Softwaretechnik / Software-Engineering

Lecture 15: Testing

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Topic Area Code Quality Assurance: Content

VL 15
- **Introduction and Vocabulary**
  - Test case, test suite, test execution.
  - Positive and negative outcomes.

⋮
- **Limits of Software Testing**

VL 16
- **Glass-Box Testing**
  - Statement-, branch-, term-**coverage**.

⋮
- **Other Approaches**
  - **Model-based testing,**
  - **Runtime verification.**

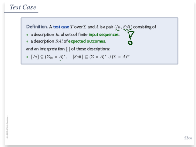
VL 17
- **Program Verification**
  - partial and total **correctness,**
  - **Proof System PD.**

⋮

VL 18
- **Review**

⋮

Recall: Test Case, Test Execution



Test Case

Definition. A **test case** T over Σ and A is a pair $(In, Soll)$ consisting of
- a description In of sets of finite **input sequences,**
- a description $Soll$ of **expected outcomes,**

and an interpretation $[\![\cdot]\!]$ of these descriptions:
- $[\![In]\!] \subseteq (\Sigma_{in} \times A)^*$, $[\![Soll]\!] \subseteq (\Sigma \times A)^* \cup (\Sigma \times A)^\omega$

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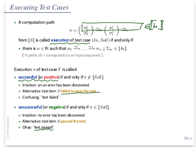

Executing Test Cases

- A computation path

$$\pi = \begin{pmatrix}\sigma_0^1\\ \sigma_0^0\end{pmatrix} \xrightarrow{\alpha_1} \begin{pmatrix}\sigma_1^1\\ \sigma_1^0\end{pmatrix} \xrightarrow{\alpha_2} \cdots \in [\![In]\!]$$

from $[\![S]\!]$ is called **execution** of test case $(In, Soll)$ if and only if
- there is $n \in \mathbb{N}$ such that $\sigma_0 \xrightarrow{\alpha_1} \dots \xrightarrow{\alpha_n} \sigma_n \downarrow \Sigma_{in} \in [\![In]\!]$.
  ("A prefix of π corresponds to an input sequence").

Execution π of test case T is called
- **successful** (or **positive**) if and only if $\pi \notin [\![Soll]\!]$.
  - Intuition: an an error has been discovered.
  - Alternative: test item S failed to pass the test.
  - Confusing: "test failed".
- **unsuccessful** (or **negative**) if and only if $\pi \in [\![Soll]\!]$.
  - Intuition: no error has been discovered.
  - Alternative: test item S passed the test.
  - Okay: "test passed".

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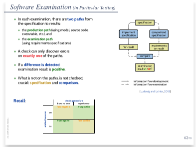

Software Examination (in Particular Testing)

- In each examination, there are **two paths** from the specification to results:
  - the **production path** (using model, source code, executable, etc.), and
  - the **examination path** (using requirements specifications).
- A check can only discover errors on **exactly one** of the paths.
- If a **difference is detected**: examination result is **positive**.
- What is not on the paths, is not checked; crucial: **specification** and **comparison**.

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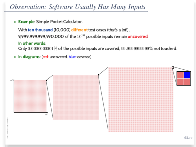

Observation: Software Usually Has Many Inputs

- **Example:** Simple Pocket Calculator.
  With **ten thousand** (10,000) **different** test cases (that's a lot!),
  9,999,999,999,990,000 of the 10^{16} possible inputs remain **uncovered**.
  In other words:
  Only 0.0000000001% of the possible inputs are covered, 99.9999999999% not touched.
- **In diagrams:** (red: uncovered, blue: covered)

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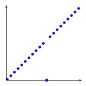
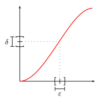
Point vs. Range Errors

- For software, (in general, without extra information) we **can not conclude** from some values to others.
- Software behaviour is (in general) **not continous.**



  - For software, adjacent inputs **may yield arbitrarily distant** output values.

    Vocabulary:
    - **Point error:** an isolated input value triggers the error.
    - **Range error:** multiple "neighbouring" inputs trigger the error.



  - Consider a continuous function, e.g. the one to the right:

    For sufficiently small ε-environments of an input, the outputs **differ only by a small amount** δ.

  - Physical systems are (to a certain extent) continous:
    - For example, if a bridge endures a single car of 1000 kg, we strongly expect the bridge to endure cars of 990 kg or 1010 kg.
    - And anything of weight smaller than 1000 kg can be expected to be endured.

Content

- **Some more vocabulary**
- **Choosing Test Cases**
  - Generic **requirements** on good test cases
  - Approaches:
    - **Statistical** testing
    - Expected outcomes: Test **Oracle** :-/
    - **Habitat**-based
    - **Glass-Box Testing**
      - **Statement / Branch / term coverage**
      - **Conclusions** from coverage measures
- **When To Stop Testing?**
- **Model-Based Testing**
- **Testing in the Development Process**
- **Formal Program Verification**
  - **Deterministic Programs**
    - **Syntax, Semantics,** Termination, Divergence

Testing Vocabulary

Specific Testing Notions

- How are the test cases **chosen**?
  - Considering only the specification (**black-box** or **function** test).
  - Considering the structure of the test item (**glass-box** or **structure** test).

- How much **effort** is put into testing?

execution trial — does the program run at all?

throw-away-test — invent input and judge output on-the-fly (→ "**rumprobieren**"),

systematic test — somebody (not author!) derives test cases, defines input/soll, documents test execution.

Experience: In the long run, **systematic tests** are more **economic**.

- **Complexity** of the test item:

unit test — a single program unit is tested (function, sub-routine, method, class, etc.)

module test — a component is tested,

integration test — the interplay between components is tested.

system test — tests a whole system.

Specific Testing Notions Cont'd

- Which **property** is tested?

function test —
functionality as specified by the requirements documents,

installation test —
is it possible to **install** the software with the provided documentation and tools?

recommissioning test —
is it possible to **bring the system back to operation** after operation was stopped?

availability test —
does the system run for the required amount of time without issues,

load and stress test —
does the system behave as required under **high or highest load**? … under overload?
"Hey, let's try how many game objects can be handled!" — that's an experiment, not a test.

resource tests —
response time, minimal **hardware (software) requirements**, etc.

regression test —
does the new version of the software **behave like the old one**
on inputs where no behaviour change is expected?

Specific Testing Notions Cont'd

- Which roles are **involved** in testing?
  - **inhouse test** —
    only developers (meaning: quality assurance roles),
  - **alpha** and **beta** test —
    selected (potential) customers,
  - **acceptance test** —
    the customer tests whether the system (or parts of it, at milestones) test whether the system is acceptable.

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Choosing Test Cases

How to Choose Test Cases?

- **A first rule-of-thumb:**

> "Everything, which is required, **must** be examined/checked. Otherwise it is **uncertain** whether the requirements have been **understood** and **realised**."
>
> (Ludewig and Lichter, 2013)

In other words:

- Not having
  - at least one (systematic) test case
    - for each (required) feature
      - is (**grossly**?) **negligent**. (Dt.: (grob?) fahrlässig).

- **In even other words:**
Without at least one test case for each feature, we can **hardly speak of** software **engineering**.

- **Good project management:** document for each test case which feature(s) it tests.

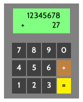
What Else Makes a Test Case a Good Test Case?

A test case is a **good test case** if it discovers — with high probability — an **unknown error**.

An **ideal test case** $(In, Soll)$ would be

- **of low redundancy**, i.e. it does not test what other test cases also test.
- **error sensitive**, i.e. has high probability to detect an error,
  (Probability should at least be greater than 0.)
- **representative**, i.e. represent a whole class of inputs,
  (i.e., software S passes $(In, Soll)$ if and only S behaves well for all In' from the class)

The idea of **representative**:



- If $(12345678, 27; 12345705)$ **was** representative for $(0, 27; 27)$, $(1, 27; 28)$, etc.
- then from a **negative** execution of test case $(12345678, 27; 12345705)$
- we **could** conclude that $(0, 27; 27)$, etc. will be negative as well.
- Is it / can we?

What Else Makes a Test Case a Good Test Case?

Thus: The wish for representative test cases is **problematic**:

- In general, we **do not know** which inputs lie in an equivalence class **wrt. a certain error**.
- Yet there is a large body on literature on how to construct representative test cases,
  assuming we know the equivalence classes.

Of course: ***If*** we ***know*** equivalence classes,
we should exploit that knowledge to optimise the number of test cases.

But it is **perfectly reasonable** to test representatives
of **equivalence classes induced by the specification**, e.g.

- valid and invalid inputs (to check whether input validation works at all),
- different classes of inputs considered in the requirements,
  like "C50", "E1" coins in the vending machine → have at least one test case with each.

Recall: one should have at least one test case per feature.

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Statistical Testing

One Approach: Statistical Tests

Classical **statistical testing** is one approach to deal with

- in practice not exhaustively testable **huge input space**,
- **tester bias**.
  (People tend to choose "good-will" inputs and disregard (tacit?) corner-cases;
  recall: the developer is not a good tester.)

Procedure:

- Randomly (!) choose test cases $T_1, \dots, T_n$ for test suite $\mathcal{T}$.
- Execute test suite $\mathcal{T}$.
- **If an error is found**:
  - **good**, we certainly know there is an error,
- **if no error is found**:
  - **refuse hypothesis** "program is **not** correct" with a certain significance niveau.
    (Significance niveau may be unsatisfactory with small test suites.)
- **Note**: Approach needs stochastical assumptions on error distribution and truly random test cases.

Statistical Testing: Discussion

(Ludewig and Lichter, 2013) name the following objections against statistical testing:

- In particular for **interactive software**, the **primary requirement** is often **no failures are experienced by the "typical user"**.
  Statistical testing (in general) may also cover a lot of "**untypical user behaviours**" unless (sophisticated) **user-models** are used.
- Statistical testing needs a method to **compute "soll"-values** for the randomly chosen inputs.
  That is easy for requirement "does not crash", but can be difficult in general.
- There is a high risk for **not finding point** or **small-range** errors.
  If they live in their "**natural habitat**", carefully crafted test cases would probably uncover them.

Findings in the literature can at best be called **inconclusive**.

Getting Soll-Values

Where Do We Get The “Soll”-Values From?

Recall: A test case is a pair $(In, Soll)$ with proper expected (or “soll”) values.

- In an **ideal world**, all “soll”-values are **defined** by the (formal) requirements specification and effectively **pre-computable**.
- In **this world**,
  - the formal requirements specification may only **reflectively** describe acceptable results without giving a **procedure** to compute the results.
  - there may not be a formal requirements specification, e.g.
    - “**the game objects should be rendered properly**”,
    - “the compiler must translate the program correctly”,
    - “**the notification message should appear on a proper screen position**”,
    - “the data must be available for at least 10 days”.
    - **etc.**

    Then: need another instance to decide whether the observation is acceptable.
- The testing community prefers to call **any instance** which decides whether results are acceptable a **(test) oracle**.

  I’d prefer **not to call** automatic derivation of “soll”-values from a **formal specification** an “oracle”… ; -) (“person or agency considered to provide wise and insightful [...] prophetic predictions or precognition of the future, inspired by the gods.” says Wikipedia)

Content

Habitat-based Testing

Choosing Test Cases Habitat-based

Some traditional popular belief on software error habitat:

- Software errors **(seem to) enjoy**
  - **range boundaries**, e.g.
    - 0, 1, 27 if software works on inputs from $[0, 27]$,
    - -1, 28 for error handling,
    - $-2^{31} - 1, 2^{31}$ on 32-bit architectures,
    - boundaries of arrays (first, last element),
    - boundaries of loops (first, last iteration),
    - etc.
  - **special cases** of the problem (empty list, use-case without actor, …),
  - special cases of the programming language semantics,
  - **complex implementations**.

→ **Good idea**: for each test case, note down why it has been chosen.
For example, “demonstrate that corner-case handling is not completely broken”.

Content

Glass-Box Testing: Coverage

Statements and Branches by Example

Definition. Software is a finite description S of a (possibly infinite) set $[\![S]\!]$ of (finite or infinite) computation paths of the form $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots$ where

- $\sigma_i \in \Sigma$, $i \in \mathbb{N}_0$, is called state (or configuration), and
- $\alpha_i \in A$, $i \in \mathbb{N}_0$, is called action (or event).

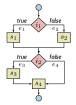
- In the following, we assume that
  - S has a control flow graph $(V, E)_S$, and statements $Stm_S \subseteq V$ and branches $Cnd_S \subseteq E$,
  - each computation path prefix $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots \xrightarrow{\alpha_n} \sigma_n$ gives information on statements and control flow graph branch edges which were executed right before obtaining σ_n:

$$stm : (\Sigma \times A)^* \to 2^{Stm_S}, \qquad cnd : (\Sigma \times A)^* \to 2^{Cnd_S},$$

```
 1: int f( int x, int y, int z )
 2: {
 3:  i1: if (x > 100 ∧ y > 10)
 4:  s1:     z = z * 2;
 5:      else
 6:  s2:     z = z/2;
 7:  i2: if (x > 500 ∨ y > 50)
 8:  s3:     z = z * 5;
 9:  s4: return z;
10: }
```

$Stm_f = \{s_1, s_2, s_3, s_4\}$

$Cnd_f = \{e_1, e_2, e_3, e_4\}$



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▷4:  s1:     z = z * 2;
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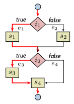

	σ_0	$\xrightarrow{\alpha_1}$	σ_1	$\xrightarrow{\alpha_2}$	σ_2	$\xrightarrow{\alpha_2}$	σ_3	$\xrightarrow{\alpha_3}$	σ_4	$\xrightarrow{\alpha_4}$	σ_5	$\xrightarrow{\alpha_5}$	σ_6
pc	1		3		4		7		8		9		10
x	501		501		501		501		501		501		501
y	11		11		11		11		11		11		11
z	0		0		0		0		0		0		0
					i_1^t		s_1						

Statements and Branches by Example

- In the following, we assume that
  - S has a control flow graph $(V, E)_S$, and statements $Stm_S \subseteq V$ and branches $Cnd_S \subseteq E$,
  - each computation path prefix $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots \xrightarrow{\alpha_n} \sigma_n$ gives information on statements and control flow graph branch edges which were executed right before obtaining σ_n:

$$stm : (\Sigma \times A)^* \to 2^{Stm_S}, \qquad cnd : (\Sigma \times A)^* \to 2^{Cnd_S},$$

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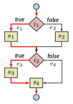


	σ_0	$\xrightarrow{\alpha_1}$	σ_1	$\xrightarrow{\alpha_2}$	σ_2	$\xrightarrow{\alpha_2}$	σ_3	$\xrightarrow{\alpha_3}$	σ_4	$\xrightarrow{\alpha_4}$	σ_5	$\xrightarrow{\alpha_5}$	σ_6
pc	1		3		4		7		8		9		10
x	501		501		501		501		501		501		501
y	11		11		11		11		11		11		11
z	0		0		0		0		0		0		0
stm:	$\{\}$		$\{\}$		$\{\}$		$\{s_1\}$		$\{\}$		$\{s_3\}$		$\{s_4\}$
cnd:	$\{\}$		$\{\}$		$\{e_1\}$		$\{\}$		$\{e_3\}$		$\{\}$		$\{\}$

Glass-Box Testing: Coverage

- **Coverage** is a property of **test cases** and **test suites**.
- Execution $\pi = \sigma_0 \xrightarrow{\alpha_1} \cdots$ of test case T achieves $p\,\%$ **statement coverage** if and only if

$$p = cov_{stm}(\pi) := \frac{|\bigcup_{i \in \mathbb{N}_0} stm(\sigma_0 \cdots \sigma_i)|}{|Stm_S|}, \; |Stm_S| \neq 0.$$

Test case T achieves $p\,\%$ **statement coverage** if and only if $p = \min_{\pi \text{ execution of } T} cov_{stm}(\pi)$.

- Execution π of T achieves $p\,\%$ **branch coverage** if and only if

$$p = cov_{cnd}(\pi) := \frac{|\bigcup_{i \in \mathbb{N}_0} cnd(\sigma_0 \cdots \sigma_i)|}{|Cnd_S|}, \; |Cnd_S| \neq 0.$$

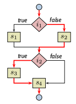
Test case T achieves $p\,\%$ **branch coverage** if and only if $p = \min_{\pi \text{ execution of } T} cov_{cnd}(\pi)$.

- **Define**: $p = 100$ for empty program. (More precisely: $Stm_S = \emptyset$ and $Cnd_S = \emptyset$, respectively.)
- Statement/branch coverage canonically extends to test suite $\mathcal{T} = \{T_1, \ldots, T_n\}$. For example, given $\pi_1 = \sigma_0^1 \cdots, \ldots, \pi_n = \sigma_0^n \cdots$, then $\mathcal{T}$ achieves

$$p = \frac{|\bigcup_{1 \le j \le n} \bigcup_{i \in \mathbb{N}_0} stm(\sigma_0^j \cdots \sigma_i^j)|}{|Stm_S|}, \; |Stm_S| \neq 0, \text{ statement coverage}.$$

Coverage Example

```
int f( int x, int y, int z )
{
  i1: if (x > 100 ∧ y > 10)
  s1:     z = z * 2;
      else
  s2:     z = z/2;
  i2: if (x > 500 ∨ y > 50)
  s3:     z = z * 5;
  s4: return z;
}
```



- **Requirement**: $\{true\}\ f\ \{true\}$ (no abnormal termination), i.e. $Soll = \Sigma^* \cup \Sigma^\omega$.

In											test suite coverage		
											%	%	i_2/%
x, y, z	i_1/t	i_1/f	s_1	s_2	i_2/t	i_2/f	c_1	c_2	s_3	s_4	stm	cnd	term
$501, 11, 0$	✓		✓		✓		✓		✓	✓	75	50	25
$501, 0, 0$		✓		✓	✓		✓		✓	✓	100	75	–

Coverage Example

```
int f( int x, int y, int z )
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i1:  if (x > 100 ∧ y > 10)
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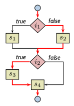

- **Requirement**: $\{\textit{true}\}\ f\ \{\textit{true}\}$ (no abnormal termination), i.e. $Soll = \Sigma^* \cup \Sigma^\omega$.

test suite coverage

In											%	%	$i_2/$%
x, y, z	i_1/t	i_1/f	s_1	s_2	i_2/t	i_2/f	c_1	c_2	s_3	s_4	stm	cnd	term
$501, 11, 0$	✓		✓		✓		✓		✓	✓	75	50	25
$501, 0, 0$		✓		✓	✓		✓		✓	✓	100	75	25
$0, 0, 0$		✓		✓		✓				✓	100	100	75
$0, 51, 0$		✓		✓	✓			✓		✓	100	100	100

Term Coverage

- Consider the statement

$$\texttt{if}\ \overbrace{(A \wedge (B \vee (C \wedge D)) \vee E)}^{expr}\ \texttt{then} \ldots;$$

  where $A, \ldots, E$ are **minimal** boolean terms, e.g. $x > 0$, but not $a \vee b$.

  Branch coverage is easy in this case:

  Use In_1 such that $(A = 0, \ldots, E = 0)$, and In_2 such that $(A = 0, \ldots, E = 1)$.

- **Additional goal**:
  check whether there are useless terms,
  or terms causing abnormal program termination.

- **Term Coverage** (for an expression $expr$):
  - Let $\beta : \{A_1, \ldots, A_n\} \to \mathbb{B}$ be a valuation of the terms.
  - Term A_i is b-**effective** in β for $expr$ if and only if

$$\beta(A_i) = b \text{ and } [\![expr]\!](\beta[A_i/\textit{true}]) \neq [\![expr]\!](\beta[A_i/\textit{false}]).$$

  - $\Xi \subseteq (\{A_1, \ldots, A_n\} \to \mathbb{B})$ achieves $p\,\%$ **term coverage** if and only if

$$p = \frac{|\{A_i^b \mid \exists \beta \in \Xi \bullet A_i \text{ is } b\text{-effective in } \beta\}|}{2n}.$$

	A	B	C	D	E	b	%
β_1	1	1	0	0	0	1	20
β_2	1	0	0	1	0	0	50
β_3	1	0	1	1	0	1	70
β_4	0	0	1	0	1	1	80

red: b-effective, black: otherwise

Unreachable Code

```
int f( int x, int y, int z )
{
i1:  if (x ≠ x)
s1:      z = y/0;
i2:  if (x = x ∨ z/0 = 27)
s2:      z = z * 2;
s3:  return z;
}
```

- Statement s_1 is **never executed** (because $x \neq x \iff \textit{false}$),
  thus 100 % statement-/branch-/term-coverage is **not achievable**.
- Assume, evaluating $n/0$ causes (undesired) **abnormal program termination**.
  Is statement s_1 an **error** in the program…?
- Term $z/0$ in i_2 also looks critical…
  (In programming languages with short-circuit evaluation, it is never evaluated.)

Conclusions from Coverage Measures

- Assume, test suite $\mathcal{T}$ tests software S for the following property φ:
  - **pre-condition**: p, **post-condition**: q,

  and S passes (!) $\mathcal{T}$, and the execution achieves $100\,\%$ statement / branch / term coverage.

What does this tell us about S? Or: what can we conclude from coverage measures?

- 100 % **statement** coverage:
  - "there is no statement, which **necessarily** violates φ"
    (Still, there may be many, many computation paths which violate φ,
    and which just have not been touched by $\mathcal{T}$.)
  - "there is no unreachable statement"
- 100 % **branch** (**term**) coverage:
  - "there is no single branch (term) which **necessarily causes** violations of φ"
    In other words: "for each condition (term), there is one computation path
    satisfying φ where the condition (term) evaluates to *true*, and one for *false*."
  - "there is no unused condition (term)"

Not more (→ exercises)!
That's definitely **something**, but not as much as "100 %" may sound like…

Coverage Measures in Certification

- (Seems that) DO-178B,
  "Software Considerations in Airborne Systems and Equipment Certification", (which deals with the safety of software used in certain airborne systems)
  requires that certain **coverage measures** are reached,
  in particular something similar to **term coverage** (MC/DC coverage).
  (Next to development process requirements, reviews, unit testing, etc.)
- If not required, ask: what is the effort / gain ratio?
  (Average effort to detect an error; term coverage needs high effort.)
- Currently, the standard moves towards accepting certain verification or
  static analysis tools to support (or even replace?) some testing obligations.

Content

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When To Stop Testing?

When To Stop Testing?

- There need to be defined **criteria** for when to stop testing;
  project planning should consider these criteria (and previous experience).

- Possible "**testing completed**" criteria:
  - all (previously) **specified test cases**
    have been executed with negative result,

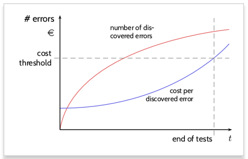
    (**Special case**: All test cases resulting from a certain strategy,
    like maximal statement coverage have been executed.)
  - **testing effort time** sums up to x (hours, days, weeks),
  - **testing effort** sums up to y (any other useful unit),
  - n **errors** have been discovered,
  - **no error** has been discovered **during**
    the last z hours (days, weeks) of testing,

  Values for x, y, n, z are fixed based on experience, estimation, budget, etc.

- **Of course**: not all criteria are equally reasonable or compatible with each testing approach.

Another Criterion

- Another possible "**testing completed**" criterion:
  - The **average cost per error discovery** exceeds a defined threshold c.



Value for c is again fixed based on experience, estimation, budget, etc..

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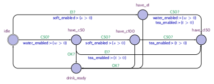
Model-Based Testing

Model-based Testing



- Does some software **implement** the given CFA model of the CoinValidator?

- **One approach**: **Location Coverage**.

  Check whether for **each location** of the model there is
  a **corresponding configuration** reachable in the software (needs to be observable somehow).

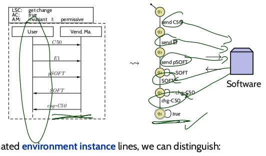
- Input sequences can **automatically be generated** from the model,
  e.g., using Uppaal's "drive-to" feature.
  - Check "can we reach 'idle', 'have_c50', 'have_c100', 'have_c150'?" by

    $$T_1 = (\text{C50}, \text{C50}, \text{C50}; \{\pi \mid \exists\, i < j < k < \ell \bullet \pi^i \sim \text{idle}, \pi^j \sim \text{h\_c50}, \pi^k \sim \text{h\_c100}, \pi^\ell \sim \text{h\_c150}\})$$
  - Check for 'have_e1' by $T_2 = (\text{C50}, \text{C50}, \text{C50}; \dots)$.
  - To check for 'drink_ready', more interaction is necessary.

- **Analogously**: **Edge Coverage**.

  Check whether **each edge** of the model has **corresponding** behaviour in the software.

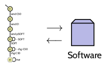
Existential LSCs as Test Driver & Monitor (Lettrari and Klose, 2001)



- If the LSC has designated **environment instance** lines, we can distinguish:
  - messages expected to **originate from** the environemnt (**driver role**),
  - messages expected **adressed to** the environemnt (**monitor role**).
- Adjust the TBA-construction algorithm to construct a **test driver & monitor** and let it (possibly with some **glue logic** in the middle) interact with the software.
- **Test passed** (i.e., test unsuccessful) if and only if TBA state q_6 is reached.

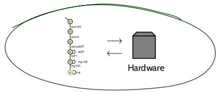
  Note: We may need to **refine** the LSC by adding an activation condition; or communication which drives the system under test into the desired start state.
- For example the **Rhapsody** tool directly supports this approach.

Vocabulary



- **Software-in-the-loop**:

  The final implementation is examined
  using a separate computer to simulate other system components.



- **Hardware-in-the-loop**:

  The final implementation is running on (prototype) hardware
  which is connected by its standard input/output interface (e.g. CAN-bus)
  to a separate computer which simulates other system components.

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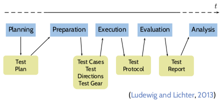
Testing in The Software Development Process

Test Conduction: Activities & Artefacts



(Ludewig and Lichter, 2013)

- **Test Gear**: (may need to be developed in the project!)

> **test driver**— A software module used to invoke a module under test and, often, provide test inputs, control and monitor execution, and report test results.
> Synonym: test harness. **IEEE 610.12 (1990)**

> **stub**—
> (1) A skeletal or special-purpose implementation of a software module, used to develop or test a module that calls or is otherwise dependent on it.
> (2) A computer program statement substituting for the body of a software module that is or will be defined elsewhere. **IEEE 610.12 (1990)**

- **Roles**: **tester** and **developer** should be different persons!

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Tell Them What You've Told Them. . .

- There is a **vast amount of literature** on how to choose test cases.
  A good starting point:
  - **at least one test case per feature**,
  - **corner-cases**, extremal values,
  - **error handling**, etc.
- **Glass-box testing**
  - considers the **control flow graph**,
  - defines **coverage measures**.
- **Other approaches:**
  - **statistical** testing, **model-based** testing,
- Define criteria for **"testing done"** (like coverage, or cost per error).
- **Process**: tester and developer should be different persons.

- There are **more approaches**
  to code quality assurance than (just) **testing**.
- For example, **program verification**.

References

References

IEEE (1990). *IEEE Standard Glossary of Software Engineering Terminology*. Std 610.12-1990.

Lettrari, M. and Klose, J. (2001). Scenario-based monitoring and testing of real-time UML models. In Gogolla, M. and Kobryn, C., editors, *UML*, number 2185 in Lecture Notes in Computer Science, pages 317–328. Springer-Verlag.

Ludewig, J. and Lichter, H. (2013). *Software Engineering*. dpunkt.verlag, 3. edition.