Software Design, Modelling and Analysis in UML

Lecture 21: Model-based Software Development

2017-02-06

Prof. Dr. Andreas Podelski, **Dr. Bernd Westphal**

Albert-Ludwigs-Universität Freiburg, Germany

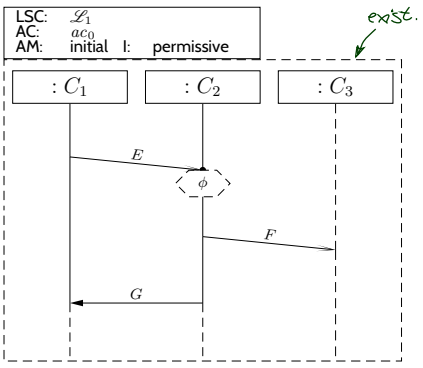
Content

Full LSCs

A **full LSC** $\mathscr{L} = (((L, \preceq, \sim), \mathcal{I}, \mathsf{Msg}, \mathsf{Cond}, \mathsf{LocInv}, \Theta), ac_0, am, \Theta_{\mathscr{L}})$ consists of

- **body** $((L, \preceq, \sim), \mathcal{I}, \mathsf{Msg}, \mathsf{Cond}, \mathsf{LocInv}, \Theta)$,
- **activation condition** $ac_0 \in Expr_{\mathscr{L}}$,
- **strictness flag** $strict$ (if *false*, $\mathscr{L}$ is called **permissive**)
- **activation mode** *am* $\in \{\mathsf{initial}, \mathsf{invariant}\}$,
- **chart mode existential** ($\Theta_{\mathscr{L}} = \mathsf{cold}$) or **universal** ($\Theta_{\mathscr{L}} = \mathsf{hot}$).

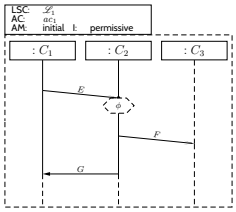
Concrete syntax:



Full LSCs

A **full LSC** $\mathscr{L} = (((L, \preceq, \sim), \mathcal{I}, \text{Msg}, \text{Cond}, \text{LocInv}, \Theta), ac_0, am, \Theta_{\mathscr{L}})$ consists of

- **body** $((L, \preceq, \sim), \mathcal{I}, \text{Msg}, \text{Cond}, \text{LocInv}, \Theta)$,
- **activation condition** $ac_0 \in Expr_{\mathcal{S}}$,
- **strictness flag** $strict$ (if *false*, $\mathscr{L}$ is called **permissive**)
- **activation mode** $am \in \{\text{initial}, \text{invariant}\}$,
- **chart mode** **existential** ($\Theta_{\mathscr{L}} = \text{cold}$) or **universal** ($\Theta_{\mathscr{L}} = \text{hot}$).



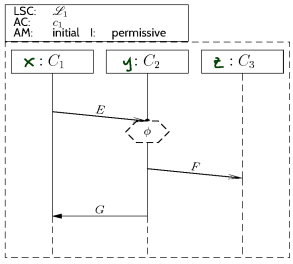
A **set of words** $W \subseteq (Expr_{\mathcal{B}} \to \mathbb{B})^\omega$ is **accepted** by $\mathscr{L}$ if and only if

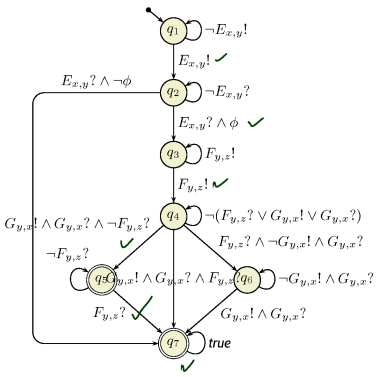
suffix of w starting at index 1

$\Theta_{\mathscr{L}}$	$am = \text{initial}$	$am = \text{invariant}$
cold	$\exists\, \beta\, \exists\, w \in W \bullet w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0)$ $\wedge\, w^0 \models_\beta \psi_{prog}(\emptyset, C_0) \wedge w/1 \in \mathcal{L}_\beta(\mathcal{B}(\mathscr{L}))$	$\exists\, \beta\, \exists\, w \in W\, \exists\, k \in \mathbb{N}_0 \bullet w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0)$ $\wedge\, w^k \models_\beta \psi_{prog}(\emptyset, C_0) \wedge w/k+1 \in \mathcal{L}_\beta(\mathcal{B}(\mathscr{L}))$
hot	$\forall\, \beta\, \forall\, w \in W \bullet w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0)$ $\implies w^0 \models_\beta \psi_{prog}(\emptyset, C_0) \wedge w/1 \in \mathcal{L}_\beta(\mathcal{B}(\mathscr{L}))$	$\forall\, \beta\, \forall\, w \in W\, \forall\, k \in \mathbb{N}_0 \bullet w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0)$ $\implies w^k \models_\beta \psi^{\text{Cond}}_{\text{hot}}(\emptyset, C_0) \wedge w/k+1 \in \mathcal{L}_\beta(\mathcal{B}(\mathscr{L}))$

where C_0 is the minimal (or **instance heads**) cut.

Full LSC Semantics: Example





$$w: \quad (\sigma, \varepsilon) \xrightarrow[u]{(cons, Snd)} \cdots \to (\sigma_0, \varepsilon_0) \xrightarrow[u_0]{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \xrightarrow[c_1]{(cons_1, \{(:E, c_2)\})} (\sigma_2, \varepsilon_2) \xrightarrow[c_2]{(\{:E\}, Snd_2)}$$
$$(\sigma_3, \varepsilon_3) \xrightarrow[c_2]{(cons_3, \{(:F, c_3)\})} (\sigma_4, \varepsilon_4) \xrightarrow[c_2]{(cons_4, \{(G(), c_1)\})} (\sigma_5, \varepsilon_5) \xrightarrow[c_3]{(\{:F\}, Snd_5)} (\sigma_6, \varepsilon_6) \to \cdots$$

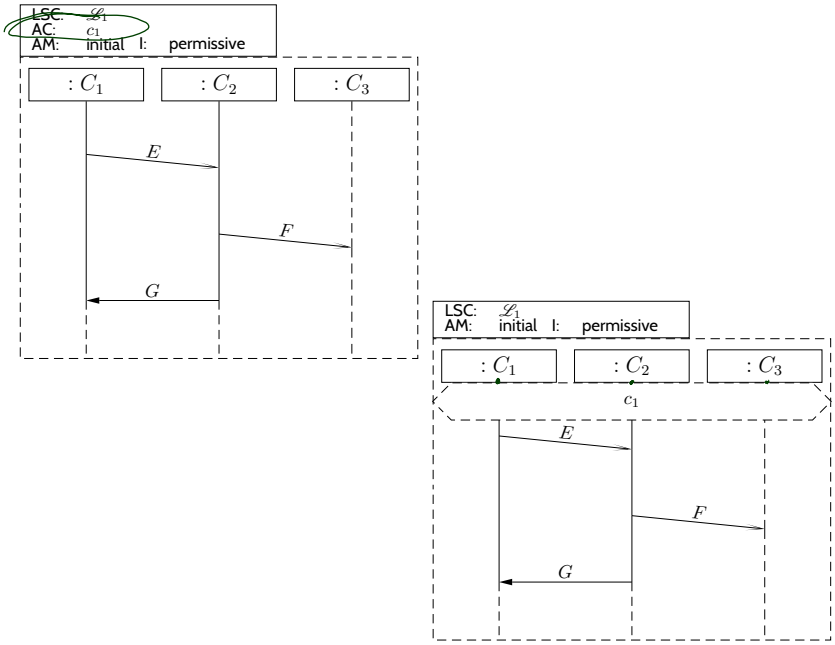
ϕ ✓

$\beta = \{x \mapsto c_1, y \mapsto c_2, z \mapsto c_3\}$

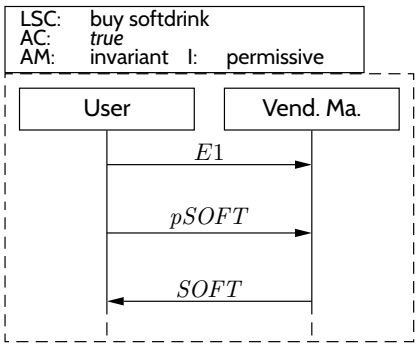
$\not\models$

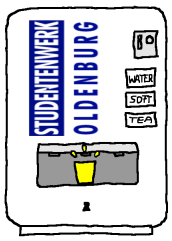
$\hookrightarrow$ w is accepted by $\mathscr{L}_1$

Note: Activation Condition

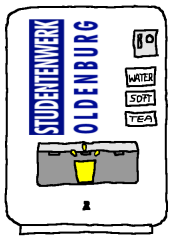


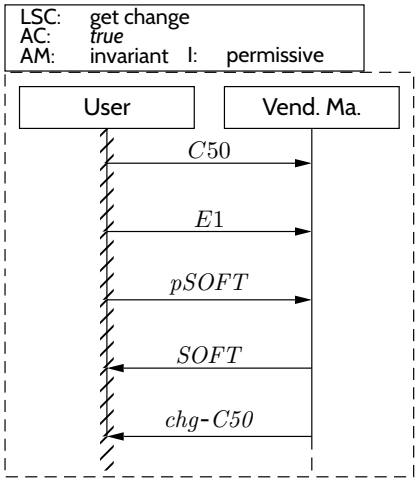
Existential LSC Example: Buy A Softdrink





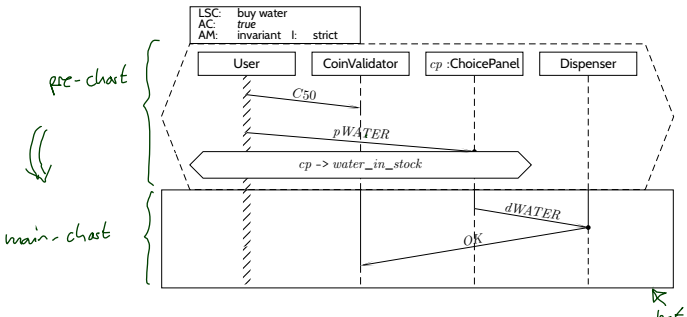
Existential LSC Example: Get Change





Live Sequence Charts — Precharts

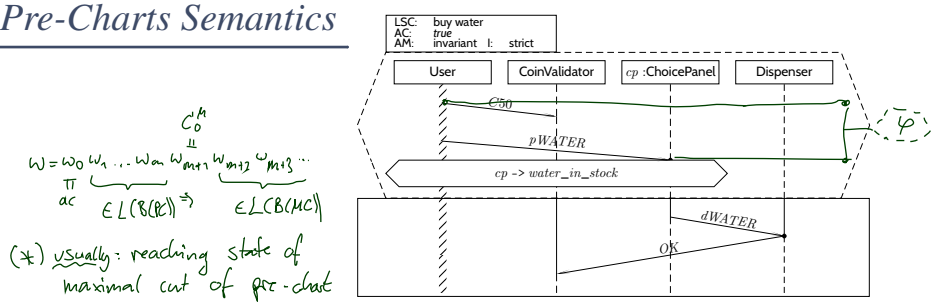
Pre-Charts



A **full LSC** $\mathscr{L} = (PC, MC, ac_0, am, \Theta_{\mathscr{L}})$ **actually** consist of

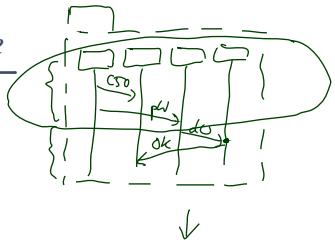
- **pre-chart** $PC = ((L_P, \preceq_P, \sim_P), \mathcal{I}_P, \mathscr{S}, \mathsf{Msg}_P, \mathsf{Cond}_P, \mathsf{LocInv}_P, \Theta_P)$ (possibly empty),
- **main-chart** $MC = ((L_M, \preceq_M, \sim_M), \mathcal{I}_M, \mathscr{S}, \mathsf{Msg}_M, \mathsf{Cond}_M, \mathsf{LocInv}_M, \Theta_M)$ (non-empty),
- **activation condition** $ac_0 : Bool \in Expr_{\mathscr{S}}$,
- **strictness flag** $strict$ (otherwise called **permissive**)
- **activation mode** $am \in \{\text{initial}, \text{invariant}\}$,
- **chart mode existential** ($\Theta_{\mathscr{L}} = \text{cold}$) or **universal** ($\Theta_{\mathscr{L}} = \text{hot}$).

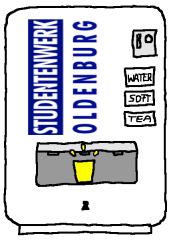
Pre-Charts Semantics

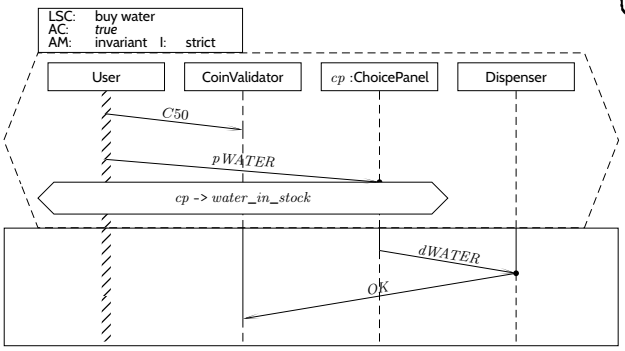


	$am = \text{initial}$	$am = \text{invariant}$
$\Theta_{\mathscr{L}} = \text{cold}$	$\exists\, \beta\, \exists\, w \in W\, \exists\, m \in \mathbb{N}_0 \bullet$ $\wedge w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^1, \ldots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\wedge\, w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$	$\exists\, \beta\, \exists\, w \in W\, \exists\, k < m \in \mathbb{N}_0 \bullet$ $\wedge w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^{k+1}, \ldots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\wedge\, w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$
$\Theta_{\mathscr{L}} = \text{hot}$	$\forall\, \beta\, \forall\, w \in W\, \forall\, m \in \mathbb{N}_0 \bullet$ $\left\{\begin{array}{l}\wedge w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)\\ \wedge\, w^1, \ldots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC)) \quad (*)\\ \wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)\end{array}\right.$ $\Longrightarrow \left\{\begin{array}{l} w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)\\ \wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))\end{array}\right.$	$\forall\, \beta\, \forall\, w \in W\, \forall\, k \leq m \in \mathbb{N}_0 \bullet$ $\wedge w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^{k+1}, \ldots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\Longrightarrow\, w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$

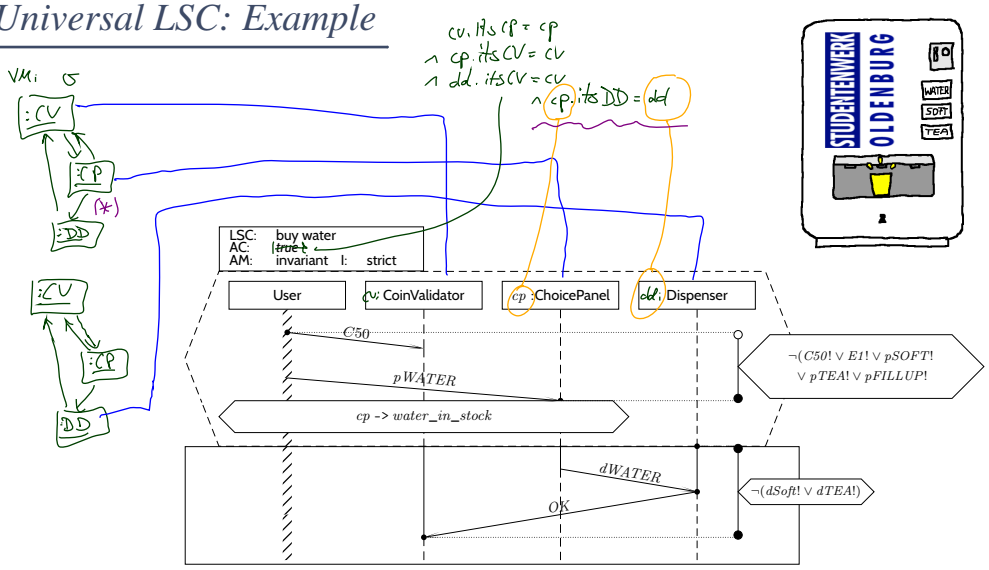
Universal LSC: Example



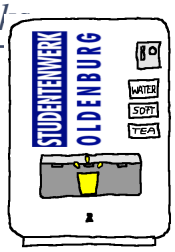


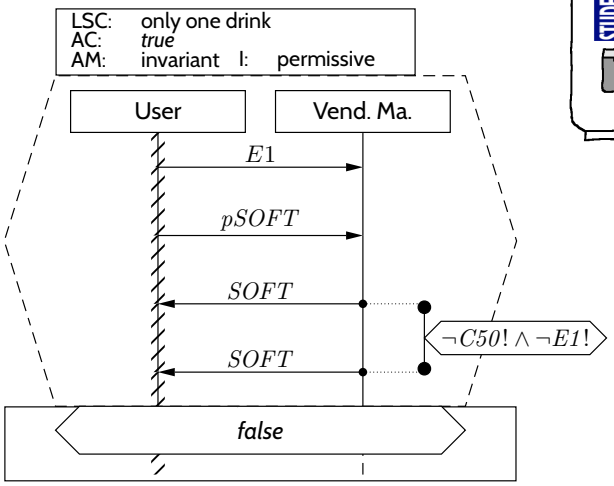


Universal LSC: Example

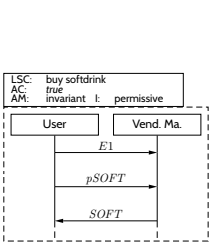


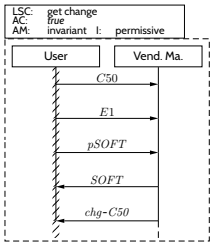
Forbidden Scenario Example: Don't Give Two Drinks

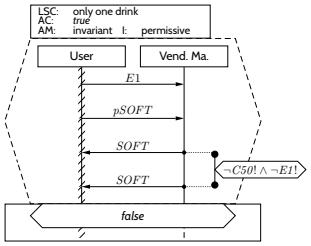




Note: Sequence Diagrams and (Acceptance) Test

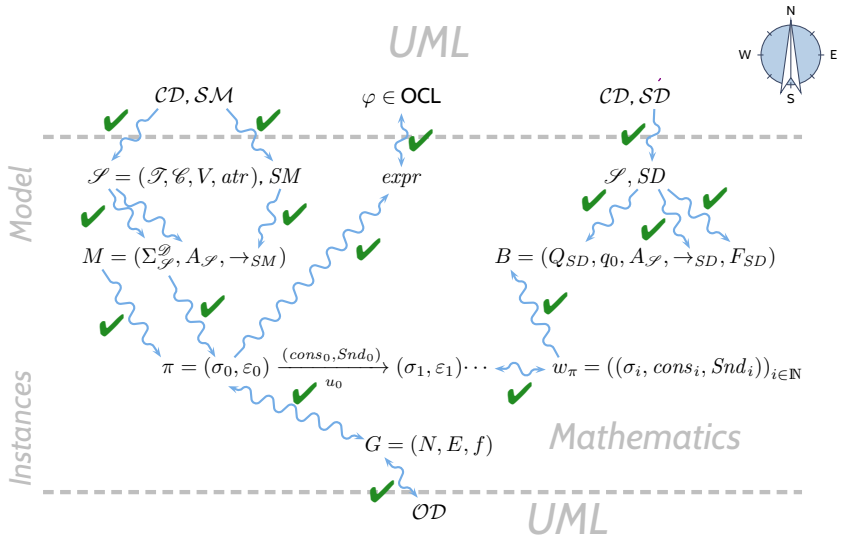






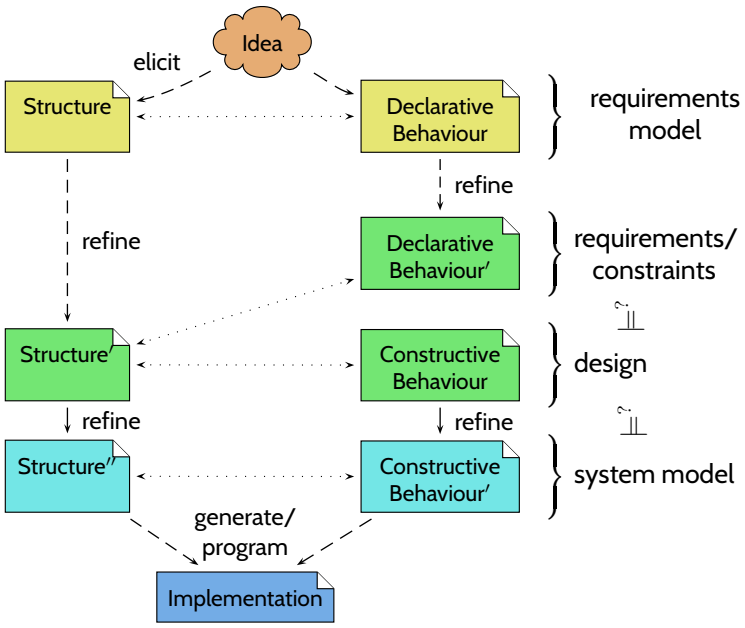
- **Existential** LSCs* may hint at **test-cases** for the **acceptance test**!
  (∗: as well as (positive) scenarios in general, like use-cases)
- **Universal** LSCs (and negative/anti-scenarios) in general need **exhaustive analysis**!
  (Because they require that the software **never ever** exhibits the unwanted behaviour.)

Course Map

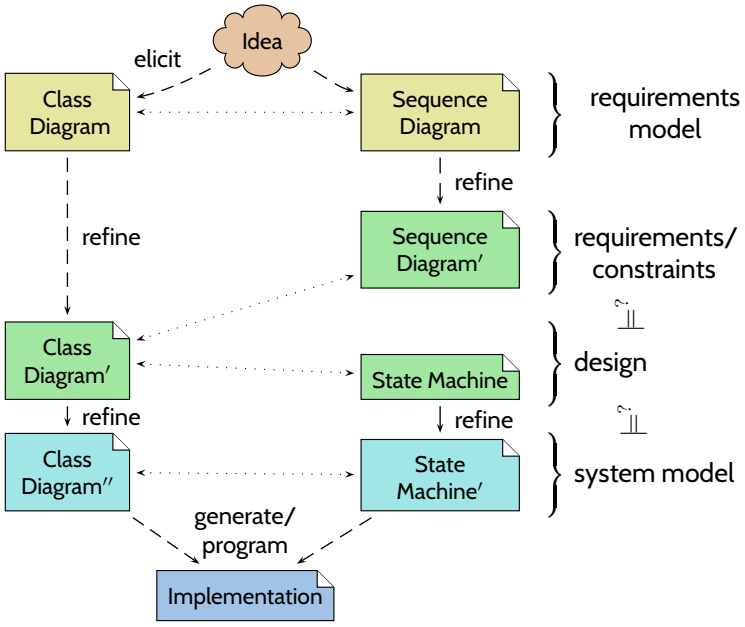


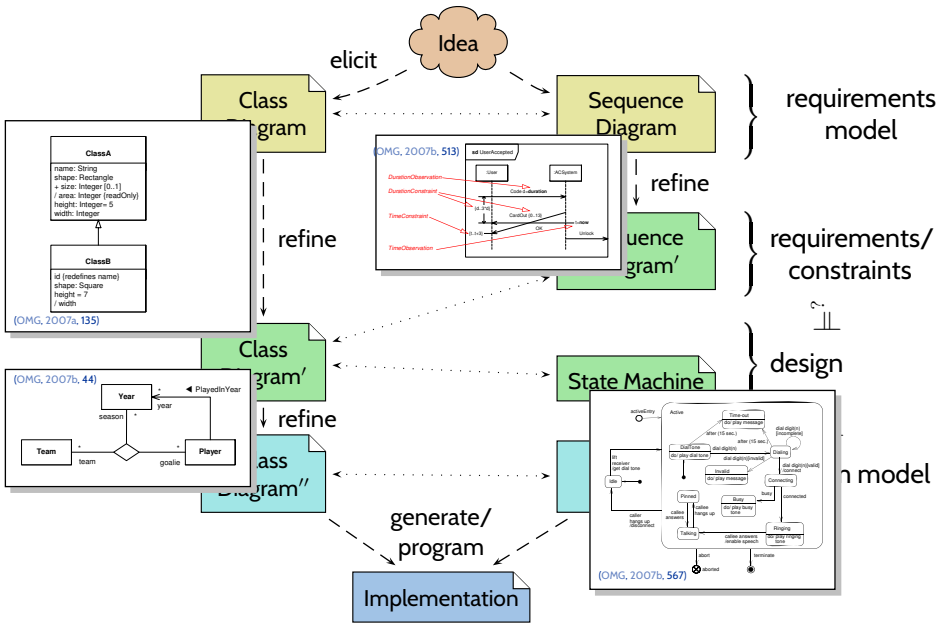
Model-Based/-Driven Software Engineering

Model-Driven Software Engineering



Model-Driven Software Engineering with UML





Model-Based Testing

Recall: Test Case

Definition. A **test case** T 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.

A **test execution** π, i.e. $((\pi^0, \ldots, \pi^n) \downarrow \Sigma_{in}) \in In$ for some $n \in \mathbb{N}_0$, is called

- **successful** (or **positive**)
  if it discovered an error,
  i.e., if $\pi \notin [\![Soll]\!]$.
  (Alternative: test item S **failed to pass test**; confusing: "test failed".)
- **unsuccessful** (or **negative**)
  if it did not discover an error,
  i.e., if $\pi \in [\![Soll]\!]$.
  (Alternative: test item S **passed test**; okay: "test passed".)

Glass-Box Testing: Coverage

- **Coverage** is a property of **test cases** and **test suites**.
- Execution π of test case T achieves $p\,\%$ **statement coverage** if and only if

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

  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

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

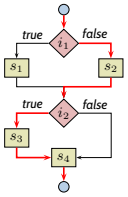
  Test case T achieves $p\,\%$ **branch coverage** if and only if $p = \min_{\pi \text{ execution of } T} cov_{cnd}(\pi)$.

- **Define**: $p = 100$ for empty program.
- Statement/branch coverage canonically extends to test suite $\mathcal{T} = \{T_1, \ldots, T_n\}$,
  e.g. given executions $\pi_1, \ldots, \pi_n$, $\mathcal{T}$ achieves

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

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: ;
}
```



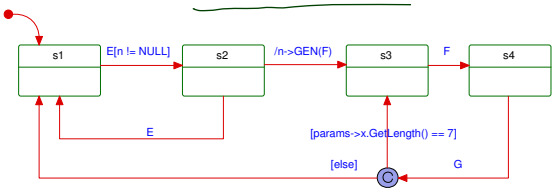
- **Requirement**: $\{true\}\ f\ \{true\}$ (no abnormal termination), i.e. $Soll = \Sigma^* \cup \Sigma^\omega$.

test suite coverage

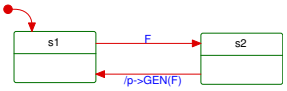
In											%	%	i_2/%
x, y, z	i_1/t	i_1/f	s_1	s_2	i_2/t	i_2/f	c_1	c_2	s_3	s_4	stm	cnd	term
$501, 11, 0$	✔		✔		✔		✔		✔	✔	75	50	25
$501, 0, 0$		✔		✔	✔		✔		✔	✔	100	75	25
$0, 0, 0$		✔		✔		✔				✔	100	100	75
$0, 51, 0$		✔		✔	✔			✔		✔	100	100	100

Model-Element Coverage

State machine of C:



State machine of D:



100 % Element coverage of C's state machine:

- a set of test cases (e.g. **Sequence Diagrams**) such that
- when conducting these test cases
  - **each state** of C is **reached at least once**, (state coverage)
  - **each transition** of C is **taken at least once**. (transition coverage)

In general: **State coverage of a set of test cases**

- number-of-states reached / number-of-states in state machine.

Excursion: Automatic Test Generation

Model-based Testing

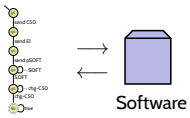
- Given a **set of test cases** passing for the model,
- and an **implementation of the model** (maybe hand-written).

- **Execute the test cases on the implementation** (or the final system).

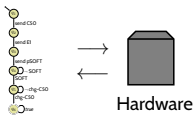
  This may need an appropriate **interpretation**. For example, if the test case says
  - send "C50" to the CoinValidator,
  - rather insert a 50 Cent coin into the vending machine.

- If the vending machine **does not behave** according to the test,
  - then **there's something wrong** (wrong test conduction, wrong implementation, etc.).
- If the vending machine **does behave** according to the test,
  - then we know that **this scenario works** – not more.

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.

38/44

References

References

Dobing, B. and Parsons, J. (2006). How UML is used. Communications of the ACM, 49(5):109–114.

OMG (2007a). Unified modeling language: Infrastructure, version 2.1.2. Technical Report formal/07-11-04.

OMG (2007b). Unified modeling language: Superstructure, version 2.1.2. Technical Report formal/07-11-02.

OMG (2011a). Unified modeling language: Infrastructure, version 2.4.1. Technical Report formal/2011-08-05.

OMG (2011b). Unified modeling language: Superstructure, version 2.4.1. Technical Report formal/2011-08-06.