# *Software Design, Modelling and Analysis in UML*

# *Lecture 10: Modelling Behaviour*

*2016-12-01*

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Albert-Ludwigs-Universität Freiburg, Germany



## *Content*

## *Design Guidelines for (Class) Diagram*

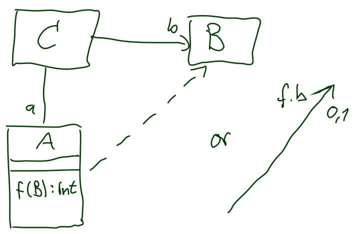
*(partly following Ambler (2005))*



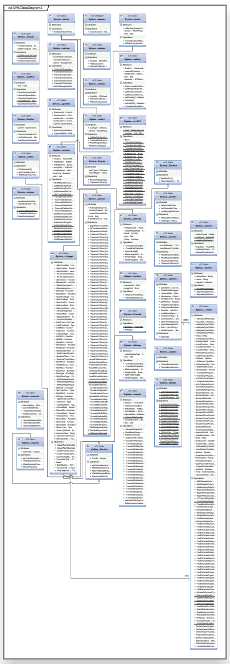


## *Class Diagram Guidelines Ambler (2005)*

- **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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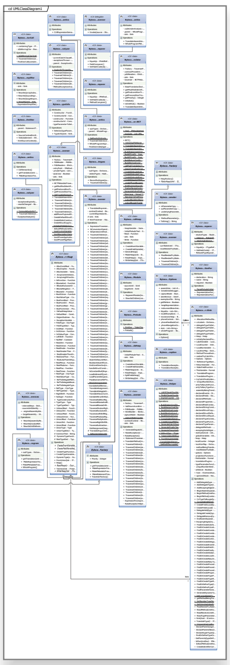

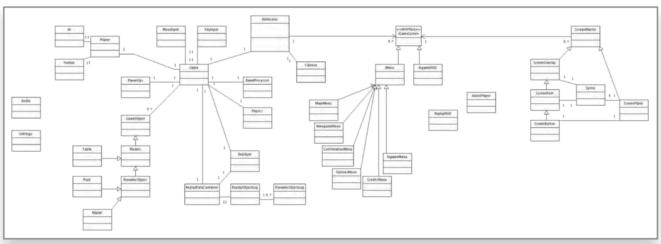

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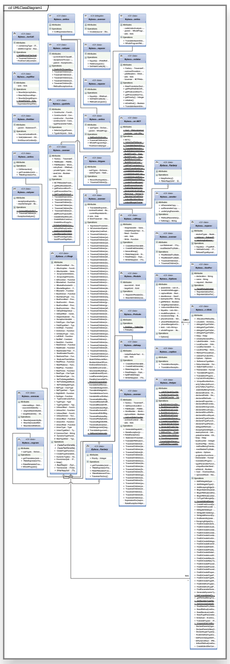

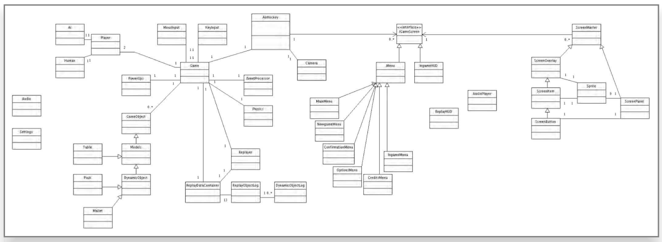

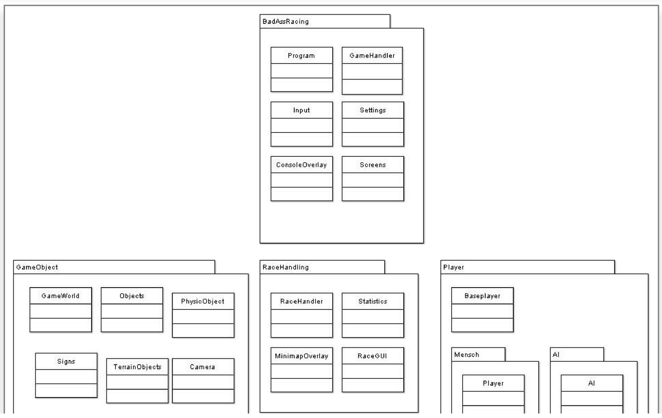




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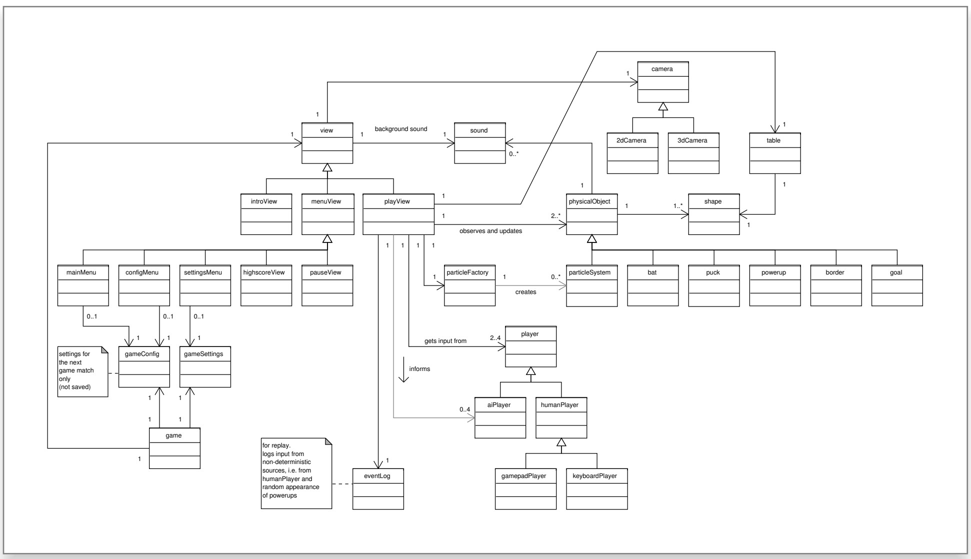

## *Example: Modelling Games*





## *Modelling Structure: Common Architectures*

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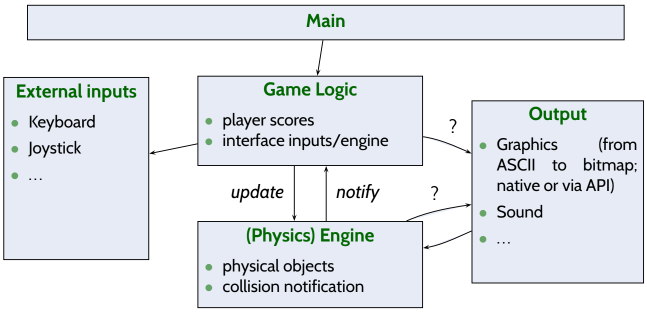
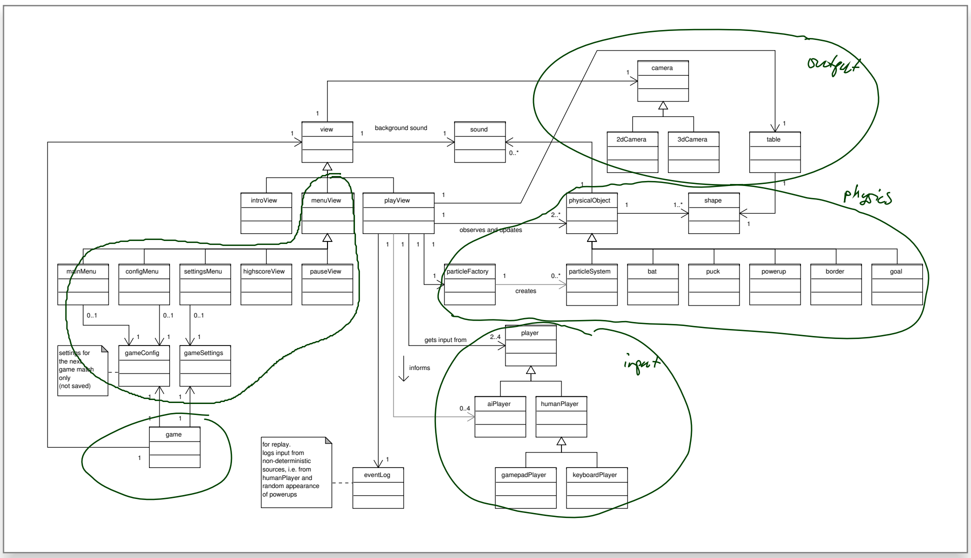



- Adept readers try to see/find/match the common architecture if they know that a model is from a particular domain.
- We can do those readers a favour by grouping/positioning things in the diagram so that seeing/finding/matching is easy.



# *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**.

## *What Can Be Purposes of Behavioural Models?*

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- **Require** Behaviour. **"System definitely does this"**
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- **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...

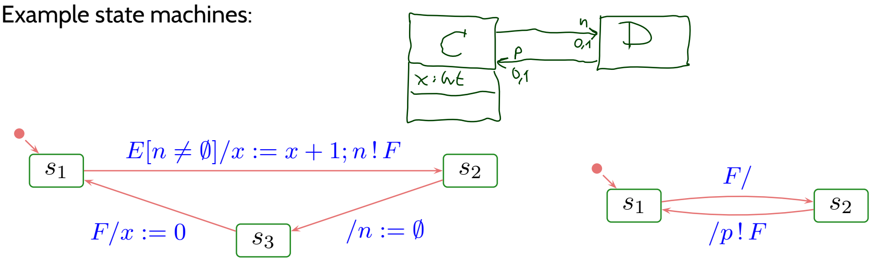
## *Constructive Behaviour in UML*

UML provides two visual formalisms for constructive description of behaviours:

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

We (exemplary) focus on State-Machines because

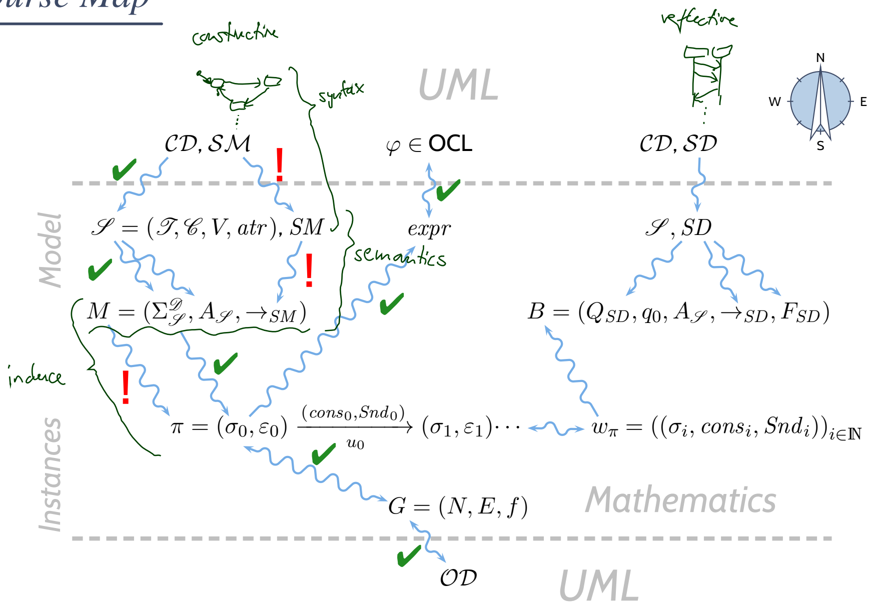
- somehow "practice proven" (in different flavours),
- prevalent in embedded systems community,
- indicated useful by Dobing and Parsons (2006) survey, and
- Activity Diagram's intuition changed (between UML 1.x and 2.x) from transition-system-like to petri-net-like...
- Example state machines:







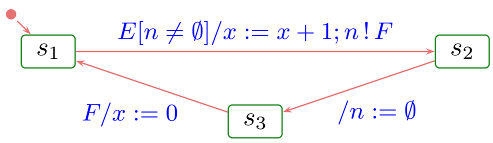

## *Course Map*



# UML State Machines: Overview



## UML State Machines

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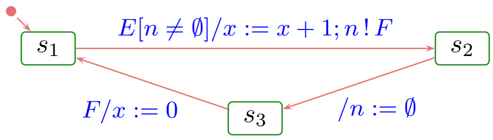


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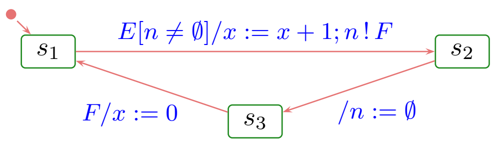


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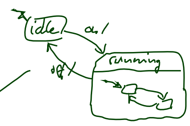

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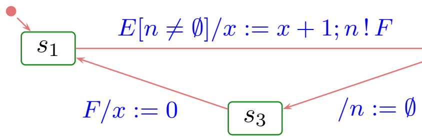


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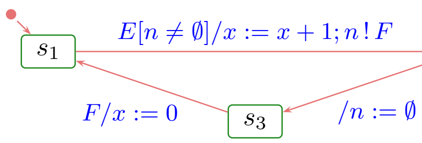


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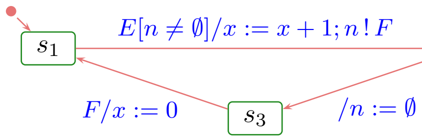


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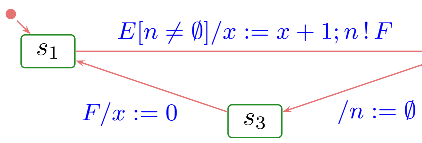


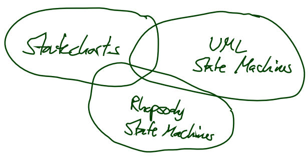


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**Note**: there is a common core, but each dialect interprets some constructs subtly different Crane and Dingel (2007). *(Would be too easy otherwise…)*

# Roadmap: Chronologically

**Syntax**:

(i) UML State Machine Diagrams.

(ii) Def.: Signature with **signals**.

(iii) Def.: **Core state machine**.

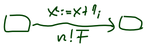
(iv) Map UML State Machine Diagrams to core state machines.

**Semantics**:
The Basic Causality Model

(v) Def.: **Ether** (aka. event pool)

(vi) Def.: **System configuration**.

(vii) Def.: **Event**.

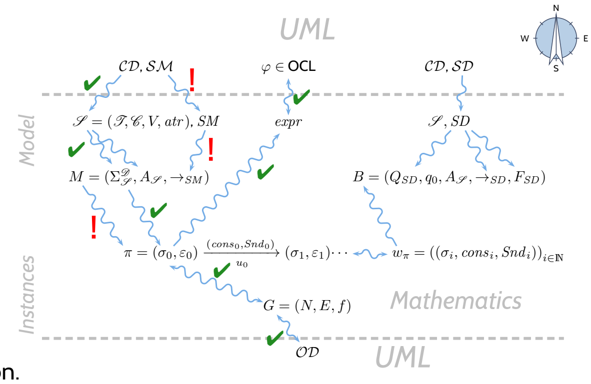
(viii) Def.: **Transformer**. 


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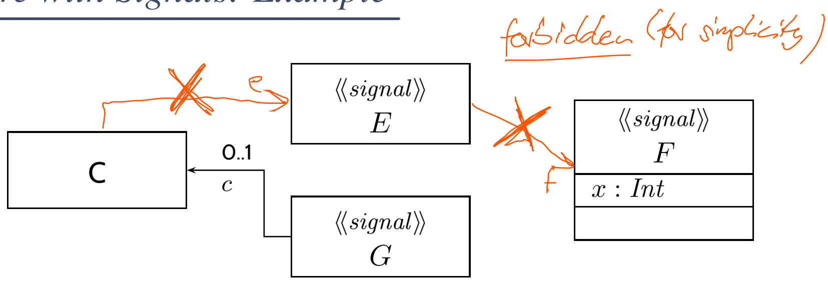
**Note**: Thus conceptually, **a signal is a class** and can have attributes of plain type, and participate in associations.

## *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

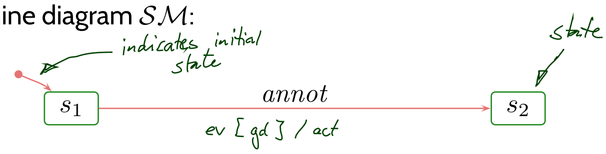
$$\to \ \subseteq \overset{\text{source state}}{S} \times \underbrace{(\mathscr{E} \,\dot\cup\, \{\_\})}_{\text{trigger}} \times \underbrace{Expr_{\mathscr{S}}}_{\text{guard}} \times \underbrace{Act_{\mathscr{S}}}_{\text{action}} \times \overset{\text{destination state}}{S}$$

  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 $\mathcal{SM}$:




$$annot ::= \big[ \langle event \rangle [\texttt{.} \langle event \rangle]^* \big] \; \big[ \texttt{[} \langle guard \rangle \texttt{]} \big] \; \big[ \texttt{/} \; [\langle action \rangle] \big]$$

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**

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



## *Abbreviations and Defaults in the Standard*

**Reconsider** the syntax of transition annotations:

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**What if things are missing?**

$$\begin{array}{rcl} & \rightsquigarrow & \_\ [true]\ /\ skip \\ / & \rightsquigarrow & \_\ [true]\ /\ skip \\ E\ / & \rightsquigarrow & E\ [true]\ /\ skip \\ /\ act & \rightsquigarrow & \_\ [true]\ /\ act \\ E\ /\ act & \rightsquigarrow & E\ [true]\ /\ act \end{array}$$



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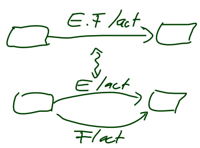


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**In the standard**, the syntax is even more elaborate:

- $E(v)$ – 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

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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** $\mathcal{SM}$).
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  If not explicitly given, then this one:

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


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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*





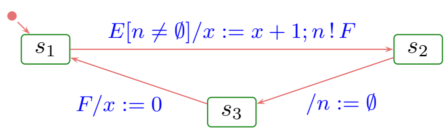
*Towards UML State Machines Semantics:
The Basic Causality Model*

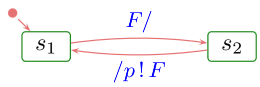
## 6.2.3 The Basic Causality Model (OMG, 2011b, 11)

*"'**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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- *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).***

*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."*

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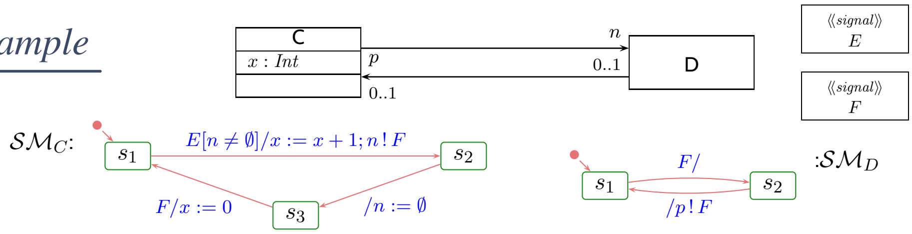
- Run-to-completion may be implemented in **various ways**. [...]

## *Example*



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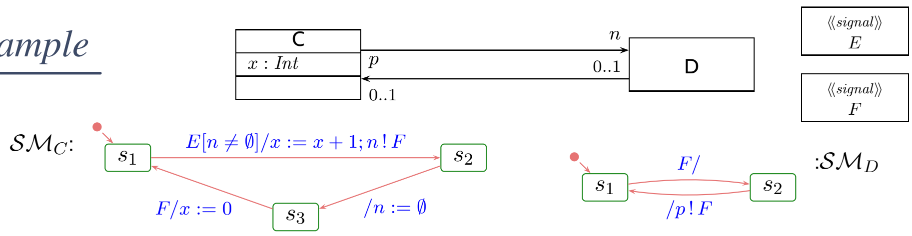


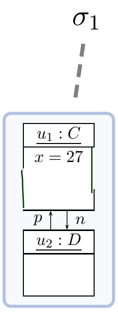


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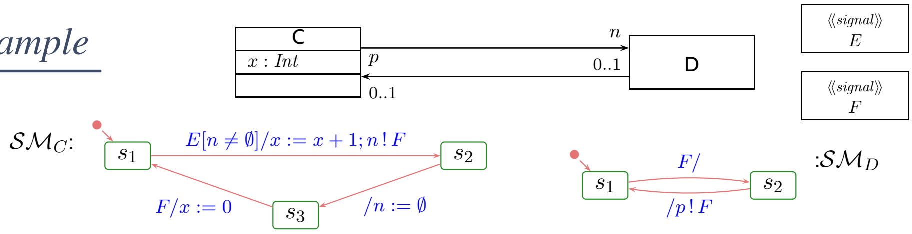


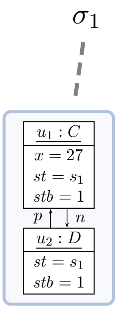




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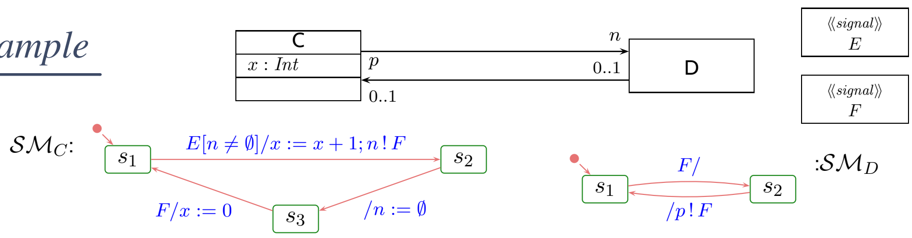


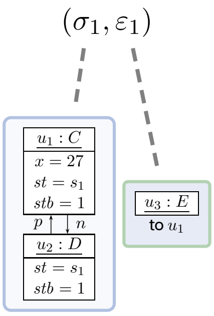

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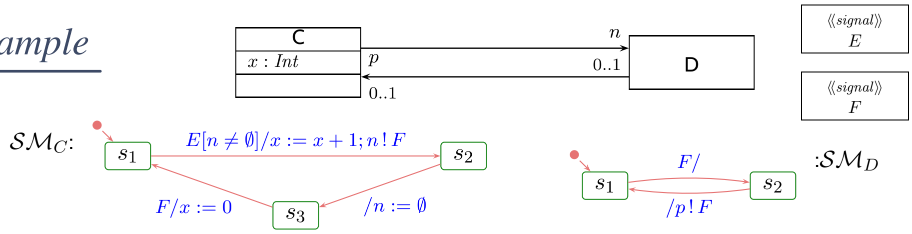


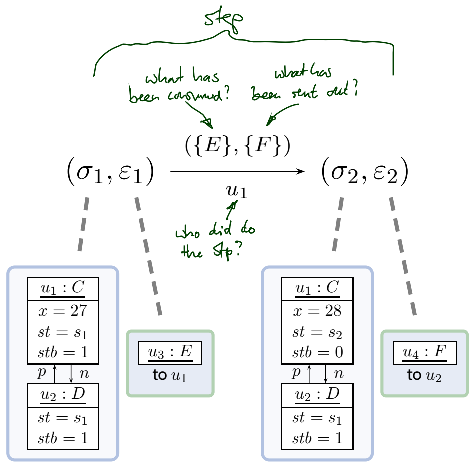




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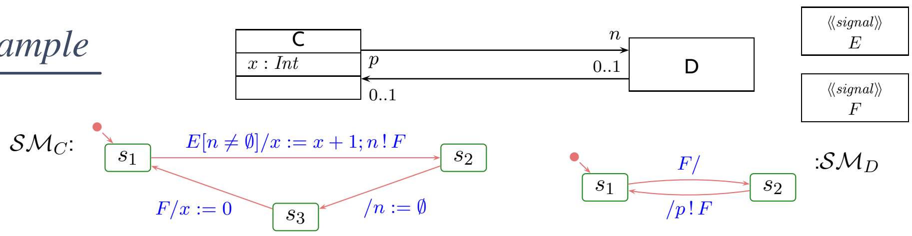


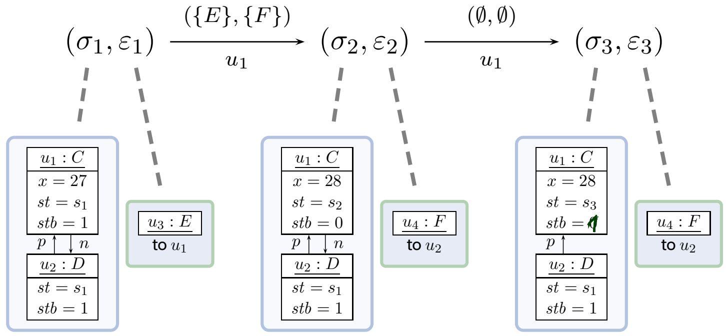

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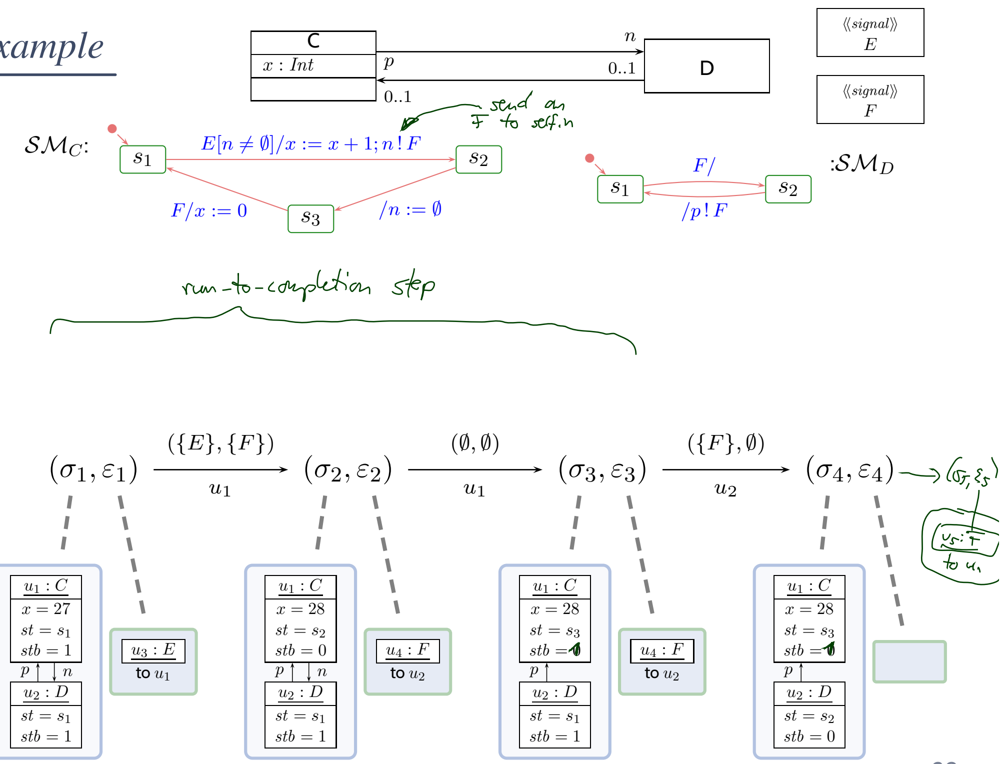




# *Tell Them What You've Told Them. . .*

- 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*





## *References*

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