levels of Testing
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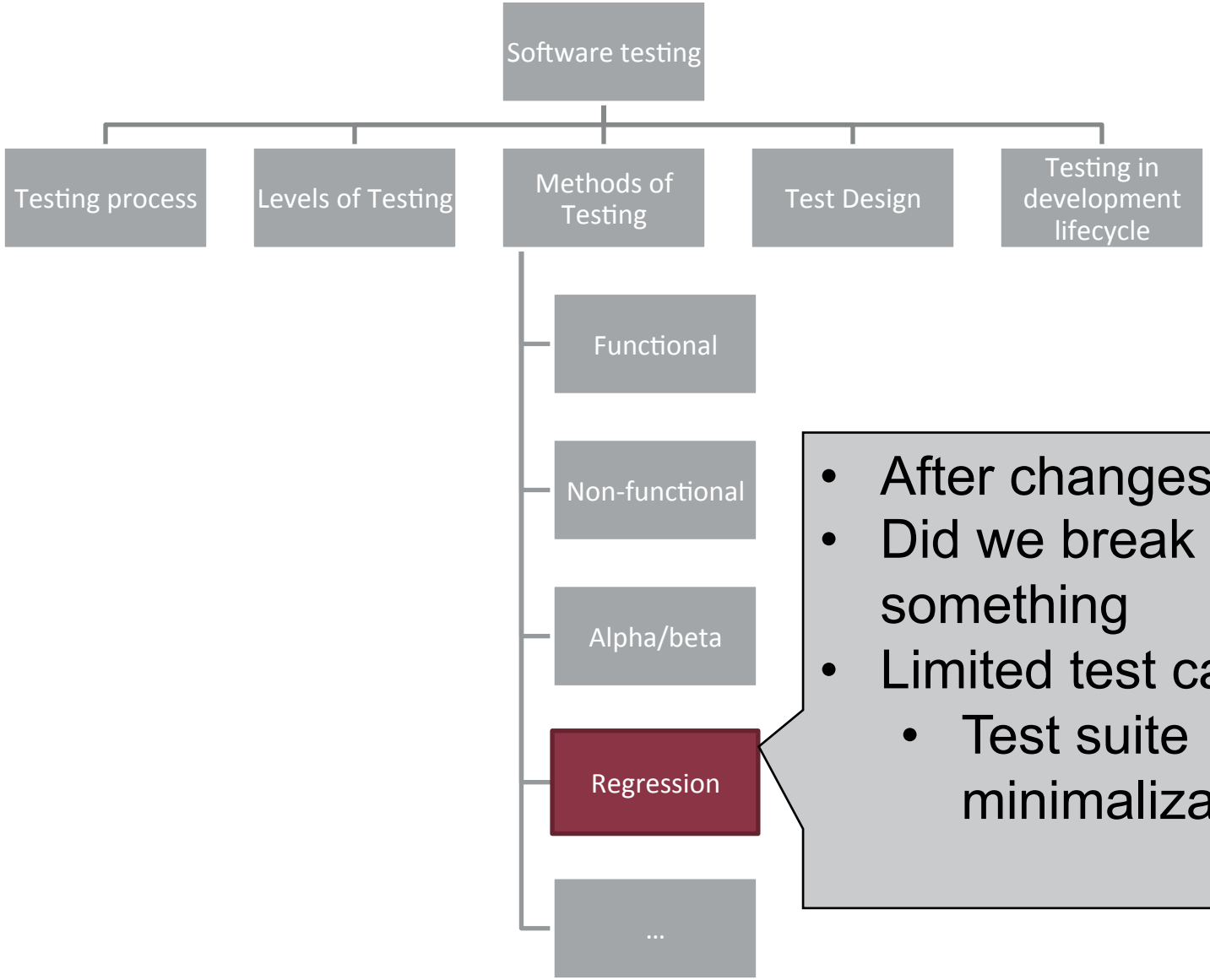
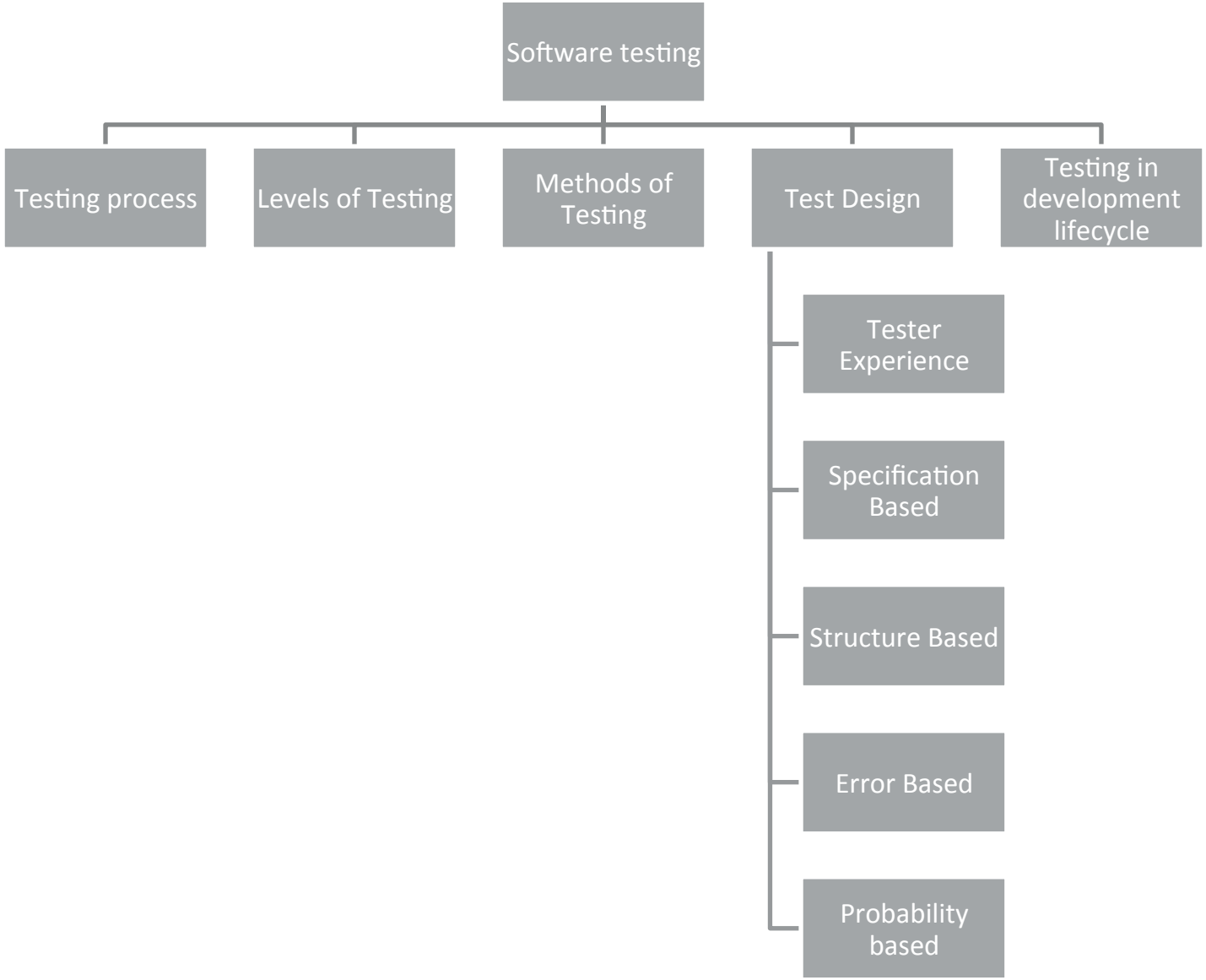
Alpha/beta
Regression
...
• Performance
• Stress testing
• Usability
• Robustness
• ...


Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
Functional
Non-functional
Alpha/beta
Regression
...
• After changes
• Did we break something
• Limited test case
• Test suite minimalization


Software testing
Testing process
Levels of Testing
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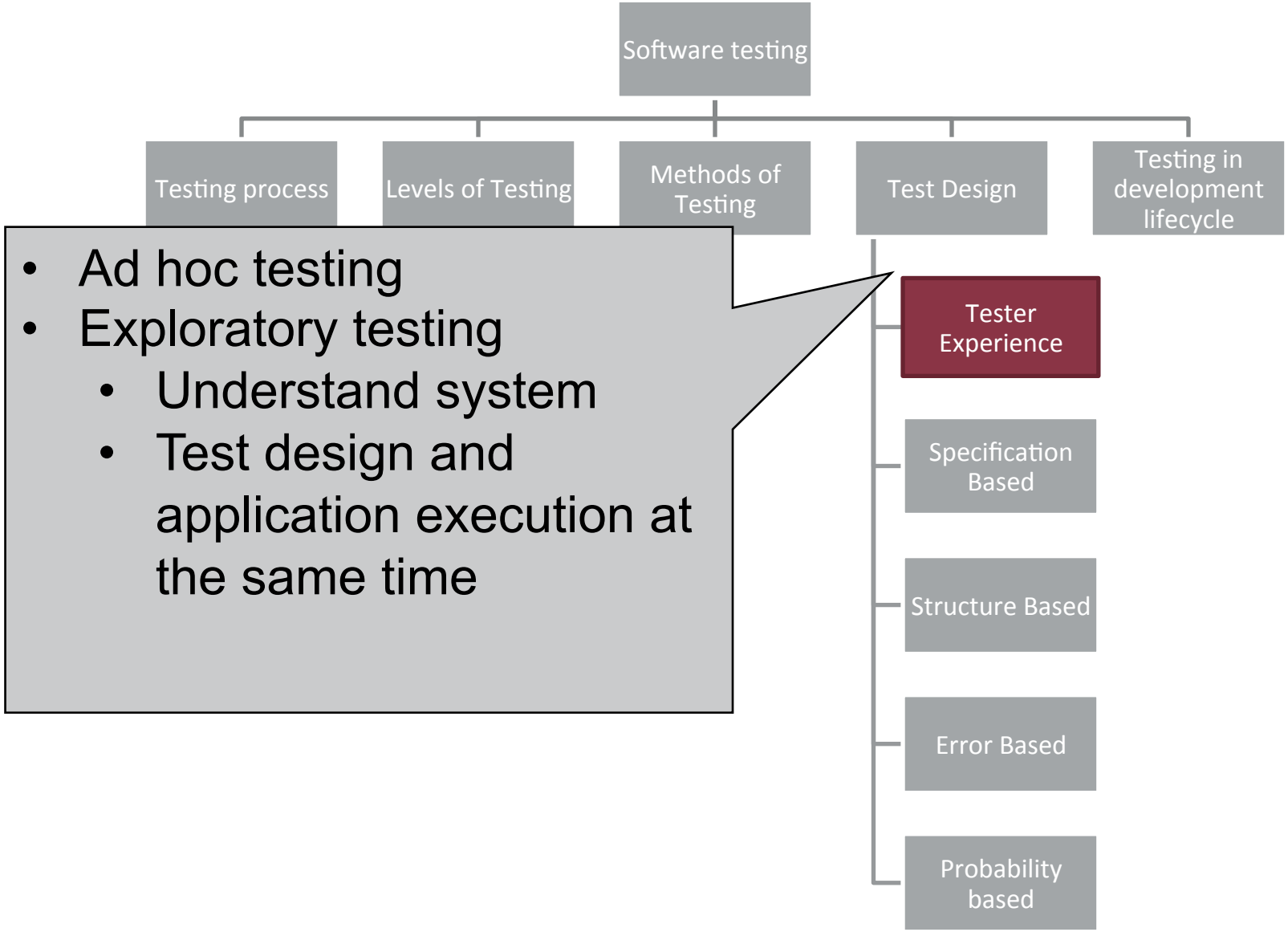
Testing in development lifecycle
Tester Experience
Specification Based
Structure Based
Error Based
Probability based


Software testing
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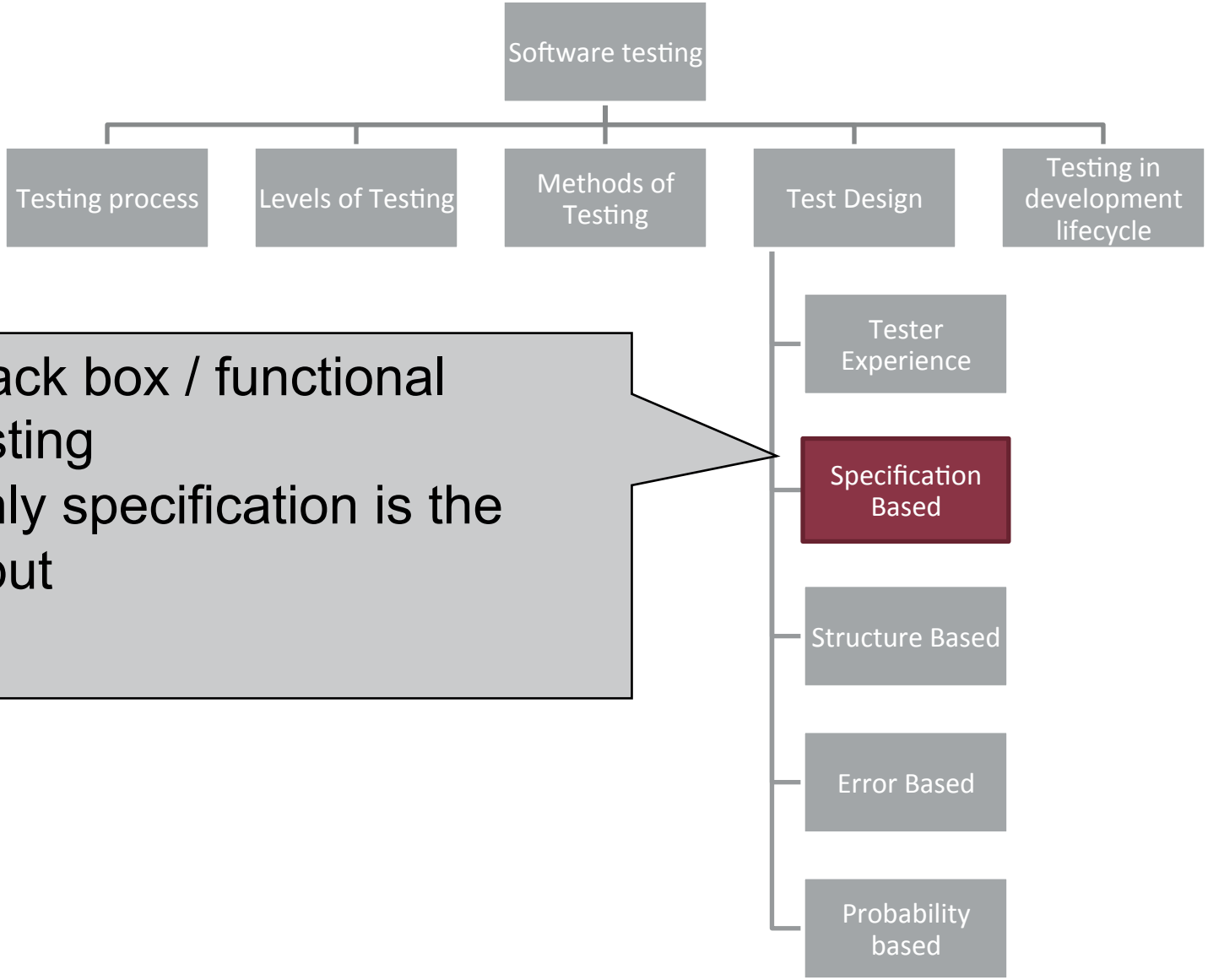
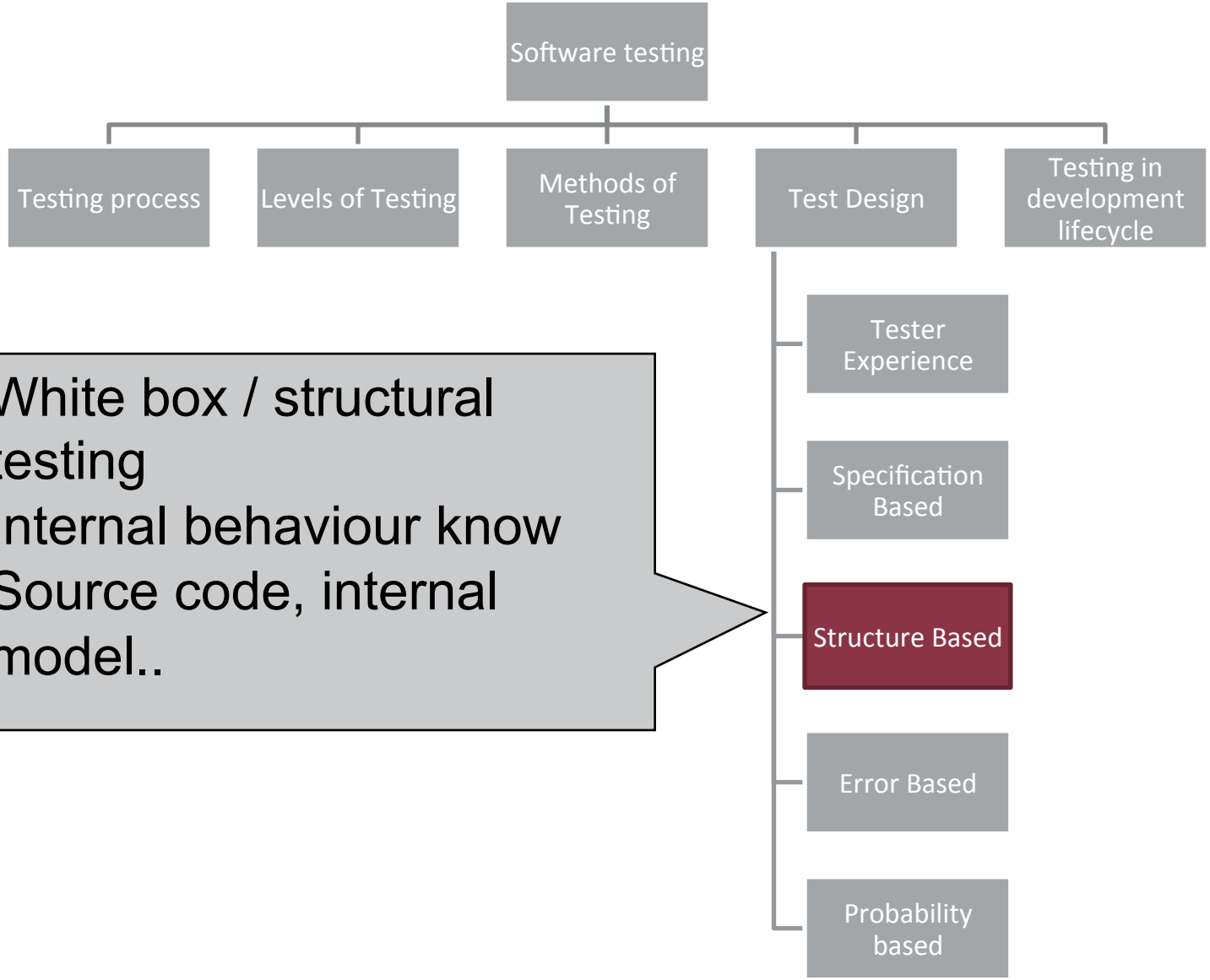
Methods of Testing
Test Design
Testing in development lifecycle
Tester Experience
Specification Based
Structure Based
Error Based
Probability based
• Ad hoc testing
• Exploratory testing
• Understand system
• Test design and application execution at the same time



- Black box / functional testing
- Only specification is the input


Software testing
Testing process
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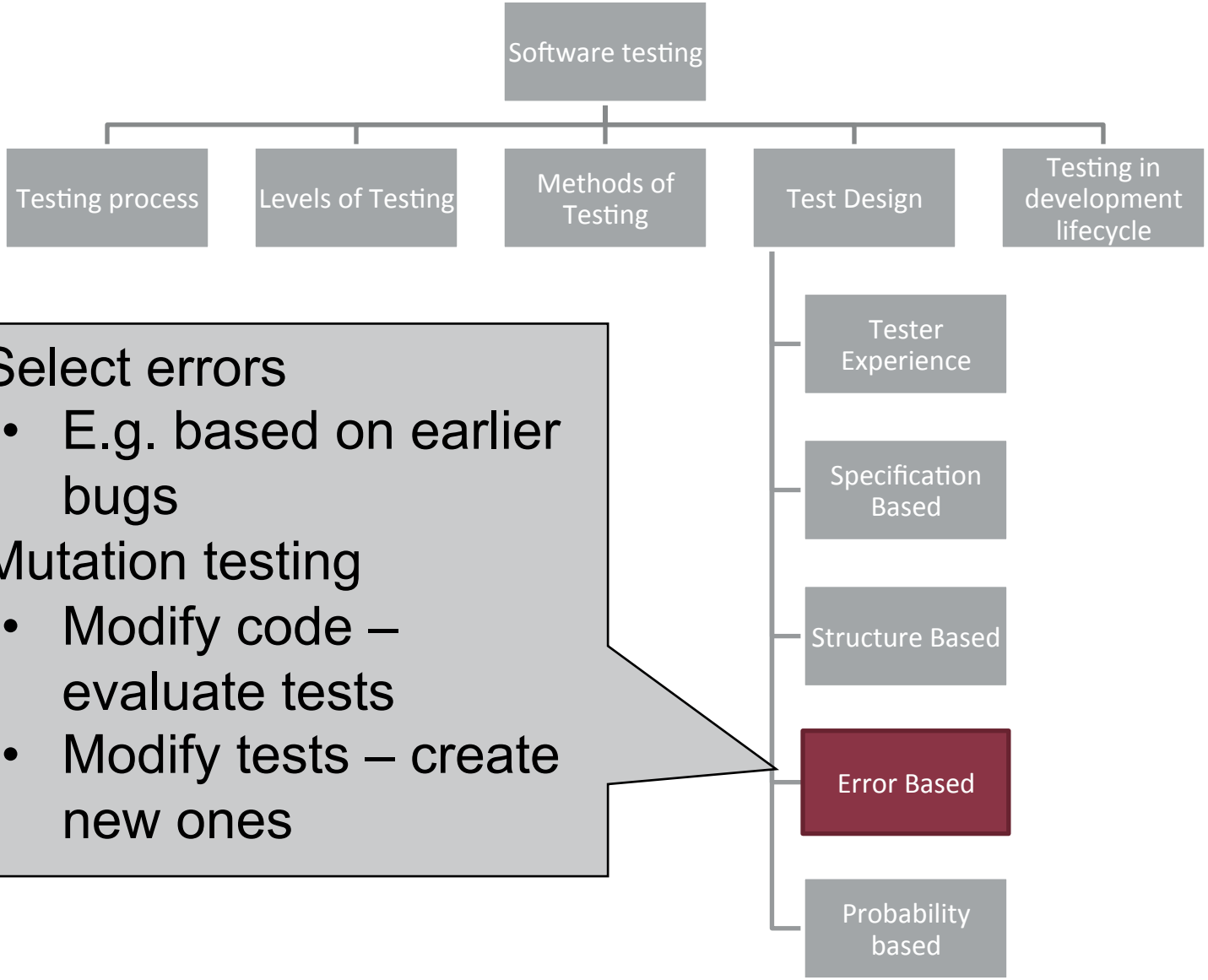
Methods of Testing
Test Design
Testing in development lifecycle
Tester Experience
Specification Based
Structure Based
Error Based
Probability based
• White box / structural testing
• Internal behaviour know
• Source code, internal model..


Software testing
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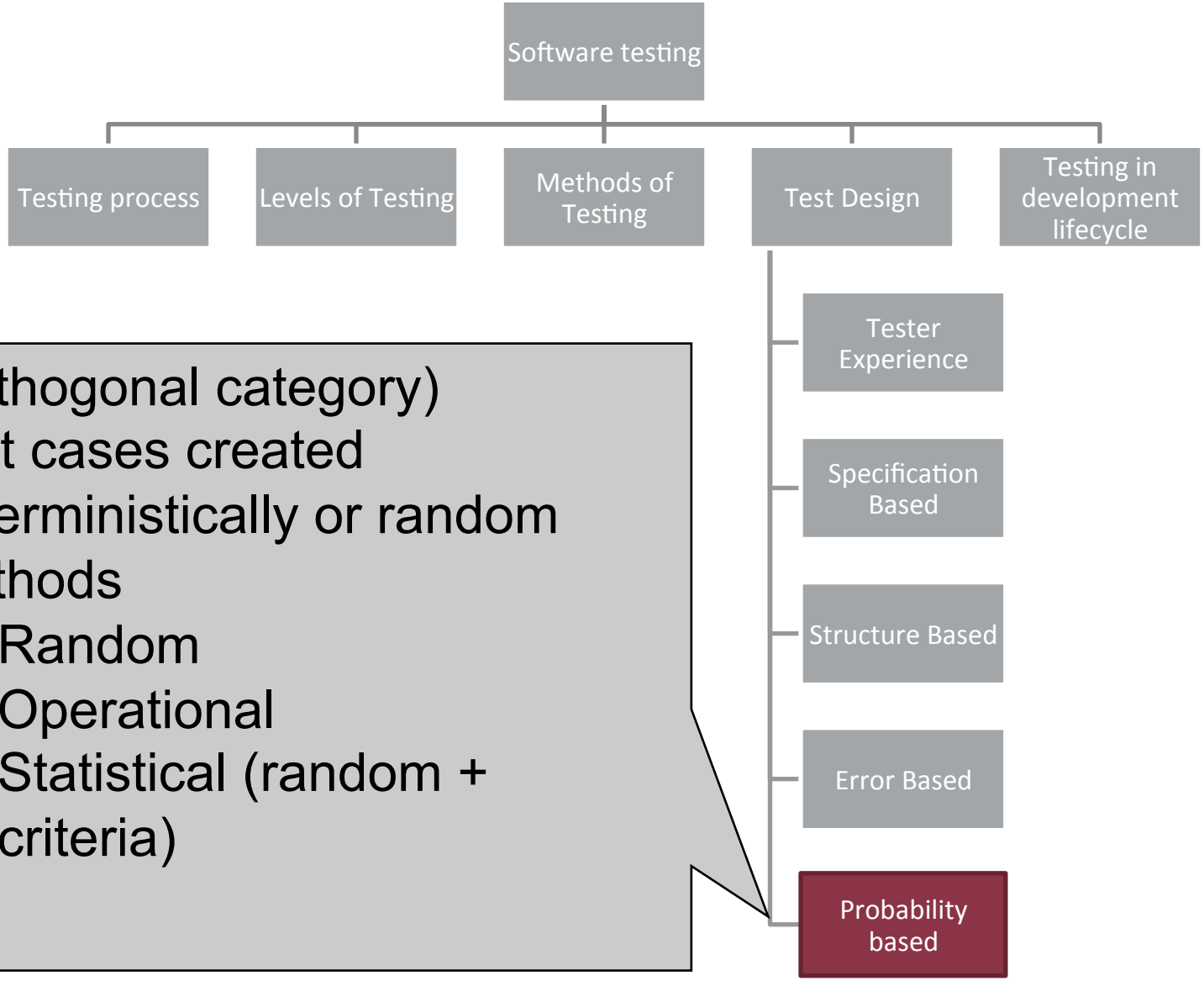
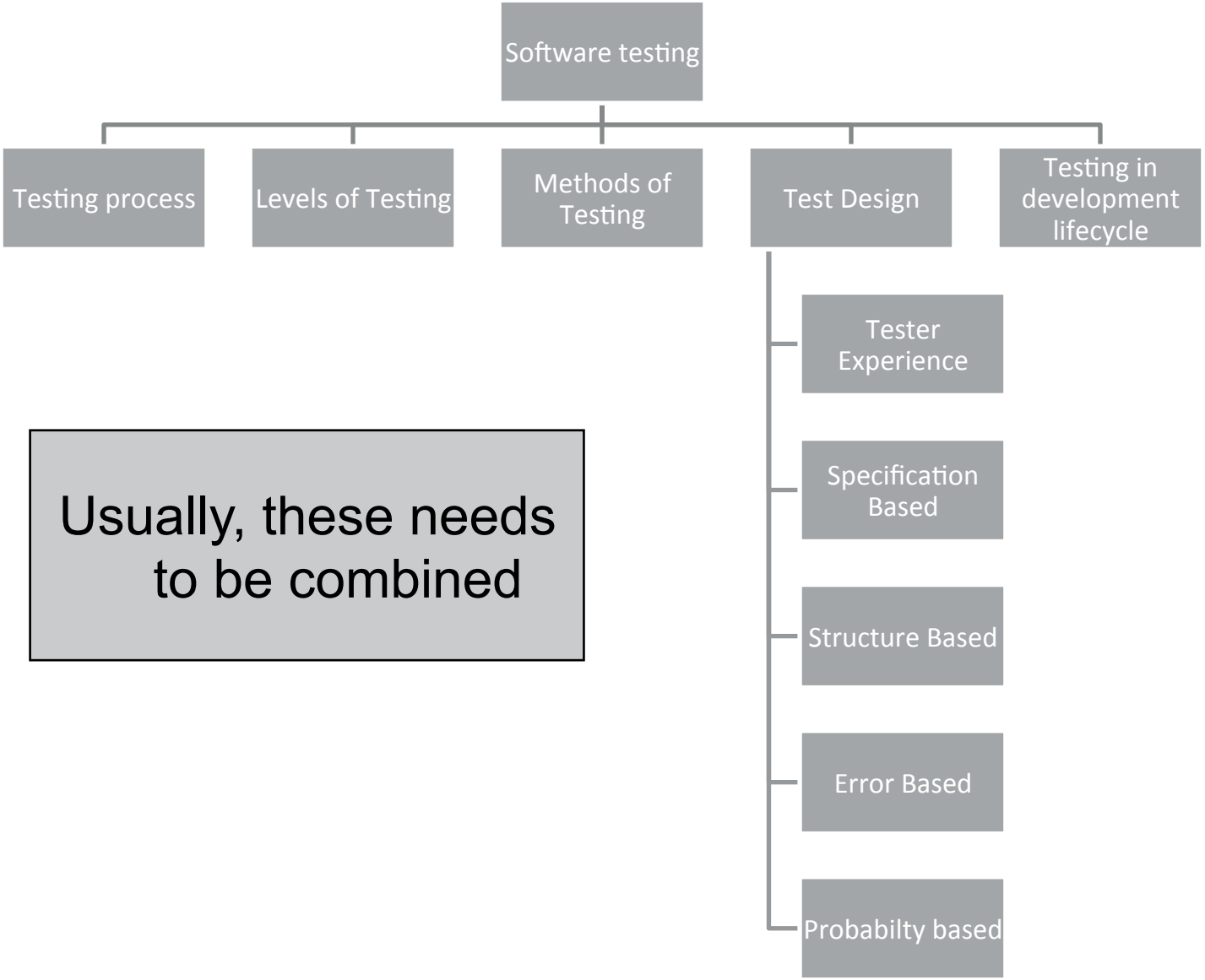
Tester Experience
Specification Based
Structure Based
Error Based
Probability based
• Select errors
• E.g. based on earlier bugs
• Mutation testing
• Modify code – evaluate tests
• Modify tests – create new ones



- (Orthogonal category)
- Test cases created deterministically or random
- Methods
  - Random
  - Operational
  - Statistical (random + criteria)


Software testing
Testing process
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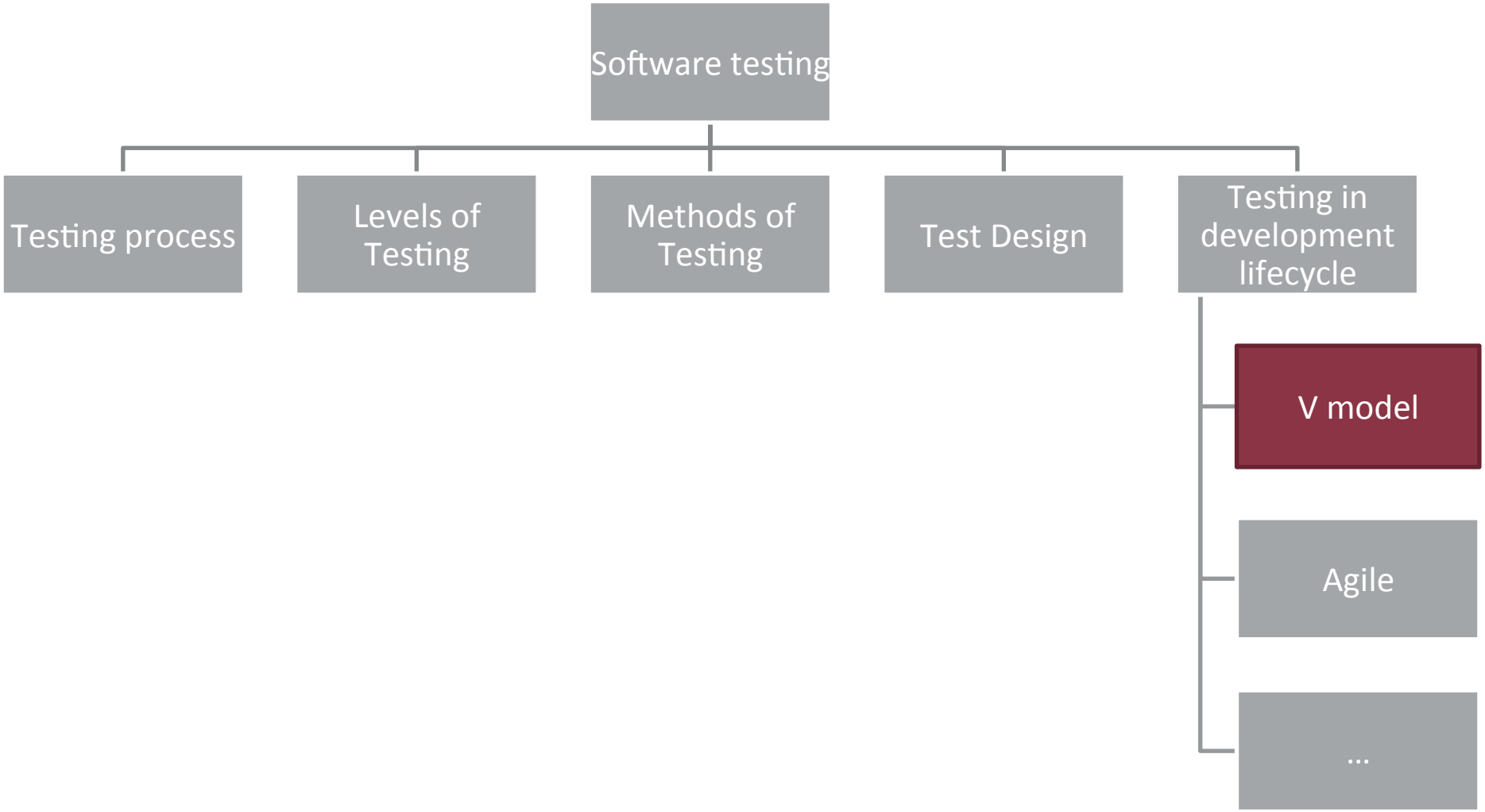
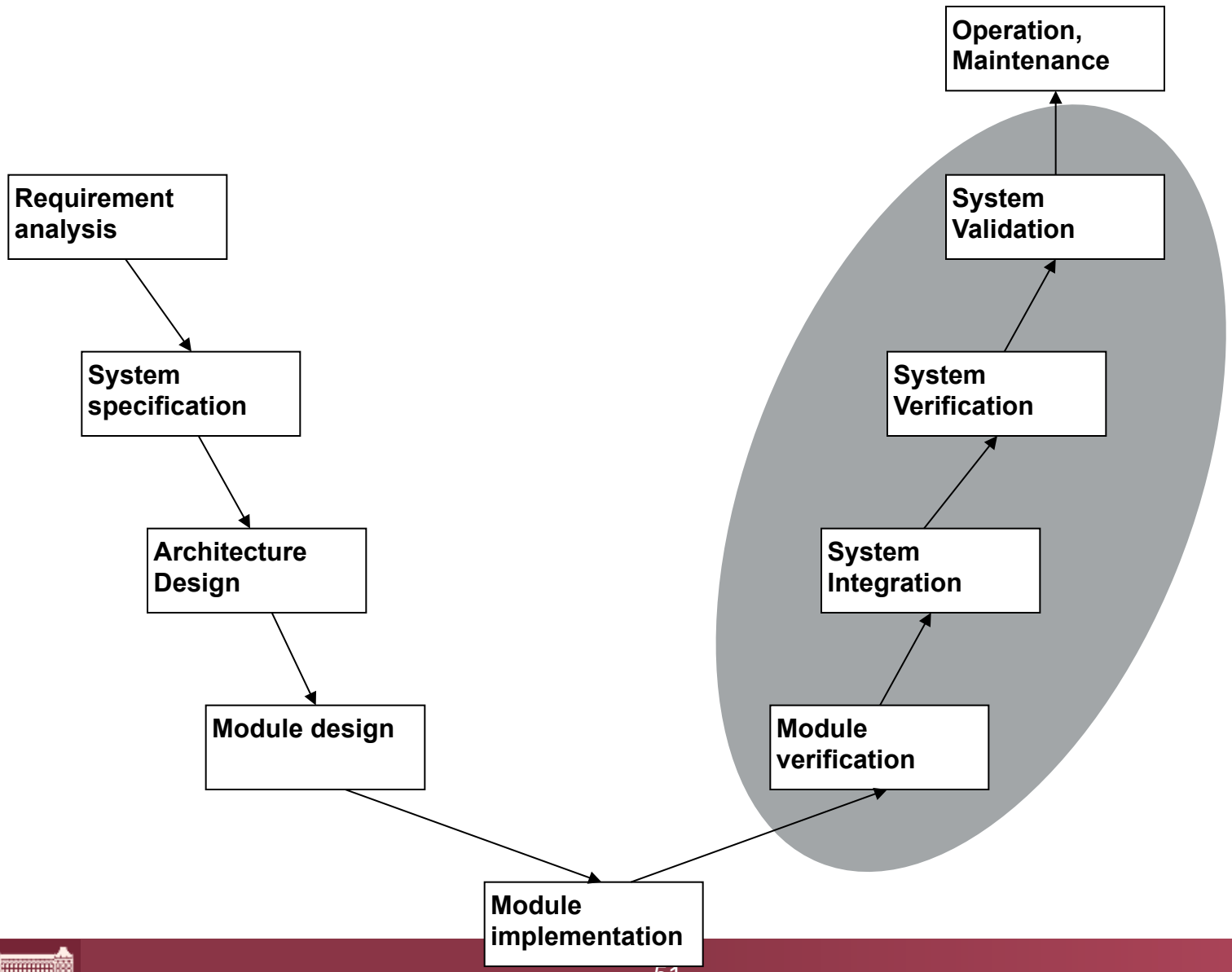
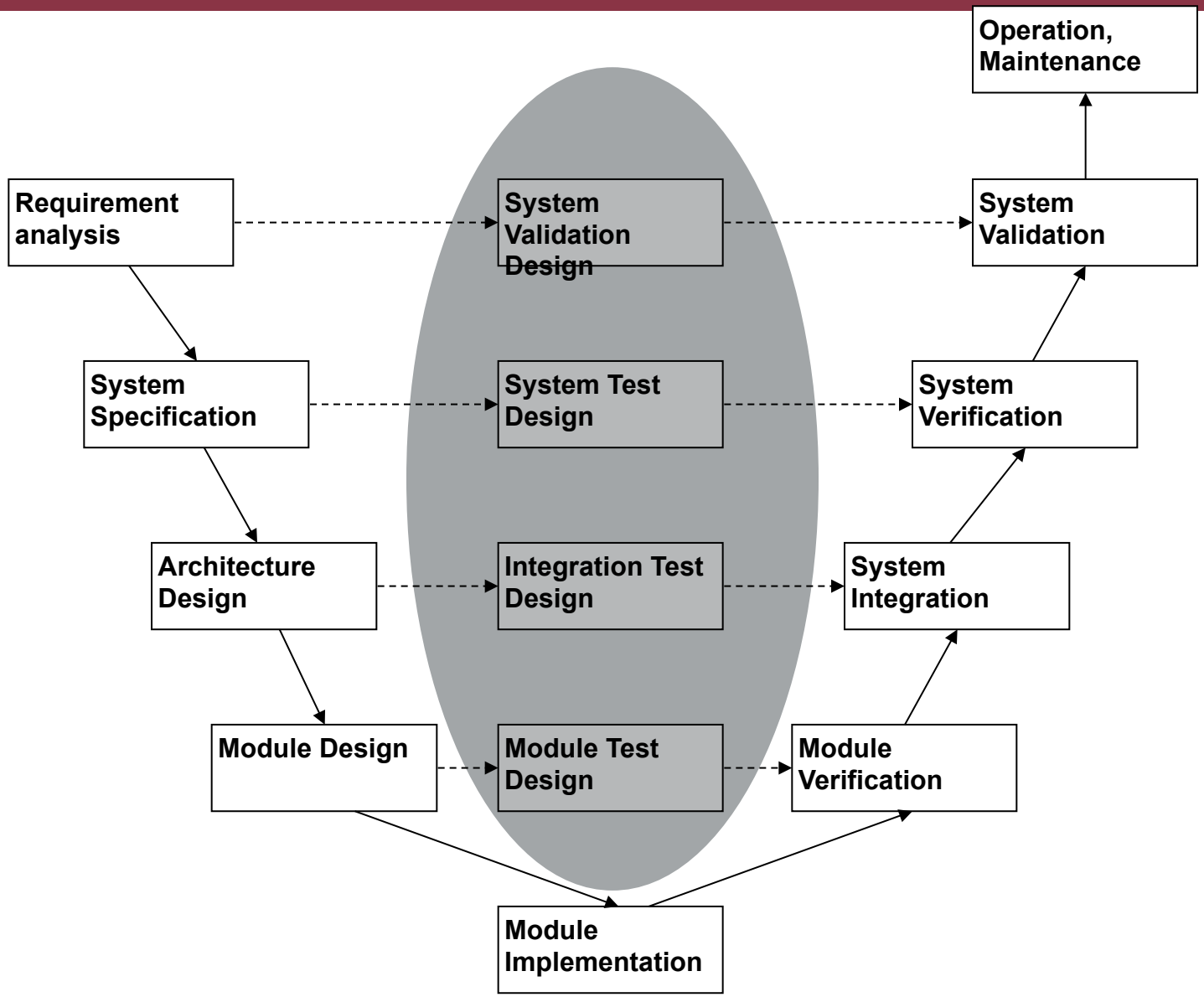
Test Design
Testing in development lifecycle
Tester Experience
Specification Based
Structure Based
Error Based
Probabilty based
Usually, these needs to be combined

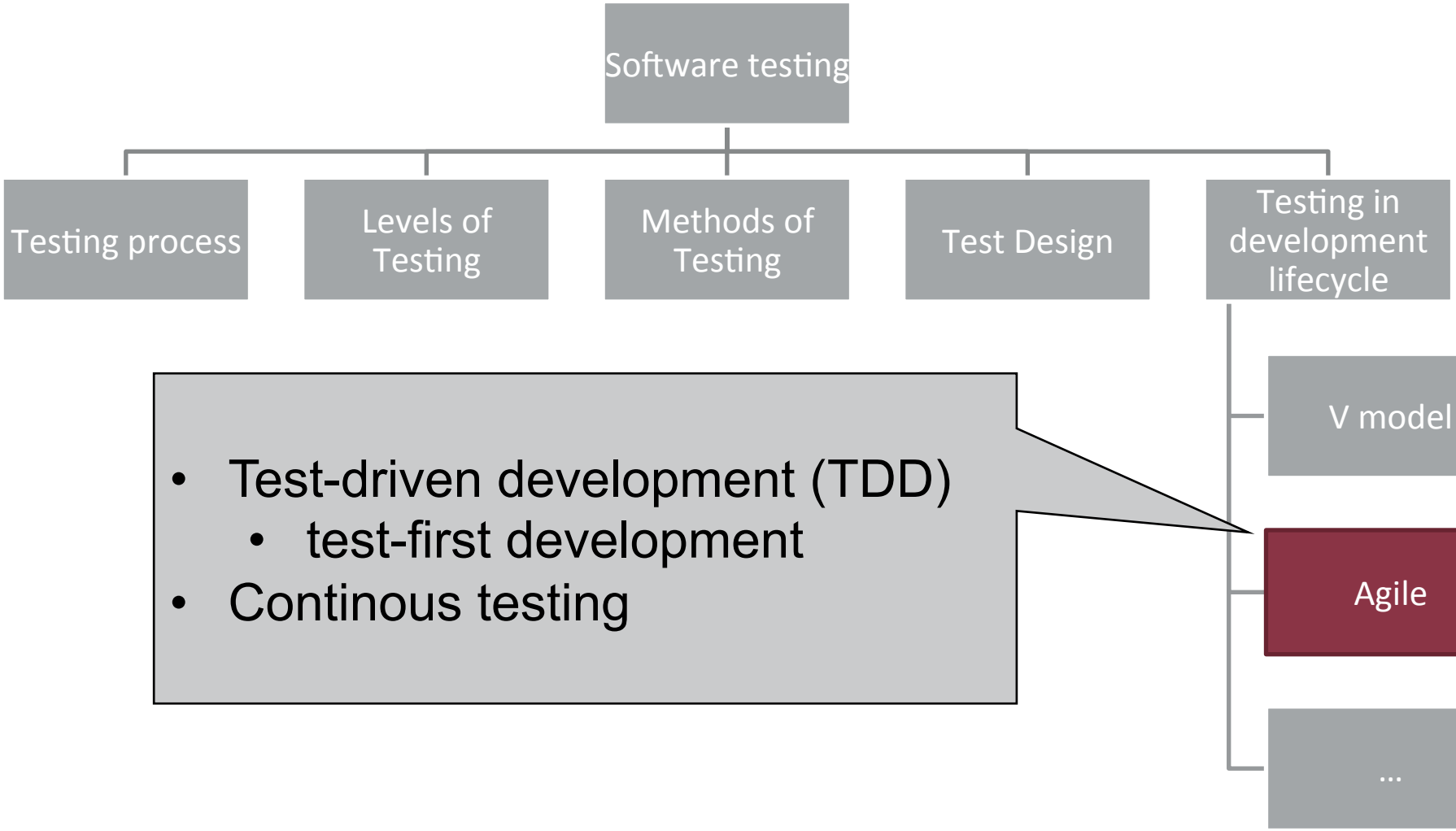

Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
V model
Agile
...

Testing in the V-model



Test Design in the V-model




Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
V model
Agile
...
• Test-driven development (TDD)
• test-first development
• Continous testing

Testing in Practice

Testing in Practice

- Testing requires more than 50% of total development cost!
  - Test data generation
  - Test code creation
  - Test execution
  - Result evaluation

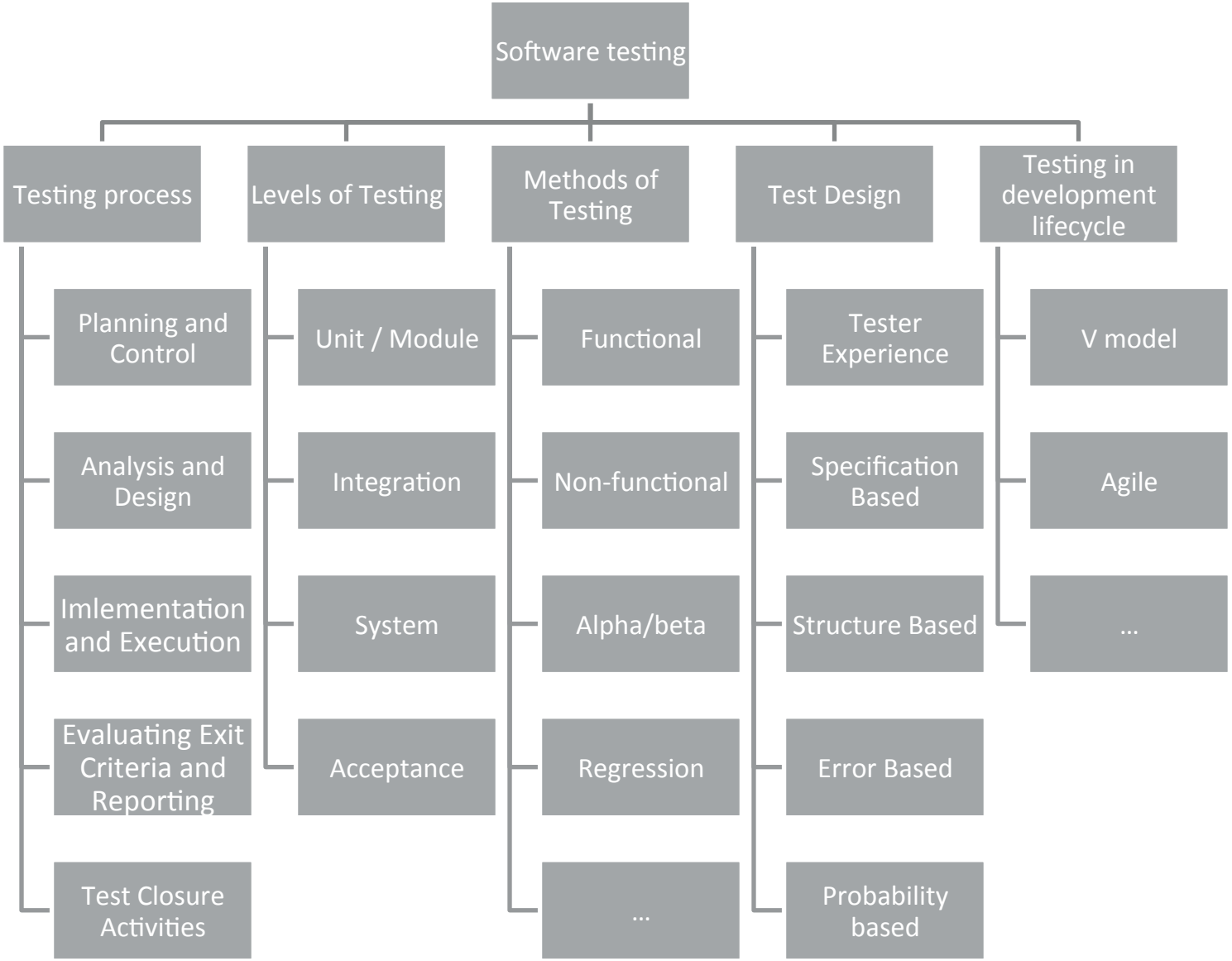
- Subtasks automatizable
  - Based on: e.g. models
    - class diagram: module interfaces
      → test controller and test stub generation
    - state machines: cooperation between modules
    - → test sequence generation

Further reading

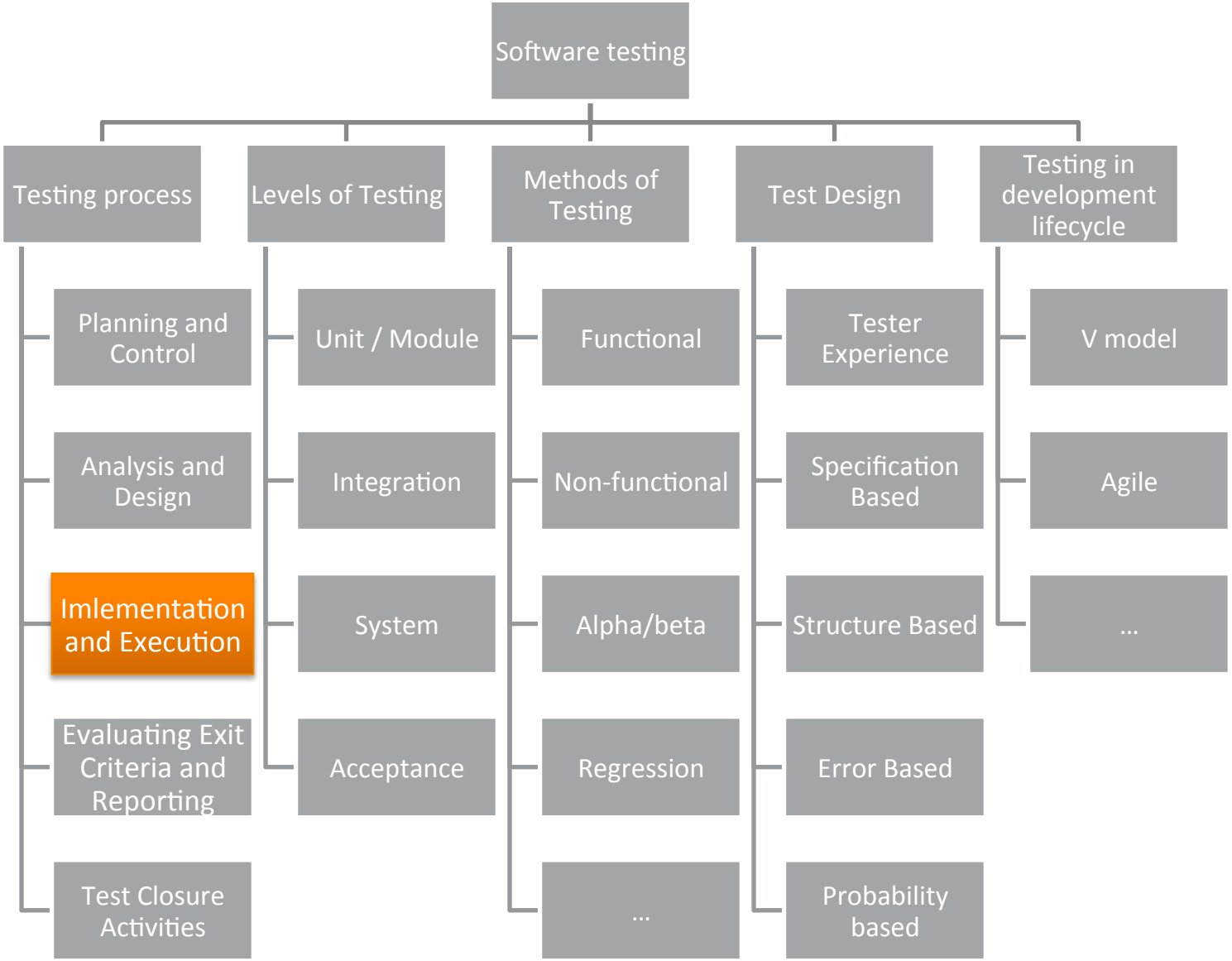
- International Software Testing Qualifications Board (ISTQB), URL: http://istqb.dedicated.adaptavist.com/
  - ISTQB Glossary of Testing Terms
  - Foundation Level Syllabus (2010)
  - Even in Hungarian: http://www.hstqb.com/index.php?title=Downloads

- IEEE, Software Engineering Body of Knowledge (SWEBOK), URL: http://www.computer.org/portal/web/swebok/
  - Chapter 5: Software Testing

- IEEE, Software and Systems Engineering Vocabulary (SE VOCAB), URL: http://pascal.computer.org/sev_display/
  - Searchable set of definitions


Software testing
Testing process
Levels of Testing
Methods of Testing
Test Design
Testing in development lifecycle
Planning and Control
Analysis and Design
Imlementation and Execution
Evaluating Exit Criteria and Reporting
Test Closure Activities
Unit / Module
Integration
System
Acceptance
Functional
Non-functional
Alpha/beta
Regression
...
Tester Experience
Specification Based
Structure Based
Error Based
Probability based
V model
Agile
...

The JUnit Framework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JUnit

- JUnit
  - Very common Java test framework
  - Original authors: Erich Gamma and Kent Beck
  - Multiple test executors
    - Command line
    - Simple GUI
    - IDE integrated
- JUnit 4
  - Uses Java 1.5 features, e.g. annotations
  - Completely different API than JUnit 3

Simple JUnit Test

- Java annotated methods
  - Similar to Eclipse 4 API
- Simple test cases:
  - At least one method annotated with `@org.junit.Test`
    - Annotated methods are the concrete test cases
    - Output validation:
      - Static methods of org.junit.Assert.*
      - E.g. assertEquals(expected, actual)

Simple JUnit Test

```
package hu.bme.mit.junit.example;

import org.junit.Test;
import junit.framework.TestCase;

public class ListTest {
   @Test
   public void testAddToEmptyList(){
        MyList l = new MyList();
        l.add(1);

        org.junit.Assert.assertEquals(1, l.getSize());
   }
}
```

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Test method

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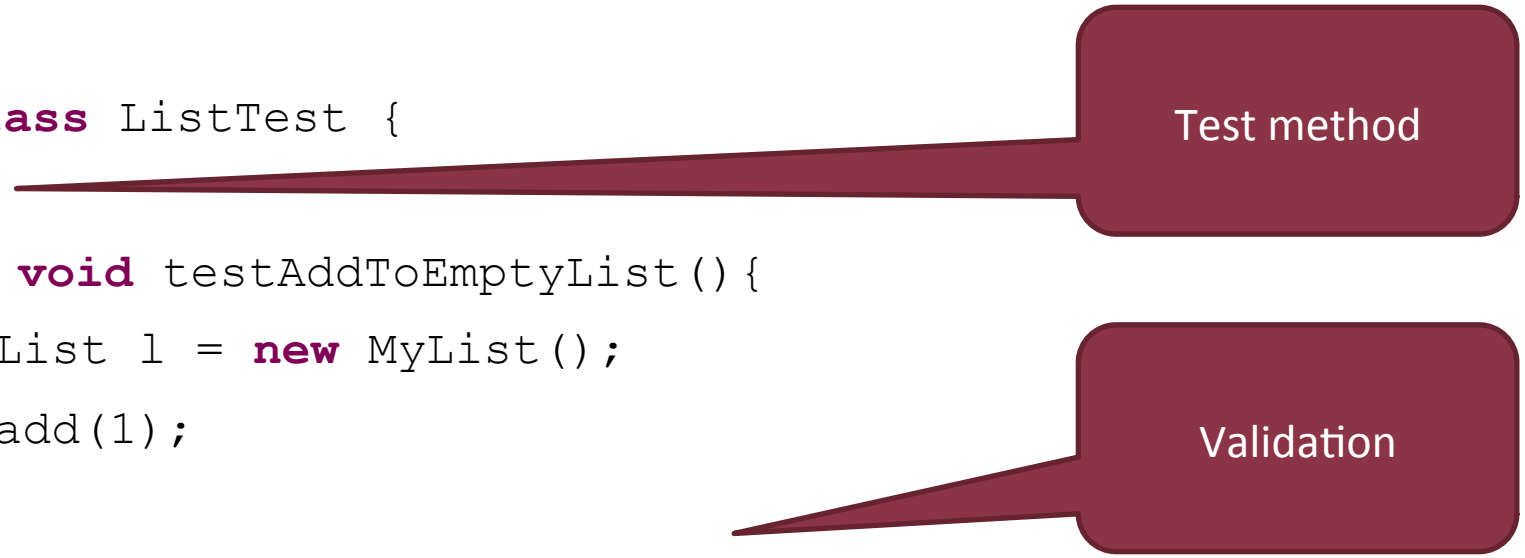
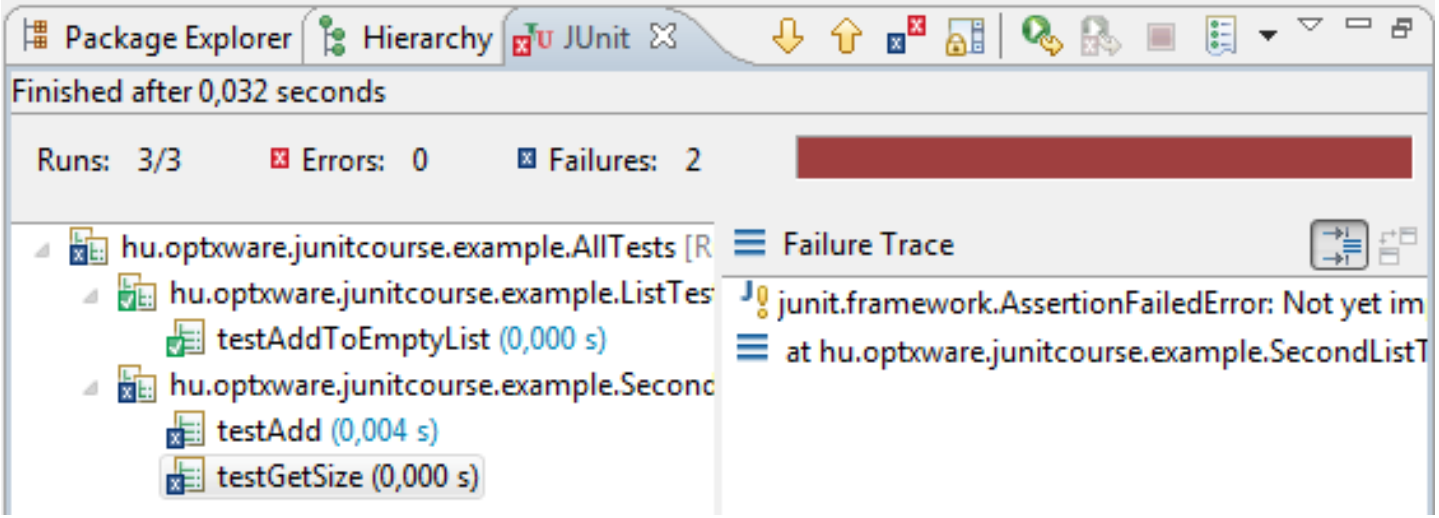


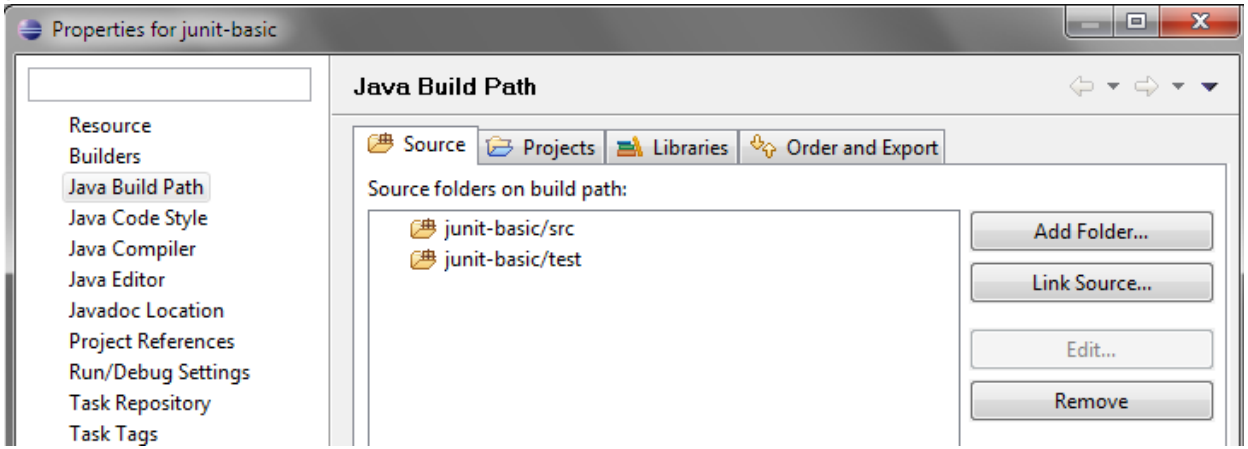
JUnit Test Execution in Eclipse

- Select class containing tests
- Run As -> JUnit test
- Results:
  - Colored by output
    - Ok, Error, Failure



Using JUnit in Eclipse - Preparations

- Convention: separate source folder for tests
  - Named: test



- JUnit Library in classpath

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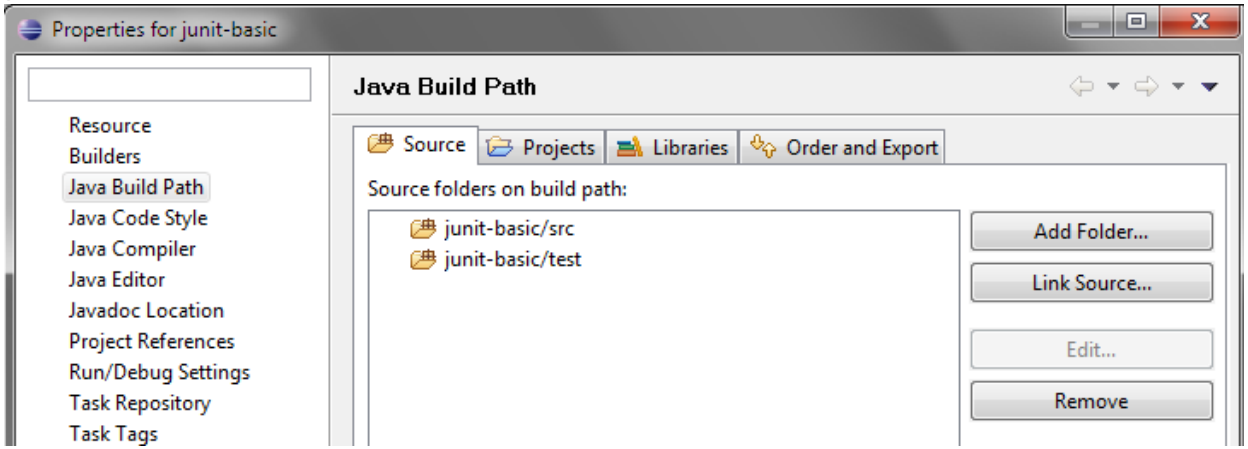
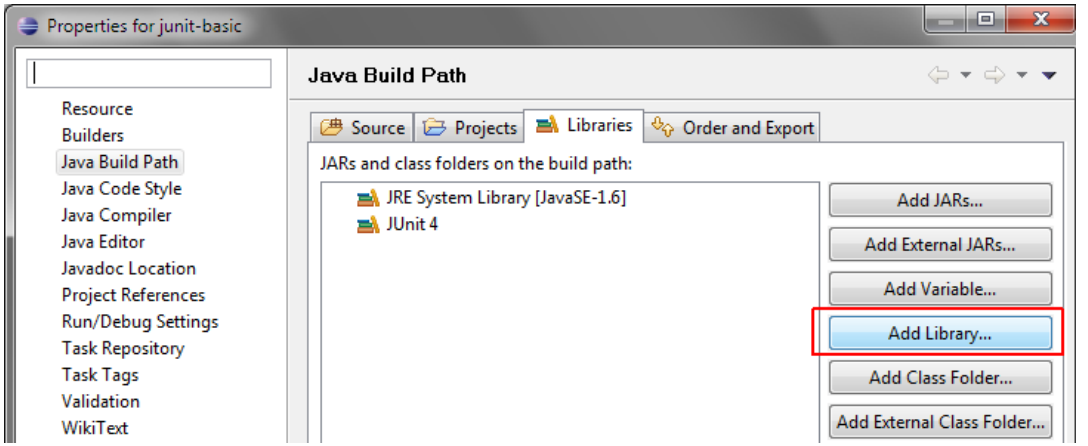
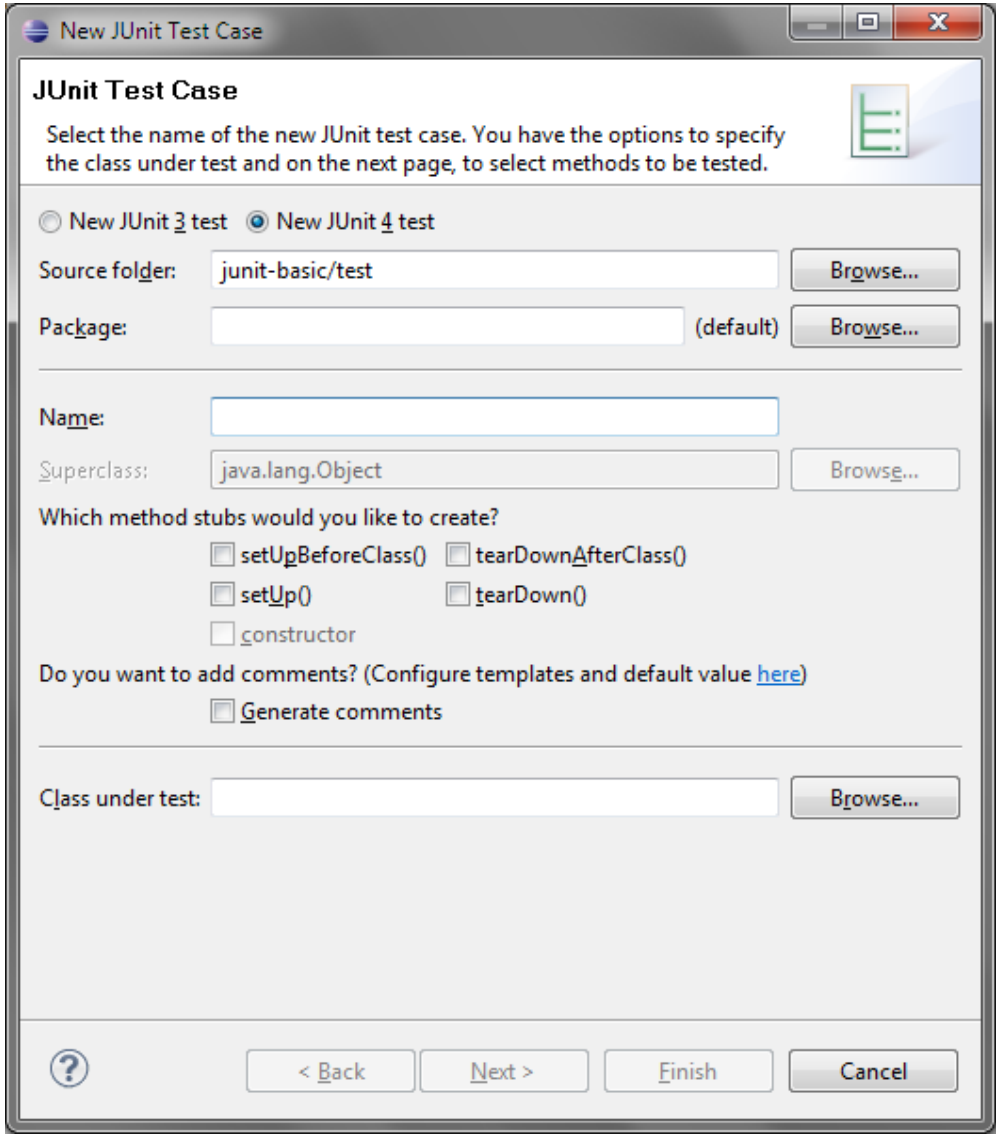


- JUnit Library in classpath



JUnit Test Creation

- Test Class Name
  - «Unit_name»Test
  - «Unit_name»Tests
- Select class under test
- Helper methods
  - „test fixture”
  - setup & teardown



Test fixture

- Prepares environment for tests:
  - May be shared between tests
  - Beware for interdependent tests!
- Once per testing process
  - @BeforeClass, @AfterClass
- Before and after each test case
  - @Before, @After

Test fixture - Example

```
public class ListTests {

    List emptyList;

    @Before
    public void setUp(){
        emptyList = Collections.EMPTY_LIST;
    }

    @After
    public void tearDown() {
        emptyList = null;
    }

    @Test
    public void testEmptyList() {
        assertEquals("Empty list should have 0 elements",
                0, emptyList.size());
    }

}
```

Assertions

- Automatic validation of test cases
  - Provide one per test case
  - Unless it is harder to find concrete issue
- Static methods of org.junit.Assert
  - assertEquals(expected,actual)
  - assertFalse(boolean)
  - assertTrue(boolean)
  - assertNull(object)
  - assertNotNull(object)
  - assertSame(expected,actual)
  - assertNotSame(expected,actual)
  - assertArrayEquals(expecteds, actuals)
  - …

JUnit Annotations

Annotation	Description
@Test public void method()	Defines test method
@Before public void method()	Executes before each test
@After public void method()	Executes after each test
@BeforeClass public void method()	Executes once before all tests
@AfterClass public void method()	Executes once after all tests
@Ignore	Skips the test; use sparingly
@Test(expected=IllegalArgumentException.class)	Test case is succesful if throws the selected exception
@Test(timeout=100)	Limits test execution time

Grouping Test cases

- Test Suites in JUnit 4:
  - @RunWith: define test executor
  - @SuiteClasses: defines members

```
import org.junit.runner.RunWith;
import org.junit.runners.Suite;


@RunWith(Suite.class)
@Suite.SuiteClasses({
   ListTest.class, VectorTest.class})
public class AllTests {
        // placeholder for the above annotations
}
```

Expected exception

- Evaluate error handling
  - We sometimes expect the trowing of exceptions

```
public class RegularExpressionJUnit4Test {
   private static String zipRegEx = "^\\d{5}([\\-]\\d{4})?$";
   private static Pattern pattern;

   @BeforeClass
   public static void setUpBeforeClass() throws Exception {
     pattern = Pattern.compile(zipRegEx);
   }

   @Test(expected=IndexOutOfBoundsException.class)
   public void verifyZipCodeGroupException() throws Exception{
     Matcher matcher = this.pattern.matcher("22101-5051");
     boolean isValid = matcher.matches();
     matcher.group(2);
   }
}
```

Parameterized tests

- Common case: many similar tests
  - only different in parameters
  - test code should not be redundant

- JUnit 4: parameterized tests
  - Separate test code and test data
  - Framework executes the test code with all data

JUnit Parameterized Tests 1/6

- Write parameterless test code

```
@Test
public void testComplexCalculation() throws Exception
{
    Integer r = calc.complexCalculation(a, b);
    assertEquals(res, r);
}
```

- Test data is yet undefined:
  - a, b: input
  - res: expected output

JUnit Parameterized Tests 2/6

- Create „feeder” method
  - Static method, returning a collection of arrays
  - Annotated with `@Parameters`
  - Arrays are used to serialize test data

```
@Parameters
public static Collection<Object[]> complexCalcValue() {
return Arrays.asList(new Object[][] {
     { 1, 1, 12 },
     { -1, 1, -10 },
     { 10, 10, 30 },
     { 2, 2, 14 } });
}
```

JUnit Parameterized Tests 3/6

- Create attributes for single test data:

```
private Integer a;

private Integer b;

private Integer res;
```

JUnit Parameterized Tests 4/6

- JUnit will call the constructor parameters in order:

```
public ParametricTest(Integer a,
Integer b, Integer res) {
    super();
    this.a = a;
    this.b = b;
    this.res = res;
}
```

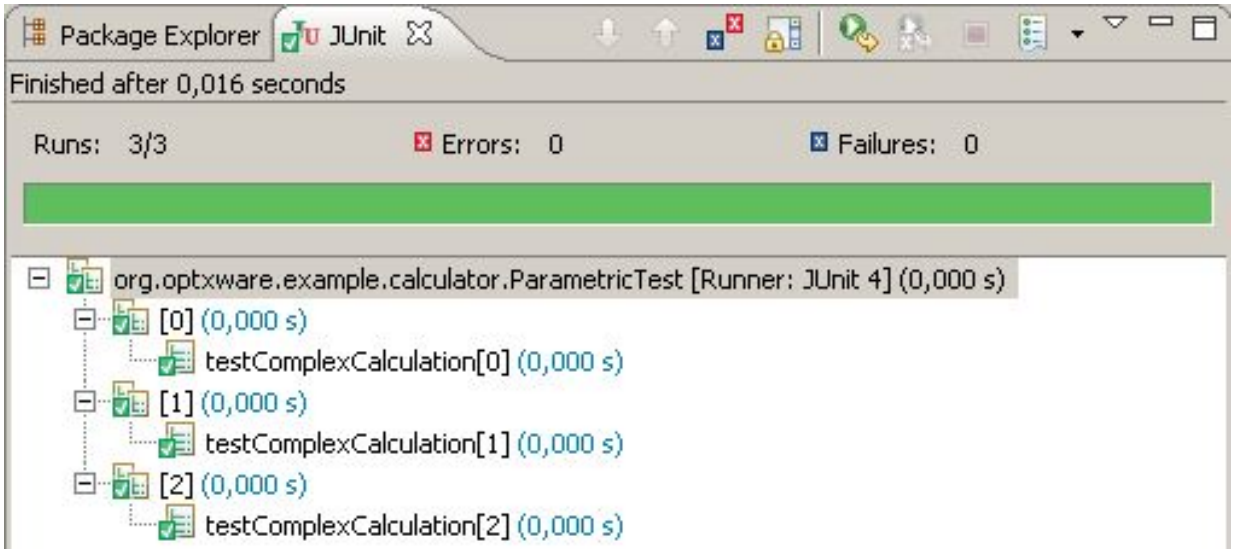
JUnit Parameterized Tests 5/6

- Selected specific test runner for the class
  - `org.junit.runners.Parametrized`

```
@RunWith(Parameterized.class)
public class ParametricTest {
    …
}
```

JUnit Parameterized Tests 6/6

- Execute tests
  - The testComplexCalculation() test executes four times
  - Executes with all values from step 2.



Categories

- Further categorization, e.g.
  - Execution time
  - Resource requirements

- Categories defined as interfaces

```
public interface FastTests {}
public interface SlowTests {}
```

- Inheritance supported

```
interface PerformanceTests extends
SlowTests{}
```

Categories /2

- Use case 1: annotate test classes

```
@Category(FastTests.class)
public class CalculatorTest {}
```

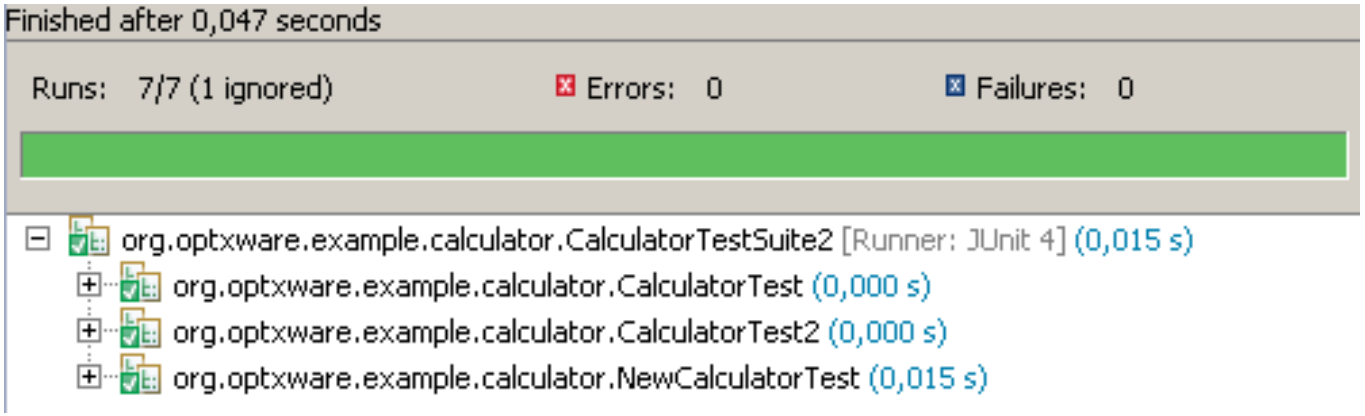
- Use case 2: annotate test cases

```
@Category(SlowTests.class)
public void complexCalc (int a, int b){}
```

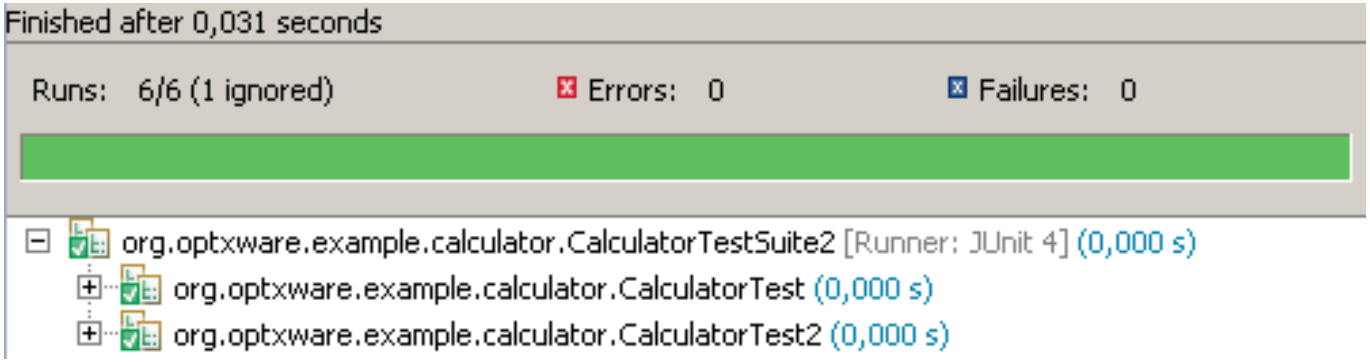
- Execution
  - `@RunWith(Categories.class)`
  - `@IncludeCategory(SlowTests.class)`
  - `@SuiteClasses( { CalculatorTest.class, ParametricTest.class })`
  - `public static class SlowTestSuite {}`

Categories /3

```
@IncludeCategory(FastTests.class)
```




```
@ExcludeCategory(SlowTests.class)
```



Rules

- JUnit extension points
- Base extensions
  - TemporaryFolder
    - For storing temporary files and folders
    - Will be removed after the test execution

```
@Rule
public TemporaryFolder tempFolder = new TemporaryFolder();

File newFile = tempFolder.newFile("myfile.txt");
```

  - ExternalResource
    - External resource that needs to be reset after testing

Rules /2

- ErrorCollector
  - In case of exception don't stop but continue
  - All exceptions will be shown in the end
- ExpectedException
  - Specifies expected exceptions inside test cases

```
@Rule
public ExpectedException exception = ExpectedException.none();
…
exception.expect(IllegalArgumentException.class);
```

- Timeout
  - Class-level timeout setting

```
@Rule
public MethodRule globalTimeout = new Timeout(20);
```

Theories

- Generalizes connection between input and output
- Simpler structure than parameterized tests
- Class annotated with `@RunWith(Theories.class)`
- Required
  - Data generation method - `@DataPoints`
  - Generated data will be used by test cases as input

```
@DataPoints
public static Integer[] data(){
        return new Integer[] {
                new Integer(10),
                new Integer(17),
                new Integer(-16)
};
```

Theories /2

- Theory
  - Test is annotated with `@Theory`
  - Must contain (at least) one assertion

```
@Theory
public void addTheory(Integer a, Integer b){
    assumeTrue(a > 0);
    assumeTrue(b > 0);

    assertEquals((a+b), calc.complexAddMethod(a, b));
 }
```

Assumptions

- Describes preconditions for test case
- If Assumption fails, test case still ok

```
assumeTrue(a>0);
assumeTrue(b>0);
```

- Useful for *Theories*
  - Filters invalid input for test case

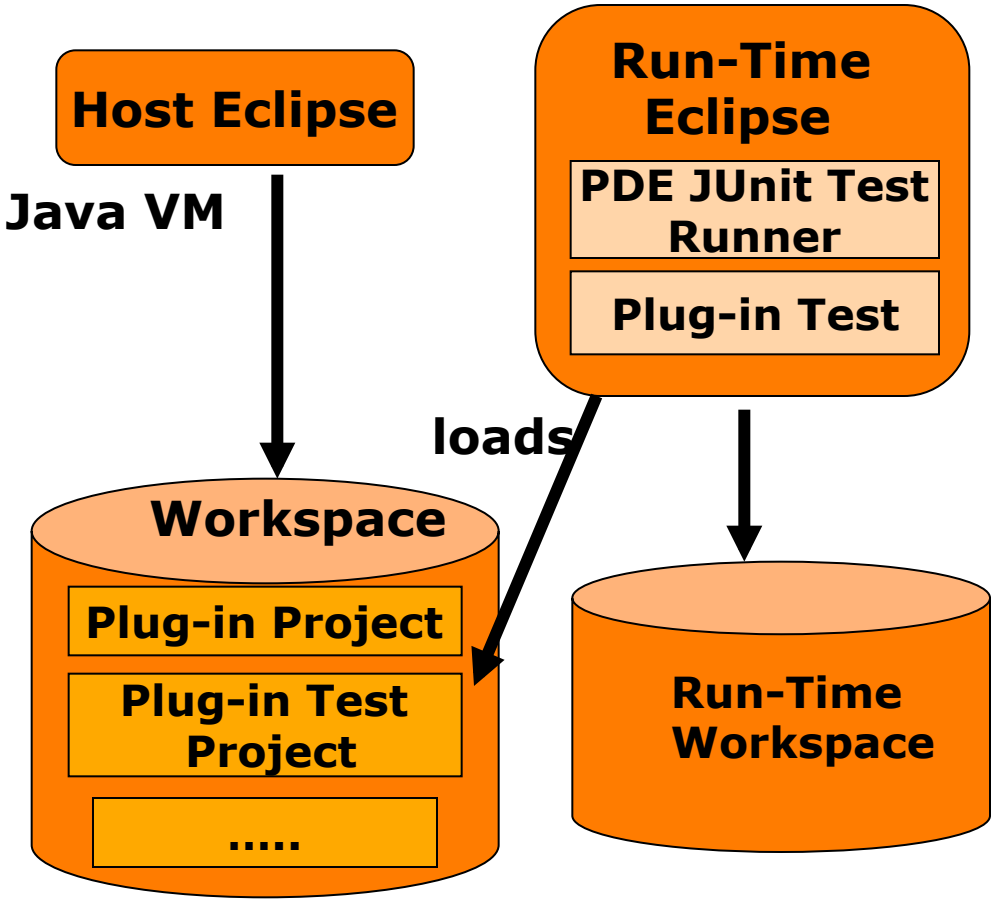
PDE JUnit Tests

JUnit Plug-in Tests

- PDE JUnit
  - Test execution for
    - Eclipse plug-ins
    - OSGi bundles
  - Part of Plug-in Development Environment 3.x/4.x
- Behaves like plain JUnit
- Differences:
  - Custom test runner: starts a new Eclipse instance
  - Similar to runtime workbench
  - Every test is executed in this workbench
    - Full Eclipse API available
    - OSGi classloading in action!

PDE JUnit

- Steps:
  - Starting runtime workbench
  - JUnit TestRunner gets control
  - Tests executed in runtime
  - Runtime workbench stopped



JUnit Plug-in Test Settings

- Test
  - What test to run
- Main
  - Run an application – Headless mode
- Plug-ins
  - What plug-ins to load
- Configuration
  - Clear the configuration area before launch

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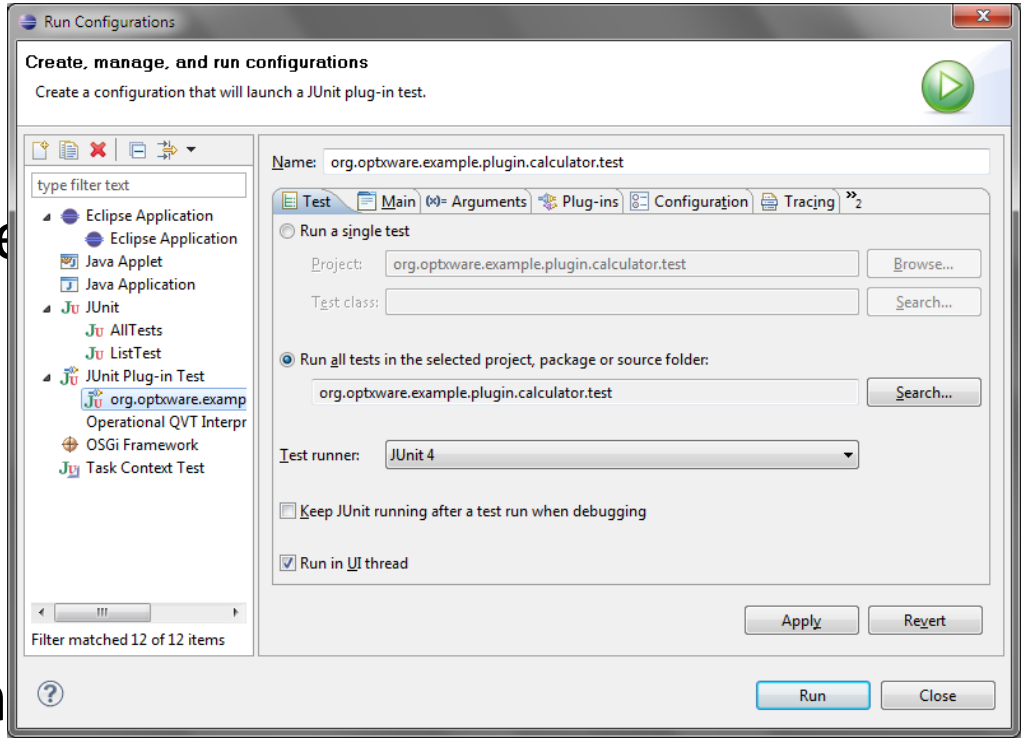

Plug-in testing

- Unit tests
  - Can be problematic because of many dependencies
  - Can be mocked if required
- Integration testing
  - More common for PDE JUnit

Test Case Placement Options

Test Case Placement Options

- Separate source folder
  - As Java projects
  - BUT: JUnit dependency for plug-in!
- Plug-in fragment
  - Sees the inside of the host
- Separate plug-in
  - Only public API is available

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Headless mode

- Testing without GUI
  - Much faster
  - For UI-independent plug-ins
  - Requires planning in advance

Related Eclipse Projects

- GUI testing
  - SWTBot
    - Supports even GEF-based editors!
  - Jubula
    - Model-based test specification
  - WindowTester Pro
    - Capture-and-playback
    - Previously developed by Instantiations
      - As WindowBuilder Pro

Further Reading

- JUnit, http://www.junit.org/
- Lars Vogel, JUnit – Tutorial, http://www.vogella.de/articles/JUnit/article.html
- Andrew Glover, Jump into JUnit 4, http://www.ibm.com/developerworks/java/tutorials/j-junit4/index.html

Profiling

Problem

- Application
  - Slow, or
  - Requires a lot of memory
- How to fix it?

Profiling

- (Performance) information collection for application
  - Dynamic, runtime techniques
- Tipical information collected:
  - Method execution count (both start and return)
  - Execution times
  - Memory usage
  - Call stack
  - Thread states
  - …

Profiling implementation

- Instrumentation
  - Flagging, logging instructions added
  - Manual / automatic
  - Code / binary / runtime level
- Framework support
  - E.g. Java (Java Virtual Machine Tool Interface), .NET
  - Events, callback methods
- Sampling
  - Periodically looks at state
  - Less intrusive, but less precise
  - HW support possible

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Java Profiler tools

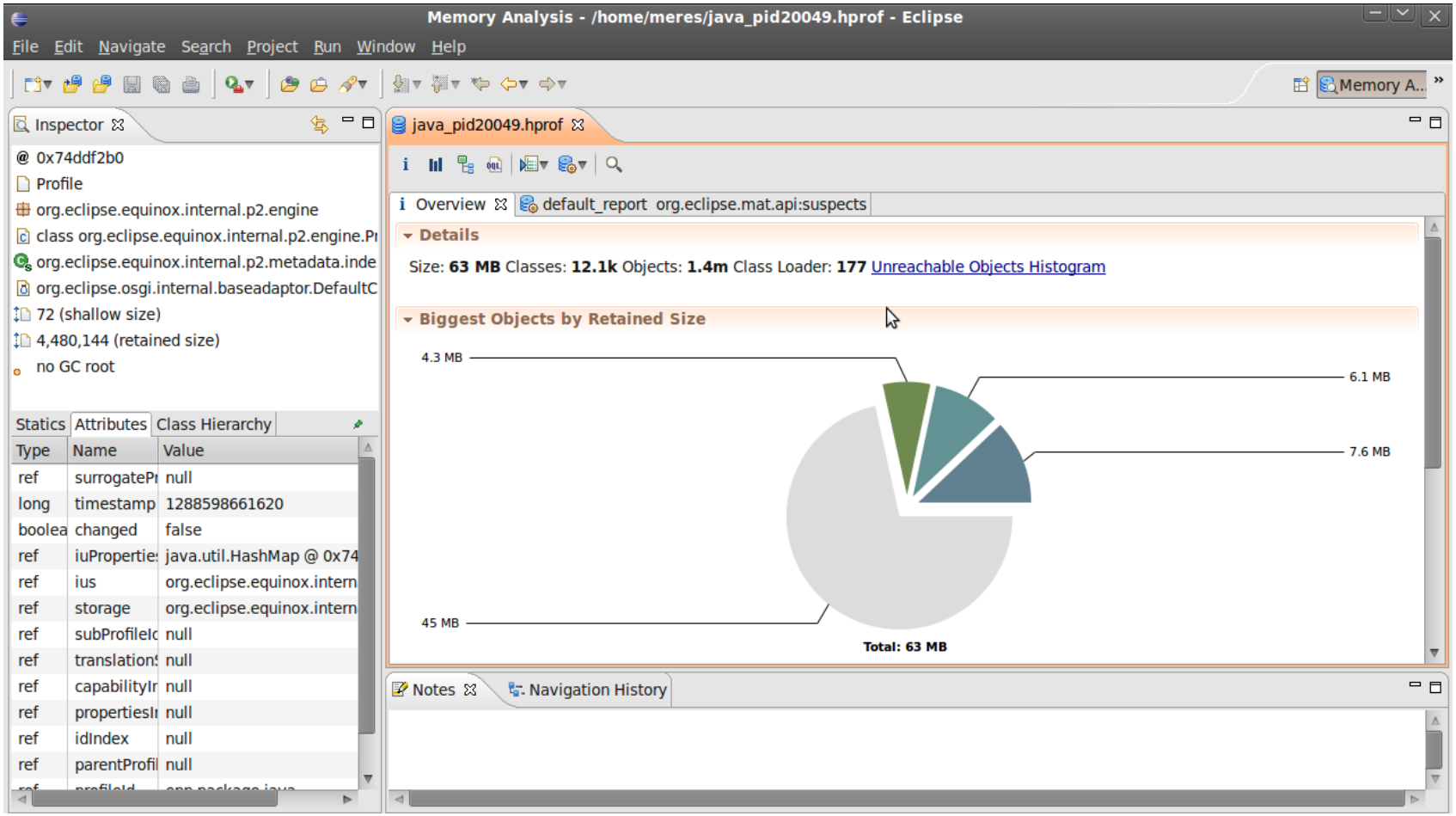
- Multiple profilers available, see
  - http://java-source.net/open-source/profilers

- jvisualvm
  - Based on JDK features
- YourKit Java Profiler
- Quest JProbe
- JIP – Java Interactive Profiler
- Netbeans Profiler
- …
- Eclipse:
  - Memory Analyzer (MAT) – heap analyzer
  - Test & Performance Tools Platform (TPTP)

Memory Analyzer (MAT)

- Heap dump file analysis
  - Can be created by JVM tools
  - Basically, memory map
- Available as RCP application or Eclipse plug-in

Memory Analyzer (MAT)



Test & Performance Tools Platform

- Top-level eclipse.org project
- Provides profiling tools
  - Be careful, project is close to dead