Software Design, Modelling and Analysis in UML

Lecture 16: Hierarchical State Machines II

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Contents & Goals

Last Lecture:

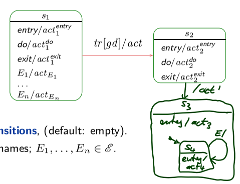
- Legal state configurations
- Legal transitions
- Rules (i) to (v) for hierarchical state machines

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - How do entry / exit actions work? What about do-actions?
  - What is the effect of shallow / deep history pseudo-states?
  - What about junction, choice, terminate, etc.?
  - What is the idea of deferred events?
  - How are passive reactive objects treated in Rhapsody's UML semantics?
  - What about methods?
- **Content:**
  - Entry / exit / do actions, internal transitions
  - Remaining pseudo-states; deferred events
  - Passive reactive objects
  - Behavioural features

Entry and Exit Actions

Entry/Do/Exit Actions



- In general, with each state $s \in S$ there is associated
  - an **entry**, a **do**, and an **exit** action (default: **skip**)
  - a possibly empty set of trigger/action pairs called **internal transitions**, (default: empty).
    Note: 'entry', 'do', 'exit' are reserved names; $E_1, \dots, E_n \in \mathscr{E}$.
- **Recall**: each action is supposed to have a transformer; assume $t_{act_1^{entry}}$, $t_{act_1^{exit}}$, ...
- Taking the transition above then amounts to applying

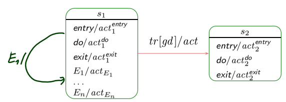
$$t_{act_2^{entry}} \circ t_{act} \circ t_{act_1^{exit}}$$

instead of just

$$t_{act}$$

$\rightsquigarrow$ adjust Rules (ii), (iii), and (v) accordingly.

Internal Transitions



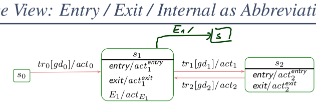
- Taking an **internal transition**, e.g. on E_1, only executes $t_{act_{E_1}}$.
- **Intuition**: The state is neither left nor entered, so: no exit, no entry action.
- **Note**: internal transitions also start a run-to-completion step.

$\rightsquigarrow$ adjust Rules (i), (ii), and (v) accordingly.

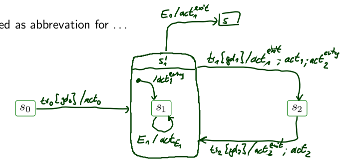
Note: the standard seems not to clarify whether internal transitions have **priority** over regular transitions with the same trigger at the same state.

Some code generators assume that internal transitions have priority!

Alternative View: Entry / Exit / Internal as Abbreviations

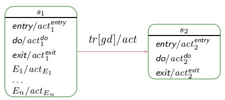


Can be viewed as abbrevation for ...



- **That is**: Entry / Internal / Exit don't add expressive power to Core State Machines.
  If internal actions should have priority, s_1 can be embedded into an OR-state.
- Abbreviation view may avoid confusion in context of hierarchical states.

Do Actions

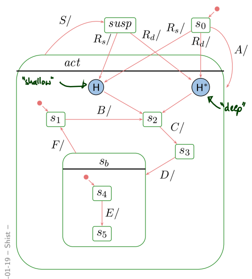


- **Intuition**: after entering a state, start its do-action.
- If the do-action terminates,
  - then the state is considered **completed** (like **final state**),
- otherwise,
  - if the state is left before termination, the do-action is stopped.
- Recall the overall UML State Machine philosophy:

  "An object is either idle or doing a run-to-completion step."
- Now, what is it exactly while the do action is executing...?

The Concept of History, and Other Pseudo-States

History and Deep History: By Example

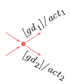


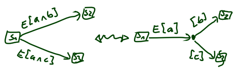
What happens on...

- R_s?
  s_0, s_2
- R_d?
  s_0, s_2
- A, B, C, S, R_s?
  $s_0, s_1, s_2, s_3, susp, s_3$
- A, B, C, S, R_d?
  $s_0, s_1, s_2, s_3, susp, s_3$
  $st = \{top, act, s_b, s_5\}$
- A, B, C, D, E, S, R_s?
  $s_0, s_1, s_2, s_3, s_4, s_5, susp, s_4$
- A, B, C, D, E, S, R_d?
  $s_0, s_1, s_2, s_3, s_4, s_5, susp, s_5$

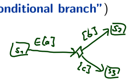
Junction and Choice

- Junction (**"static conditional branch"**):



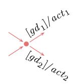


- Choice: (**"dynamic conditional branch"**)



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

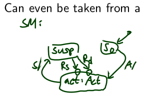


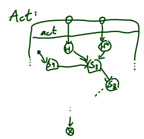
- Choice: (**"dynamic conditional branch"**)
  - **evil**: may get stuck
  - enters the transition **without knowing** whether there's an enabled path
  - at best, use "else" and convince yourself that it cannot get stuck
  - maybe even better: **avoid**

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 and Exit Point, Submachine State, Terminate

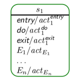
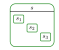
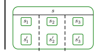
- Hierarchical states can be **"folded"** for readability.
  (but: this can also hinder readability.)
- Can even be taken from a different state-machine for re-use. $S : s$
- **Entry/exit points** ○ ⊗
  - Provide connection points for finer integration into the current level, than just via initial state.
  - 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**

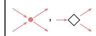
  - When a terminate pseudo-state is reached, the object taking the transition is immediately killed.

Are We Done?

The Full Story

UML distinguishes the following **kinds of states**:

	example
simple state	
final state	◉
composite state	
OR	
AND	

	example
pseudo-state	
initial	●
(shallow) history	(H)
deep history	(H*)
fork/join	
junction, choice	
entry point	○
exit point	⊗
terminate	×
submachine state	$S : s$

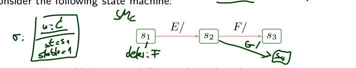
Deferred Events in State-Machines

Deferred Events: Idea

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 our course**, F is **discarded**.
- But we **may** find it a pity to discard the poor event and we **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 Rule (i) (discard) would apply,
  - **but** 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 ε) or into the local state of the object (= extend σ))
  - 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.

Active and Passive Objects

What about non-Active Objects?

Recall:

- We're **still** working under the assumption that all classes in the class diagram (and thus all objects) are **active**.
- That is, each object has its own thread of control and is (if stable) at any time ready to process an event from the ether.
  → steps of active objects can **interleave**.

But the world doesn't consist of only active objects.

For instance, ~~in the crossing controller from the exercises~~ we could wish to have the whole system live in one thread of control.

So we have to address questions like:

- Can we send events to a non-active object?
- And if so, when are these events processed?
- etc.

Active and Passive Objects: Nomenclature

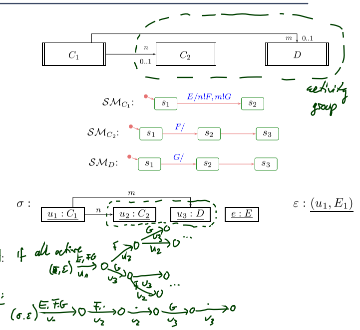
Harel and Gery (1997) propose the following (**orthogonal!**) notions:

- A class (and thus the instances of this class) is either **active** or **passive** as defined by the class diagram.
  - An **active** object has (in the operating system sense) an own thread: an own program counter, an own stack, etc.
  - A **passive** object doesn't.
- A class is either **reactive** or **non-reactive**.
  - A **reactive** class has a (non-trivial) state machine.
  - A **non-reactive** one hasn't.

Which combinations do we (not) understand yet?

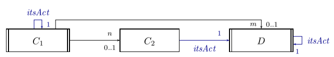
	active	passive
reactive	✓	!
non-reactive	(✓)	(✓)

Passive and Reactive / Rhapsody Style: Example



Passive Reactive / Rhapsody Style

- In each class, add (implicit) link $itsAct$ and use it to make each object u **know the active object** u_a which is responsible for dispatching events to u.
  If u is an instance of an active class, then $u_a = u$.



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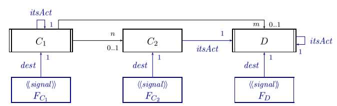
  If u is an instance of an active class, then $u_a = u$.
- Equip all signals with (implicit) association $dest$ and use it to point to the destination object.
  For each signal F, have a version F_C with an association $dest : C_{0,1}$, $C \in \mathscr{C}$ (no inheritance yet).



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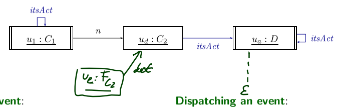

Sending an event:

- $n!F$ in $u_1 : C_1$ becomes:
- Create an instance u_e of F_{C_2} and set u_e's $dest$ to $u_d := \sigma(u_1)(n)$.
- Send to $u_a := \sigma(\sigma(u_1)(n))(itsAct)$, i.e., $\varepsilon' = \varepsilon \oplus (u_a, u_e)$.

Dispatching an event:

- Observation: the ether only has events for active objects.
- Say u_e is ready in the ether for u_a.
- Then u_a asks $\sigma(u_e)(dest) = u_d$ to process u_e — and waits until completion of corresponding RTC.
- u_d may in particular discard event.

Discussion

Semantic Variation Points

Pessimistic view: They are legion...

- **For instance,**
  - allow **absence of initial pseudo-states**
    object may then "be" in enclosing state without being in any substate;
    or assume one of the children states non-deterministically
  - (implicitly) **enforce determinism**, e.g.
    by considering the order in which things have been added to the CASE tool's repository,
    or some graphical order (left to right, top to bottom)
  - allow **true concurrency**
  - etc. etc.

  Exercise: Search the standard for "semantical variation point".

Optimistic view: tools exist with complete and consistent code generation.

- Crane and Dingel (2007), e.g., provide an in-depth comparison of Statemate, UML, and Rhapsody state machines — the bottom line is:
  - **the intersection is not empty**
    (i.e. there are pictures that mean the same thing to all three communities)
  - **none is the subset of another**
    (i.e. for each pair of communities exist pictures meaning different things)

And What About Methods?

And What About Methods?

- In the current setting, the (local) state of objects is **only** modified by actions of transitions, which we abstract to transformers.
- In general, there are also **methods**.
- UML follows an approach to separate
  - the **interface declaration** from
  - the **implementation**.

  In C++-lingo: distinguish **declaration** and **definition** of method.
- In UML, the former is called **behavioural feature** and can (roughly) be
  - a **call interface** $f(T_{1_1}, \ldots, T_{n_1}) : T_1$
  - a **signal name** E

C
$\xi_1\ f(T_{1,1}, \ldots, T_{1,n_1}) : T_1\ P_1$ $\xi_2\ F(T_{2,1}, \ldots, T_{2,n_2}) : T_2\ P_2$
$\langle\langle signal \rangle\rangle\ E$

Note: The signal list can be seen as redundant (can be looked up in the state machine) of the class. But: certainly useful for documentation (or sanity check).

Behavioural Features

C
$\xi_1\ f(T_{1,1}, \ldots, T_{1,n_1}) : T_1\ P_1$ $\xi_2\ F(T_{2,1}, \ldots, T_{2,n_2}) : T_2\ P_2$
$\langle\langle signal \rangle\rangle\ E$

Semantics:

- The **implementation** of a behavioural feature can be provided by:
  - An **operation**.

    In our setting, we simply assume a transformer like T_f.

    It is then, e.g. clear how to admit method calls as actions on transitions: function composition of transformers (clear but tedious: non-termination).

    In a setting with Java as action language: operation is a method body.
  - The class' **state-machine** ("triggered operation").
    - Calling F with n_2 parameters for a stable instance of C creates an auxiliary event F and dispatches it (bypassing the ether).
    - Transition actions may fill in the return value.
    - On completion of the RTC step, the call returns.
    - For a non-stable instance, the caller blocks until stability is reached again.

Behavioural Features: Visibility and Properties

C
$\xi_1\ f(T_{1,1},\ldots,T_{1,n_1}) : T_1\ P_1$ $\xi_2\ F(T_{2,1},\ldots,T_{2,n_2}) : T_2\ P_2$
$\langle\langle signal \rangle\rangle\ E$

- **Visibility**:
  - Extend typing rules to sequences of actions such that a well-typed action sequence only calls visible methods.
- **Useful properties**:
  - **concurrency**
    - **concurrent** — is thread safe
    - **guarded** — some mechanism ensures/should ensure mutual exclusion
    - **sequential** — is not thread safe, users have to ensure mutual exclusion
  - **isQuery** — doesn't modify the state space (thus thread safe)
- For simplicity, we leave the notion of steps untouched, we construct our semantics around state machines. Yet we could explain pre/post in OCL (if we wanted to).

References

References

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