

# *Software Design, Modelling and Analysis in UML*

## *Lecture 17: Reflective Description of Behaviour, Live Sequence Charts I*

2014-01-27

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## Contents & Goals

### Last Lecture:

- Hierarchical State Machines
- **Later:** active vs. passive; behavioural feature (aka. methods).

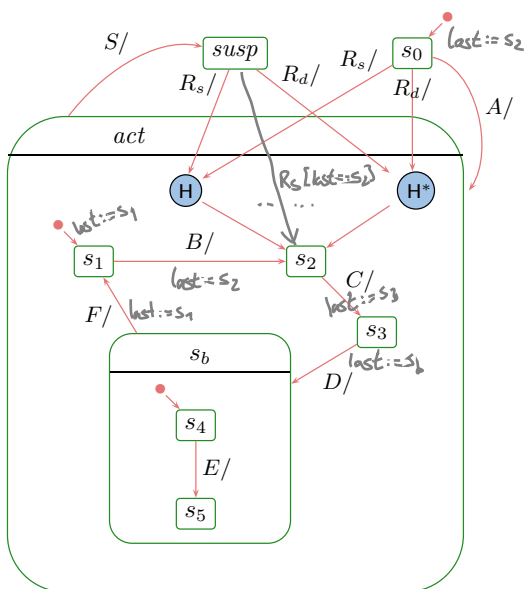
### This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this LSC mean?
  - Are this UML model's state machines consistent with the interactions?
  - Please provide a UML model which is consistent with this LSC.
  - What is: activation, hot/cold condition, pre-chart, etc.?
- **Content:**
  - Remaining pseudo-states, such as shallow/deep history
  - Reflective description of behaviour.
  - LSC concrete and abstract syntax.
  - LSC intuitive semantics.
  - Symbolic Büchi Automata (TBA) and its (accepted) language.

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# The Concept of History, and Other Pseudo-States

## History and Deep History: By Example

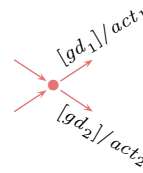


What happens on... (right after creation)

- $R_s$ ?  
 $s_0, s_2$
- $R_d$ ?  
 $s_0, s_2$
- $A, B, C, S, R_s$ ?  
 $s_0, s_1, s_2, s_3, \text{ susp}, s_3$
- $A, B, S, R_d$ ?  
 $s_0, s_1, s_2, s_3, \text{ resp}, s_3$
- $A, B, C, D, E, R_s$ ?  
 $s_0, s_1, s_2, s_4, s_5, \text{ susp}, s_4$  "shallow"
- $A, B, C, D, R_d$ ?  
 $s_0, s_1, s_2, s_4, s_5, \text{ susp}, s_5$  "deep"

## Junction and Choice

- Junction (“**static conditional branch**”):



- Choice: (“**dynamic conditional branch**”)



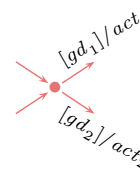
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Note: not so sure about naming and symbols, e.g.,  
**I'd guessed** it was just the other way round...

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## Junction and Choice

- Junction (“**static conditional branch**”):



- **good**: abbreviation
- unfolds to so many similar transitions with different guards, the unfolded transitions are then checked for enabledness
- at best, start with trigger, branch into conditions, then apply actions

- Choice: (“**dynamic conditional branch**”)



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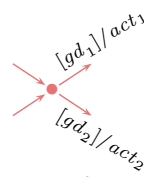
Note: not so sure about naming and symbols, e.g.,  
**I'd guessed** it was just the other way round...

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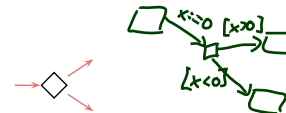
## Junction and Choice



- Junction (“**static conditional branch**”):
  - **good**: abbreviation
  - unfolds to so many similar transitions with different guards, the unfolded transitions are then checked for enabledness
  - at best, start with trigger, branch into conditions, then apply actions



- Choice: (“**dynamic conditional branch**”)
- **evil**: may get stuck
- enters the transition **without knowing** whether there’s an enabled path
- at best, use “else” and convince yourself that it cannot get stuck
- maybe even better: **avoid**



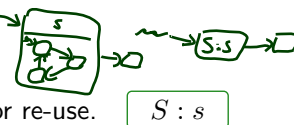
Note: not so sure about naming and symbols, e.g.,  
**I’d guessed** it was just the other way round...

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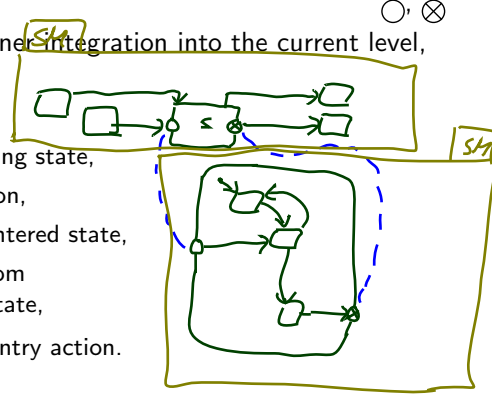
## Entry and Exit Point, Submachine State, Terminate



- Hierarchical states can be “**folded**” for readability. (but: this can also hinder readability.)
- Can even be taken from a different state-machine for re-use.  $S : s$



- **Entry/exit points**
  - Provide connection points for finer integration into the current level, than just via initial state.
  - Semantically a bit tricky:
    - **First** the exit action of the exiting state,
    - **then** the actions of the transition,
    - **then** the entry actions of the entered state,
    - **then** action of the transition from the entry point to an internal state,
    - and **then** that internal state’s entry action.



- **Terminate Pseudo-State**
  - When a terminate pseudo-state is reached, the object taking the transition is immediately killed.



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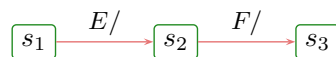
## Deferred Events in State-Machines

### Deferred Events: Idea

For ages, UML state machines comprises the feature of **deferred events**.

The idea is as follows:

- Consider the following state machine:



- Assume we're stable in  $s_1$ , and  $F$  is ready in the ether.
- In **the framework of the course**,  $F$  is **discarded**.
- But we **may** find it a pity to discard the poor event and **may** want to remember it for later processing, e.g. in  $s_2$ , in other words, **defer** it.

General options to satisfy such needs:

- Provide a pattern how to "program" this (use self-loops and helper attributes).
- Turn it into an original language concept. (**← OMG's choice**)

## Deferred Events: Syntax and Semantics

- **Syntactically,**
  - Each state has (in addition to the name) a set of deferred events.
  - **Default:** the empty set.
- The **semantics** is a bit intricate, something like
  - if an event  $E$  is dispatched,
  - and there is no transition enabled to consume  $E$ ,
  - and  $E$  is in the deferred set of the current state configuration,
  - then stuff  $E$  into some “deferred events space” of the object, (e.g. into the ether (= extend  $\varepsilon$ ) or into the local state of the object (= extend  $\sigma$ ))
  - and turn attention to the next event.
- **Not so obvious:**
  - Is there a priority between deferred and regular events?
  - Is the order of deferred events preserved?
  - ...

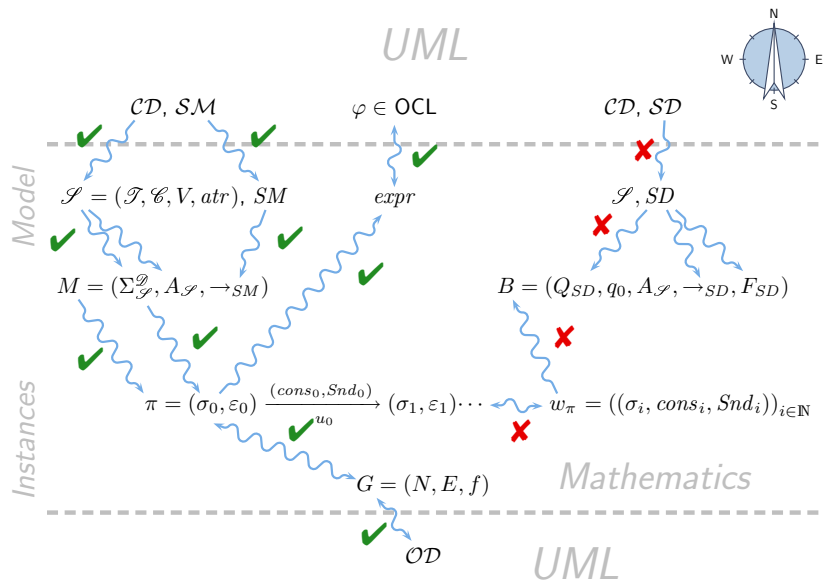
[Fecher and Schönborn, 2007], e.g., claim to provide semantics for the complete Hierarchical State Machine language, including deferred events.

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*You are here.*

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# Course Map



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*Motivation: Reflective, Dynamic Descriptions of Behaviour*

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## Recall: 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!

## Recall: What is a Requirement?

**Recall:**

- The **semantics** of the **UML model**  $\mathcal{M} = (\mathcal{C}\mathcal{D}, \mathcal{M}, \mathcal{O}\mathcal{D})$  is the **transition system**  $(S, \rightarrow, S_0)$  constructed according to discard/dispatch/commence-rules.
- The **computations of**  $\mathcal{M}$ , denoted by  $\llbracket \mathcal{M} \rrbracket$ , are the computations of  $(S, \rightarrow, S_0)$ .

**Now:**

A reflective description tells **what** shall or shall not be computed.

**More formally:** a requirement  $\vartheta$  is a property of computations, sth. which is either satisfied or not satisfied by a computation

$$\pi = (\sigma_0, \varepsilon_0) \xrightarrow{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \xrightarrow{(cons_1, Snd_1)} \dots \in \llbracket \mathcal{M} \rrbracket,$$

denoted by  $\pi \models \vartheta$  and  $\pi \not\models \vartheta$ , resp.



## OCL as Reflective Description of Certain Properties

- **invariants:**  $\mathcal{M} \models \vartheta$  iff.  $\forall \pi \in \llbracket \mathcal{M} \rrbracket \forall i \in \mathbb{N} : \pi^i \models \vartheta$ , ↖ the  $i$ -th  $(\sigma, \varepsilon)$ -pair in  $\pi$

- **non-reachability of configurations:**

$$\nexists \pi \in \llbracket \mathcal{M} \rrbracket \nexists i \in \mathbb{N} : \pi^i \models \vartheta$$

$$\iff \forall \pi \in \llbracket \mathcal{M} \rrbracket \forall i \in \mathbb{N} : \pi^i \models \neg \vartheta$$

- **reachability of configurations:**

$$\exists \pi \in \llbracket \mathcal{M} \rrbracket \exists i \in \mathbb{N} : \pi^i \models \vartheta$$

$$\iff \neg(\forall \pi \in \llbracket \mathcal{M} \rrbracket \forall i \in \mathbb{N} : \pi^i \models \neg \vartheta)$$

where

- $\vartheta$  is an OCL expression or an object diagram and
- “ $\models$ ” is the corresponding OCL satisfaction or the “is represented by object diagram” relation.

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## In General Not OCL: Temporal Properties

**Dynamic** (by example)

- **reactive behaviour**
  - “for each  $C$  instance, each reception of  $E$  is finally answered by  $F$ ”
$$\forall \pi \in \llbracket \mathcal{M} \rrbracket : \pi \models \vartheta$$

- **non-reachability** of system configuration sequences
  - “there mustn't be a system run where  $C$  first receives  $E$  and then sends  $F$ ”
$$\nexists \pi \in \llbracket \mathcal{M} \rrbracket : \pi \models \vartheta$$

- **reachability** of system configuration sequences
  - “there must be a system run where  $C$  first receives  $E$  and then sends  $F$ ”
$$\exists \pi \in \llbracket \mathcal{M} \rrbracket : \pi \models \vartheta$$

**But:** what is “ $\models$ ” and what is “ $\vartheta$ ”?

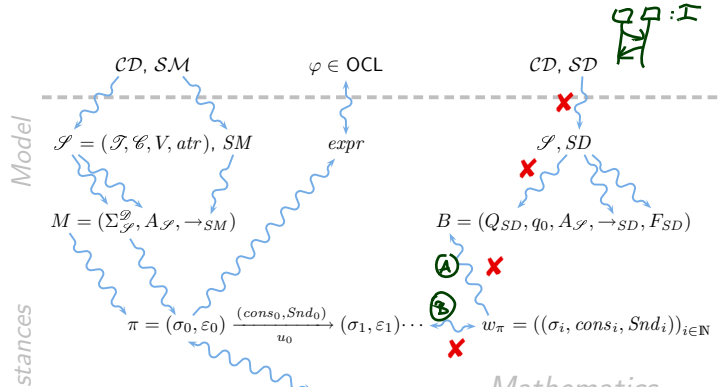
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## Interactions: Problem and Plan

In general:  $\forall(\exists) \pi \in \llbracket \mathcal{M} \rrbracket : \pi \models (\neq) \vartheta$   
 Problem: what is " $\models$ " and what is " $\vartheta$ "?

### Plan:

- Ⓐ • Define the **language**  $\mathcal{L}(\mathcal{I})$  of an **interaction**  $\mathcal{I}$  — via Büchi automata.
- Ⓑ • Define the **language**  $\mathcal{L}(\mathcal{M})$  of a **model**  $\mathcal{M}$  — basically its computations.  
 Each computation  $\pi \in \llbracket \mathcal{M} \rrbracket$  corresponds to a **word**  $w_\pi$ .
- Then (conceptually)  $\pi \models \vartheta$  if and only if  $w_\pi \in \mathcal{L}(\mathcal{I})$ .



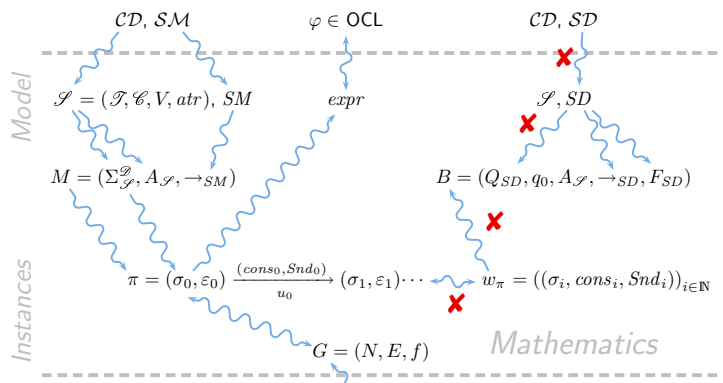
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## Interactions: Plan

- In the following, we consider **Sequence Diagrams** as **interaction**  $\mathcal{I}$ ,
- more precisely: **Live Sequence Charts** [Damm and Harel, 2001].
- We define the **language**  $\mathcal{L}(\mathcal{I})$  of an LSC — via Büchi automata.
- Then (conceptually)  $\pi \models \vartheta$  if and only if  $w_\pi \in \mathcal{L}(\mathcal{I})$ .

without "rectangles":

Why LSC, relation LSCs/UML SDs, other kinds of interactions: **later**.



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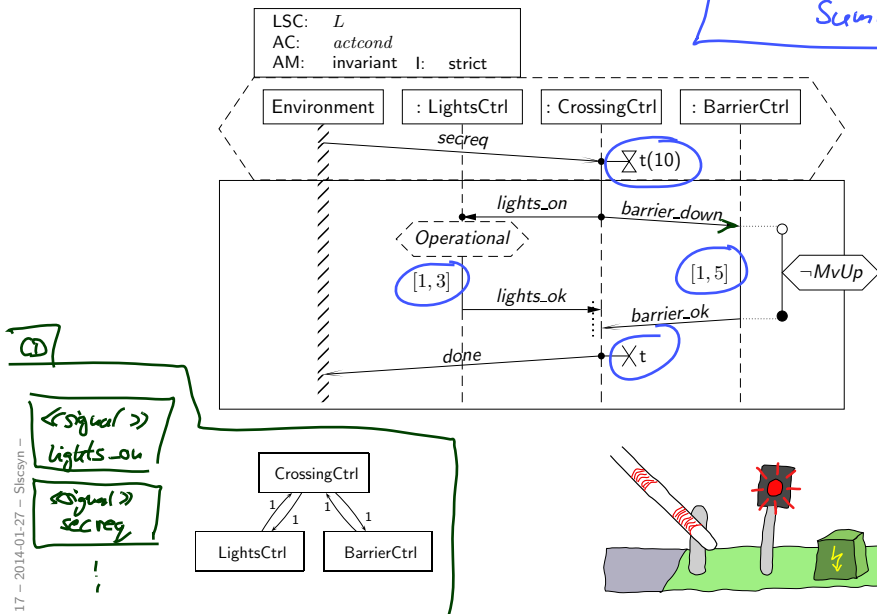
# Live Sequence Charts — Concrete Syntax

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## Example

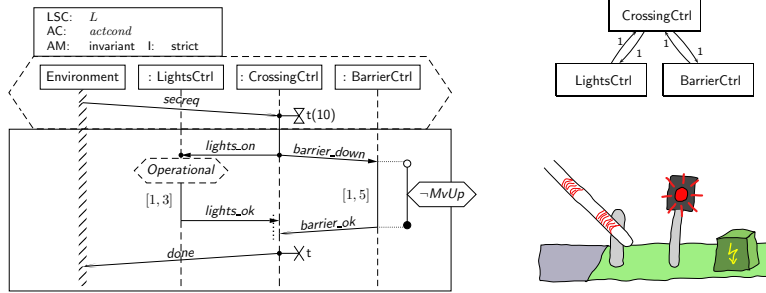
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## Example: What Is Required?

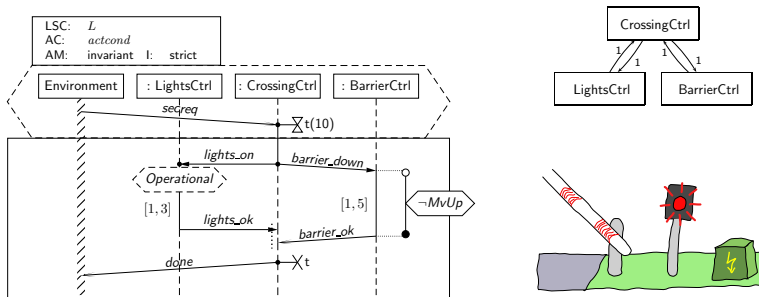


- **Whenever** the CrossingCtrl has consumed a 'secreq' event
- **then** it shall finally send 'lights\_on' and 'barrier\_down' to LightsCtrl and BarrierCtrl,
- if LightsCtrl **is not** 'operational' when receiving that event, the rest of this scenario doesn't apply; maybe there's another LSC for that case.
- if LightsCtrl **is** 'operational' when receiving that event, it shall reply with 'lights\_ok' within 1–3 time units,
- the BarrierCtrl shall reply with 'barrier\_ok' within 1–5 time units, during this time (dispatch time not included) it shall not be in state 'MvUp',
- 'lights\_ok' and 'barrier\_ok' may occur in any order.
- After having consumed both, CrossingCtrl may reply with 'done' to the environment.

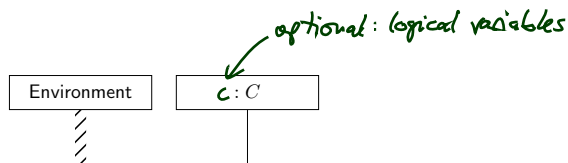
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## Building Blocks



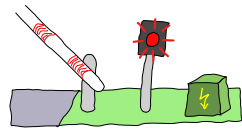
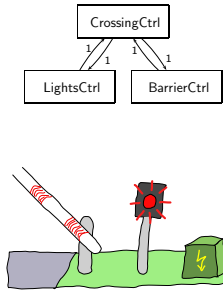
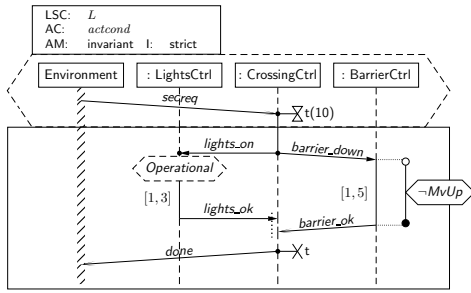
- **Instance Lines:**



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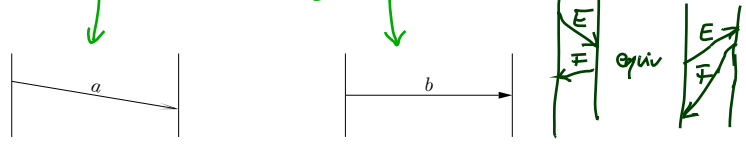
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# Building Blocks

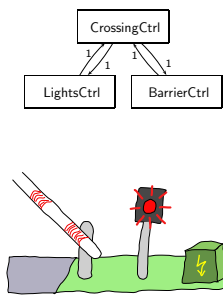
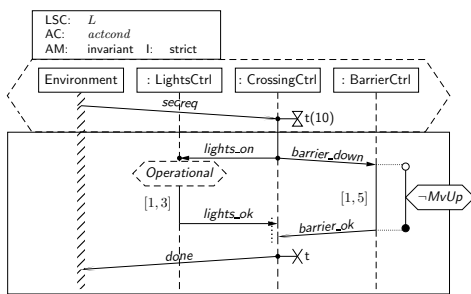


Note: angle of signal vsys. does not matter

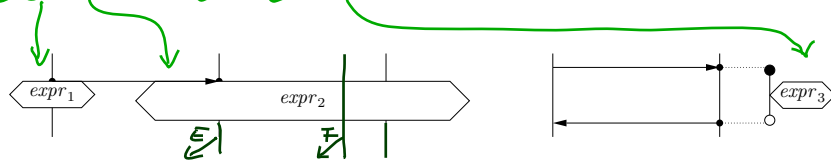
- Messages: (asynchronous or synchronous/instantaneous)



# Building Blocks

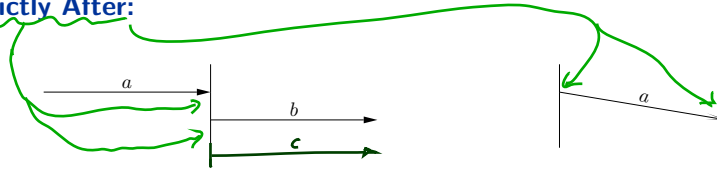


- Conditions and Local Invariants: ( $expr_1, expr_2, expr_3 \in Expr_{\mathcal{S}}$ )

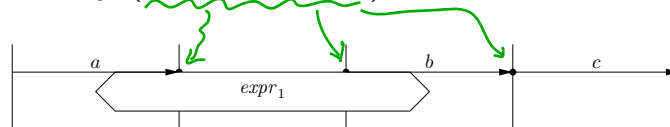


## Intuitive Semantics: A Partial Order on Simclasses

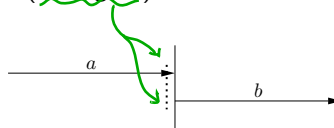
(i) **Strictly After:**



(ii) **Simultaneously:** (simultaneous region)



(iii) **Explicitly Unordered:** (co-region)



**Intuition:** A computation path **violates** an LSC if the occurrence of some events doesn't adhere to the partial order obtained as the **transitive closure** of (i) to (iii).

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## LSC Specialty: Modes

With LSCs,

- whole charts,
- locations, and
- elements

have a **mode** — one of **hot** or **cold** (graphically indicated by outline).

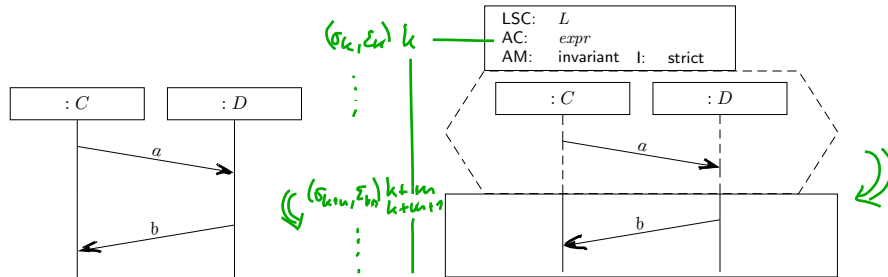
	chart	location	message	condition/ local inv.
<b>hot:</b>				
<b>cold:</b>				
	always vs. at least once	must vs. may progress	mustn't vs. may get lost	necessary vs. legal exit

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## LSC Specialty: Activation

One **major defect** of **MSCs and SDs**: they don't say **when** the scenario has to/may be observed.

**LSCs**: Activation condition ( $AC \in Expr_{\mathcal{S}}$ ), activation mode ( $AM \in \{init, inv\}$ ), and pre-chart.



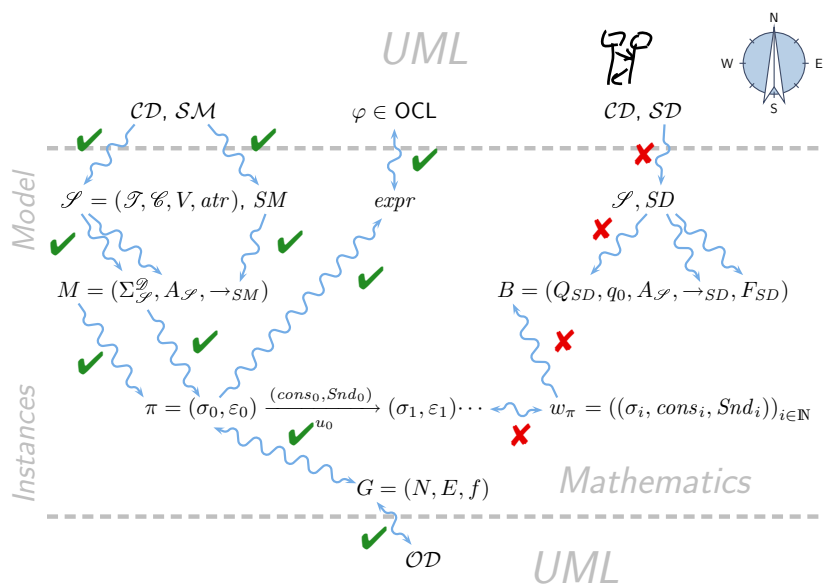
**Intuition:** (universal case)

- given a computation  $\pi$ , **whenever**  $expr$  holds in a configuration  $(\sigma_k, \epsilon_k)$  of  $\xi$ 
  - which is initial, i.e.  $k = 0$ , or ( $AM = initial$ )
  - whose  $k$  is not further restricted, ( $AM = invariant$ )
- and if** the pre-chart is observed from  $k$  to  $k + m$
- then** the main-chart has to follow from  $k + m + 1$ .

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## Course Map



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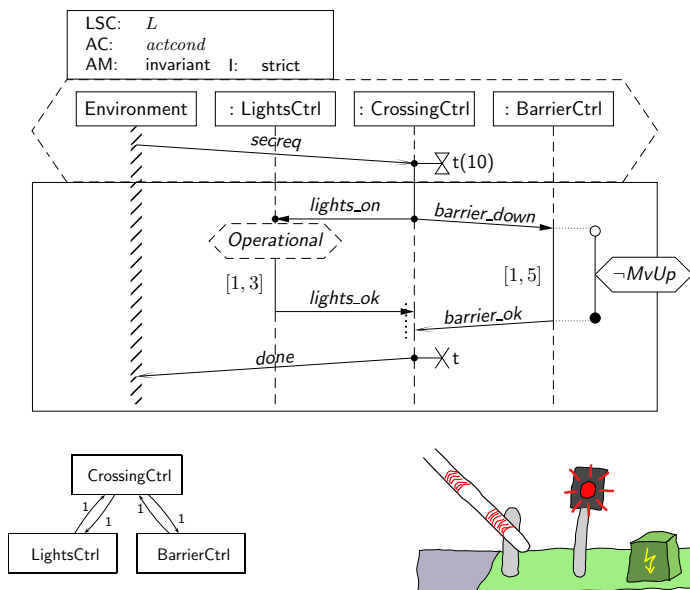
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# Live Sequence Charts — Abstract Syntax

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## Example



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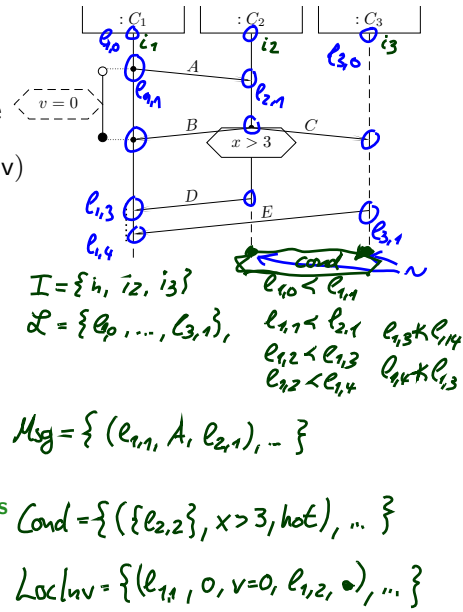


## LSC Body: Abstract Syntax

Let  $\Theta = \{\text{hot, cold}\}$ . An **LSC body** is a tuple

$$(I, (\mathcal{L}, \preceq), \sim, \mathcal{S}, \text{Msg}, \text{Cond}, \text{LocInv})$$

- $I$  is a finite set of **instance lines**,
- $(\mathcal{L}, \preceq)$  is a finite, non-empty, **partially ordered** set of **locations**; each  $l \in \mathcal{L}$  is associated with a temperature  $\theta(l) \in \Theta$  and an instance line  $i_l \in I$ ,
- $\sim \subseteq \mathcal{L} \times \mathcal{L}$  is an **equivalence relation** on locations, the **simultaneity** relation,
- $\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, \text{atr}, \mathcal{E})$  is a signature,
- $\text{Msg} \subseteq \mathcal{L} \times \mathcal{E} \times \mathcal{L}$  is a set of **asynchronous messages** with  $(l, b, l') \in \text{Msg}$  only if  $l \preceq l'$ ,  
**Not: instantaneous messages** — could be linked to method/operation calls.
- $\text{Cond} \subseteq (2^{\mathcal{L}} \setminus \emptyset) \times \text{Expr}_{\mathcal{S}} \times \Theta$  is a set of **conditions** where  $\text{Expr}_{\mathcal{S}}$  are OCL expressions over  $W = I \cup \{\text{self}\}$  with  $(L, \text{expr}, \theta) \in \text{Cond}$  only if  $l \sim l'$  for all  $l, l' \in L$ ,
- $\text{LocInv} \subseteq \mathcal{L} \times \{o, \bullet\} \times \text{Expr}_{\mathcal{S}} \times \Theta \times \mathcal{L} \times \{o, \bullet\}$  is a set of **local invariants**,



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## Well-Formedness

**Bondedness/no floating conditions:** (could be relaxed a little if we wanted to)

- For each location  $l \in \mathcal{L}$ , **if**  $l$  is the location of

- a **condition**, i.e.

$$\exists (L, \text{expr}, \theta) \in \text{Cond} : l \in L, \text{ or}$$

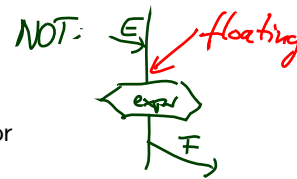
- a **local invariant**, i.e.

$$\exists (l_1, i_1, \text{expr}, \theta, l_2, i_2) \in \text{LocInv} : l \in \{l_1, l_2\}, \text{ or}$$

**then** there is a location  $l'$  **equivalent** to  $l$ , i.e.  $l \sim l'$ , which is the location of

- an **instance head**, i.e.  $l'$  is minimal wrt.  $\preceq$ , or
- a **message**, i.e.

$$\exists (l_1, b, l_2) \in \text{Msg} : l \in \{l_1, l_2\}.$$



**Note:** if messages in a chart are **cyclic**, then there doesn't exist a partial order (so such charts **don't even have** an abstract syntax).

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## References

## References

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