Software Design, Modelling and Analysis in UML

Lecture ~~09~~: Constructive Behaviour, State Machines Overview

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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**

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

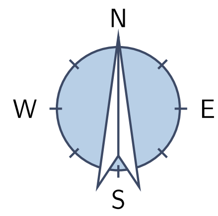
not real-time, discrete time

of system states.

Course Map

later:

UML



$\mathcal{CD}$, $\mathcal{SM}$ ① **!**

$\varphi \in$ OCL

$\mathcal{CD}$, $\mathcal{SD}$

Model

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

$expr$

$\mathscr{S}$, SD

!

$(\Sigma_{\mathscr{S}}^{\mathscr{D}}, A_{\mathscr{S}}, \to_{SM}) = M$

$B = (Q_{SD}, q_0, A_{\mathscr{S}}, \to_{SD}, F_{SD})$

!

Instances

$(\sigma_0, \varepsilon_0) \xrightarrow{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \xrightarrow{(cons_1, Snd_1)} \ldots$

$G = (N, E, f)$

Mathematics

$\mathcal{OD}$

UML

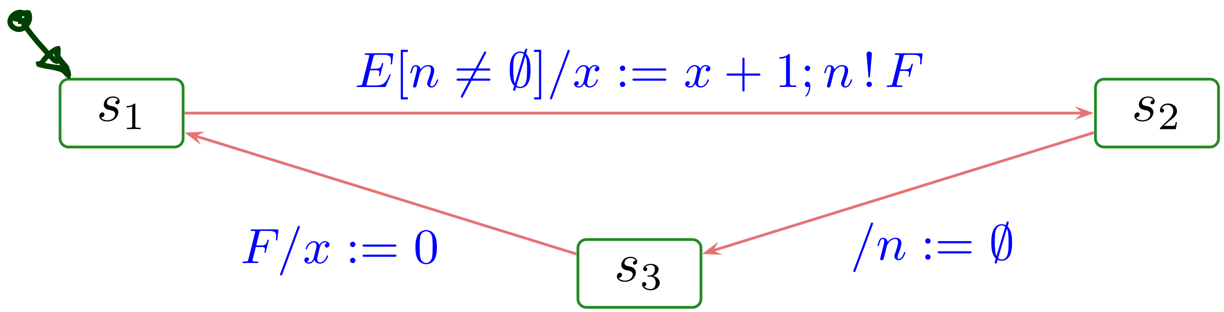
Constructive UML

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:

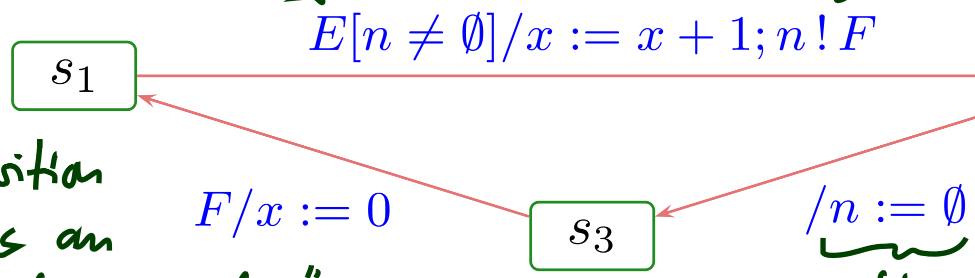


UML State Machines: Overview

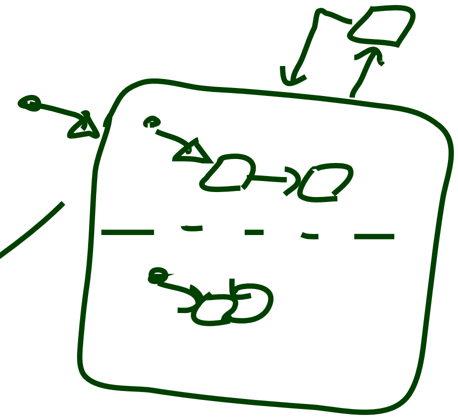
UML State Machines

“we” can take this transition if there is an E ready for us and ...”

“send an F to object denoted by link n”



action, has corresponding transformer



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**.

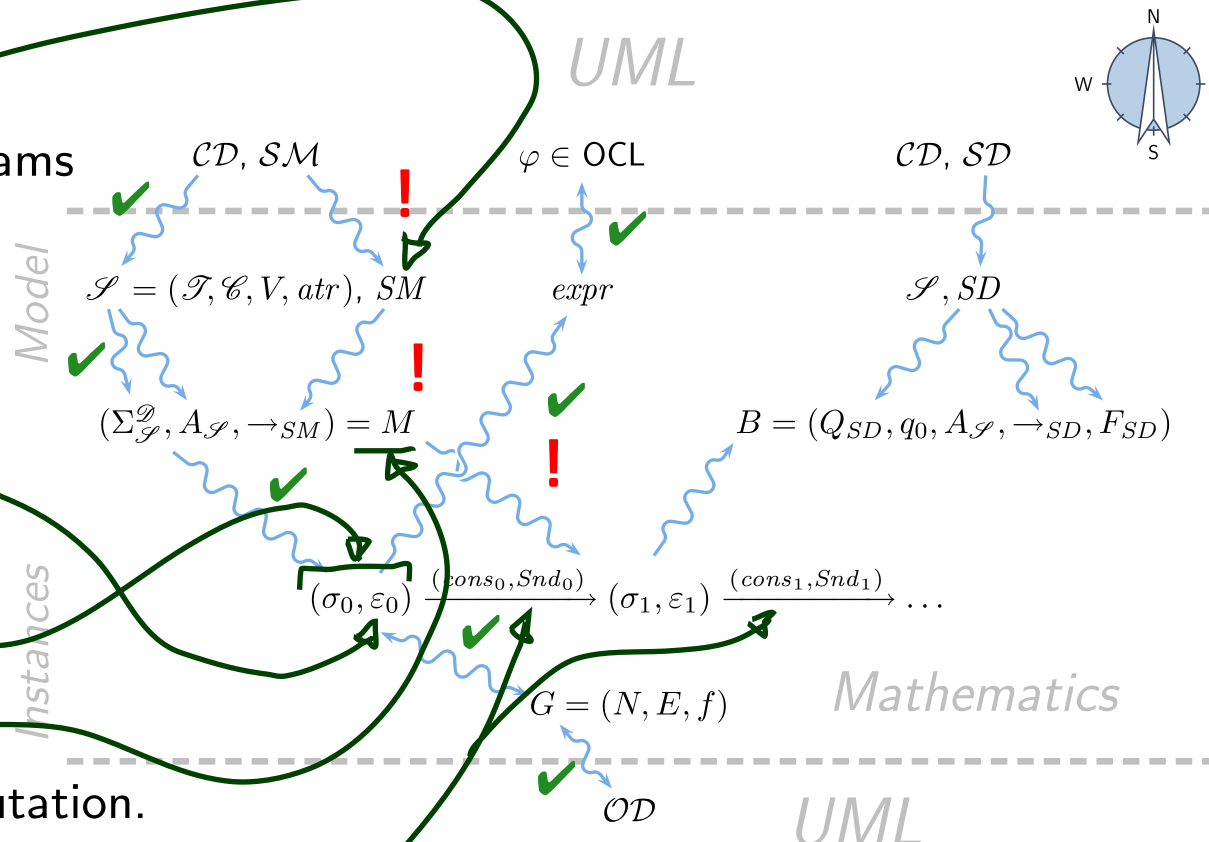
(viii) Def.: **Transformer**.

(ix) Def.: **Transition system**, computation.

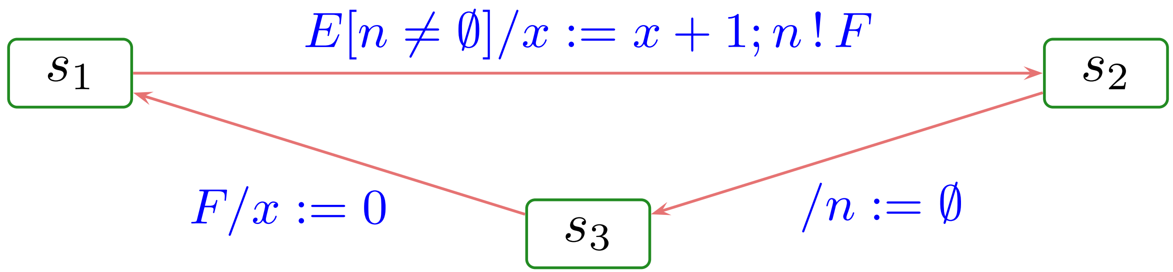
(x) Transition relation induced by core state machine.

(xi) Def.: **step**, **run-to-completion step**.

(xii) Later: Hierarchical state machines.



UML State Machines



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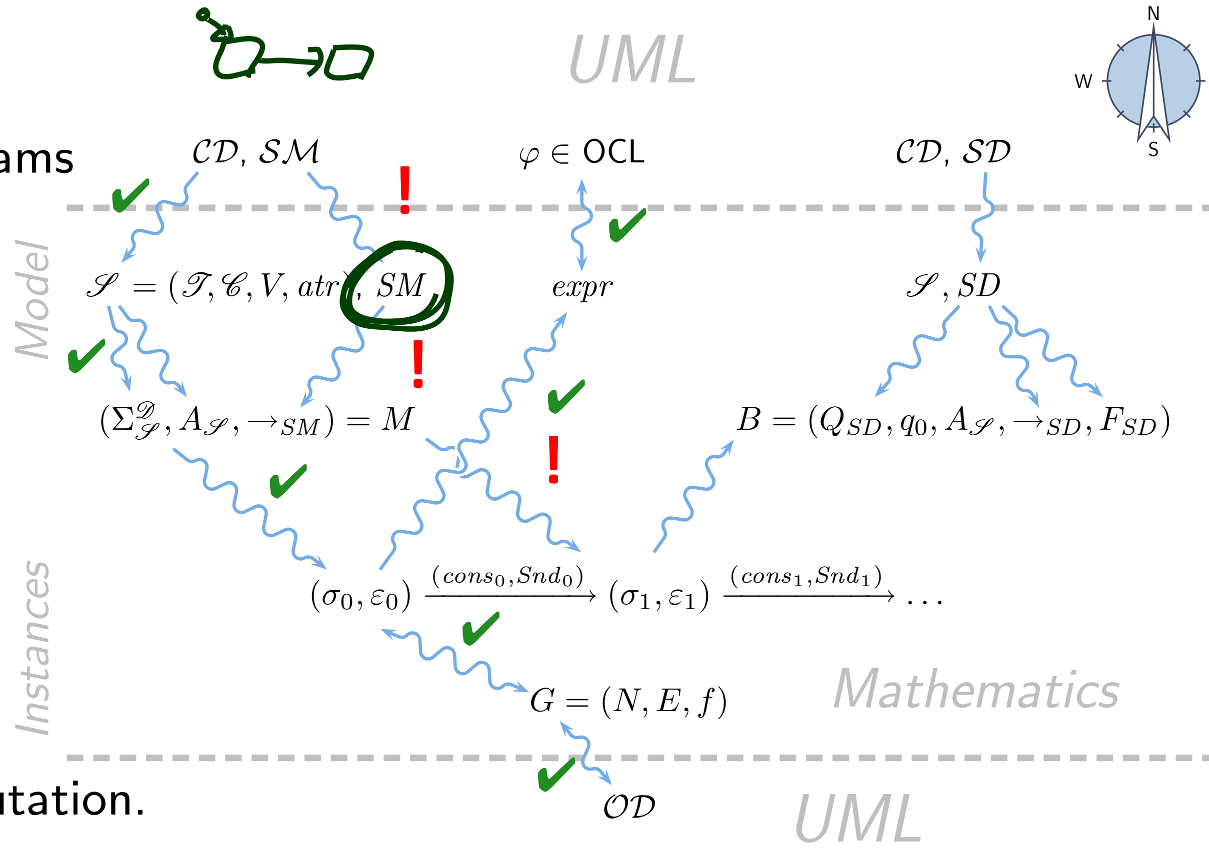
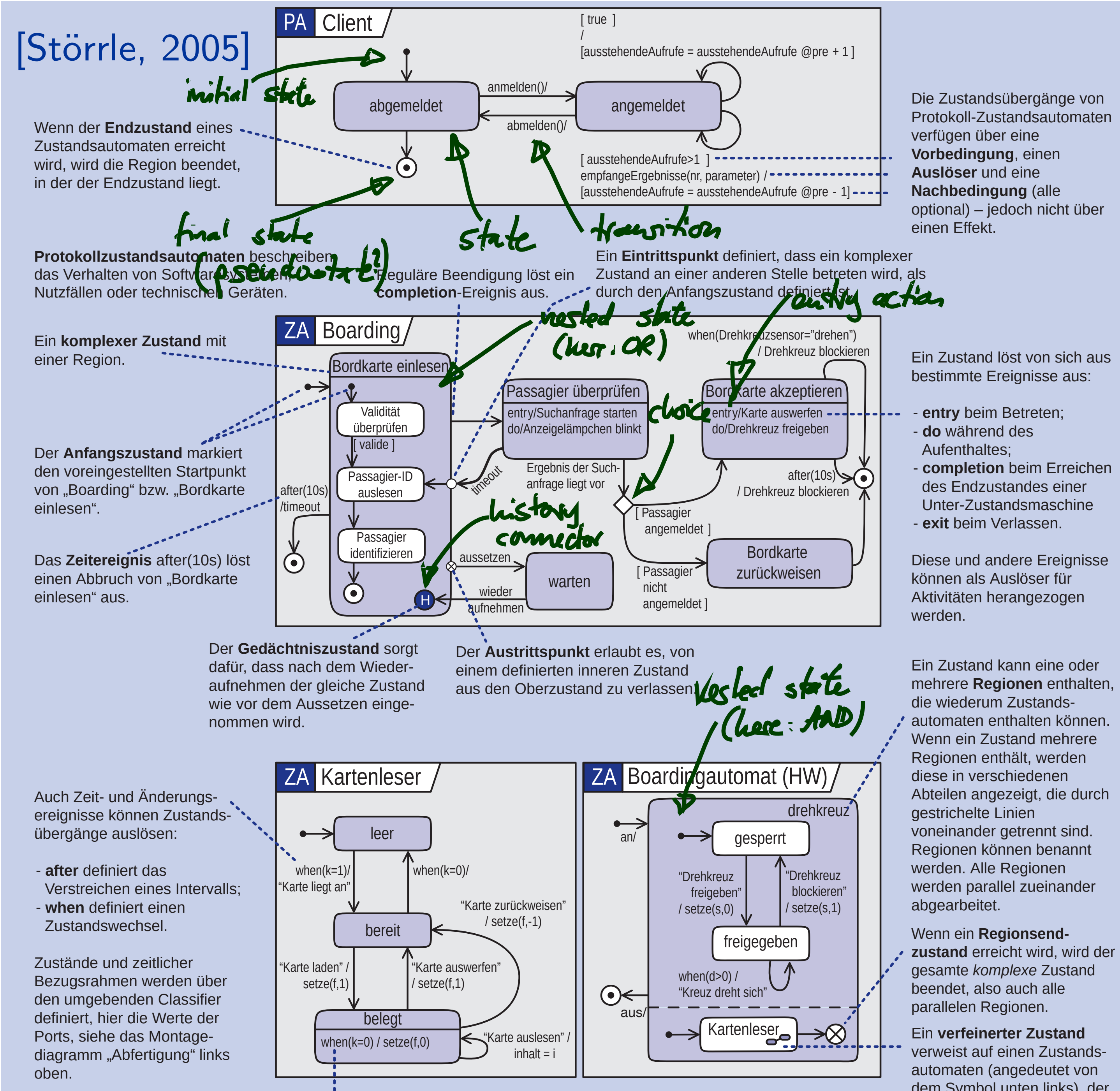
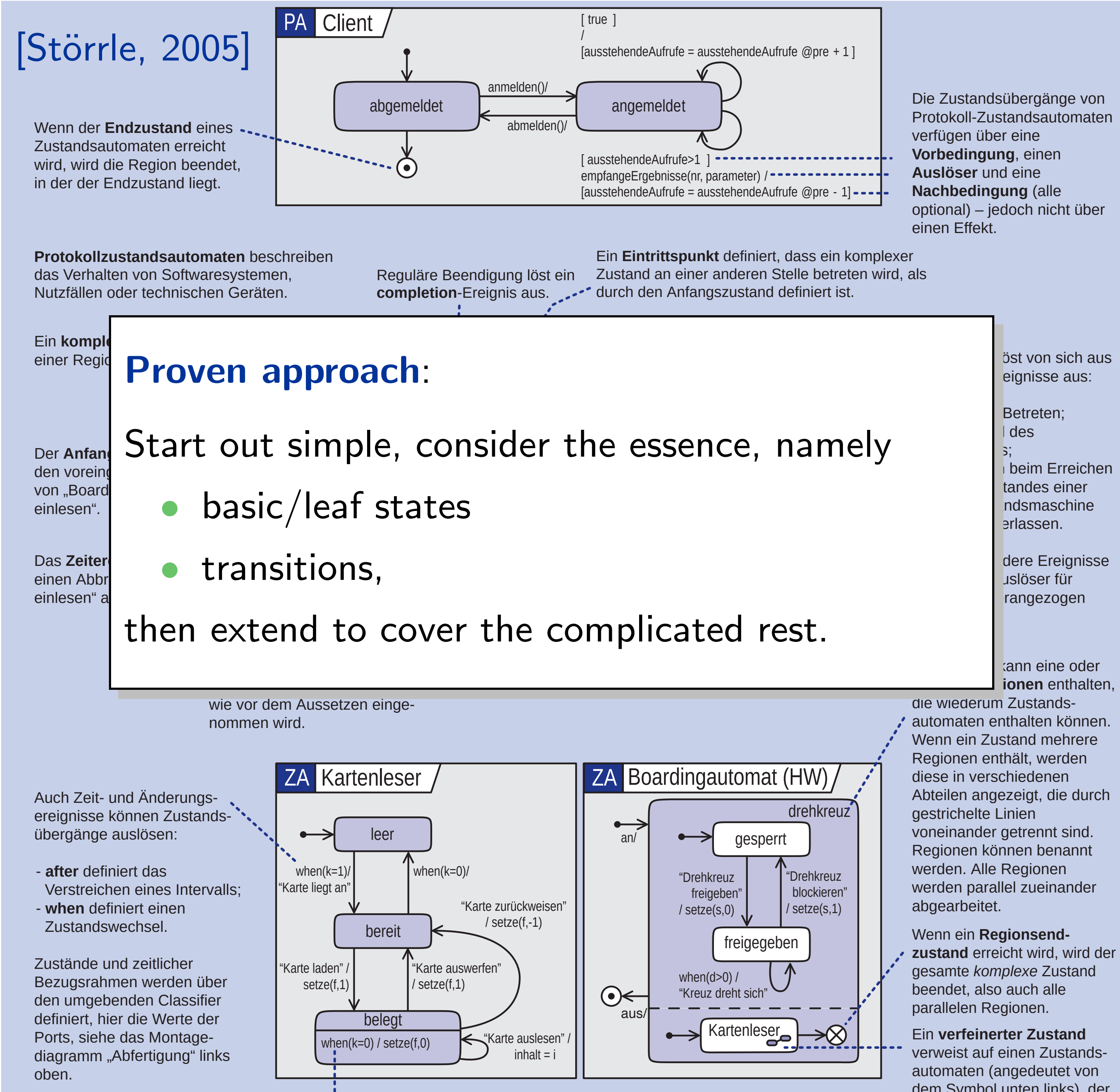


UML State Machines: Syntax

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



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



Proven approach:

Start out simple, consider the essence, namely

- basic/leaf states
- transitions,

then extend to cover the complicated rest.

Signature With Signals

new

Definition. A tuple

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

is called signature (with signals) if and only if

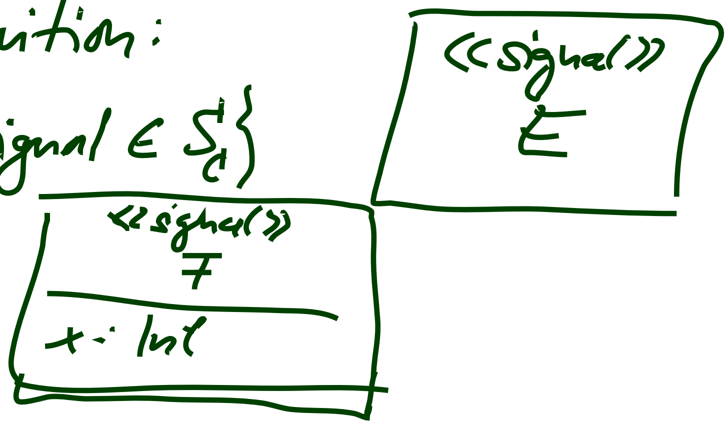
$$(\mathscr{T}, \mathscr{C} \cup \mathscr{E}, V, atr)$$

is a signature (as before).

WE USE THIS

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

example:



Alternative (maybe even better) definition:

$$\mathscr{E}(\mathscr{S}) = \{\langle C, S_C, a, t\rangle \in \mathscr{C} \mid signal \in S_C\}$$

disjoint union: _ should not already be in $\mathscr{E}$ (otherwise rename first)

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

$$M = (S, s_0, \rightarrow)$$

where

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

signals in $\mathscr{S}$

source state   dest. state

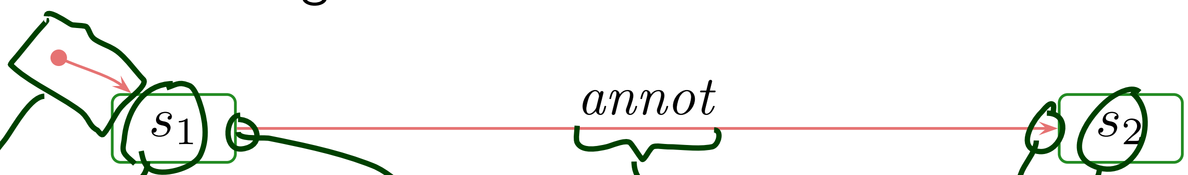
$$\rightarrow \subseteq S \times \underbrace{(\mathscr{E} \dot\cup \{\_\})}_{\text{trigger}} \times \underbrace{Expr_{\mathscr{S}}}_{\text{guard}} \times \underbrace{Act_{\mathscr{S}}}_{\text{action}} \times S$$

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 $\mathcal{SM}$:



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

with

- $event \in \mathscr{E}$, (default: — if no trigger)
- $guard \in Expr_{\mathscr{S}}$ (default: *true*, assumed to be in $Expr_{\mathscr{S}}$)
- $action \in Act_{\mathscr{S}}$ (default: skip, assumed to be in $Act_{\mathscr{S}}$)

maps to

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

initial state

Annotations and Defaults in the Standard

Reconsider the syntax of transition annotations:

$$annot ::= \Big[\ \big[\langle event\rangle[\ \text{`.'}\ \langle event\rangle]^*\big]\ \ [\ \text{`['}\ \langle guard\rangle\ \text{`]'}\ ]\ \ \ [\ \text{`/'}[\langle action\rangle]\ ]\ \Big]$$

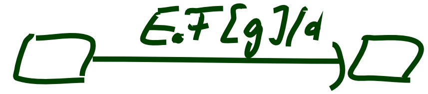
$s_1 \xrightarrow{annot} s_2$

and let's play a bit with the defaults:

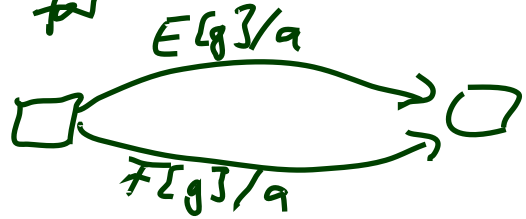
(empty annot:)	$\rightsquigarrow$	$(s_1, \_, true, skip, s_2)$
$/$	$\rightsquigarrow$	$(s_1, \_, true, skip, s_2)$
$E\ /$	$\rightsquigarrow$	$(s_1, E, true, skip, s_2)$
$/\ act$	$\rightsquigarrow$	$(s_1, \_, true, act, s_2)$
$E\ /\ act$	$\rightsquigarrow$	$(s_1, E, true, act, s_2)$
$E[e]/act$	$\rightsquigarrow$	(s_1, E, e, act, s_2)

In the standard, the syntax is even more elaborate: (we don't discuss those)

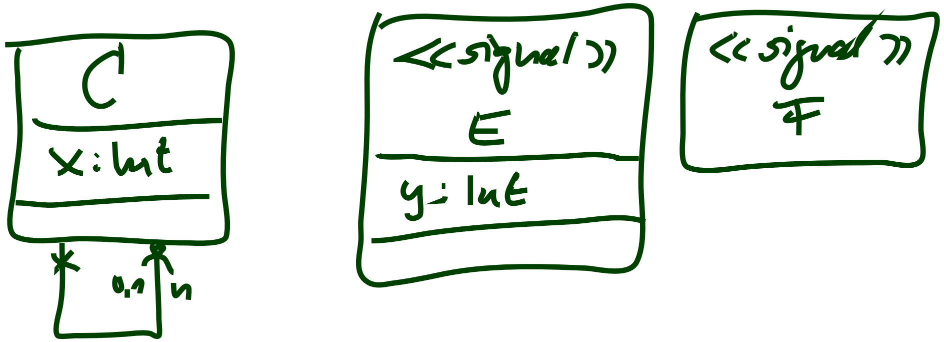
- $E(v)$ — when consuming E in object u, attribute v of u is assigned the corresponding attribute of $E \in \mathcal{E}$.
- $E(v : \tau)$ — similar, but v is a local variable, scope is the transition

- 

we view as an abbrev. for



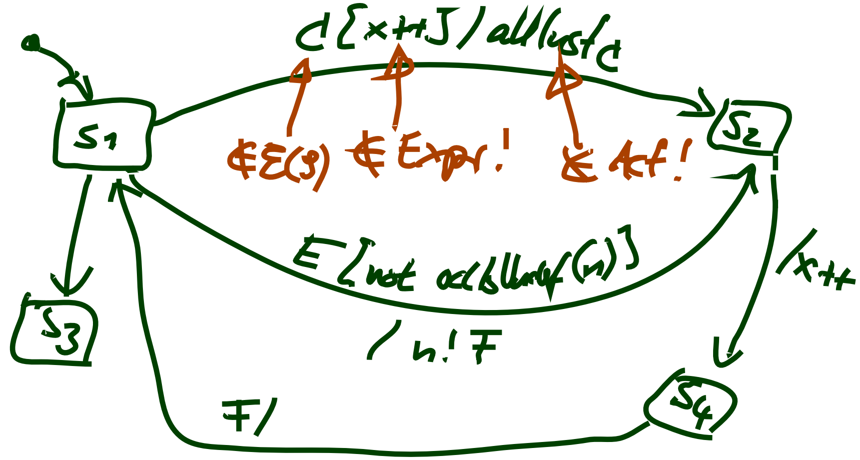
CD:



$Expr_{\mathscr{S}}$: OCL over $\mathscr{S}$

$Act_{\mathscr{S}} : \{ skip,\ x{+}{+},\ n!F \}$

UML

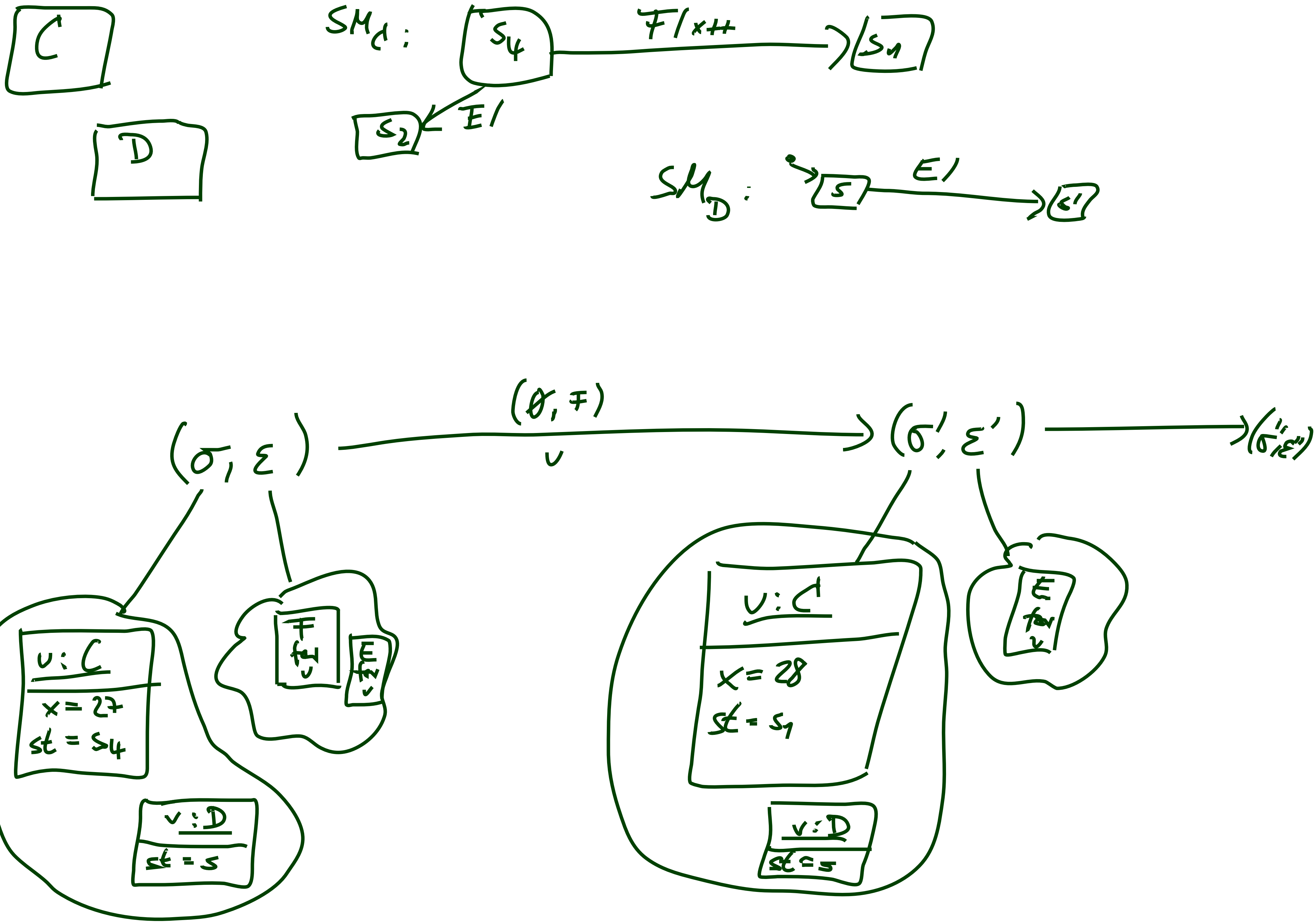


$$\mathscr{S} = \Big(\{Int\},\ \{\langle C, \emptyset, 0, 0\rangle, \langle E, \{signal\}, 0, 0\rangle, \langle F, \{signal\}, 0, 0\rangle\},\ \{x : Int,\ y : Int,\ n : C_{0,1}\},\ \{ C \mapsto \{x, n\},\ E \mapsto \{y\} \} \Big)$$

$$\mathscr{E}(\mathscr{S}) = \{E, F\}$$

$$M = \Big(\{s_1, s_2, s_3, s_4\},\ s_1,\ \{ (s_1, \_, true, skip, s_3),\ (s_1, E, not\ oclIsUndef(n), n!F, s_2),\ \ldots \} \Big)$$

MATH



C
D
SM_C :
s4
F/x++
s1
E/
s2
SM_D :
s
E/
s'
(σ, ε)
(σ, F)
u
(σ', ε')
(σ'', ε'')
u : C
x = 27
st = s4
v : D
st = s
F for u
E for v
u : C
x = 28
st = s1
v : D
st = s
E for v

State-Machines belong to Classes

- 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 each that each state machine $\mathcal{SM} \in \mathscr{SM}$ is **associated with a class** $C_{\mathcal{SM}} \in \mathscr{C}(\mathscr{S})$. $\setminus \mathscr{E}(\mathscr{S})$

- For simplicity, we even assume a bijection, i.e. we assume that each class $C \in \mathscr{C}(\mathscr{S})$ $\setminus \mathscr{E}(\mathscr{S})$ has a state machine $\mathcal{SM}_C$ and that its class $C_{\mathcal{SM}_C}$ is C.

  If not explicitly given, then this one:

$$\mathcal{SM}_0 := (\{s_0\}, s_0, (s_0, \_, \mathit{true}, \mathtt{skip}, s_0)).$$

  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 $\mathcal{SM}_C$.
  "a copy of", "an instance of"

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

References

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