Software Design, Modelling and Analysis in UML

Lecture 12: Core State Machines III

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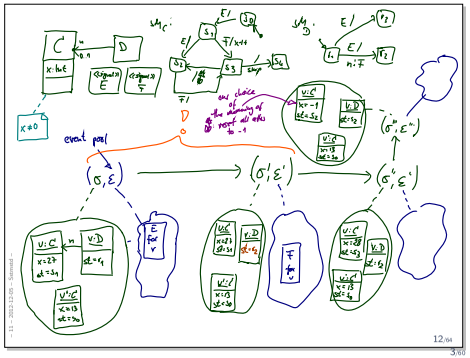
Contents & Goals

Last Lecture:

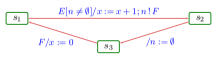
- The basic causality model
- Ether

This Lecture:

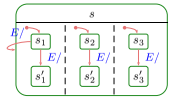
- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
  - What is: Signal, Event, Ether, Transformer, Step, RTC.
- **Content:**
  - System Configuration, Transformer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



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**.

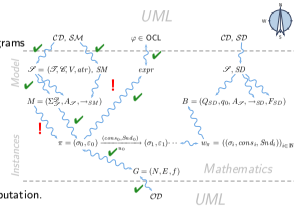
(viii) Def.: **Transformer**.

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

(x) Transition relation induced by core state machine.

(xi) Def.: **step**, **run-to-completion step**.

(xii) Later: Hierarchical state machines.



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 ~~structure~~ $(Eth, ready, \oplus, \ominus, [\cdot])$ 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.
$$[\cdot] : Eth \times \mathscr{D}(\mathscr{C}) \to Eth.$$

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Ether and [OMG, 2007b]

The standard distinguishes (among others)

- **SignalEvent** [OMG, 2007b, 450] and **Reception** [OMG, 2007b, 447].

On **SignalEvents**, it says

> *A signal event represents the receipt of an asynchronous signal instance. A signal event may, for example, cause a state machine to trigger a transition.* [OMG, 2007b, 449]
> [...]
> **Semantic Variation Points**
> *The means by which requests are transported to their target depend on the type of requesting action, the target, the properties of the communication medium, and numerous other factors.*
> *In some cases, this is instantaneous and completely reliable while in others it may involve transmission delays of variable duration, loss of requests, reordering, or duplication.*
> *(See also the discussion on page 421.)* [OMG, 2007b, 450]

Our **ether** is a general representation of the possible choices.

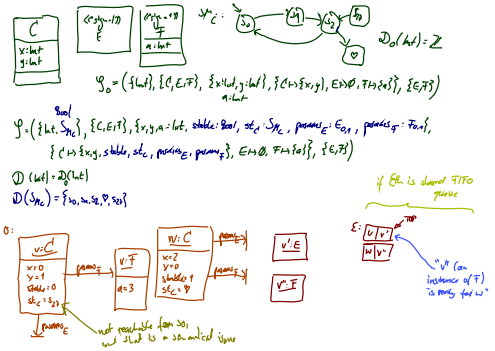
Often seen minimal requirement: order of sending **by one object** is preserved.
But: we'll later briefly discuss "discarding" of events.

System Configuration

Definition. Let $\mathscr{S}_0 = (\mathscr{T}_0, \mathscr{C}_0, V_0, atr_0, \mathscr{E})$ be a signature with signals, $\mathscr{D}_0$ a structure of $\mathscr{S}_0$, $(Eth, ready, \oplus, \ominus, [\cdot])$ an ether over $\mathscr{S}_0$ and $\mathscr{D}_0$. Furthermore assume there is one core state machine M_C per class $C \in \mathscr{C}$.

A system configuration over $\mathscr{S}_0$, $\mathscr{D}_0$, and Eth is a pair
$$(\sigma, \varepsilon) \in \Sigma^{\mathscr{D}}_{\mathscr{S}} \times Eth$$
where

- $\mathscr{S} = (\mathscr{T}_0 \dot\cup \{S_{M_C} \mid C \in \mathscr{C}\},\quad \mathscr{C}_0,$
$V_0 \dot\cup \{\langle stable : Bool, -, \mathsf{true}, \emptyset\rangle\}$
$\dot\cup \{\langle st_C : S_{M_C}, +, s_0, \emptyset\rangle \mid C \in \mathscr{C}\}$
$\dot\cup \{\langle params_E : E_{0,1}, +, \emptyset, \emptyset\rangle \mid E \in \mathscr{E}_0\},$
$\{C \mapsto atr_0(C)$
$\cup \{stable, st_C\} \cup \{params_E \mid E \in \mathscr{E}_0\} \mid C \in \mathscr{C}\},\quad \mathscr{E}_0)$
- $\mathscr{D} = \mathscr{D}_0 \dot\cup \{S_{M_C} \mapsto S(M_C) \mid C \in \mathscr{C}\}$, and
- $\sigma(u)(r) \cap \mathscr{D}(\mathscr{E}_0) = \emptyset$ for each $u \in \mathrm{dom}(\sigma)$ and $r \in V_{0,\tau_0}$



System Configuration Step-by-Step

- We start with some signature with signals $\mathscr{S}_0 = (\mathscr{T}_0, \mathscr{C}_0, V_0, atr_0, \mathscr{E})$.
- A **system configuration** is a pair (σ, ε) which comprises a system state σ wrt. $\mathscr{S}$ (not wrt. $\mathscr{S}_0$).
- Such a **system state** σ wrt. $\mathscr{S}$ provides, for each object $u \in \mathrm{dom}(\sigma)$,
  - values for the **explicit attributes** in V_0,
  - values for a number of **implicit attributes**, namely
    - a **stability flag**, i.e. $\sigma(u)(stable)$ is a boolean value,
    - a **current (state machine) state**, i.e. $\sigma(u)(st)$ denotes one of the states of core state machine M_C,
    - a temporary association to access **event parameters** for each class, i.e. $\sigma(u)(params_E)$ is defined for each $E \in \mathscr{E}$.
- For convenience require: there is **no link to an event** except for $params_E$.

Stability

Definition.
Let (σ, ε) be a system configuration over some $\mathscr{S}_0$, $\mathscr{D}_0$, Eth.

We call an object $u \in \mathrm{dom}(\sigma) \cap \mathscr{D}(\mathscr{C}_0)$ stable in σ if and only if
$$\sigma(u)(stable) = \mathsf{true}.$$

Events Are Instances of Signals

Definition. Let $\mathscr{D}_0$ be a structure of the signature with signals $\mathscr{S}_0 = (\mathscr{T}_0, \mathscr{C}_0, V_0, atr_0, \mathscr{E})$ and let $E \in \mathscr{E}_0$ be a **signal**.

Let $atr(E) = \{v_1, \ldots, v_n\}$. We call

$$e = (E, \{v_1 \mapsto d_1, \ldots, v_n \mapsto d_n\}),$$

or shorter (if mapping is clear from context)

$$(E, (d_1, \ldots, d_n)) \text{ or } (E, \vec{d}),$$

an event (or an instance) of signal E (if type-consistent).

We use $Evs(\mathscr{E}_0, \mathscr{D}_0)$ to denote the set of all events of all signals in $\mathscr{S}_0$ wrt. $\mathscr{D}_0$.

As we always try to maximize confusion...:

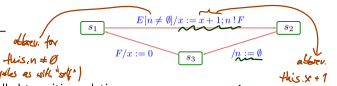
- By our existing naming convention, $u \in \mathscr{D}(E)$ is also called **instance** of the (signal) class E in system configuration (σ, ε) if $u \in \mathrm{dom}(\sigma)$.
- The corresponding event is then $(E, \sigma(u))$.

Signals? Events...? Ether...?!

The idea is the following:

- **Signals** are **types** (classes).
- **Instances of signals** (in the standard sense) are kept in the **system state** component σ of system configurations (σ, ε).
- **Identities** of signal instances are kept in the **ether**.
- Each signal instance is in particular an **event** — somehow "a recording that this signal occurred" (without caring for its identity)
- The main difference between **signal instance** and **event**:
  Events don't have an identity.
- Why is this useful? In particular for **reflective** descriptions of behaviour, we are typically not interested in the identity of a signal instance, but only whether it is an "E" or "F", and which parameters it carries.

Where are we?



- **Wanted**: a labelled transition relation

$$(\sigma, \varepsilon) \xrightarrow{(cons, Snd)} (\sigma', \varepsilon')$$

  on system configuration, labelled with the **consumed and sent** events, (σ', ε') being the result (or effect) of **one object** u_x taking a transition of **its** state machine from the current state mach. state $\sigma(u_x)(st_C)$.

- **Have**: system configuration (σ, ε) comprising current state machine state and stability flag for each object, and the ether.
- **Plan**:
  (i) Introduce **transformer** as the semantics of action annotions.
  Intuitively, (σ', ε') is the effect of applying the transformer of the taken transition.
  (ii) Explain how to choose transitions depending on ε and when to stop taking transitions — the **run-to-completion "algorithm"**.

Transformer

Definition.
Let $\Sigma^{\mathscr{D}}_{\mathscr{S}}$ the set of system configurations over some $\mathscr{S}_0, \mathscr{D}_0, Eth$.

We call a relation

$$t \subseteq \mathscr{D}(\mathscr{C}) \times (\Sigma^{\mathscr{D}}_{\mathscr{S}} \times Eth) \times (\Sigma^{\mathscr{D}}_{\mathscr{S}} \times Eth)$$

a (system configuration) **transformer**.

- In the following, we assume that each application of a transformer t to some system configuration (σ, ε) for object u_x is associated with a set of **observations**

$$Obs_t[u_x](\sigma, \varepsilon) \in 2^{\mathscr{D}(\mathscr{C}) \times (\mathscr{D}(\mathscr{E}) \times Evs(\mathscr{E} \cup \{*, \dagger\}, \mathscr{D}) \times \mathscr{D}(\mathscr{C}))}.$$

- An observation $(u_{src}, u_x, (E, \vec{d}), u_{dst}) \in Obs_t[u_x](\sigma, \varepsilon)$ represents the information that, as a "side effect" of u_x executing t, an event (!) $(E, \vec{d})$ has been sent from u_{src} to u_{dst}.

  Special cases: creation/destruction.

Why Transformers?

- **Recall** the (simplified) syntax of transition annotations:

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

- **Clear**: $\langle event \rangle$ is from $\mathscr{E}$ of the corresponding signature.
- **But:** What are $\langle guard \rangle$ and $\langle action \rangle$?
  - UML can be viewed as being **parameterized** in **expression language** (providing $\langle guard \rangle$) and **action language** (providing $\langle action \rangle$).
  - **Examples**:
    - **Expression Language**:
      · OCL
      · Java, C++, ... expressions
      · ...
    - **Action Language**:
      · UML Action Semantics, "Executable UML"
      · Java, C++, ... statements (plus some event send action)
      · ...

In the following, we consider:

$ActExp := \{\text{skip}\}$
$\cup \{\text{update}(exp_1, v, exp_2) \mid exp_1, exp_2 \in OCLExp,\ v \in V\}$
$\cup \{\text{send}(exp_1, E, exp_2) \mid exp_1, exp_2 \in OCLExp,\ E \in \mathscr{E}\}$
$\cup \{\text{create}(C, exp, v) \mid exp \in OCLExp,\ C \in \mathscr{C},\ v \in V\}$
$\cup \{\text{destroy}(exp) \mid exp \in OCLExp\}$

Expty: OCL expressions over $\mathscr{S}$

Transformers as Abstract Actions!

In the following, we assume that we're **given**

- an **expression language** $Expr$ for guards, and
- an **action language** Act for actions,

and that we're **given**

- a **semantics** for boolean expressions in form of a partial function

$$I[\![\cdot]\!](\,\cdot\,,\,\cdot\,) : Expr \rightarrow ((\Sigma^{\mathscr{D}}_{\mathscr{S}} \times (\{\text{this}\} \rightarrow \mathscr{D}(\mathscr{C}))) \rightharpoonup \mathbb{B})$$

which evaluates expressions in a given system configuration,

Assuming I to be partial is a way to treat "undefined" during runtime. If I is not defined (for instance because of dangling-reference navigation or division-by-zero), we want to go to a designated "error" system configuration.

- a **transformer** for each action: for each $act \in Act$, we assume to have

$$t_{act} \subseteq \mathscr{D}(\mathscr{C}) \times (\Sigma^{\mathscr{D}}_{\mathscr{S}} \times Eth) \times (\Sigma^{\mathscr{D}}_{\mathscr{S}} \times Eth)$$

Expression/Action Language Examples

We can make the assumptions from the previous slide because **instances exist**:

- for OCL, we have the OCL semantics from Lecture 03. Simply remove the pre-images which map to "$\bot$".
- for Java, the operational semantics of the SWT lecture uniquely defines transformers for sequences of Java statements.

We distinguish the following kinds of transformers:

- **skip**: do nothing — recall: this is the default action
- **send**: modifies ε — interesting, because state machines are built around sending/consuming events
- **create**/**destroy**: modify domain of σ — not specific to state machines, but let's discuss them here as we're at it
- **update**: modify own or other objects' local state — boring

Transformer Examples: Presentation

abstract syntax	concrete syntax
op	
intuitive semantics	
...	
well-typedness	
...	
semantics	
$((\sigma,\varepsilon),(\sigma',\varepsilon')) \in t_{\text{op}}[u_x]$ iff ...	
or	
$t_{\text{op}}[u_x](\sigma,\varepsilon) = \{(\sigma',\varepsilon')\}$ where ...	
observables	
$Obs_{\text{op}}[u_x] = \{\ldots\}$, not a relation, depends on choice	
(error) conditions	
Not defined if ...	

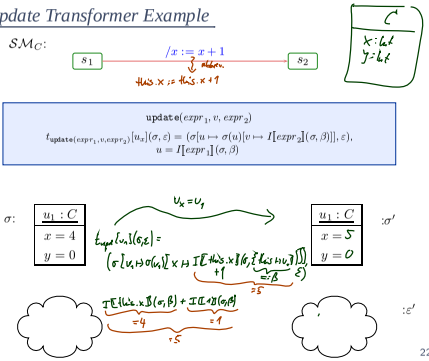
Transformer: Skip

abstract syntax	concrete syntax
skip	skip
intuitive semantics	
do nothing	
well-typedness	
$./.$	
semantics	
$t[u_x](\sigma,\varepsilon) = \{(\sigma,\varepsilon)\}$	
observables	
$Obs_{\text{skip}}[u_x](\sigma,\varepsilon) = \emptyset$	
(error) conditions	

Transformer: Update

abstract syntax	concrete syntax
update$(expr_1, v, expr_2)$	$expr_1.v := expr_2$
intuitive semantics	
Update attribute v in the object denoted by $expr_1$ to the value denoted by $expr_2$.	
well-typedness	
$expr_1 : \tau_C$ and $v : \tau \in atr(C)$; $expr_2 : \tau$; $expr_1, expr_2$ obey visibility and navigability	
semantics	
$t_{\text{update}(expr_1,v,expr_2)}[u_x](\sigma,\varepsilon) = \{(\sigma',\varepsilon)\}$	
where $\sigma' = \sigma[u \mapsto \sigma(u)[v \mapsto I[\![expr_2]\!](\sigma,\beta)]]$ with $u = I[\![expr_1]\!](\sigma,\beta), \beta = \{\text{this} \mapsto u_x\}$.	
observables	
$Obs_{\text{update}(expr_1,v,expr_2)}[u_x] = \emptyset$	
(error) conditions	
Not defined if $I[\![expr_1]\!](\sigma,\beta)$ or $I[\![expr_2]\!](\sigma,\beta)$ not defined.	

Update Transformer Example



References

References

[Harel and Gery, 1997] Harel, D. and Gery, E. (1997). Executable object modeling with statecharts. *IEEE Computer*, 30(7):31–42.

[OMG, 2007a] OMG (2007a). Unified modeling language: Infrastructure, version 2.1.2. Technical Report formal/07-11-04.

[OMG, 2007b] OMG (2007b). Unified modeling language: Superstructure, version 2.1.2. Technical Report formal/07-11-02.

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