Software Design, Modelling and Analysis in UML

Lecture 10: Modelling Behaviour

2016-12-01

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Content

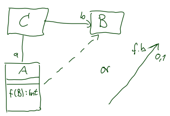
- What makes a class diagram a good class diagram?
  - The Elements of UML 2.0 Style Cont'd
  - Example: Game Architecture
- Purposes of **Behavioural Models**
- **Constructive Behavioural Models in UML**
- UML **State Machines**
  - Brief History
  - **Syntax**
  - **The Basic Causality Model**

Design Guidelines for (Class) Diagram

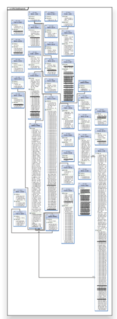
(partly following Ambler (2005))

Class Diagram Guidelines Ambler (2005)

- **5.3 Relationships**
  - 112. Model Relationships Horizontally
  - 115. Model a Dependency When the Relationship is Transitory
  - 117. Always Indicate the Multiplicity
  - 118. Avoid Multiplicity "∗"
  - 119. Replace Relationship Lines with Attribute Types



Some Example Class Diagrams



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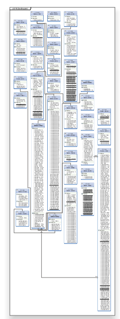

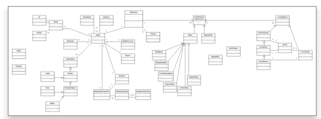

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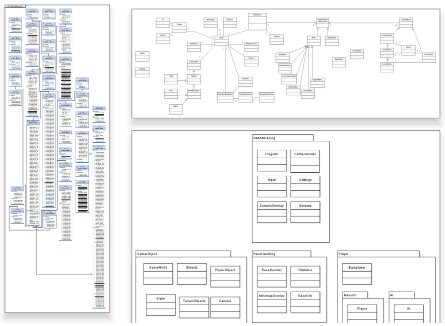
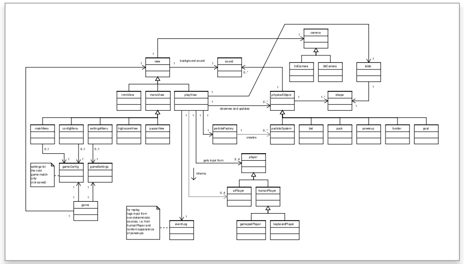


More Example Class Diagrams



Example: Modelling Games

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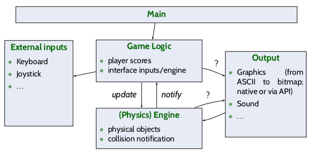
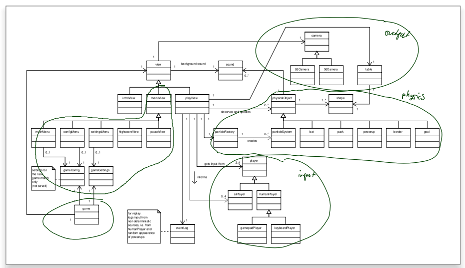


- Adept readers try to see/find/match the common architecture if they know that a model is from a particular domain.
- We can do those readers a favour by grouping/positioning things in the diagram so that seeing/finding/matching is easy.

Example Re-Considered



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**

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

of **system states**.

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

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- **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...

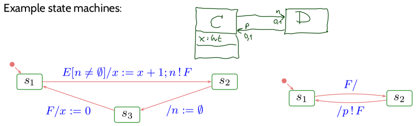
Constructive Behaviour in UML

UML provides two visual formalisms for constructive description of behaviours:

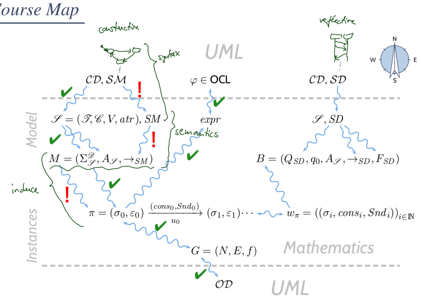
- **Activity Diagrams**
- **State-Machine Diagrams**

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 machines:

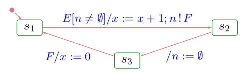


Course Map



UML State Machines: Overview

UML State Machines



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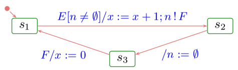

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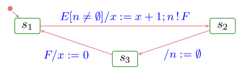

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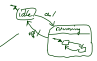

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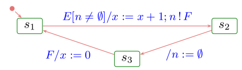

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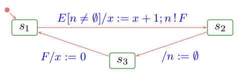

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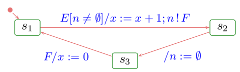

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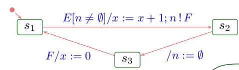

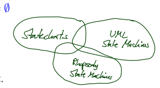

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Note: there is a common core, but each dialect interprets some constructs subtly different Crane and Dingel (2007). *(Would be too easy otherwise...)*

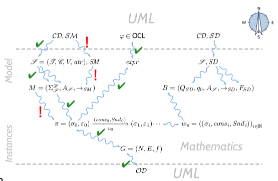
Roadmap: Chronologically

Syntax:

(i) UML State Machine Diagrams.
(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

Signature With Signals

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

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

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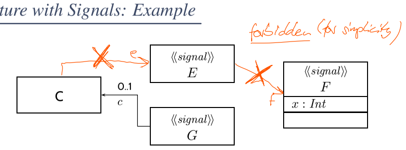
Note: Thus conceptually, **a signal is a class** and can have attributes of plain type, and participate in associations.

Signature with Signals: Example



$\mathscr{S} = (\{Int\}, \{C\}, \{x : Int, c : C_{0,1}\},$
$\{C \mapsto \emptyset, E \mapsto \emptyset, G \mapsto \{c\}, F \mapsto \{x\}\},$
$\{E, F, G\})$

Core State Machine

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

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

where

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

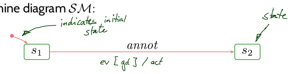
$$\to \subseteq \overset{\text{source state}}{S} \times \underbrace{(\mathscr{E} \,\dot\cup\, \{\_\})}_{\text{trigger}} \times \underbrace{Expr_{\mathscr{S}}}_{\text{guard}} \times \underbrace{Act_{\mathscr{S}}}_{\text{action}} \times \overset{\text{destination state}}{S}$$

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 $\mathcal{SM}$:



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

with

- $event \in \mathscr{E}$,
- $guard \in Expr_{\mathscr{S}}$ (**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

$$M(\mathcal{SM}) = \big(\underbrace{\{s_1, s_2\}}_{=S}, \underbrace{\{s_1\}}_{=s_0} \underbrace{\{(s_1, ev, gd, act, s_2)\}}_{=\rightarrow}\big)$$

Abbreviations and Defaults in the Standard

Reconsider the syntax of transition annotations:

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What if things are missing?

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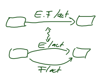

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In the standard, the syntax is even more elaborate:

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

State-Machines belong to Classes

In the following, we assume that

- a UML model consists of a set $\mathscr{CD}$ of class diagrams and a set $\mathscr{SM}$ of **state chart diagrams** (each comprising one **state machine** $\mathcal{SM}$).
- each state machine $\mathcal{SM} \in \mathscr{SM}$ is **associated with a class** $C_{\mathcal{SM}} \in \mathscr{C}(\mathscr{S})$.

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  If not explicitly given, then this one:

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

  

  We will see later that this choice does no harm semantically.

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Note: we don't consider **multiple state machines** per class. We will see later that this case can be viewed as a single state machine with as many AND-states.

Rhapsody Demo II

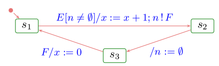
Towards UML State Machines Semantics: The Basic Causality Model

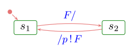
6.2.3 The Basic Causality Model (OMG, 2011b, 11)

*"'**Causality model**' is a specification of how things happen at run time [...].*

The causality model is quite straightforward:

- *Objects respond to **messages** that are generated by objects executing communication actions.*
- *When these messages arrive, the receiving objects eventually respond by executing the behavior that is **matched** to that message.*
- *The dispatching method by which a particular behavior is associated with a given message depends on the higher-level formalism used and is not defined in the UML specification*
  (i.e., it is a semantic variation point).





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*The causality model also **subsumes** behaviors **invoking each other** and passing information to each other through arguments to parameters of the invoked behavior, [...].*

This purely 'procedural' or 'process' model can be used by itself or in conjunction with the object-oriented model of the previous example."

15.3.12 StateMachine (OMG, 2011b, 574)

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- The semantics of event occurrence processing is based on the **run-to- completion assumption**, interpreted as **run-to-completion processing**.
- **Run-to-completion processing** means that an event [...] can only be taken from the pool and dispatched if the processing of the previous [...] is fully completed.

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- The **run-to-completion assumption** simplifies the transition function of the StM, since concurrency conflicts are avoided during the processing of event, allowing the StM to safely complete its **run-to-completion step**.

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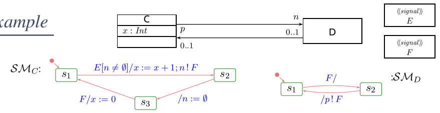
- The order of dequeuing is **not defined**, leaving open the possibility of modeling different priority-based schemes.
- Run-to-completion may be implemented in **various ways**. [...]

Example



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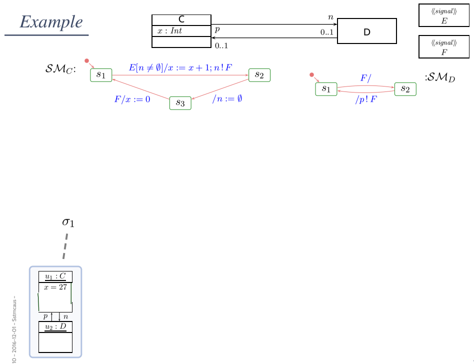

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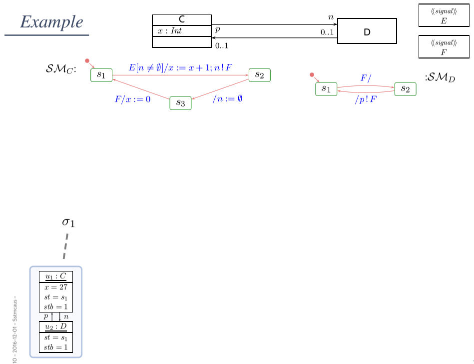

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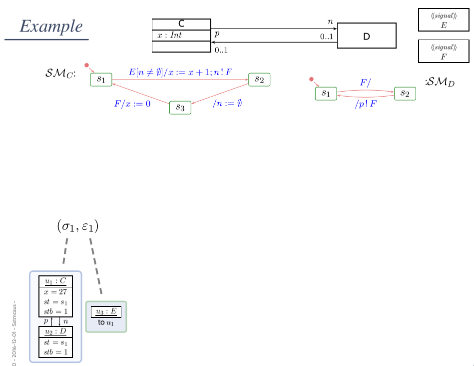

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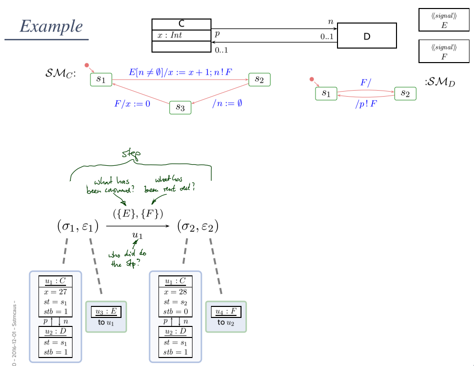

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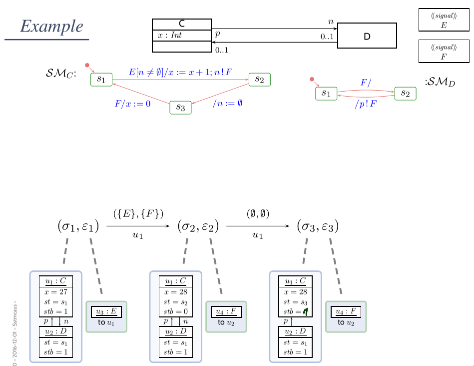

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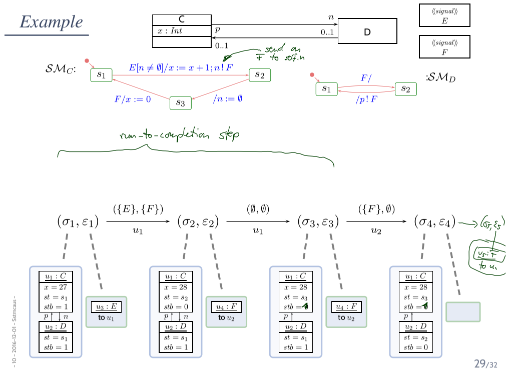

Tell Them What You've Told Them...

- Ambler (2005): **The Elements of UML 2.0 Style**.
- One rule-of-thumb:
  if there is a standard architecture, make it easy to recognise how the standard architecture is concretised.

- Behaviour can be modelled using UML **State Machines**.
- UML **State Machines** are inspired by Harel's **Statecharts**.
- State Machines **belong to** Classes.
- State machine behaviour follows the **Basic Causality Model** of UML, in particular
  - Objects process **events**.
  - Objects can be **stable** or not.
  - Events are processed in a **run-to-completion step**, processing only starts when being **stable**.

References

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