Software Design, Modelling and Analysis in UML

Lecture 10: Constructive Behaviour, State Machines Overview

2012-11-28

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

Albert-Ludwigs-Universität Freiburg, Germany

Contents & Goals

Last Lecture:

- Completed discussion of modelling **structure**.

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - Discuss the style of this class diagram.
  - What's the difference between reflective and constructive descriptions of behaviour?
  - What's the purpose of a behavioural model?
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
- **Content:**
  - Purposes of Behavioural Models
  - Constructive vs. Reflective
  - UML Core State Machines (first half)

Modelling Behaviour

Stocktaking...

Have: Means to model the **structure** of the system.

- Class diagrams graphically, concisely describe sets of system states.
- OCL expressions logically state constraints/invariants on system states.

Want: Means to model **behaviour** of the system.

- Means to describe how system states **evolve over time**, that is, to describe sets of **sequences**

$$\sigma_0, \sigma_1, \cdots \in \Sigma^\omega$$

not real-time, just counting steps here

of system states.

What Can Be Purposes of Behavioural Models?

(We will discuss this in more detail in Lecture 22.)

Example: Pre-Image
(the UML model is supposed to be the blue-print for a software system).

A description of behaviour could serve the following purposes:

- **Require** Behaviour.
  "This sequence of inserting money and requesting and getting water must be possible."
  (Otherwise the software for the vending machine is completely broken.)
- **Allow** Behaviour.
  "After (inserting money and choosing a drink), the drink is dispensed (if in stock)."
  (If the implementation insists on taking the money first, that's a fair choice.)
- **Forbid** Behaviour.
  "This sequence of getting both, a water and all money back, must not be possible." (Otherwise the software is broken.)

What Can Be Purposes of Behavioural Models?

(We will discuss this in more detail in Lecture 22.)

Example: Pre-Image **Image**
(the UML model is supposed to be the blue-print for a software system).

A description of behaviour could serve the following purposes:

- **Require** Behaviour. **"System definitely does this"**
  "This sequence of inserting money and requesting and getting water must be possible."
  (Otherwise the software for the vending machine is completely broken.)
- **Allow** Behaviour. **"System does subset of this"**
  "After (inserting money and choosing a drink) the drink is dispensed (if in stock)."
  (If the implementation insists on taking the money first, that's a fair choice.)
- **Forbid** Behaviour. **"System never does this"**
  "This sequence of getting both, a water and all money back, must not be possible." (Otherwise the software is broken.)

Note: the latter two are trivially satisfied by doing nothing...

Constructive vs. Reflective Descriptions

[Harel, 1997] proposes to distinguish constructive and reflective descriptions:

- *"A language is* **constructive** *if it contributes to the dynamic semantics of the model. That is, its constructs contain information needed in executing the model or in translating it into executable code."*
  A constructive description tells **how** things are computed (which can then be desired or undesired).
- *"Other languages are* **reflective** *or* **assertive**, *and can be used by the system modeler to capture parts of the thinking that go into building the model – behavior included –, to derive and present views of the model, statically or during execution, or to set constraints on behavior in preparation for verification."*
  A reflective description tells **what** shall or shall not be computed.

Note: No sharp boundaries!

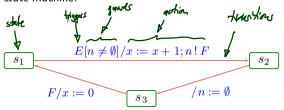
Constructive UML

UML provides two visual formalisms for constructive description of behaviours:

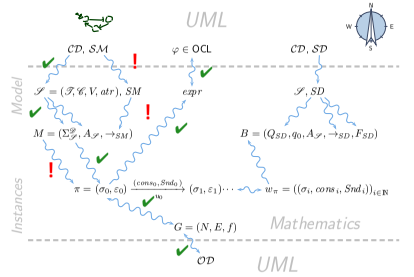
- **Activity Diagrams**
- **State-Machine Diagrams**

We (exemplary) focus on State-Machines because

- somehow "practice proven" (in different flavours),
- prevalent in embedded systems community,
- indicated useful by [Dobing and Parsons, 2006] survey, and
- Activity Diagram's intuition changed (between UML 1.x and 2.x) from transition-system-like to petri-net-like...
- Example state machine:

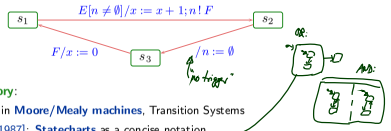


Course Map



UML State Machines: Overview

UML State Machines



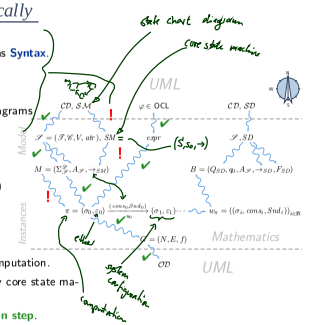
Brief History:

- Rooted in **Moore/Mealy machines**, Transition Systems
- [Harel, 1987]: **Statecharts** as a concise notation, introduces in particular hierarchical states.
- Manifest in tool Statemate [Harel et al., 1990] (simulation, code-generation); nowadays also in **Matlab/Simulink**, etc.
- From UML 1.x on: **State Machines**
  (not the official name, but understood: UML-Statecharts)
- Late 1990's: tool Rhapsody with code-generation for state machines.

Note: there is a common core, but each dialect interprets some constructs subtly different [Crane and Dingel, 2007]. *(Would be too easy otherwise...)*

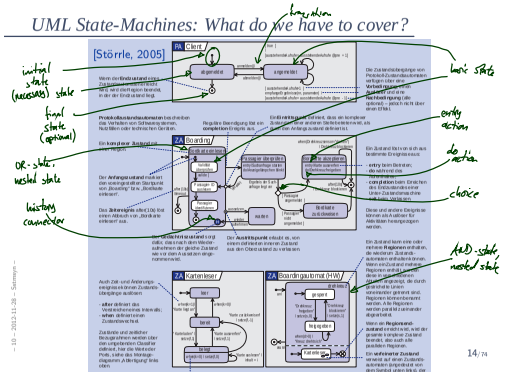
Roadmap: Chronologically

(i) What do we (have to) cover?
UML State Machine Diagrams **Syntax**.
(ii) Def.: Signature with **signals**.
(iii) Def.: **Core state machine**.
(iv) Map UML State Machine Diagrams to core state machines.
Semantics:
The Basic Causality Model
(v) Def.: **Ether** (aka. event pool)
(vi) Def.: **System configuration**.
(vii) Def.: **Event**.
(viii) Def.: **Transformer**.
(ix) Def.: **Transition system**, computation.
(x) Transition relation induced by core state machine.
(xi) Def.: **step**, **run-to-completion step**.
(xii) Later: Hierarchical state machines.

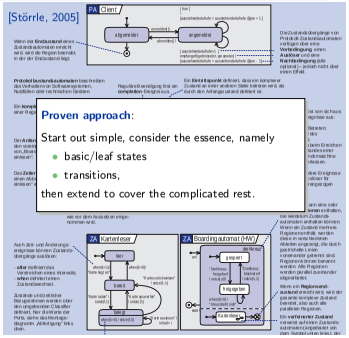


UML State Machines: Syntax

UML State-Machines: What do we have to cover?



UML State-Machines: What do we have to cover?



Signature With Signals

Definition. A tuple

$$\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr, \mathcal{E}) \quad \mathcal{E} \text{ a set of signals,}$$

is called signature (with signals) if and only if

$$(\mathscr{T}, \mathscr{C}, V, atr)$$

is a signature (as before).

Note: Thus conceptually, **a signal is a class** and can have attributes of plain type and associations.

Core State Machine

Definition.
A core state machine over signature $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr, \mathcal{E})$ is a tuple

$$\mathcal{SM} = (S, s_0, \rightarrow)$$

where

- S is a non-empty, finite set of **(basic) states**,
- $s_0 \in S$ is an **initial state**,
- and

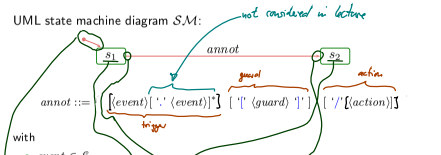
$$\rightarrow \subseteq S \times (\mathcal{E}^* \cup \{\_\}) \times Expr_{\mathscr{S}} \times Act_{\mathscr{S}} \times S$$

is a labelled transition relation.

We assume a set $Expr_{\mathscr{S}}$ of boolean expressions over $\mathscr{S}$ (for instance OCL, may be something else) and a set $Act_{\mathscr{S}}$ of **actions**.

From UML to Core State Machines: By Example

UML state machine diagram $\mathcal{SM}$:



with

- $event \in \mathcal{E}$,
- $guard \in Expr_{\mathscr{S}}$
- $action \in Act_{\mathscr{S}}$

(default: *true*, assumed to be in $Expr_{\mathscr{S}}$)
(default: skip, assumed to be in $Act_{\mathscr{S}}$)

maps to

$$\mathcal{SM}(\mathcal{SM}) = (\underbrace{\{s_1, s_2\}}_{S}, \underbrace{s_1}_{s_0}, \underbrace{(s_1, event, guard, action, s_2)}_{\rightarrow})$$

Annotations and Defaults in the Standard

Reconsider the syntax of transition annotations:

$$annot ::= [\langle event\rangle[\text{ ','} \langle event\rangle]^*][\text{ '['} \langle guard\rangle \text{ ']'}][\text{ '/'}[\langle action\rangle]]$$

and let's play a bit with the defaults:

	$\rightsquigarrow$	$\_$, true, skip
/	$\rightsquigarrow$	$\_$, true, skip
E /	$\rightsquigarrow$	E, true, skip
/ act	$\rightsquigarrow$	$\_$, true, act
E / act	$\rightsquigarrow$	E, true, act
E [g] / act	$\rightsquigarrow$	E, g, act

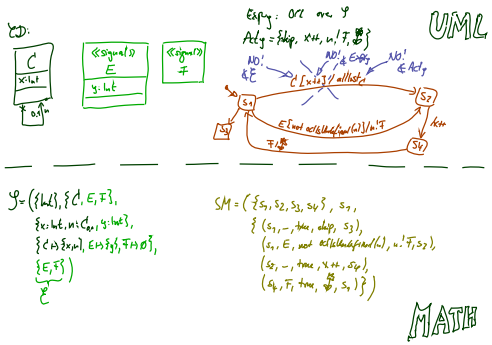
In the standard, the syntax is even more elaborate:

- $E(v)$ — when consuming E in object u, attribute v of u is assigned the corresponding attribute of E.
- $E(v:\tau)$ — similar, but v is a local variable, scope is the transition

State-Machines belong to Classes, An Execution by Objects

- In the following, we assume that a UML models consists of a set $\mathscr{CD}$ of class diagrams and a set $\mathscr{SM}$ of **state chart diagrams** (each comprising one **state machines** $\mathcal{SM}$).
- Furthermore, we assume that each state machine $\mathcal{SM} \in \mathscr{SM}$ is **associated with a class** $C_{\mathcal{SM}} \in \mathscr{C}(\mathscr{S})$.
- For simplicity, we even assume a bijection, i.e. we assume that each class $C \in \mathscr{C}(\mathscr{S})$ has a state machine $\mathcal{SM}_C$ and that its class $C_{\mathcal{SM}_C}$ is C.
  If not explicitly given, then this one:
  $$\mathcal{SM}_0 := (\{s_0\}, s_0, \{(s_0, \_, true, \mathrm{skip}, s_0)\}).$$
  We'll see later that, semantically, this choice does no harm.
- **Intuition 1**: $\mathcal{SM}_C$ describes the behaviour of **the instances** of class C.
  Intuition 2: Each instance of class C executes $\mathcal{SM}_C$ but with a local "program counter".

Note: we don't consider **multiple state machines** per class.
Because later (when we have AND-states) we'll see that this case can be viewed as a single state machine with as many AND-states.



References

[Crane and Dingel, 2007] Crane, M. L. and Dingel, J. (2007). UML vs. classical vs. rhapsody statecharts: not all models are created equal. *Software and Systems Modeling*, 6(4):415–435.

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

[Harel, 1987] Harel, D. (1987). Statecharts: A visual formalism for complex systems. *Science of Computer Programming*, 8(3):231–274.

[Harel, 1997] Harel, D. (1997). Some thoughts on statecharts, 13 years later. In Grumberg, O., editor, *CAV*, volume 1254 of *LNCS*, pages 226–231. Springer-Verlag.

[Harel and Gery, 1997] Harel, D. and Gery, E. (1997). Executable object modeling with statecharts. *IEEE Computer*, 30(7):31–42.

[Harel et al., 1990] Harel, D., Lachover, H., et al. (1990). Statemate: A working environment for the development of complex reactive systems. *IEEE Transactions on Software Engineering*, 16(4):403–414.

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

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

References