Software Design, Modelling and Analysis in UML

Lecture 12: Core State Machines II

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Contents & Goals

Last Lecture:

- State machine syntax
- Core state machines

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
  - What is: Signal, Event, Ether, Transformer, Step, RTC.
- **Content:**
  - The basic causality model
  - Ether
  - System Configuration, Transformer
  - Examples for transformer
  - Run-to-completion Step

Recall: Core State Machines

Recall: 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

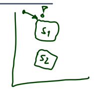
$$\to \subseteq S \times \underbrace{(\mathscr{E} \dot\cup \{\_\})}_{\text{trigger}} \times \underbrace{Expr_\mathscr{S}}_{\text{guard}} \times \underbrace{Act_\mathscr{S}}_{\text{action}} \times S$$

is a labelled transition relation.

We assume a set $Expr_\mathscr{S}$ of boolean expressions (may be OCL, may be something else) and a set $Act_\mathscr{S}$ of **actions** over $\mathscr{S}$.

From UML to Core State Machines: By Example

UML state machine diagram $\mathcal{SM}$:



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

with

- $event \in \mathscr{E}$, — if not given
- $guard \in Expr_\mathscr{S}$ (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

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

Annotations and Defaults in the Standard

Reconsider the syntax of transition annotations:

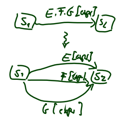
$$annot ::= [\ \langle event\rangle[\text{'.'}\ \langle event\rangle]^*\ \ [\text{'['}\ \langle guard\rangle\ \text{']'}]\ \ [\text{'/'}\ \langle action\rangle]\ \ ]$$

and let's play a bit with the defaults:

annotation		trigger	guard	action
(the empty annotation)	⇝	_	true	skip
/	⇝	_	true	skip
E /	⇝	E	true	skip
/ act	⇝	_	true	act
E / act	⇝	E	true	act
[expr]	⇝	_	expr	skip
[expr] / act	⇝	_	expr	act

$(s_1, \_, true, skip, s_2)$

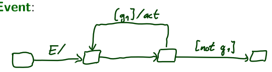
In the standard, the syntax is even more elaborate:



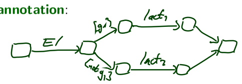
- $E(v)$ — when consuming E in object u, attribute v of u is assigned the corresponding attribute of E.
- $E(v : \tau)$ — similar, but v is a local variable, scope is the transition

What is that useful for?

- **No Event**:



- **No annotation**:



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

  If not explicitly given, then this one:

$$\mathcal{SM}_0 := (\{s_0\}, s_0, \emptyset).$$

  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 C executes $\mathcal{SM}_C$ with own "program counter".

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.)

The Basic Causality Model

6.2.3 The Basic Causality Model [?, 12]

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

The causality model is quite straightforward:

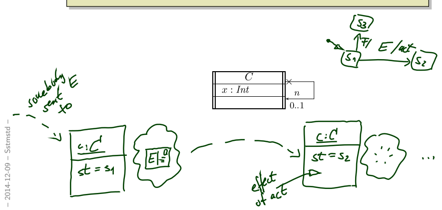
- *Objects respond to **messages** that are generated by objects executing communication actions.*
- *When these messages arrive, the receiving objects eventually respond by executing the behavior that is **matched** to that message.*
- *The dispatching method by which a particular behavior is associated 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).

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."

6.2.3 The Basic Causality Model [?, 12]

- *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.*

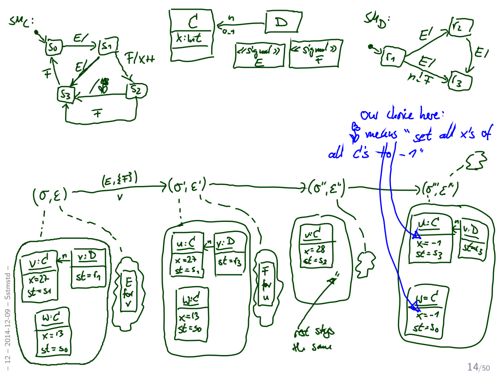


15.3.12 StateMachine [?, 563]

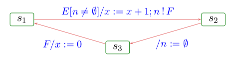
- Event occurrences are detected, dispatched, and then processed by the state machine, one at a time.
- The semantics of event occurrence processing is based on the **run-to- completion assumption**, interpreted as **run-to-completion processing**.
- **Run-to-completion processing** means that an event [...] can only be taken from the pool and dispatched if the processing of the previous [...] is fully completed.
- The processing of a single event occurrence by a state machine is known as a **run-to-completion step**.
- Before commencing on a **run-to-completion step**, a state machine is in a **stable state** configuration with all entry/exit/internal-activities (but not necessarily do-activities) completed.
- The same conditions apply after the **run-to-completion step** is completed.
- Thus, an event occurrence will never be processed [...] in some intermediate and inconsistent situation.
- [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**.

15.3.12 StateMachine [?, 563]

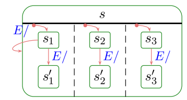
- The order of dequeuing is **not defined**, leaving open the possibility of modeling different priority-based schemes.
- Run-to-completion may be implemented in **various ways**. [...]



And?



- ...:
  - We have to formally define what **event occurrence** is.
  - We have to define where events **are stored** – what the event pool is.
  - We have to explain how **transitions are chosen** – "matching".
  - We have to explain what the **effect of actions** is – on state and event pool.
  - We have to decide on the **granularity** — micro-steps, steps, run-to-completion steps (aka. super-steps)?
  - We have to formally define a notion of **stability** and RTC-step **completion**.
  - And then: hierarchical state machines.



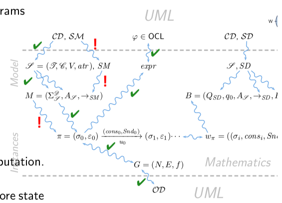
Roadmap: Chronologically

(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**.



System Configuration, Ether, Transformer

Ether aka. Event Pool

Definition. Let $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr, \mathscr{E})$ be a signature with signals and $\mathscr{D}$ a structure.

We call a tuple $(Eth, ready, \oplus, \ominus, [\cdot])$ an **ether** over $\mathscr{S}$ and $\mathscr{D}$ if and only if it provides

- a **ready** operation which yields a set of events that are ready for a given object, i.e.
$$ready : Eth \times \mathscr{D}(\mathscr{C}) \to 2^{\mathscr{D}(\mathscr{E})}$$
- a operation to **insert** an event destined for a given object, i.e.
$$\oplus : Eth \times \mathscr{D}(\mathscr{C}) \times \mathscr{D}(\mathscr{E}) \to Eth$$
- a operation to **remove** an event, i.e.
$$\ominus : Eth \times \mathscr{D}(\mathscr{E}) \to Eth$$
- an operation to clear the ether for a given object, i.e.
$$[\cdot] : Eth \times \mathscr{D}(\mathscr{C}) \to Eth.$$

Ether: Examples

- A (single, global, shared, reliable) FIFO queue is an ether:
  - $Eth = (\mathcal{D}(\mathcal{C}) \times \mathcal{D}(\mathcal{E}))^*$ e.g. $\varepsilon = (v, e_1), (v, f_1), (u, e_2)$
    the set of all finite sequences of pairs $(u,e) \in \mathcal{D}(\mathcal{C}) \times \mathcal{D}(\mathcal{E})$
  - $ready((u,e).\varepsilon, v) = \begin{cases} \{(u,e)\} & \text{if } v = u \\ \emptyset & \text{otherwise} \end{cases}$ $ready(\epsilon, v) = \emptyset$
  - $\oplus(\varepsilon, u, e) = \varepsilon . (u,e)$
  - $\ominus((u,e).\varepsilon, f) = \begin{cases} \varepsilon & \text{if } f = e \\ (u,e).\varepsilon & \text{otherwise} \end{cases}$ $\ominus(\epsilon, f) = \epsilon$ (empty seq.)
  - $[\cdot]$: remove all (u,e) pairs from a given sequence
- One FIFO queue per active object is an ether.
- Lossy queue ($\oplus$ becomes a relation then).
- One-place buffer.
- Priority queue.
- Multi-queues (one per sender).
- Trivial example: sink, "black hole".
- ...

15.3.12 StateMachine [?, 563]

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