Software Design, Modelling and Analysis in UML

Lecture 10: Modelling Behaviour

2016-12-01

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

Albert-Ludwigs-Universität Freiburg, Germany

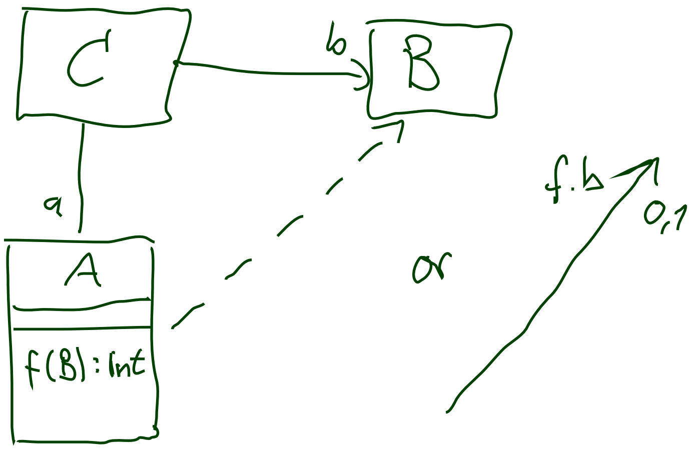
Content

- 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**

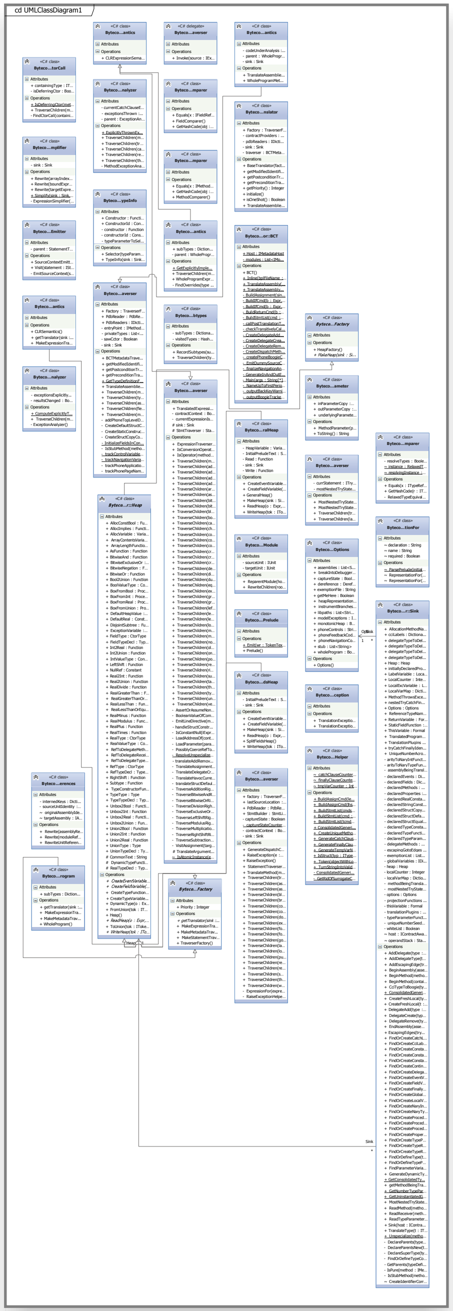
Design Guidelines for (Class) Diagram

(partly following Ambler (2005))

- **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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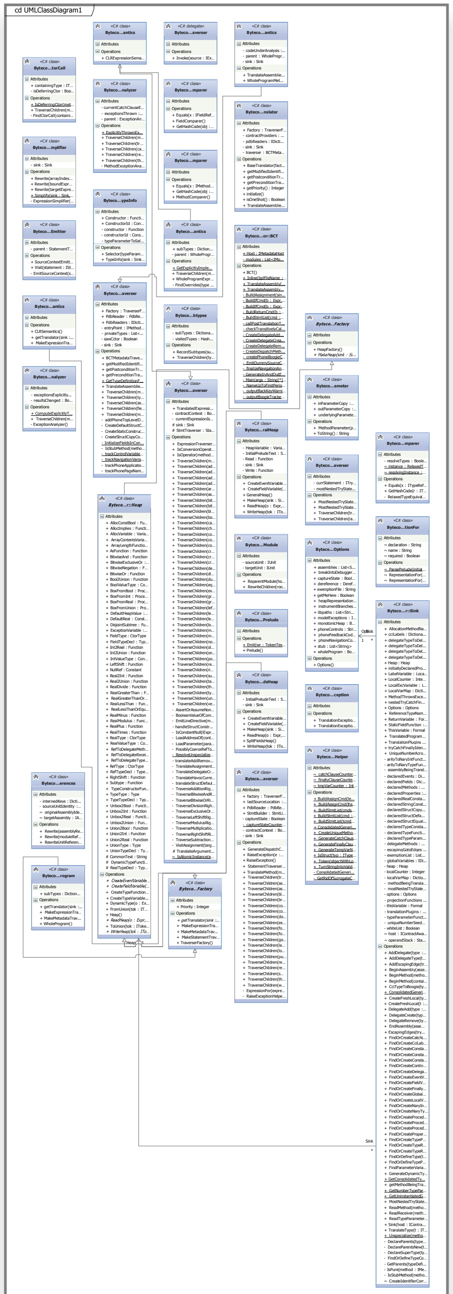

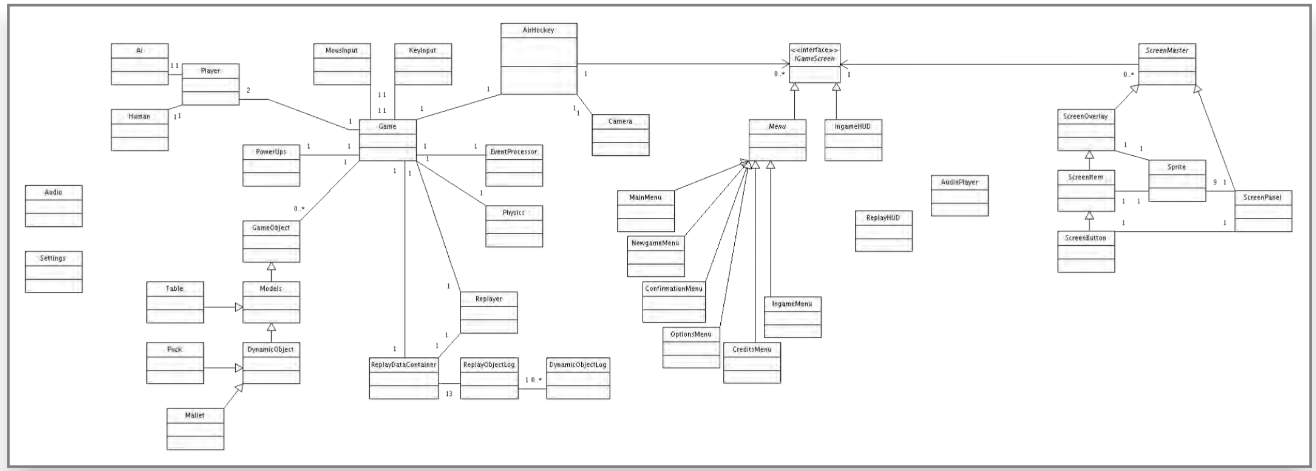

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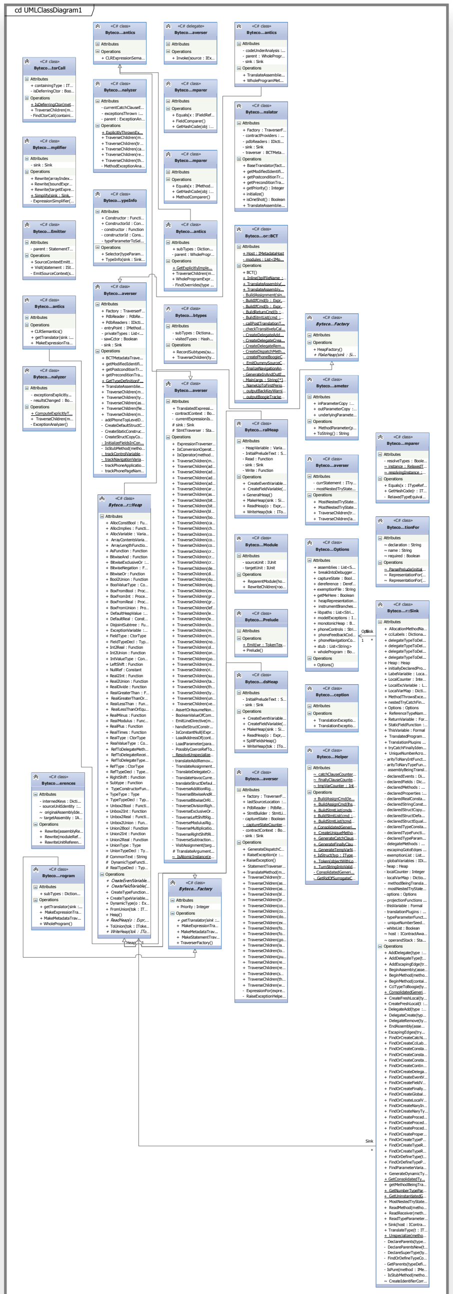
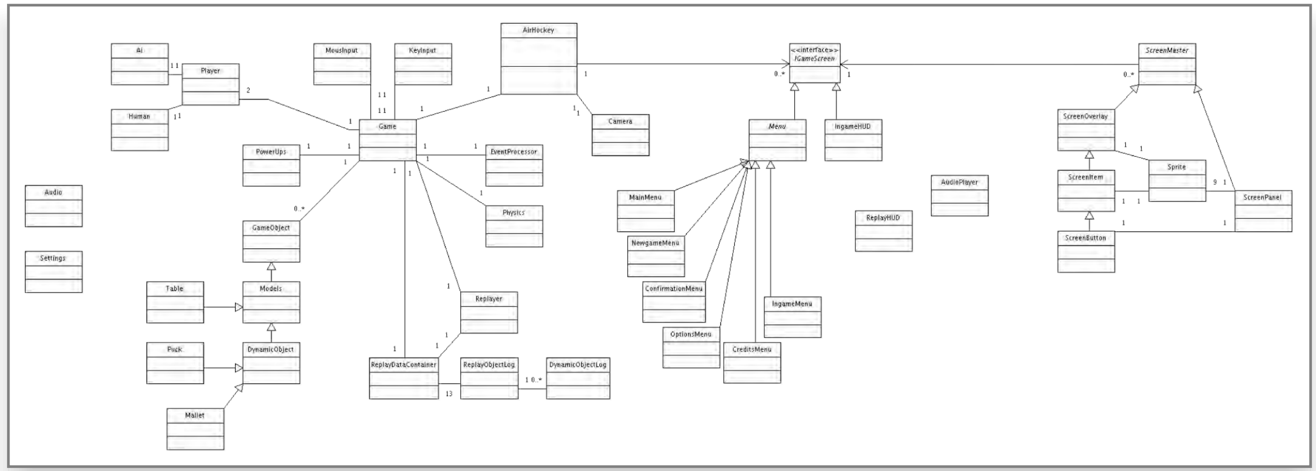
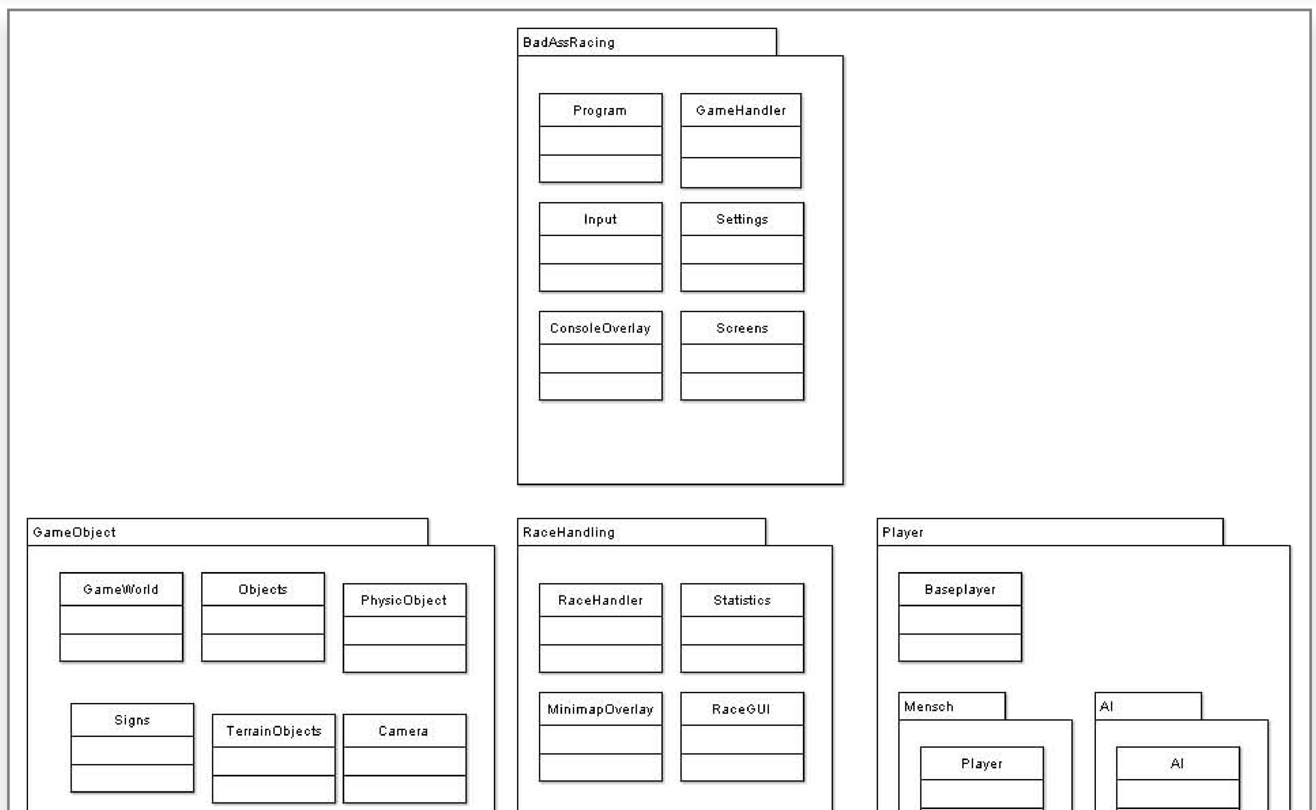
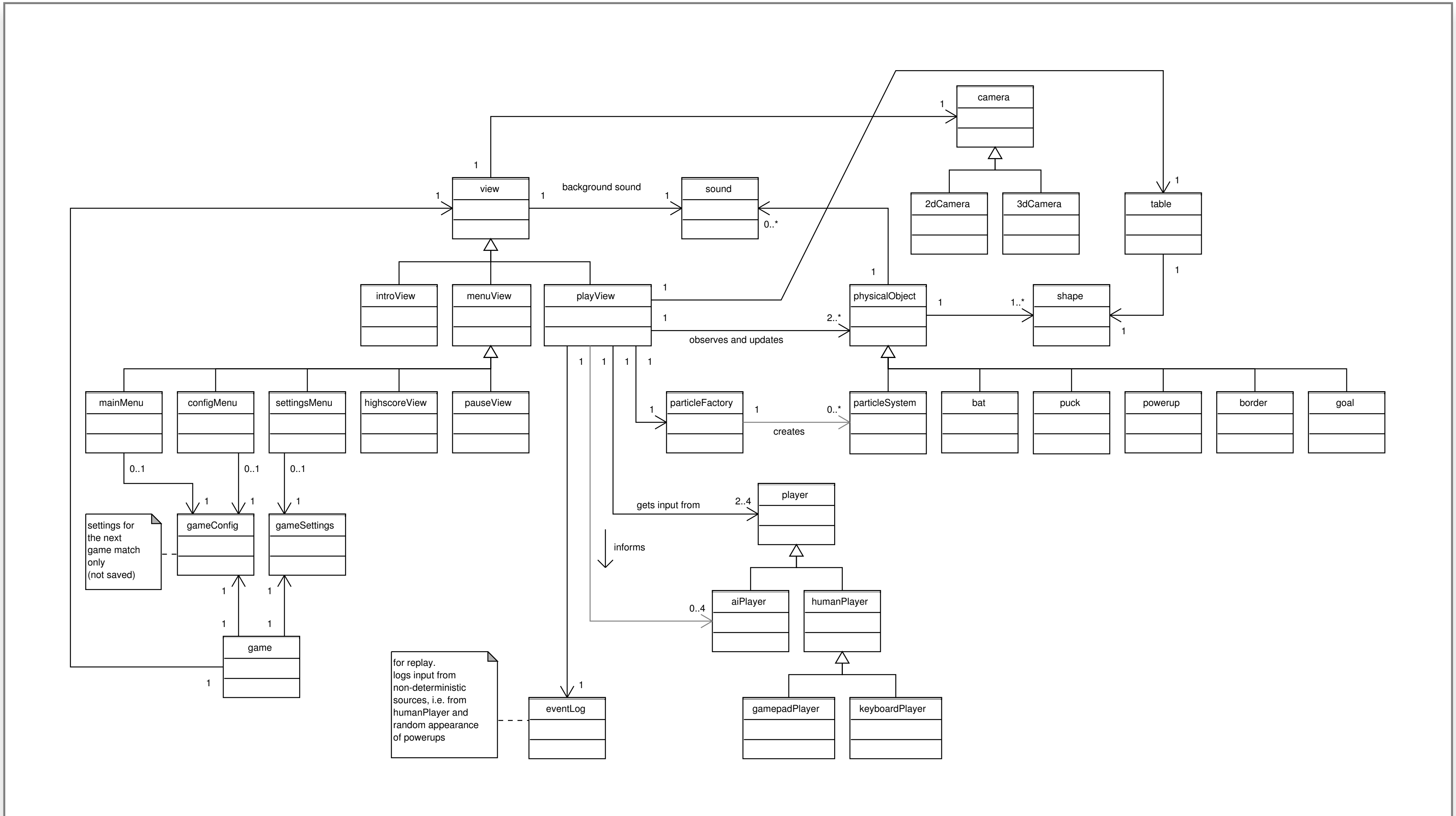






More Example Class Diagrams



Example: Modelling Games

Modelling Structure: Common Architectures

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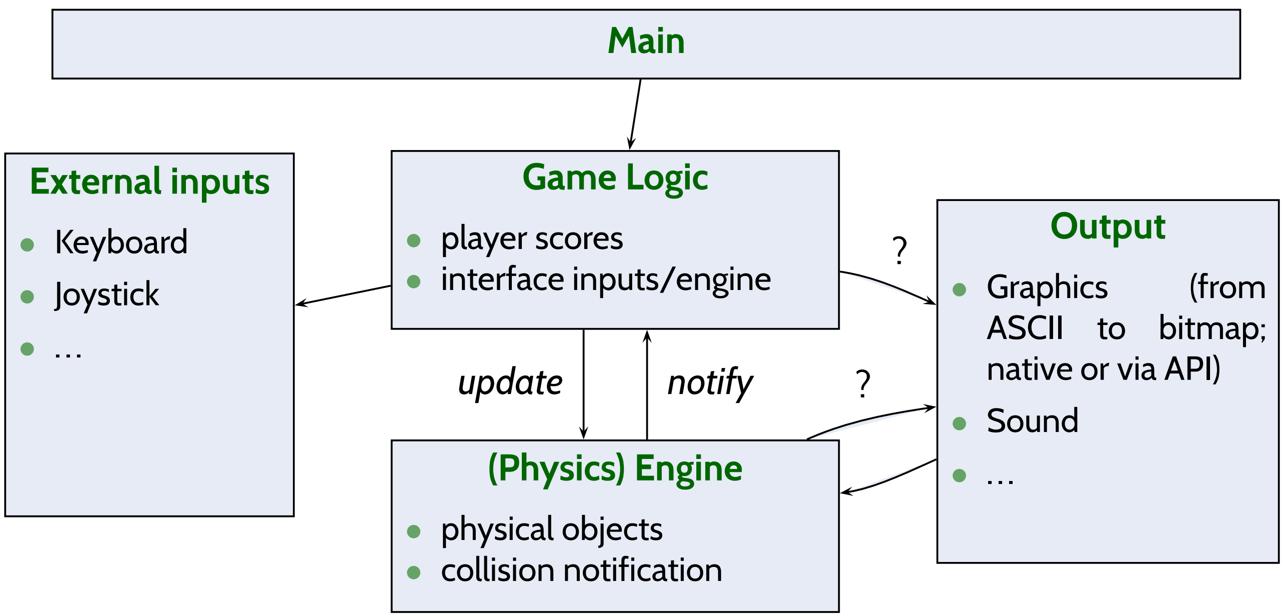
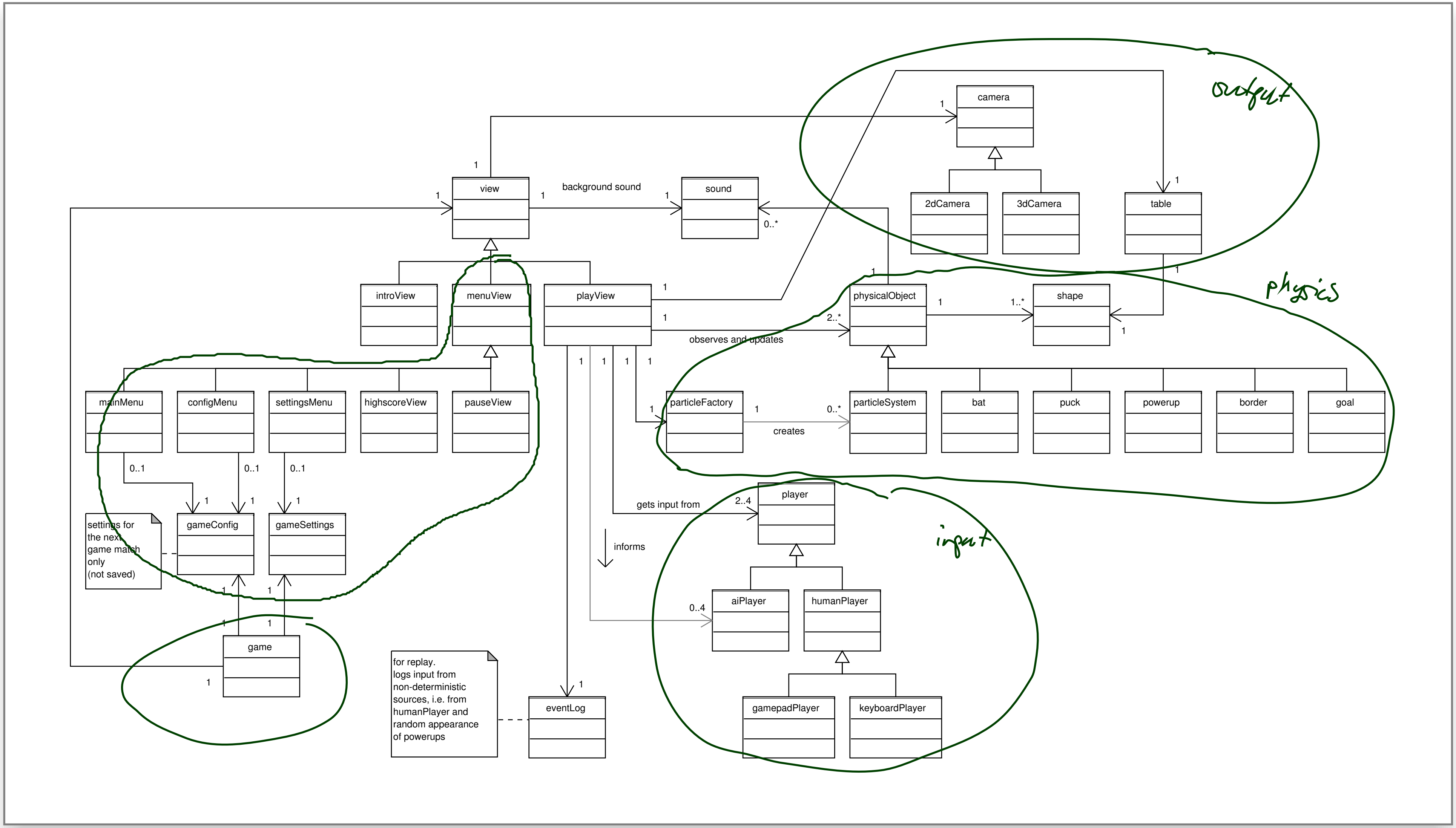


- Adept readers try to see/find/match the common architecture if they know that a model is from a particular domain.
- We can do those readers a favour by grouping/positioning things in the diagram so that seeing/finding/matching is easy.

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**.

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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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  "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.)

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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)."
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- **Forbid** Behaviour. **"System never does this"**

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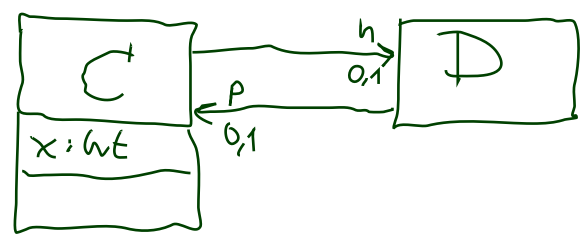
Constructive Behaviour in UML

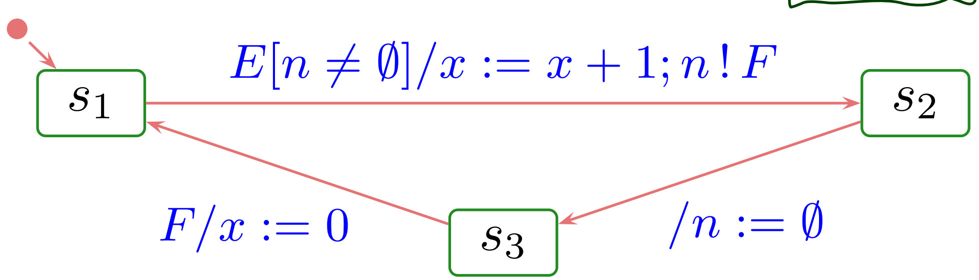
UML provides two visual formalisms for constructive description of behaviours:

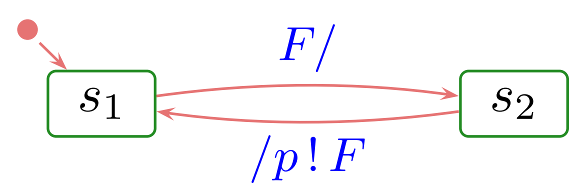
- **Activity Diagrams**
- **State-Machine Diagrams**

We (exemplary) focus on State-Machines because

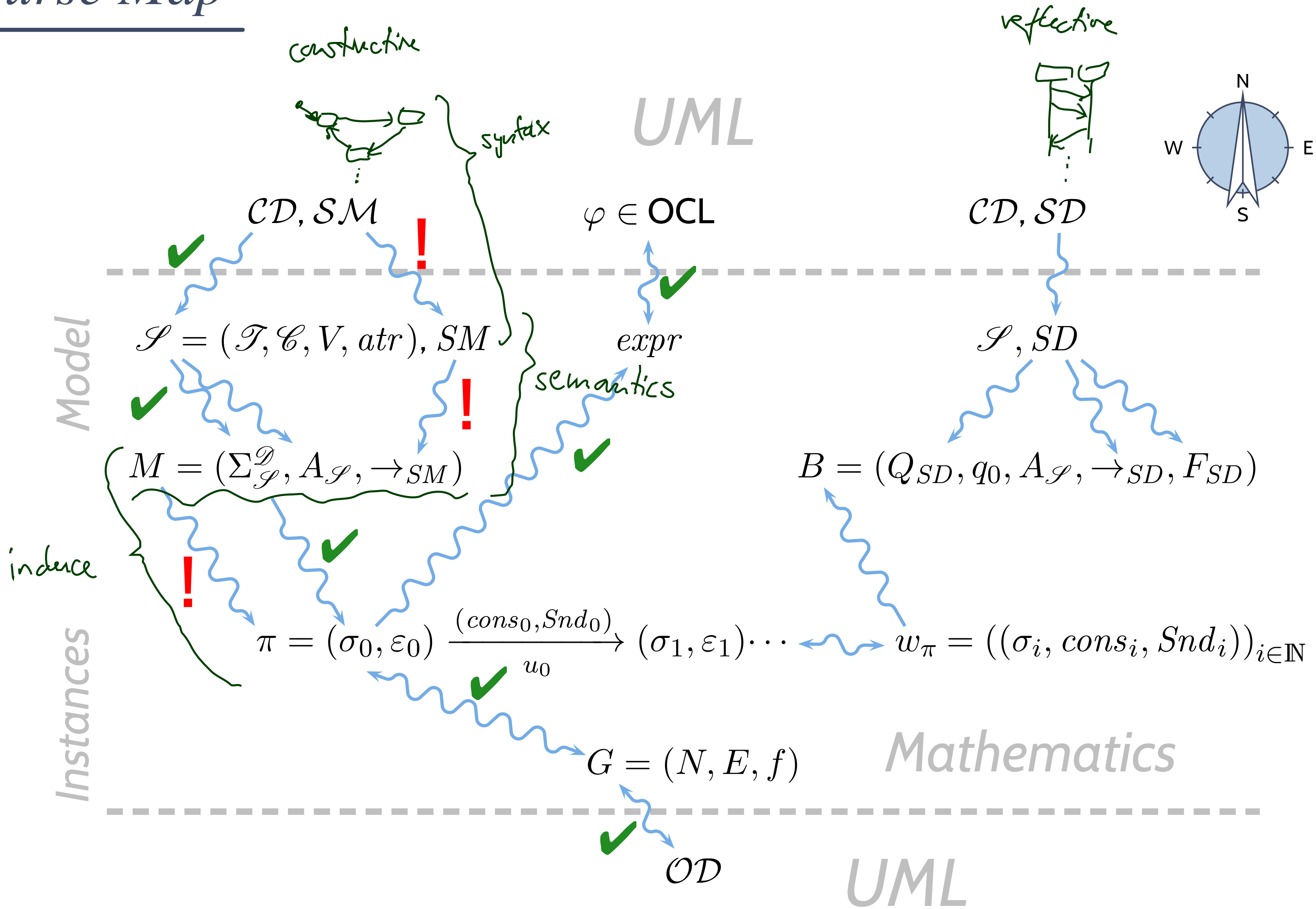
- somehow "practice proven" (in different flavours),
- prevalent in embedded systems community,
- indicated useful by Dobing and Parsons (2006) survey, and
- Activity Diagram's intuition changed (between UML 1.x and 2.x) from transition-system-like to petri-net-like...
- Example state machines:





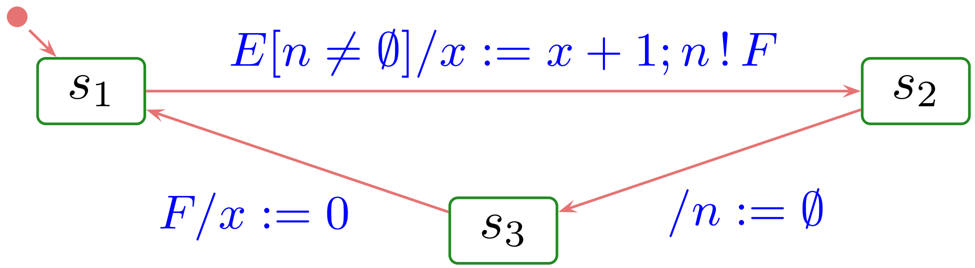


Course Map


constructive
syntax
UML
reflective
N
W
E
S
$\mathcal{CD}, \mathcal{SM}$
$\varphi \in$ OCL
$\mathcal{CD}, \mathcal{SD}$
Model
$\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr), SM$
$expr$
$\mathscr{S}, SD$
semantics
$M = (\Sigma_{\mathscr{S}}^{\mathscr{D}}, A_{\mathscr{S}}, \rightarrow_{SM})$
$B = (Q_{SD}, q_0, A_{\mathscr{S}}, \rightarrow_{SD}, F_{SD})$
induce
Instances
$\pi = (\sigma_0, \varepsilon_0) \xrightarrow[u_0]{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \cdots$
$w_\pi = ((\sigma_i, cons_i, Snd_i))_{i \in \mathbb{N}}$
$G = (N, E, f)$
Mathematics
$\mathcal{OD}$
UML

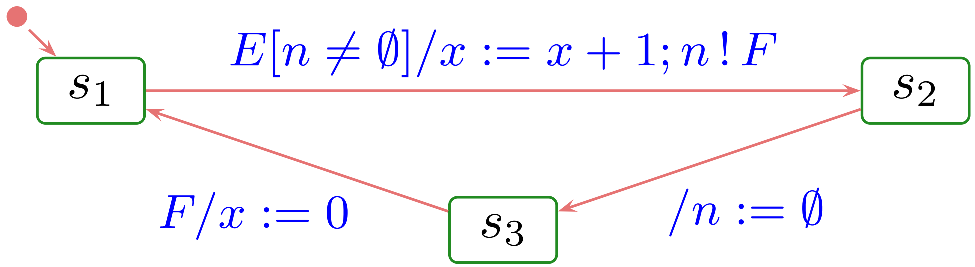
UML State Machines: Overview

UML State Machines



Brief History:

UML State Machines



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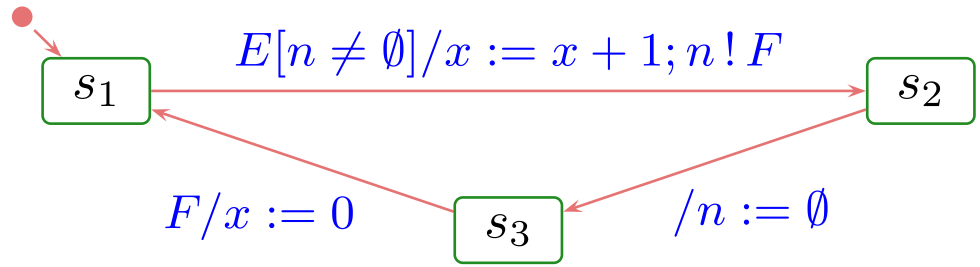

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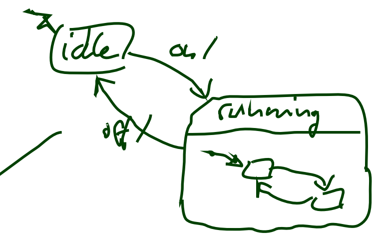

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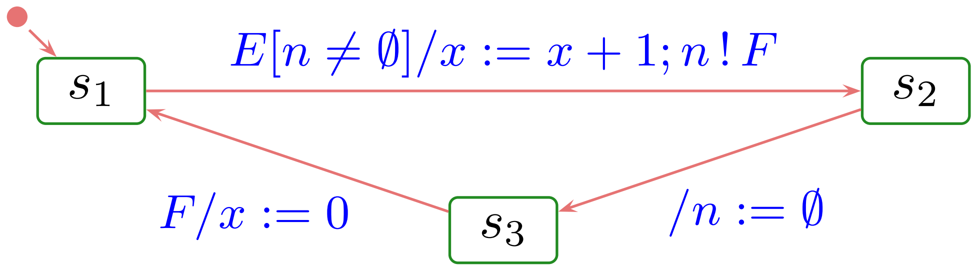

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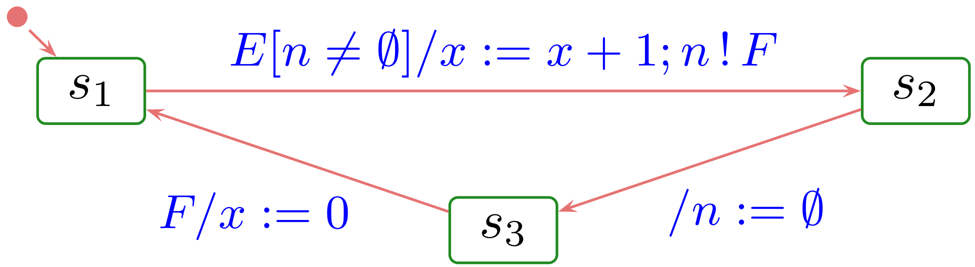

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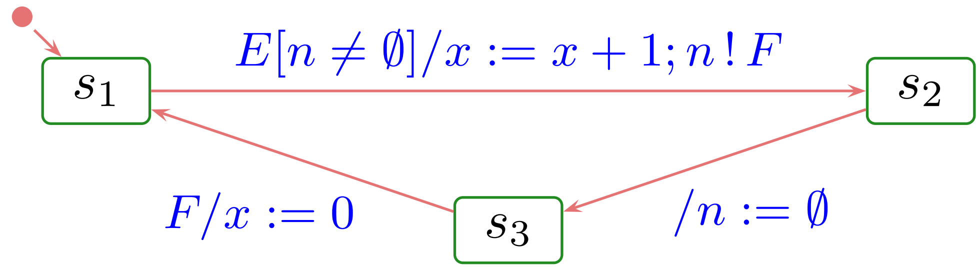

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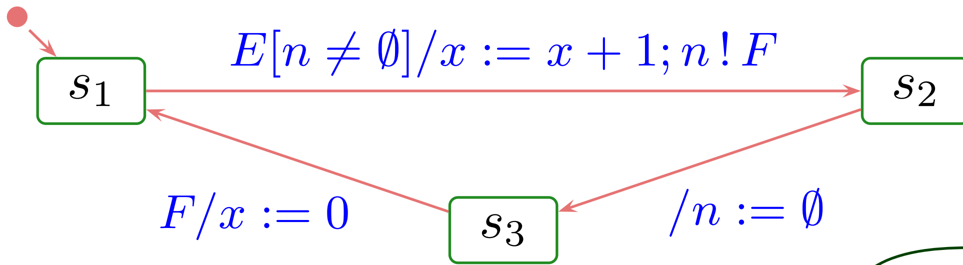

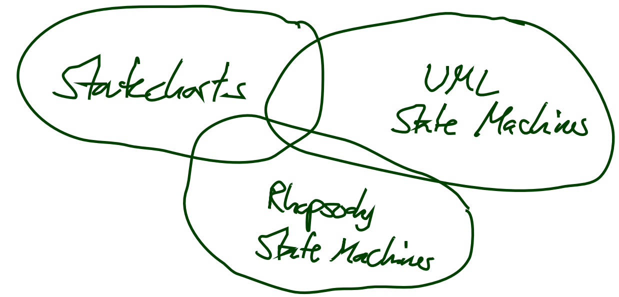

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Note: there is a common core, but each dialect interprets some constructs subtly different Crane and Dingel (2007). *(Would be too easy otherwise...)*

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.

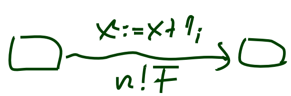
Semantics:
The Basic Causality Model

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

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

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

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

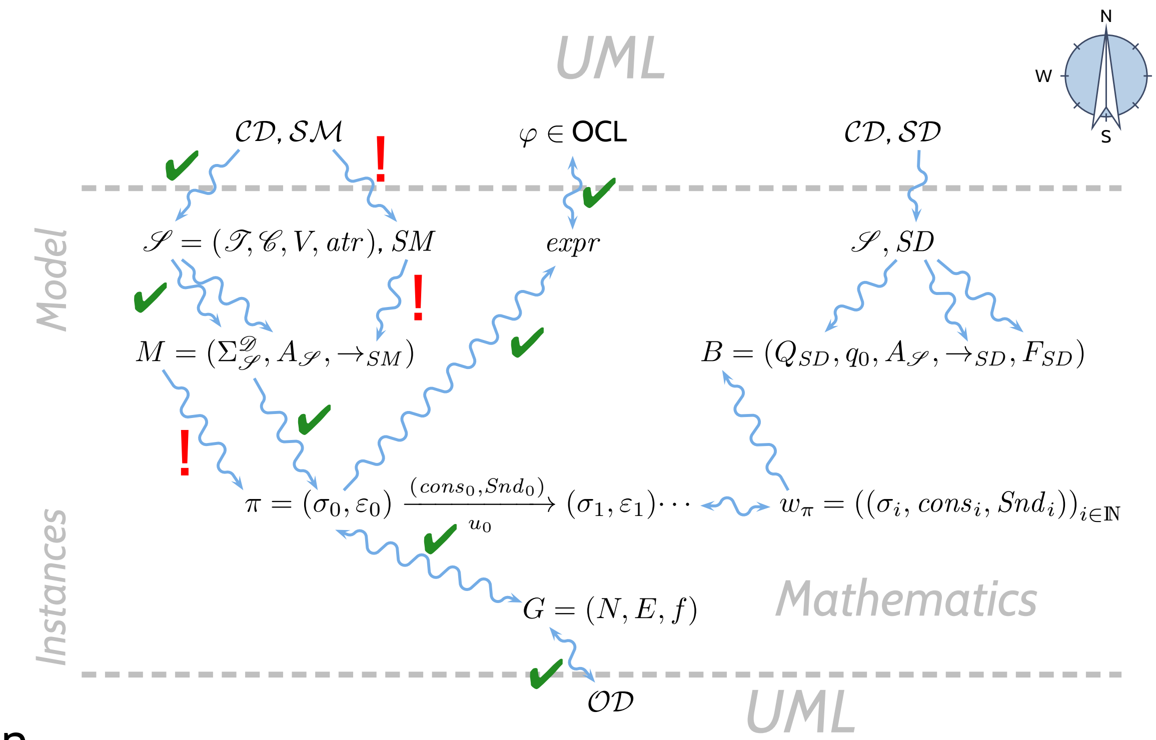


(ix) Def.: **Transition system**, computation.

(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

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

is a signature (as before).

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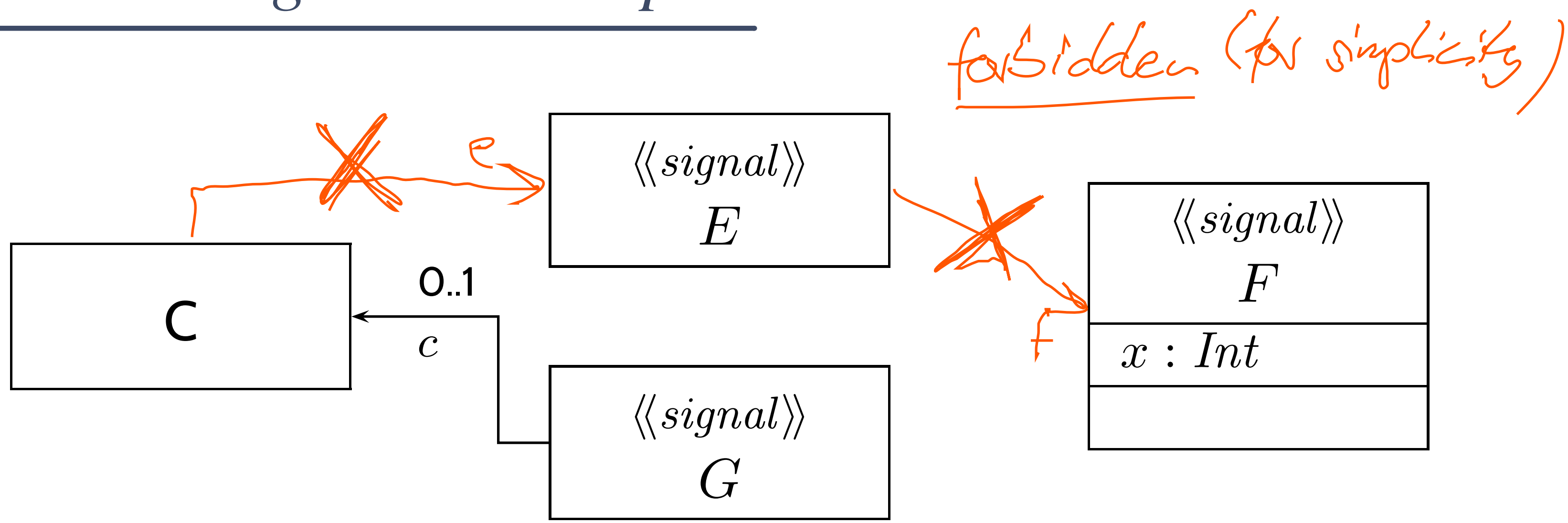
Note: Thus conceptually, **a signal is a class** and can have attributes of plain type, and participate in associations.

Signature with Signals: Example



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

Core State Machine

Definition.

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

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

where

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

source state

destination state

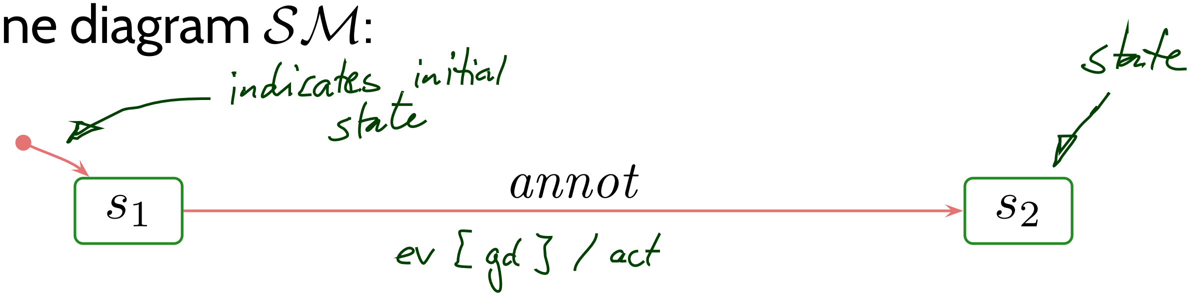
$$\rightarrow \;\subseteq S \times \underbrace{(\mathscr{E} \,\dot{\cup}\, \{\_\})}_{\text{trigger}} \times \underbrace{Expr_{\mathscr{S}}}_{\text{guard}} \times \underbrace{Act_{\mathscr{S}}}_{\text{action}} \times S$$

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 $\mathcal{SM}$:



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

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

$$\mathcal{M}(\mathcal{SM}) = \Big(\underbrace{\{s_1, s_2\}}_{=S}, \underbrace{\{s_1\}}_{=S_0}, \underbrace{\{(s_1, ev, gd, act, s_2)\}}_{=\rightarrow}\Big)$$

Abbreviations and Defaults in the Standard

Reconsider the syntax of transition annotations:

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

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What if things are missing?

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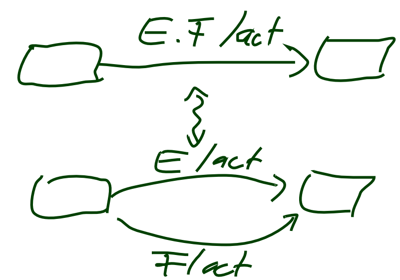

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E\ /\ act & \rightsquigarrow & E\ [true]\ /\ act
\end{array}$$

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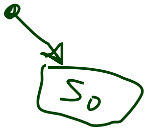
  If not explicitly given, then this one:

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



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Intuition 1: $\mathcal{SM}_C$ describes the behaviour of **the instances** of class C.

Intuition 2: Each instance of class C executes $\mathcal{SM}_C$.

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

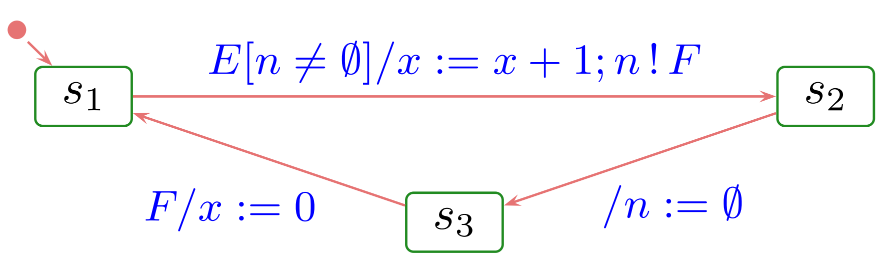
Towards UML State Machines Semantics: The Basic Causality Model

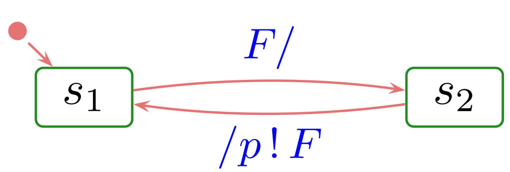
6.2.3 The Basic Causality Model (OMG, 2011b, 11)

*"'**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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- [IOW,] The **run-to-completion step** is the passage between two state configurations of the state machine.
- 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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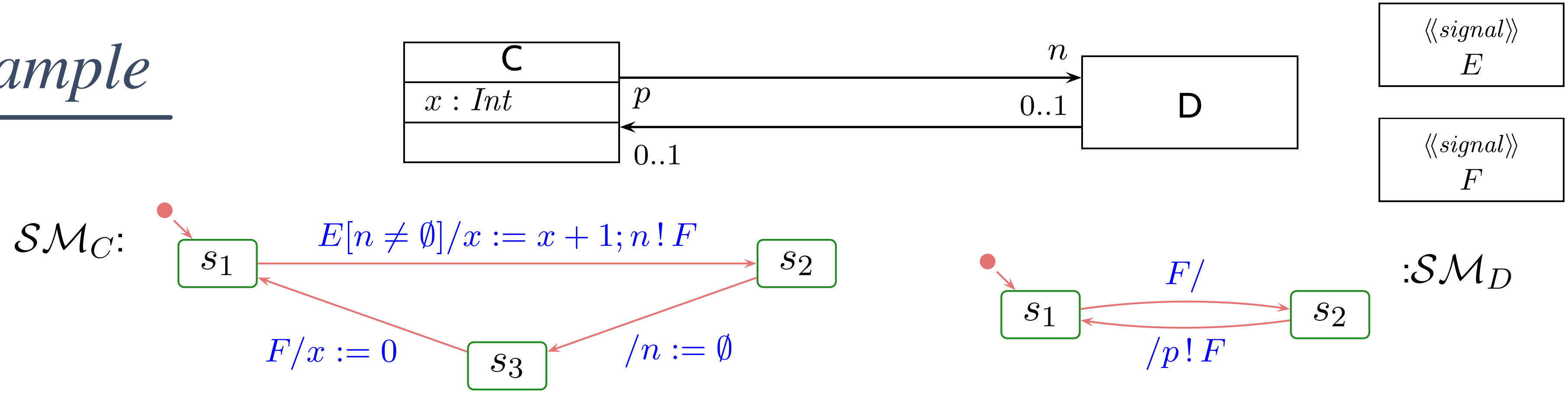
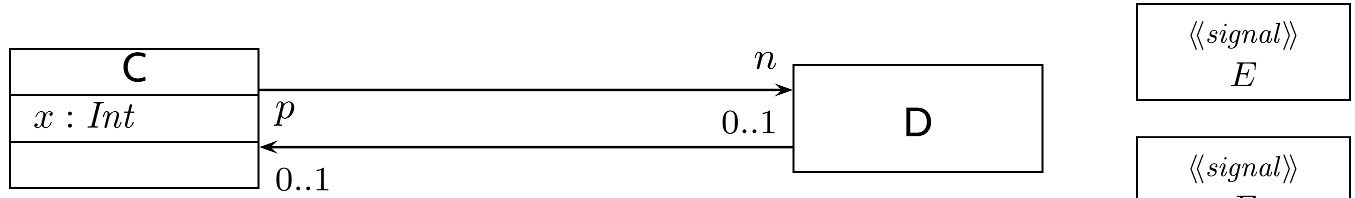
- The order of dequeuing is **not defined**, leaving open the possibility of modeling different priority-based schemes.
- Run-to-completion may be implemented in **various ways**. [...]

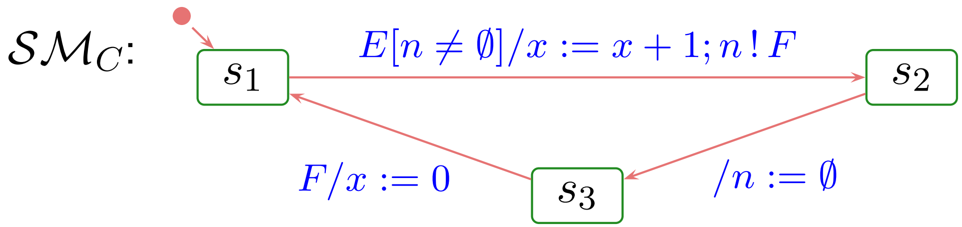
Example


C
$x : Int$
n
$0..1$
p
$0..1$
D
$\langle\langle signal \rangle\rangle$ E
$\langle\langle signal \rangle\rangle$ F
$\mathcal{SM}_C$:
s_1
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
s_2
$F/x := 0$
s_3
$/n := \emptyset$
s_1
$F/$
s_2
$/p\,!\,F$
:$\mathcal{SM}_D$

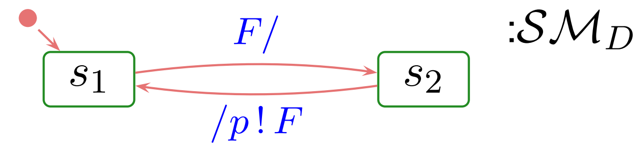
Example



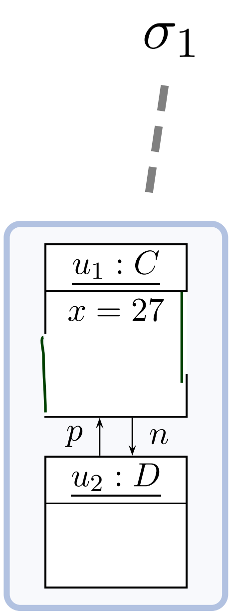
C
$x : Int$
n
$0..1$
p
$0..1$
D
⟪signal⟫
E
⟪signal⟫
F



$\mathcal{SM}_C$:
s_1
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
s_2
$F/x := 0$
s_3
$/n := \emptyset$

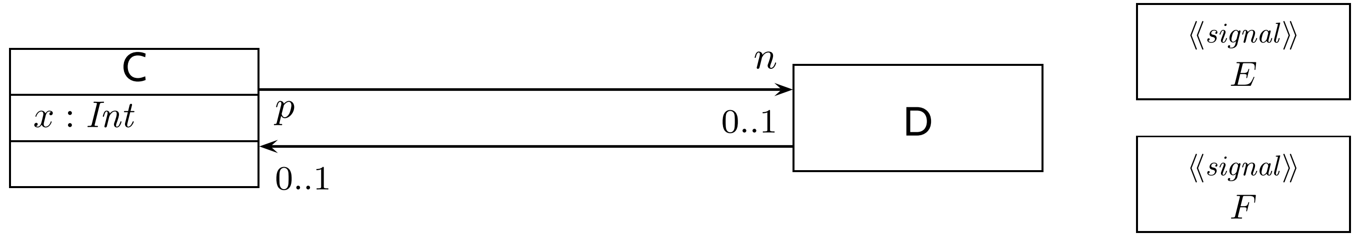


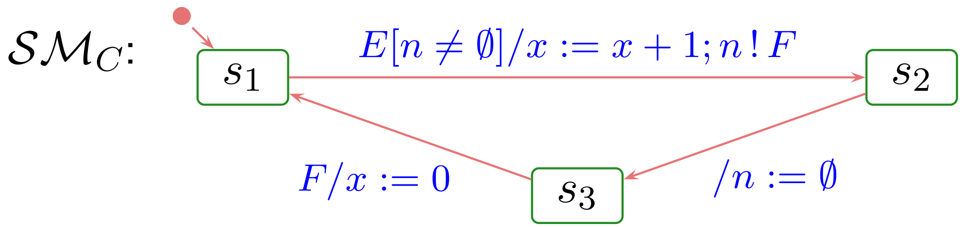
s_1
$F/$
s_2
$/p\,!\,F$
$:\mathcal{SM}_D$

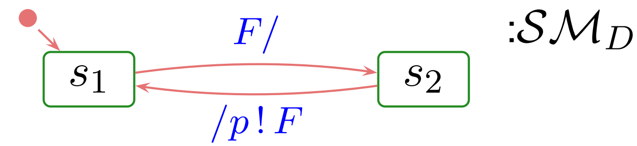


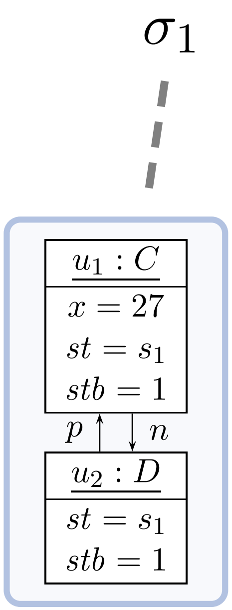
σ_1
$u_1 : C$
$x = 27$
p
n
$u_2 : D$

Example

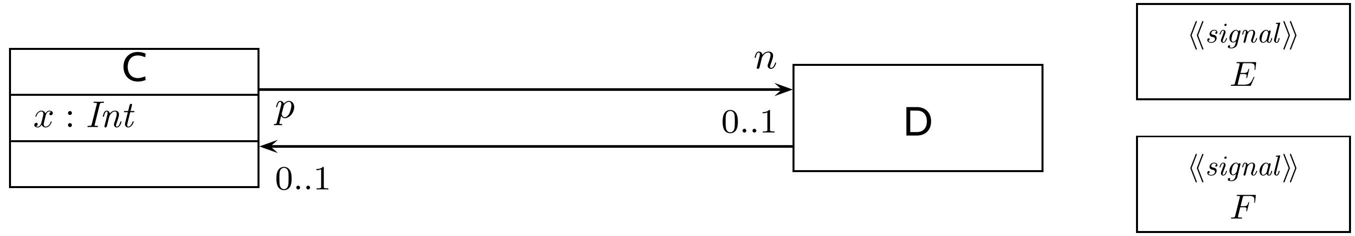

C
$x : Int$
n
$0..1$
p
$0..1$
D
⟨⟨signal⟩⟩
E
⟨⟨signal⟩⟩
F


$\mathcal{SM}_C$:
s_1
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
s_2
$F/x := 0$
s_3
$/n := \emptyset$

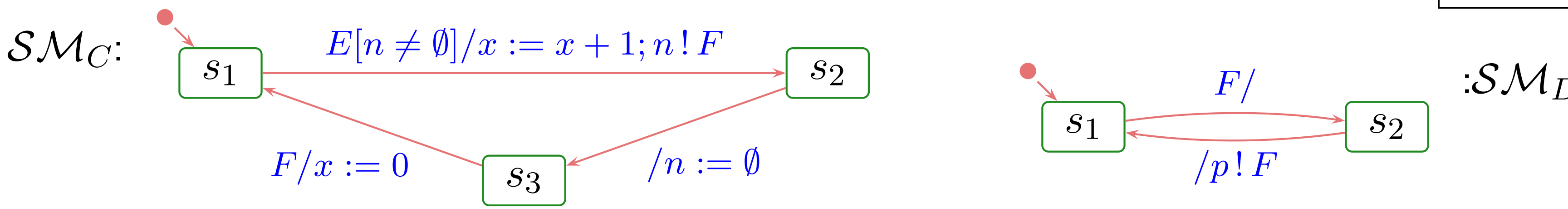

s_1
$F/$
s_2
$/p\,!\,F$
:$\mathcal{SM}_D$


σ_1
$u_1 : C$
$x = 27$
$st = s_1$
$stb = 1$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$

Example



C
$x : Int$
n
p
$0..1$
$0..1$
D
$\langle\langle signal\rangle\rangle$ E
$\langle\langle signal\rangle\rangle$ F



$\mathcal{SM}_C$:
s_1
s_2
s_3
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
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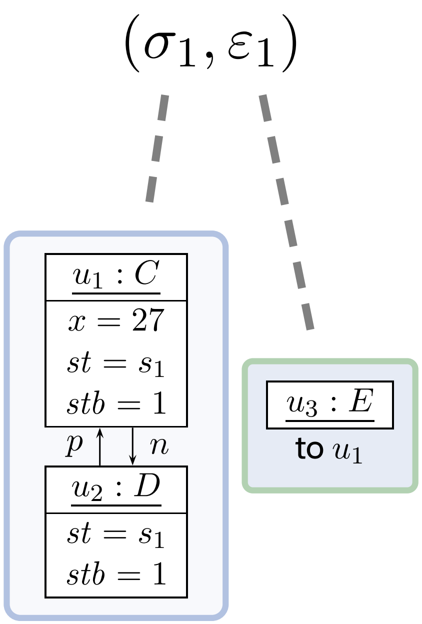
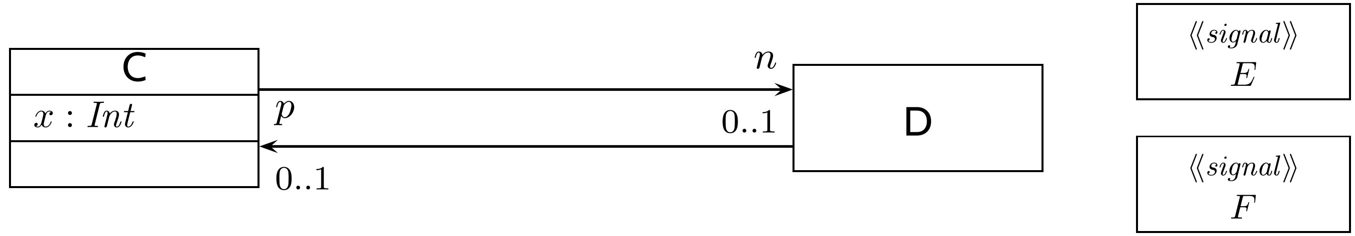
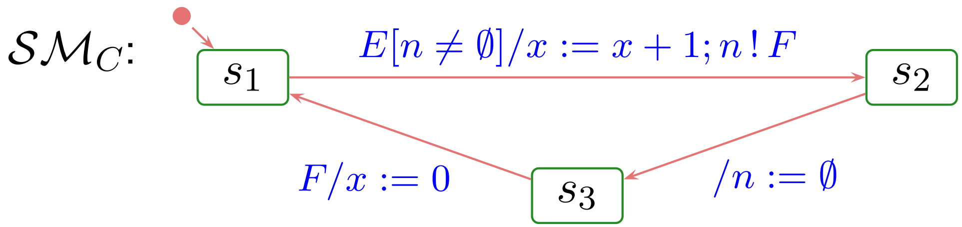
$/n := \emptyset$
s_1
s_2
$F/$
$/p\,!\,F$
:$\mathcal{SM}_D$



$(\sigma_1, \varepsilon_1)$
$\underline{u_1 : C}$
$x = 27$
$st = s_1$
$stb = 1$
p
n
$\underline{u_2 : D}$
$st = s_1$
$stb = 1$
$\underline{u_3 : E}$
to u_1

Example


C
$x : Int$
n
p
$0..1$
$0..1$
D
⟨⟨signal⟩⟩ E
⟨⟨signal⟩⟩ F


$\mathcal{SM}_C$:
s_1
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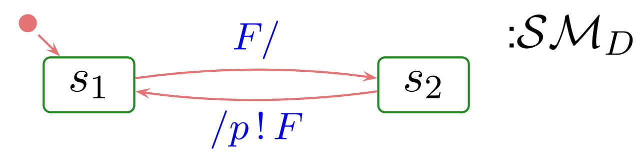
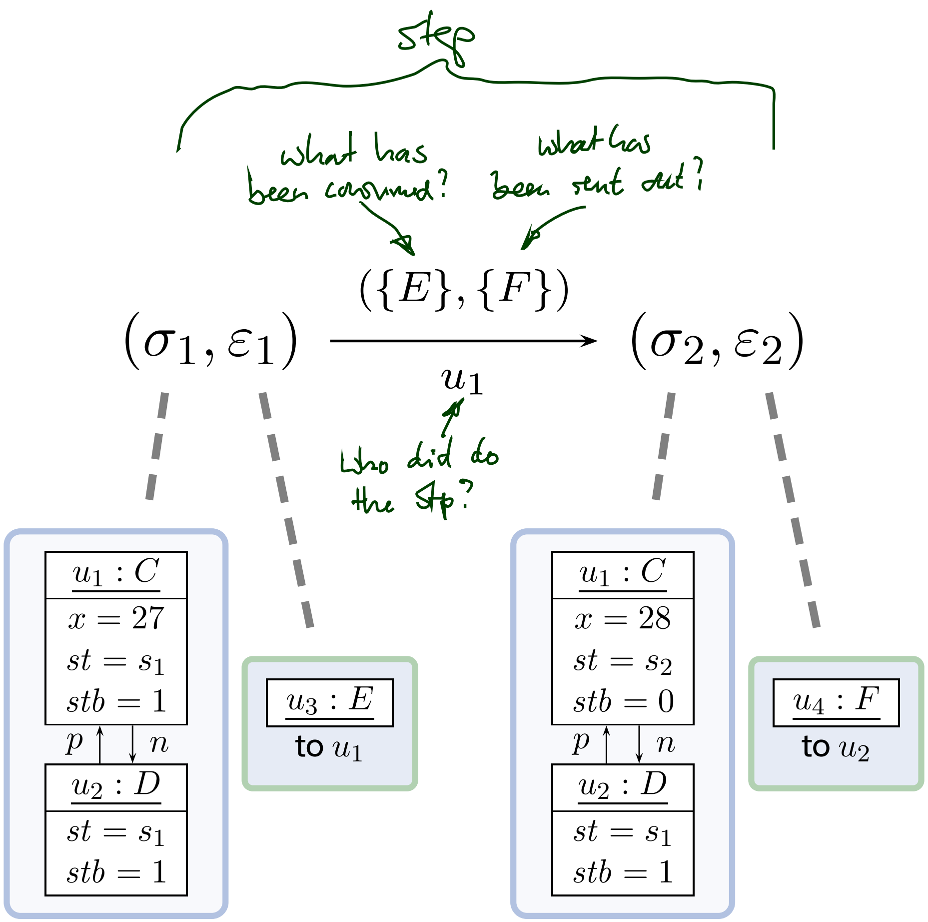
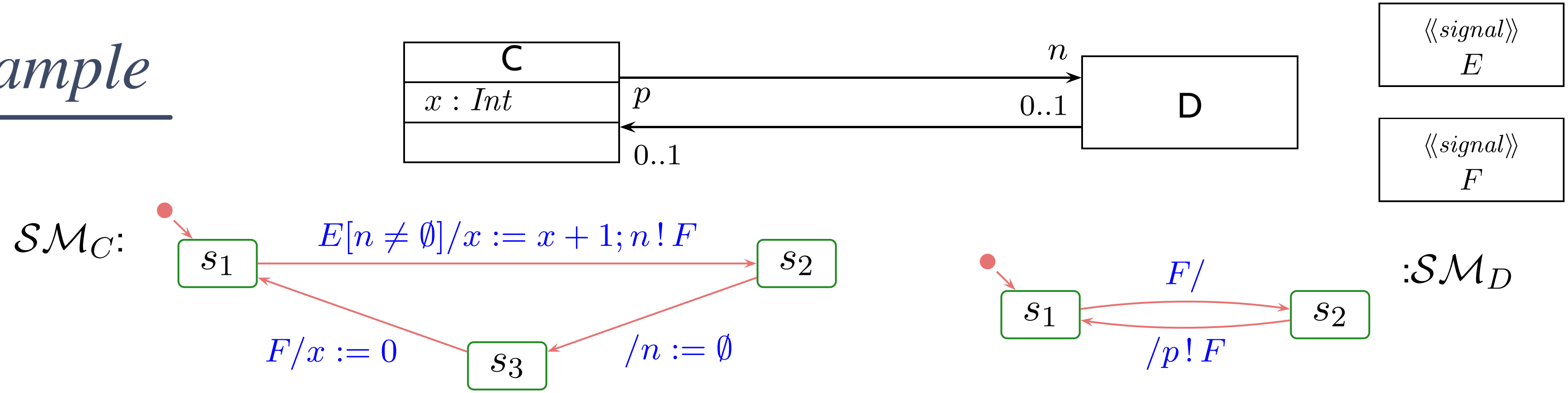
s_2
$F/x := 0$
s_3
$/n := \emptyset$

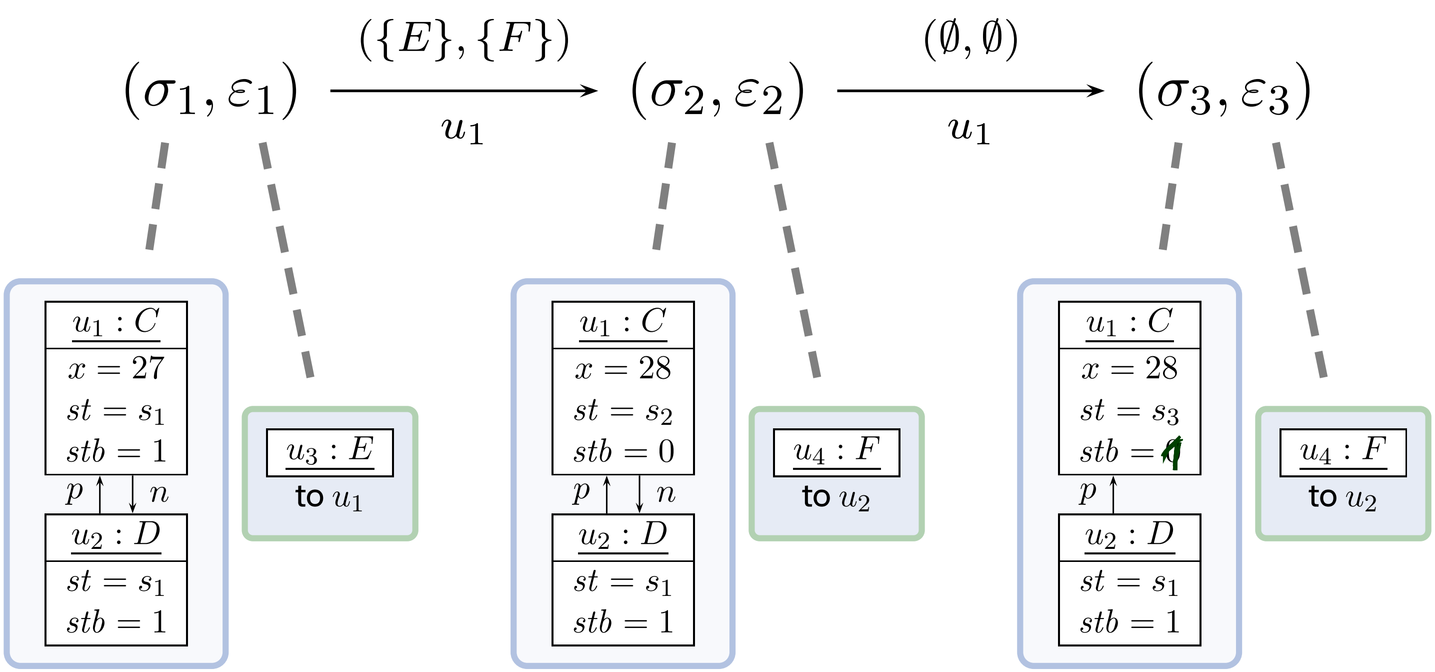

s_1
$F/$
s_2
$/p\,!\,F$
$:\mathcal{SM}_D$


step
what has been consumed?
what has been sent out?
$(\{E\}, \{F\})$
$(\sigma_1, \varepsilon_1)$
u_1
$(\sigma_2, \varepsilon_2)$
Who did do the step?
$u_1 : C$
$x = 27$
$st = s_1$
$stb = 1$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$
$u_3 : E$
to u_1
$u_1 : C$
$x = 28$
$st = s_2$
$stb = 0$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$
$u_4 : F$
to u_2

Example

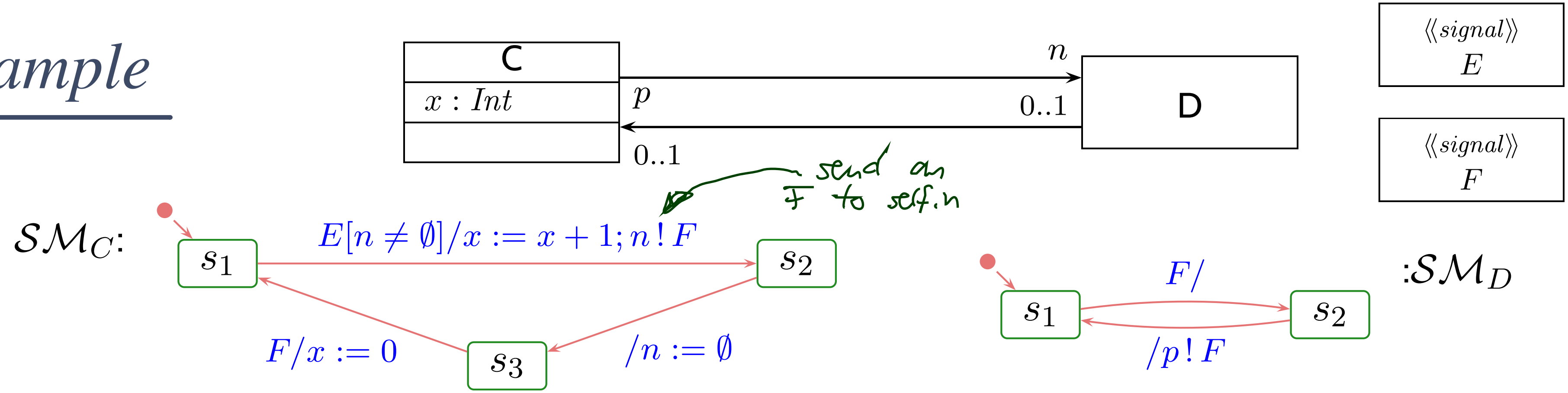


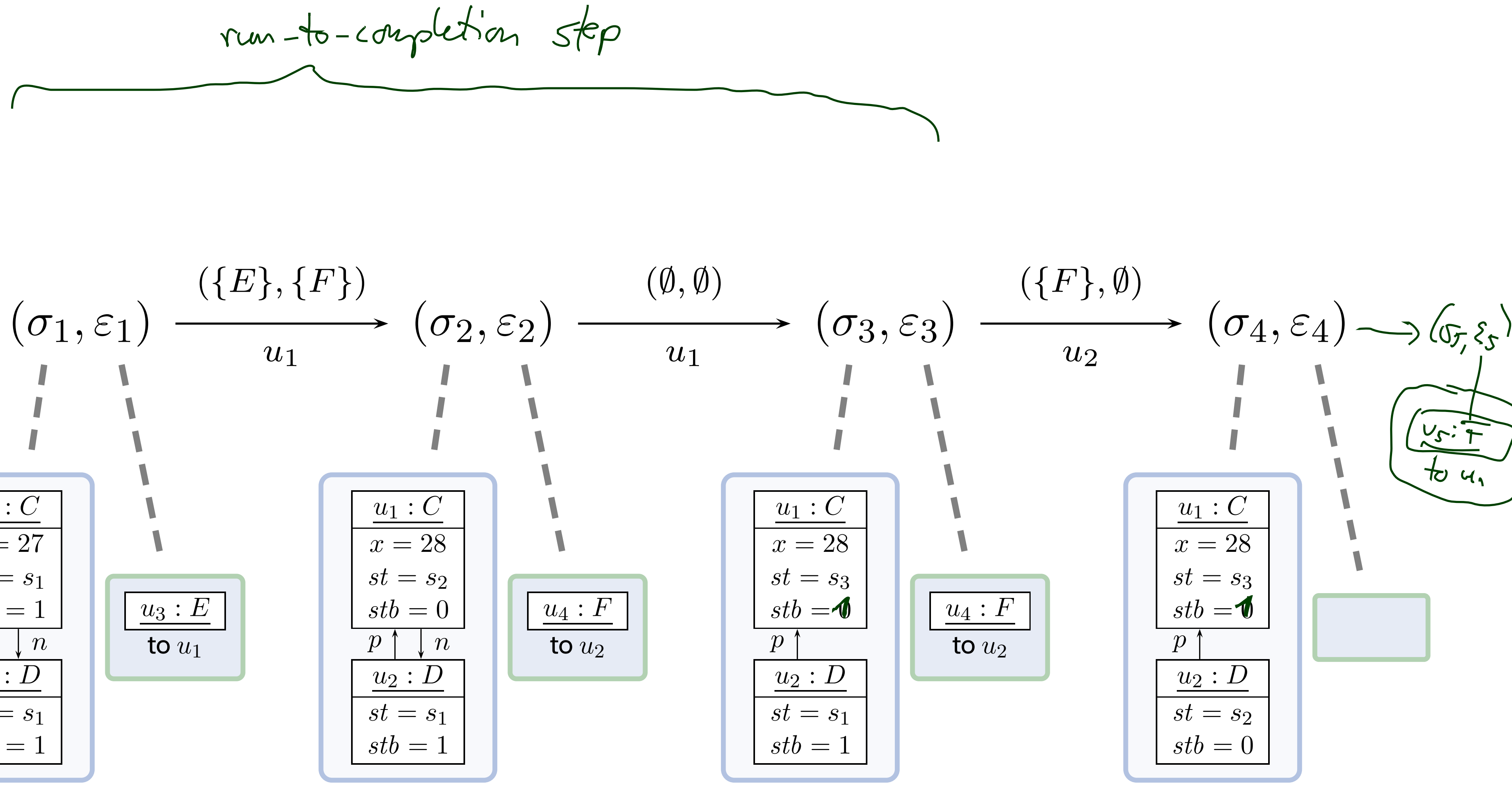
C
$x : Int$
D
n
$0..1$
p
$0..1$
$\langle\langle signal \rangle\rangle$ E
$\langle\langle signal \rangle\rangle$ F
$\mathcal{SM}_C$:
s_1
s_2
s_3
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
$F/x := 0$
$/n := \emptyset$
:$\mathcal{SM}_D$
s_1
s_2
$F/$
$/p\,!\,F$



$(\sigma_1, \varepsilon_1) \xrightarrow[u_1]{(\{E\},\{F\})} (\sigma_2, \varepsilon_2) \xrightarrow[u_1]{(\emptyset,\emptyset)} (\sigma_3, \varepsilon_3)$
$u_1 : C$
$x = 27$
$st = s_1$
$stb = 1$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$
$u_3 : E$
to u_1
$u_1 : C$
$x = 28$
$st = s_2$
$stb = 0$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$
$u_4 : F$
to u_2
$u_1 : C$
$x = 28$
$st = s_3$
$stb = 1$
p
$u_2 : D$
$st = s_1$
$stb = 1$
$u_4 : F$
to u_2

Example


C
$x : Int$
D
n
p
$0..1$
$0..1$
⟨⟨signal⟩⟩ E
⟨⟨signal⟩⟩ F
$\mathcal{SM}_C$:
s_1
s_2
s_3
$E[n \neq \emptyset]/x := x + 1; n\,!\,F$
send an F to self.n
$F/x := 0$
$/n := \emptyset$
s_1
s_2
$F/$
$/p\,!\,F$
:$\mathcal{SM}_D$


run-to-completion step
$(\sigma_1, \varepsilon_1) \xrightarrow[u_1]{(\{E\},\{F\})} (\sigma_2, \varepsilon_2) \xrightarrow[u_1]{(\emptyset,\emptyset)} (\sigma_3, \varepsilon_3) \xrightarrow[u_2]{(\{F\},\emptyset)} (\sigma_4, \varepsilon_4) \rightarrow (\sigma_5, \varepsilon_5)$
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$x = 27$
$st = s_1$
$stb = 1$
p
n
$u_2 : D$
$st = s_1$
$stb = 1$
$u_3 : E$
to u_1
$u_1 : C$
$x = 28$
$st = s_2$
$stb = 0$
$u_2 : D$
$st = s_1$
$stb = 1$
$u_4 : F$
to u_2
$u_1 : C$
$x = 28$
$st = s_3$
$stb = 1$
$u_2 : D$
$st = s_1$
$stb = 1$
$u_4 : F$
to u_2
$u_1 : C$
$x = 28$
$st = s_3$
$stb = 1$
$u_2 : D$
$st = s_2$
$stb = 0$
$u_5 : F$
to u_1

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**,

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