Software Design, Modelling and Analysis in UML

Lecture 21: Model-based Software Development

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Content

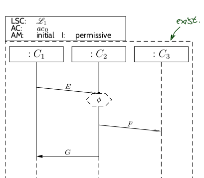
Live Sequence Charts — Full LSC Semantics

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** $ac_0 \in Expr_{\mathscr{S}}$,
- **strictness flag** $strict$ (if *false*, $\mathscr{L}$ is called permissive)
- **activation mode** *am* $\in$ {initial, invariant},
- **chart mode** existential ($\Theta_{\mathscr{L}}$ = cold) or universal ($\Theta_{\mathscr{L}}$ = hot).

Concrete syntax:



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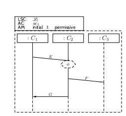


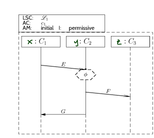
A **set of words** $W \subseteq (Expr_{\mathcal{B}} \to \mathbb{B})^\omega$ is **accepted** by $\mathscr{L}$ if and only if

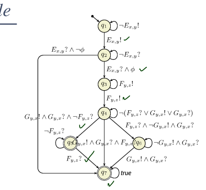
suffix of w starting at index 1

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

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

Full LSC Semantics: Example





w:

$$(\sigma, \varepsilon) \xrightarrow[u]{(cons, Snd)} \cdots \to (\sigma_0, \varepsilon_0) \xrightarrow[u_0]{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \xrightarrow[c_1]{(cons_1, \{(:E, c_2)\})} (\sigma_2, \varepsilon_2) \xrightarrow[c_2]{(\{:E\}, Snd_2)}$$

$$(\sigma_3, \varepsilon_3) \xrightarrow[c_2]{(cons_3, \{(:F, c_3)\})} (\sigma_4, \varepsilon_4) \xrightarrow[c_2]{(cons_4, \{(G(), c_1)\})} (\sigma_5, \varepsilon_5) \xrightarrow[c_3]{(\{:F\}, Snd_5)} (\sigma_6, \varepsilon_6) \to \cdots$$

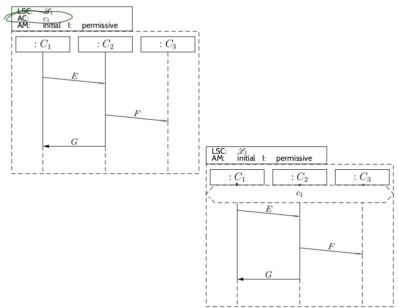
$\models \phi$

$\cancel{q_6}$ 7

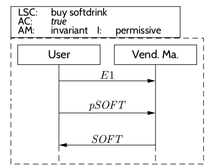
$\beta = \{x \mapsto c_1, y \mapsto c_2, z \mapsto c_3\}$

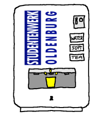
$\hookrightarrow$ w is accepted by $\mathscr{L}_1$

Note: Activation Condition

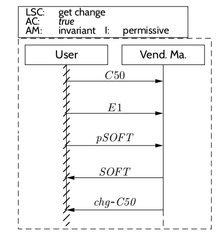


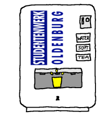
Existential LSC Example: Buy A Softdrink





Existential LSC Example: Get Change



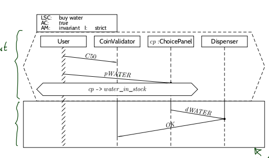


Live Sequence Charts — Precharts

Pre-Charts

pre-chart

main-chart



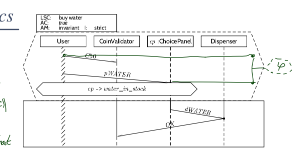
A **full LSC** $\mathscr{L} = (PC, MC, ac_0, am, \Theta_\mathscr{L})$ **actually** consist of (temperature of main-chart) hot

- **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

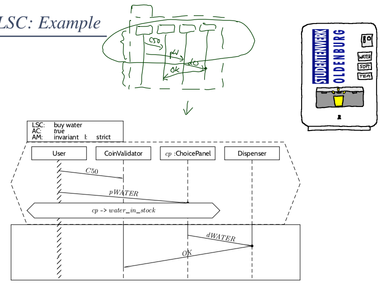
$w = w_0 \underbrace{w_1 \dots w_m}_{\in \mathcal{L}(\mathcal{B}(PC))} \overset{C_0^M}{w_{m+1}} \underbrace{w_{m+2}\, w_{m+3} \dots}_{\in \mathcal{L}(\mathcal{B}(MC))}$, $w_0 \models ac$

(∗) usually: reaching state of maximal cut of pre-chart

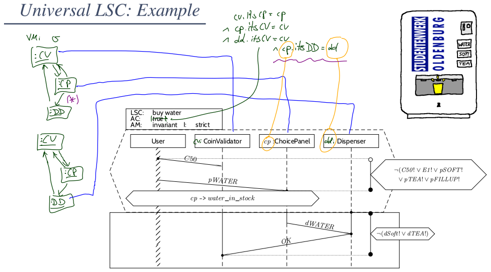


	$am =$ initial	$am =$ invariant
$\Theta_\mathscr{L} =$ cold	$\exists\, \beta\, \exists\, w \in W\, \exists\, m \in \mathbb{N}_0 \bullet$ $\wedge w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^1, \dots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\wedge\, w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$	$\exists\, \beta\, \exists\, w \in W\, \exists\, k < m \in \mathbb{N}_0 \bullet$ $\wedge w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^{k+1}, \dots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\wedge\, w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$
$\Theta_\mathscr{L} =$ hot	$\forall\, \beta\, \forall\, w \in W\, \forall\, m \in \mathbb{N}_0 \bullet$ $\wedge w^0 \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, \underbrace{w^1, \dots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))}$ (∗) $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\implies w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$	$\forall\, \beta\, \forall\, w \in W\, \forall\, k \leq m \in \mathbb{N}_0 \bullet$ $\wedge w^k \models_\beta ac \wedge \neg\psi_{exit}(C_0^P) \wedge \psi_{prog}(\emptyset, C_0^P)$ $\wedge\, w^{k+1}, \dots, w^m \in \mathcal{L}_\beta(\mathcal{B}(PC))$ $\wedge\, w^{m+1} \models_\beta \neg\psi_{exit}(C_0^M)$ $\implies w^{m+1} \models_\beta \psi_{prog}(\emptyset, C_0^M)$ $\wedge\, w/m+2 \in \mathcal{L}_\beta(\mathcal{B}(MC))$

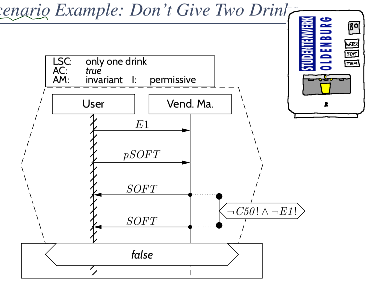
Universal LSC: Example



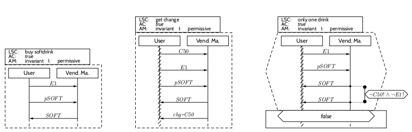
Universal LSC: Example



Forbidden Scenario Example: Don't Give Two Drinks

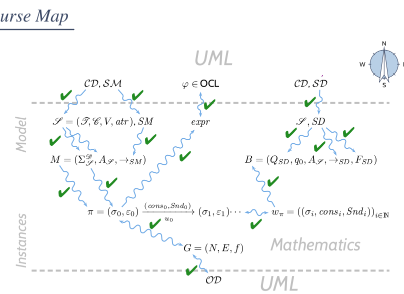


Note: Sequence Diagrams and (Acceptance) Test



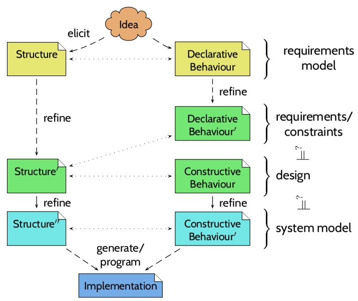
- **Existential** LSCs* may hint at **test-cases** for the **acceptance test**!
  (*: as well as (positive) scenarios in general, like use-cases)
- **Universal** LSCs (and negative/anti-scenarios) in general need **exhaustive analysis**!
  (Because they require that the software never ever exhibits the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

Course Map

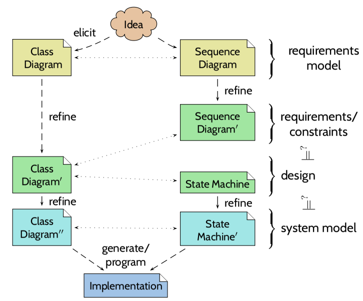


Model-Based/-Driven Software Engineering

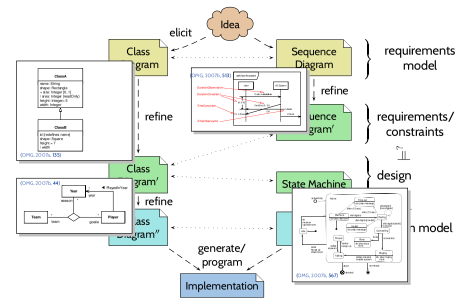
Model-Driven Software Engineering



Model-Driven Software Engineering with UML



Model-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. $((\pi^0, \dots, \pi^n) \downarrow \Sigma_{in}) \in In$ 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

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

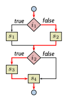
  Test case T achieves $p\,\%$ **branch coverage** if and only if $p = \min_{\pi \text{ execution of } T} cov_{cnd}(\pi)$.

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

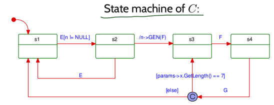
test suite coverage

In 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	i_2/% 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

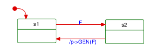
Model-Element Coverage

C → D
E, G

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.

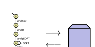
Excursion: Automatic Test Generation

Model-based Testing

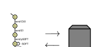
- Given a **set of test cases** passing for the model,
- and an **implementation of the model** (maybe hand-written).
- **Execute the test cases on the implementation** (or the final system).

  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

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