Systeme hoher Sicherheit und Qualität
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Lecture 07:

Testing

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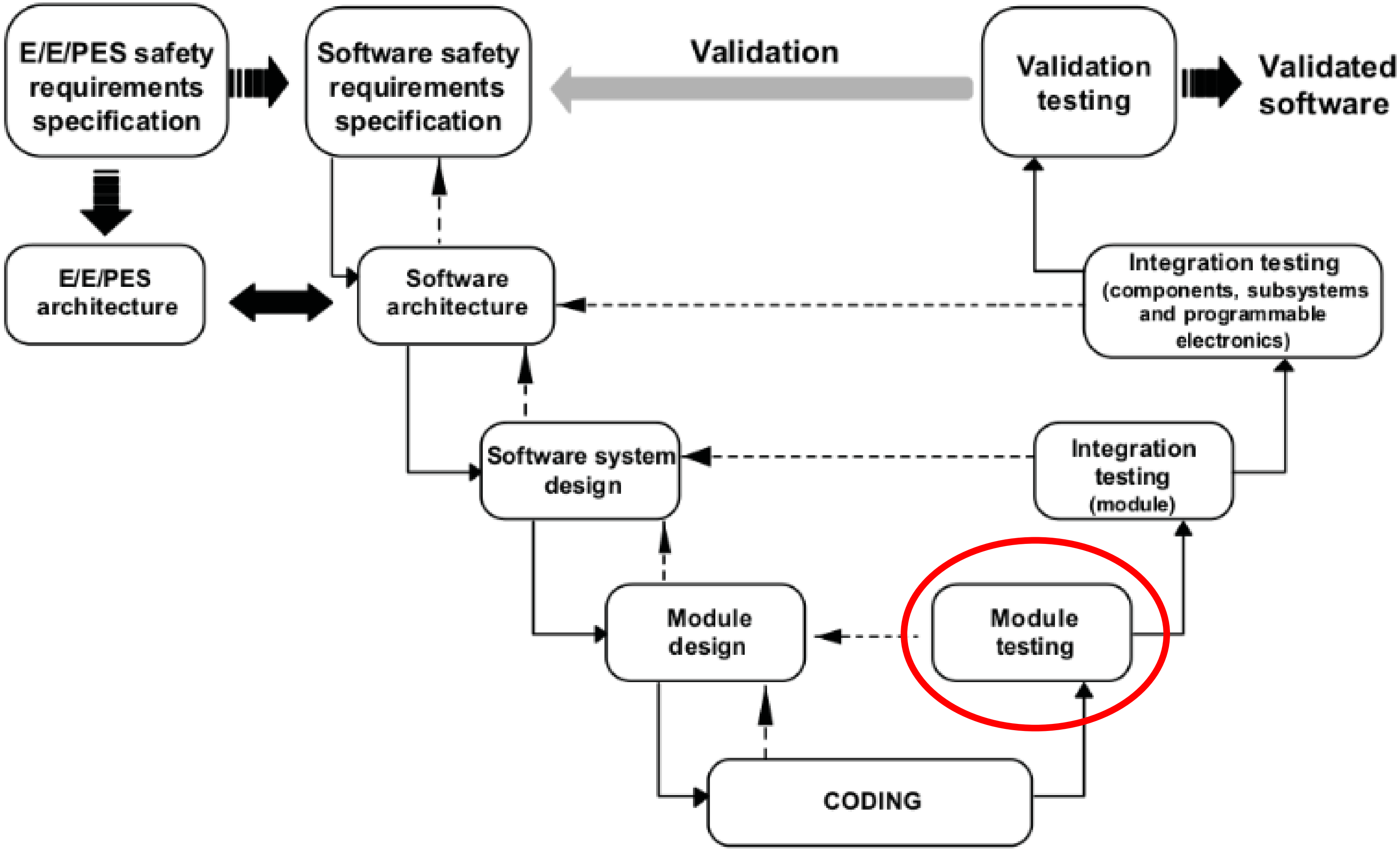
Where are we?

- 01: Concepts of Quality
- 02: Legal Requirements: Norms and Standards
- 03: The Software Development Process
- 04: Hazard Analysis
- 05: High-Level Design with SysML
- 06: Formal Modelling with OCL
- 07: Testing
- 08: Static Program Analysis
- 09-10: Software Verification
- 11-12: Model Checking
- 13: Conclusions

Testing in the Development Cycle



What is Testing?

> Testing is the process of executing a program or system with the intent of finding errors.
>
> *G.J. Myers, 1979*

- In our sense, testing is selected, controlled program execution
- The **aim** of testing is to detect bugs, such as
  - derivation of occurring characteristics of quality properties compared to the specified ones
  - inconsistency between specification and implementation
  - structural features of a program that cause a faulty behavior of a program

> Program testing can be used to show the presence of bugs, but never to show their absence.
>
> *E.W. Dijkstra, 1972*

The Testing Process

- Test cases, test plan, etc.
- System-under-test (s.u.t.) (cf. TOE in CC)
- Warning -- test literature is quite expansive

> Testing is any activity aimed at evaluating an attribute or capability of a program or system and determining that it meets its required results.
>
> *Hetzel, 1983*

Test Levels

- **Component** and **unit tests**
  - test at the interface level of single components (modules, classes)
- **Integration test**
  - testing interfaces of components fit together
- **System test**
  - functional and non-functional test of the complete system from the user's perspective
- **Acceptance test**
  - testing if system implements contract details

Test Methods

- Static vs. dynamic
  - With **static** tests, the code is **analyzed** without being run. We cover these methods as static program analysis later
  - With **dynamic** tests, we **run** the code under controlled conditions, and check the results against a given specification
- Central question: where do the **test cases** come from?
  - **Black-box**: the inner structure of the s.u.t. is opaque, test cases are derived from specification **only.**
  - **Grey-box:** some inner structure of the s.u.t. is known, e.g. module architecture.
  - **White-box**: the inner structure of the s.u.t. is known, and tests cases are derived from the source code.

Black-Box Tests

- Limit analysis:
  - If the specification limits input parameters, then values **close** to these limits should be chosen
  - Idea is that programs behave **continuously**, and errors occur at these limits
- Equivalence classes:
  - If the input parameter values can be decomposed into **classes** which are treated equivalently, test cases have to cover all classes
- Smoke test:
  - “Run it, and check it does not go up in smoke.”

Example: Black-Box Testing

- Equivalence classes or limits?

> **Example: A Company Bonus System**
> The loyalty bonus shall be computed depending on the time of employment. For employees of more than three years, it shall be 50% of the monthly salary, for employees of more than five years, 75%, and for employees of more than eight years, it shall be 100%.

- Equivalence classes or limits?

> **Example: Air Bag**
> The air bag shall be released if the vertical acceleration a_v equals or exceeds $15\ {}^{m}/_{s^2}$. The vertical acceleration will never be less than zero, or more than $40\ {}^{m}/_{s^2}$.

Black-Box Tests

- Quite typical for **GUI tests**, or **functional testing**

- Testing **invalid input**: depends on programming language – the stronger the typing, the less testing for invalid input is required

  - Example: consider lists in C, Java, Haskell
  - Example: consider object-relational mappings[1] (ORM) in Python, Java

1) Translating e.g. SQL-entries to objects

Property- based Testing

- In property-based testing (or random testing), we generate **random** input values, and check the results against a given **executable** specification.
- Attention needs to be paid to the **distribution** values.
- Works better with **high-level languages,** where the datatypes represent more information on an abstract level and where the language is powerful enough to write comprehensive executable specifications (i.e. Boolean expressions).
  - Implementations for e.g. Haskell, Scala, Java
- Example: consider list reversal in C, Java, Haskell
  - Executable spec: reversal is idempotent and distributes over concatenation.
  - Question: how to generate random lists?

White-Box Tests

- In white-box tests, we derive test cases based on the structure of the program (**structural testing**)
  - To abstract from the source code (which is a purely syntactic artefact), we consider the **control flow graph** of the program.

Def: Control Flow Graph (CFG)

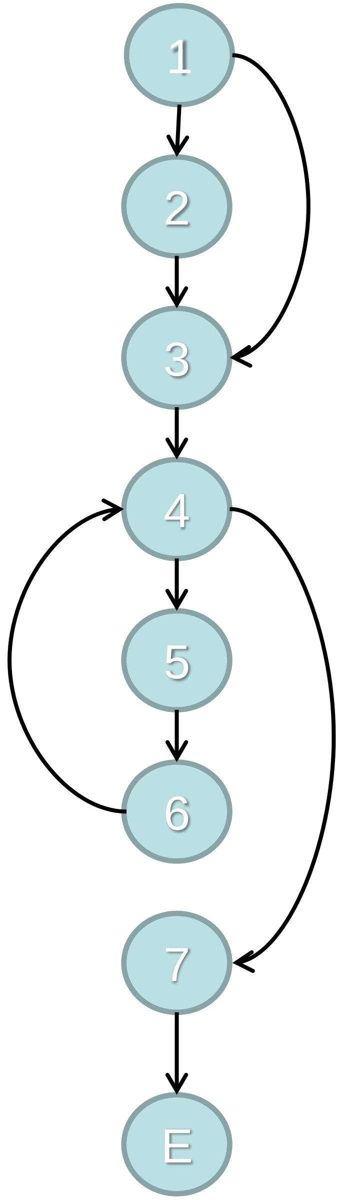
- nodes as elementary statements (e.g. assignments, **return**, **break**, . . .), as well as control expressions (e.g. in conditionals and loops), and
- vertices from *n* to *m* if the control flow can reach a node *m* coming from a node *n*.

- Hence, **paths** in the CFG correspond to **runs** of the program.

Example: Control-Flow Graph

```
if (x < 0)  /*1*/  {
   x:= – x /*2*/
}
z = 1;  /*3*/

while (x > 0)  /*4*/ {
  z = z * y;  /*5*/
  x = x – 1   /*6*/
}
return z  /*7*/
```



An execution path is a path though the cfg.

Examples:

- [1,3,4,7, E]
- [1,2,3,4,7, E]
- [1,2,3,4,5,6,4,7, E]
- [1,3,4,5,6,4,5,6,4,7, E]
- …

Coverage

- **Statement coverage**:
  Each **node** in the CFG is visited at least once.

- **Branch coverage**:
  Each **vertex** in the CFG is traversed at least once.

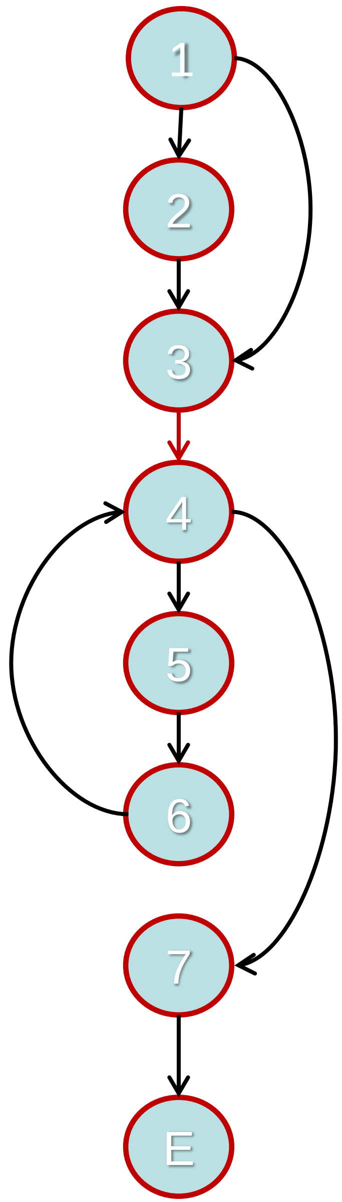
- **Decision coverage**:
  Like branch coverage, but specifies how often **conditions** (branching points) must be evaluated.

- **Path coverage**:
  Each **path** in the CFG is executed at least once.

Example: Statement Coverage

```
if (x < 0)  /*1*/  {
  x:= – x /*2*/
}
z = 1;  /*3*/

while (x > 0)  /*4*/ {
 z = z * y;  /*5*/
 x = x – 1   /*6*/
}
return z  /*7*/
```



- Which (minimal) path covers all statements?

  p = [1,2,3,4,5,6,4,7,E]

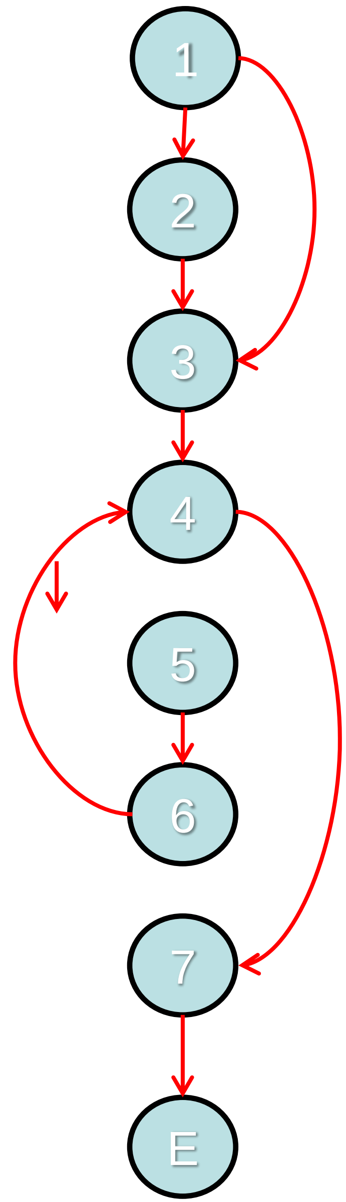
- Which state generates p?

  x = -1
  y any
  z any

Example: Branch Coverage

```
if (x < 0) /*1*/ {
  x:= – x /*2*/
}
z = 1; /*3*/

while (x > 0) /*4*/ {
 z = z * y; /*5*/
 x = x – 1  /*6*/
}
return z /*7*/
```



- Which (minimal) path covers all vertices?

$$p_1 = [1,2,3,4,5,6,4,7,E]$$
$$p_2 = [1,3,4,7,E]$$

- Which states generate p_1, p_2?

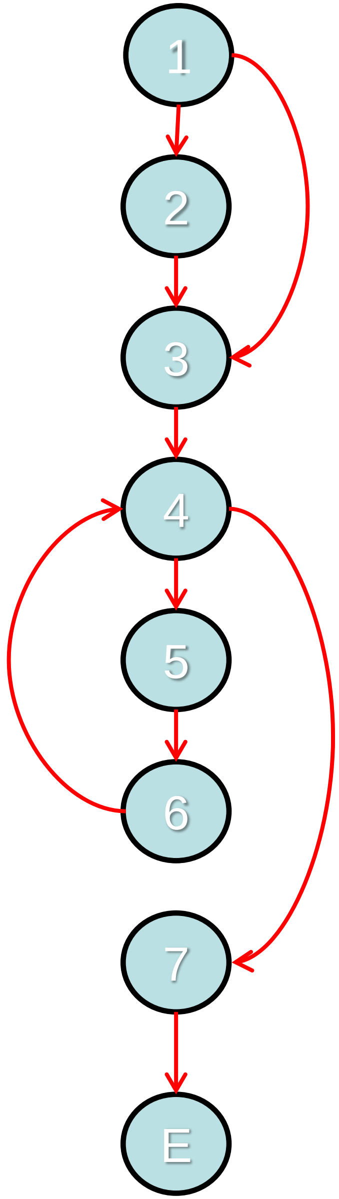
	p_1	p_2
x	-1	0
y	any	any
z	any	any

- Note p_3 (x= 1) does not add coverage.

Example: Path Coverage

```
if (x < 0)  /*1*/  {
  x:= – x /*2*/
}
z = 1;  /*3*/

while (x > 0)  /*4*/ {
 z = z * y;  /*5*/
 x = x – 1   /*6*/
}
return z  /*7*/
```



- How many paths are there?
- Let $q_1 = [1,2,3]$
  $q_2 = [1,3]$
  $p = [4,5,6]$
  $r = [4,7,E]$

  then all paths are

  $$P = (q_1|q_2)\ p^*\ r$$
- Number of possible paths:

  $$|P| = 2 \cdot MaxInt - 1$$

Statement, Branch and Path Coverage

- **Statement Coverage**:
  - Necessary but not sufficient, not suitable as only test approach.
  - Detects dead code (code which is never executed).
  - About 18% of all defects are identified.
- **Branch coverage**:
  - Least possible single approach.
  - Detects dead code, but also frequently executed program parts.
  - About 34% of all defects are identified.
- **Path Coverage**:
  - Most powerful structural approach;
  - Highest defect identification rate (100%);
  - But no **practical** relevance.

Decision Coverage

- Decision coverage is **more** then branch coverage, but less then full **path** coverage.
- Decision coverage requires that for all decisions in the program, each possible outcome is considered once.
- **Problem**: cannot sufficiently distinguish Boolean expressions.
  - For A || B, the following are sufficient:

A	B	Result
false	false	false
true	false	true

  - But this does not distinguish A || B from A;
    B is effectively not tested.

Decomposing Boolean Expressions

- The binary Boolean operators include conjunction $x \wedge y$, disjunction $x \vee y$, or anything expressible by these (e.g. exclusive disjunction, implication)

> **Elementary Boolean Terms**
> An elementary Boolean term does not contain binary Boolean operators, and cannot be further decomposed.

- An elementary term is a variable, a Boolean-valued function, a relation (equality $=$, orders $<, \leq, >, \geq$, etc.), or a negation of these.
- This is a fairly syntactic view, e.g. $x \leq y$ is elementary, but $x < y \vee x = y$ is not, even though they are equivalent.
- In formal logic, these are called **literals.**

Simple Condition Coverage

- For each condition in the program, each elementary Boolean term evaluates to *True* and *False* at least once
- Note that this does not say much about the possible value of the condition
- Examples and possible solutions:

```
if (temperature > 90 && pressure > 120) {... }
```

C1	*C2*	*Result*
True	True	True
True	False	False
False	True	False
False	False	False

Modified Condition Coverage

- It is not always possible to generate all possible combi-nations of elementary terms, e.g. 3 <= x && x < 5.
- In modified (or minimal) condition coverage, all possible combinations of those elementary terms the value of which determines the value of the whole condition need to be considered.
- Example:

3 <= x && x < 5

False	False	False	← not needed
False	True	False	
True	False	False	
True	True	True	

- Another example: (x > 1 && ! p) || p

Modified Condition/Decision Coverage

- Modified Condition/Decision Coverage (MC/DC) is required by **DO-178B** for Level A software.
- It is a **combination** of the previous coverage criteria defined as follows:
  - Every point of entry and exit in the program has been invoked at least once;
  - Every decision in the program has taken all possible outcomes at least once;
  - Every condition in a decision in the program has taken all possible outcomes at least once;
  - Every condition in a decision has been shown to independently affect that decision's outcome.

How to achieve MC/DC

- **Not**: Here is the source code, what is the minimal set of test cases?
- **Rather**: From requirements we get test cases, do they achieve MC/DC?
- Example:
  - Test cases:

Source Code:

Z := (A || B) && (C || D)

Test case	1	2	3	4	5
Input A	F	F	T	F	T
Input B	F	T	F	T	F
Input C	T	F	F	T	T
Input D	F	T	F	F	F
Result Z	F	T	F	T	T

Question: do test cases achieve MC/DC?

Source: Hayhurst *et al*, A Practical Tutorial on MC/DC. NASA/TM2001-210876

Summary

- (Dynamic) Testing is the controlled execution of code, and comparing the result against an expected outcome
- Testing is (traditionally) the main way for **verification.**
- Depending on how the test cases are derived, we distinguish **white-box** and **black-box** tests
- In black-box tests, we can consider **limits** and **equivalence classes** for input values to obtain test cases
- In white-box tests, we have different notions of **coverage**: statement coverage, path coverage, condition coverage, etc.
- Next week: **Static testing** aka. static **program analysis**