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

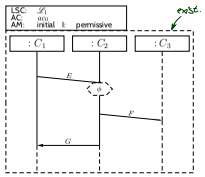
Live Sequence Charts — Full LSC Semantics

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** $am \in \{\text{initial}, \text{invariant}\}$,
- **chart mode** existential ($\Theta_{\mathscr{L}} = \text{cold}$) or universal ($\Theta_{\mathscr{L}} = \text{hot}$).

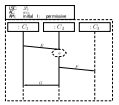
Concrete syntax:



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** $am \in \{\text{initial}, \text{invariant}\}$,
- **chart mode** existential ($\Theta_{\mathscr{L}} = \text{cold}$) or universal ($\Theta_{\mathscr{L}} = \text{hot}$).

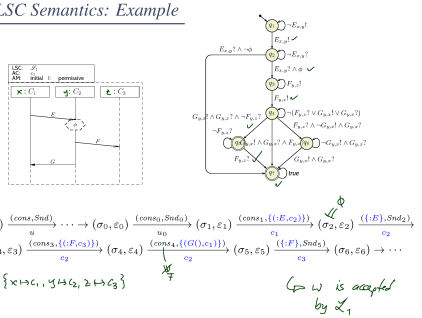


A **set of words** $W \subseteq (Expr_{\mathcal{B}} \to \mathbb{B})^\omega$ is **accepted** by $\mathscr{L}$ if and only if

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

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

Full LSC Semantics: Example

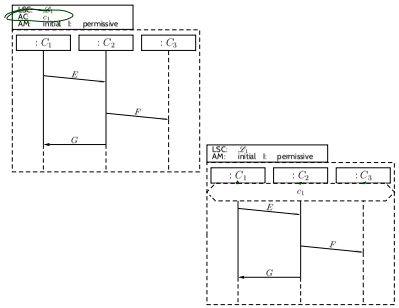


$$w: (\sigma_1, \varepsilon) \xrightarrow{(cons_1, Snd)}_{u} \cdots \to (\sigma_0, \varepsilon_0) \xrightarrow[u_0]{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \xrightarrow[c_1]{(cons_1, \{(E, c_2)\})} (\sigma_2, \varepsilon_2) \xrightarrow[c_2]{(\{!E\}, Snd_2)}$$
$$(\sigma_3, \varepsilon_3) \xrightarrow[c_2]{(cons_3, \{(F, c_3)\})} (\sigma_4, \varepsilon_4) \xrightarrow[c_2]{(cons_4, \{(G(), c_1)\})} (\sigma_5, \varepsilon_5) \xrightarrow[c_3]{(\{!F\}, Snd_3)} (\sigma_6, \varepsilon_6) \to \cdots$$

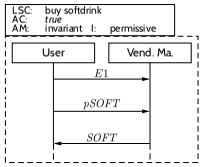
$\beta = \{x \mapsto c_1, y \mapsto c_2, z \mapsto c_3\}$

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

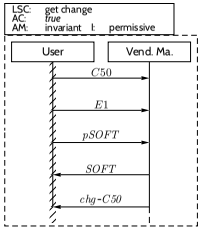
Note: Activation Condition



Existential LSC Example: Buy A Softdrink

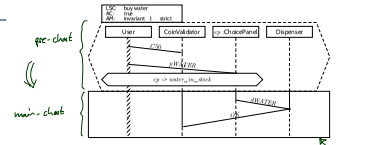


Existential LSC Example: Get Change



Live Sequence Charts — Precharts

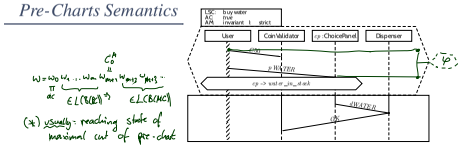
Pre-Charts



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

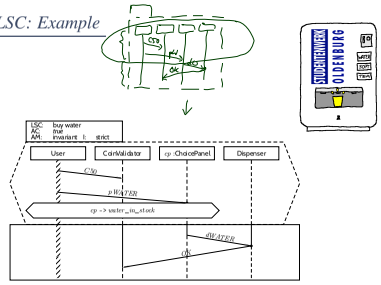
- **pre-chart** $PC = ((L_P, \preceq_P, \sim_P), \mathcal{I}_P, \mathscr{S}, \mathsf{Msg}_P, \mathsf{Cond}_P, \mathsf{LocInv}_P, \Theta_P)$ (possibly empty).
- **main-chart** $MC = ((L_M, \preceq_M, \sim_M), \mathcal{I}_M, \mathscr{S}, \mathsf{Msg}_M, \mathsf{Cond}_M, \mathsf{LocInv}_M, \Theta_M)$ (non-empty).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

Pre-Charts Semantics

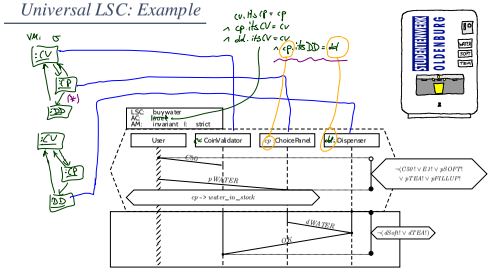


	$am =$ initial	$am =$ invariant
$\Theta_{\mathscr{L}} =$ cold	$\exists\,\beta\,\exists\,w \in W\,\exists\,m \in \mathbb{N}_0 \bullet$ $\wedge\, w^0 \models_\beta ac \wedge \neg\psi_{ent}(C_0^M) \wedge \psi_{proj}(\emptyset, C_0^P)$ $\wedge\, w^1, \ldots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\,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

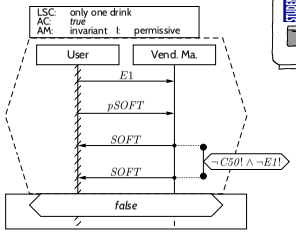
Universal LSC: Example



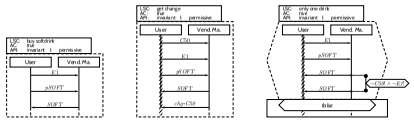
Universal LSC: Example



Forbidden Scenario Example: Don't Give Two Drin!

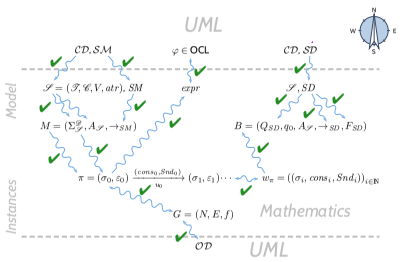


Note: Sequence Diagrams and (Acceptance) Test

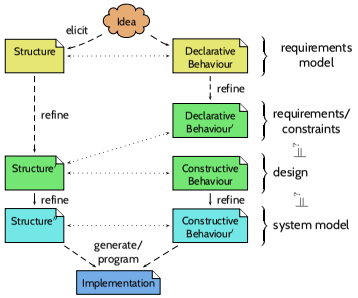


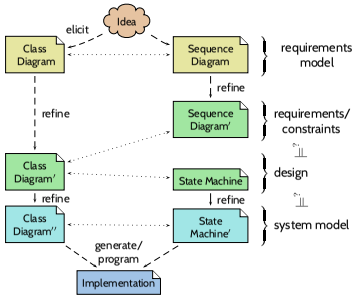
- **Existential** LSCs* may hint at **test-cases** for the **acceptance test**!
  (*: as well as (positive) scenarios in general, like use-cases)
- **Universal** LSCs (and negative/anti-scenarios) in general need **exhaustive analysis**!
  (Because they require that the software **never ever** exhibits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

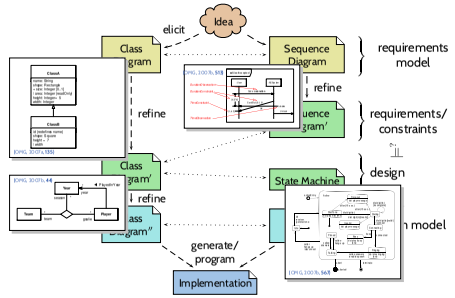
Course Map



Model-Based/-Driven Software Engineering







Model-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:  ;
}
```

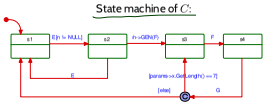
- **Requirement**: $\{true\}\ f\ \{true\}$ (no abnormal termination), i.e. $Soll = \Sigma^* \cup \Sigma^\omega$.

testsuite 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	tem
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.

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.