# *Software Design, Modelling and Analysis in UML*

## *Lecture 15: Hierarchical State Machines III*

*2012-01-18*

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

Albert-Ludwigs-Universität Freiburg, Germany

# Contents & Goals

**Last Lecture:**

- Hierarchical State Machines: partial order, "lca", orthogonality, ...

**This Lecture:**

- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this **hierarchical** State Machine mean? What **may happen** if I inject this event?
  - What is: AND-State, OR-State, pseudo-state, entry/exit/do, final state, ...
- **Content:**
  - Legal Transitions
  - Exit/Entry, internal transitions
  - History and others
  - Rhapsody Demo

# *Composite States*

*(formalisation follows [Damm et al., 2003])*

# *Legal Transitions*

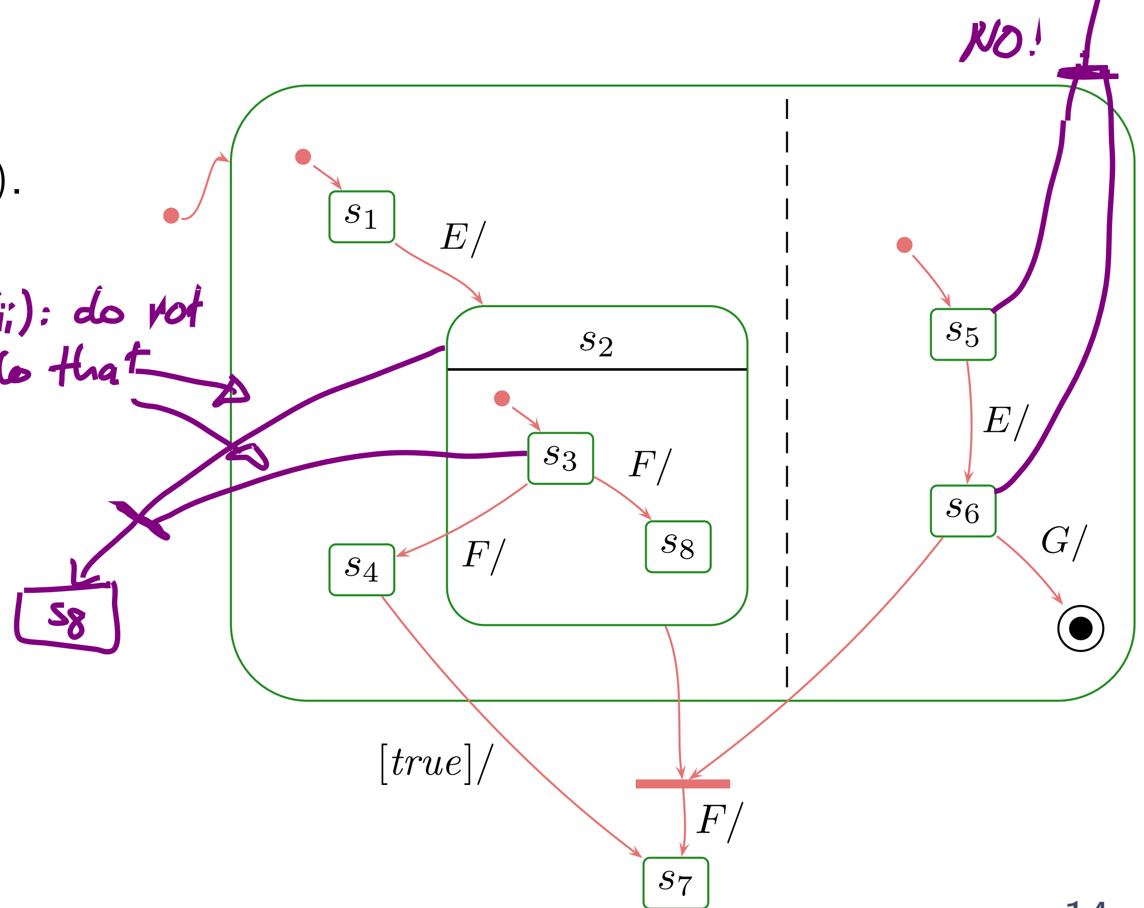
A hiearchical state-machine $(S, kind, region, \rightarrow, \psi, annot)$ is called **well-formed** if and only if for all transitions $t \in \rightarrow$,

- (i) source and destination are consistent, i.e. $\downarrow source(t)$ and $\downarrow target(t)$, redundant
- (ii) source (and destination) states are pairwise ~~unordered~~, i.e. orthogonal
  - forall $s, s' \in source(t)$ $(\in target(t))$, $s \perp s'$,
- (iii) the top state is neither source nor destination, i.e.
  - $top \notin source(t) \cup source(t)$.
- Recall: final states are not sources of transitions.

(ii): do not do that

**Example**:

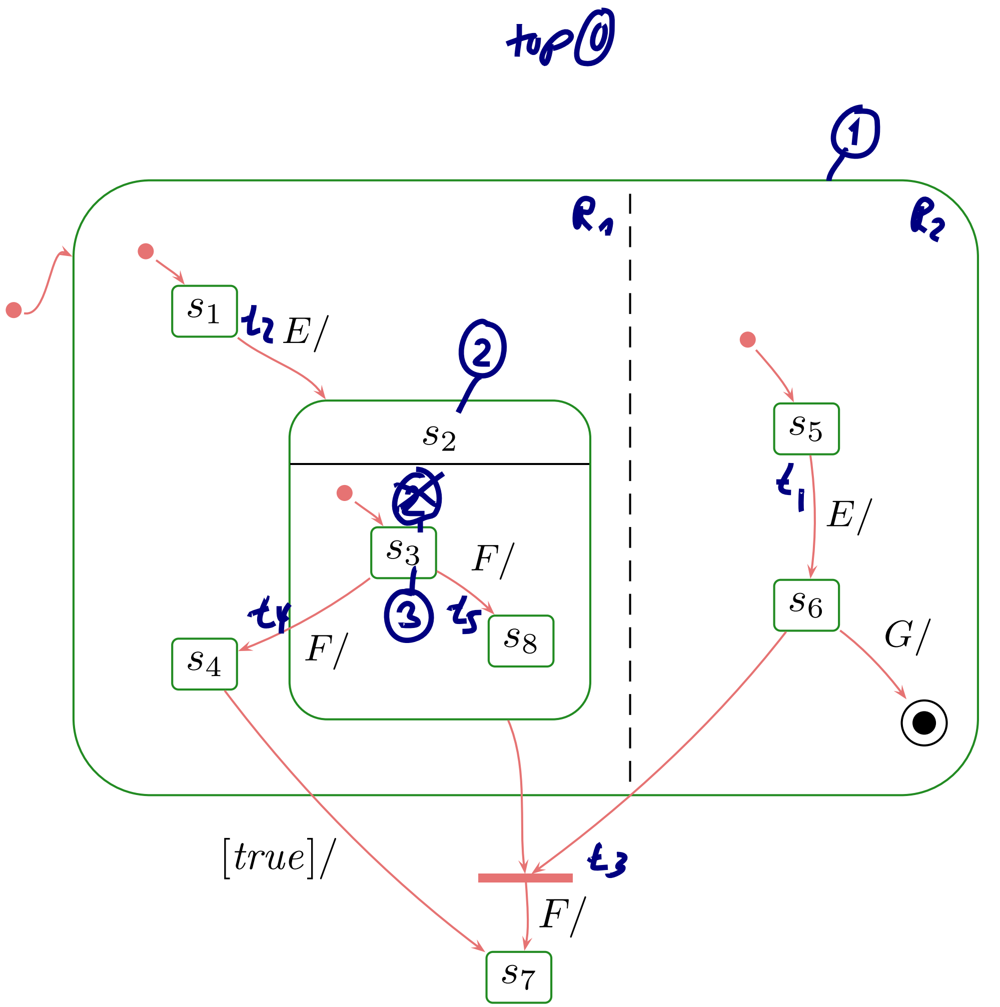
CLAIM:
(ii) $\Rightarrow$ (i)



# *The Depth of States*

- $depth(top) = 0$,
- $depth(s') = depth(s) + 1$, for all $s' \in child(s)$

**Example**:




- {t1, t2} cons.
- {t3, t4} not cons.
- {~~t3~~ t5, t4} not cons

# *Enabledness in Hierarchical State-Machines*

- The **scope** ("set of possibly affected states") of a transition $t$ is the **least** **common region** of

maximal wrt. to $\leq$

$$source(t) \cup target(t).$$

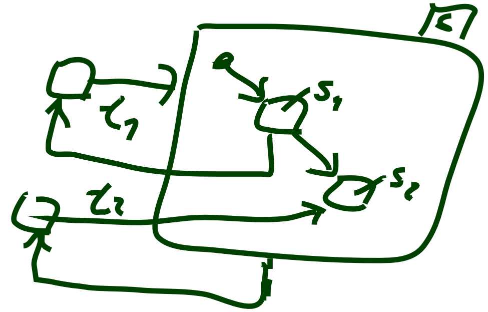
- Two transitions $t_1, t_2$ are called **consistent** if and only if their scopes are orthogonal (i.e. states in scopes pairwise orthogonal).
- The **priority** of transition $t$ is the depth of its innermost source state, i.e.

$$prio(t) := \max\{depth(s) \mid s \in source(t)\}$$

- A set of transitions $T \subseteq \rightarrow$ is **enabled** in an object $u$ if and only if
  - $T$ is consistent,
  - $T$ is maximal wrt. priority,
  - all transitions in $T$ share the same trigger,
  - all guards are satisfied by $\sigma(u)$, and
  - for all $t \in T$, the source states are active, i.e.

$$source(t) \subseteq \sigma(u)(st) \ (\subseteq S).$$

# *Transitions in Hierarchical State-Machines*



- Let $T$ be a set of transitions enabled in $u$.
- Then $(\sigma, \varepsilon) \xrightarrow[u]{(cons, Snd)} (\sigma', \varepsilon')$ if
  - $\sigma'(u)(st)$ consists of the target states of $T$, (and their recursive parents)

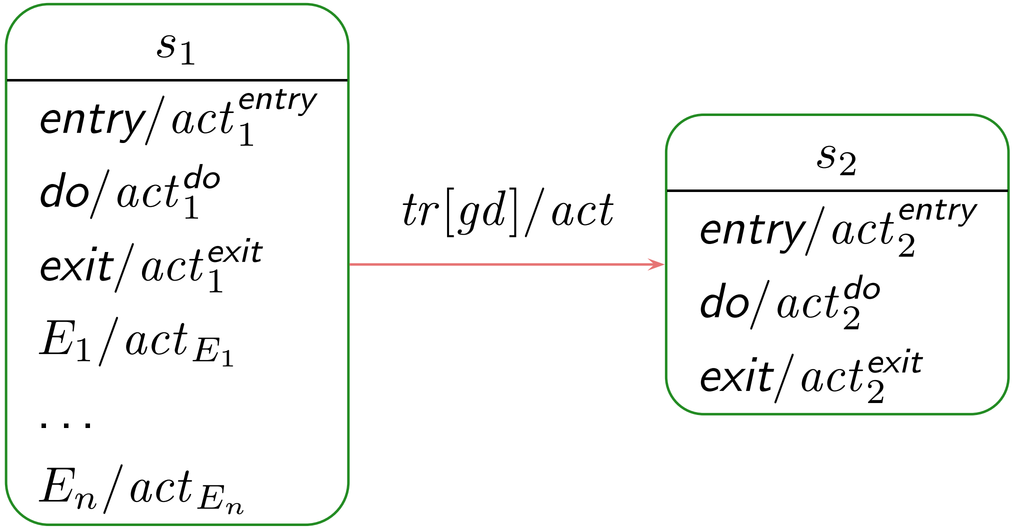
    i.e. for simple states the simple states themselves, for composite states the initial states,
  - $\sigma'$, $\varepsilon'$, $cons$, and $Snd$ are the effect of firing each transition $t \in T$ **one by one**, **in any order**, i.e. for each $t \in T$,
    - the exit transformer of all affected states, highest depth first,
    - the transformer of $t$,
    - the entry transformer of all affected states, lowest depth first.

$\rightsquigarrow$ adjust (2.), (3.), (5.) accordingly.

# *Entry/Do/Exit Actions, Internal Transitions*

# *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). $E_1, \dots, E_n \in \mathcal{E}$ $\emptyset$, 'entry', 'do', 'exit' are reserved names!




- Recall: each action's supposed to have a transformer. Here: $t_{act_1^{\text{entry}}}$, $t_{act_1^{\text{exit}}}$, ...
- Taking the transition above then amounts to applying

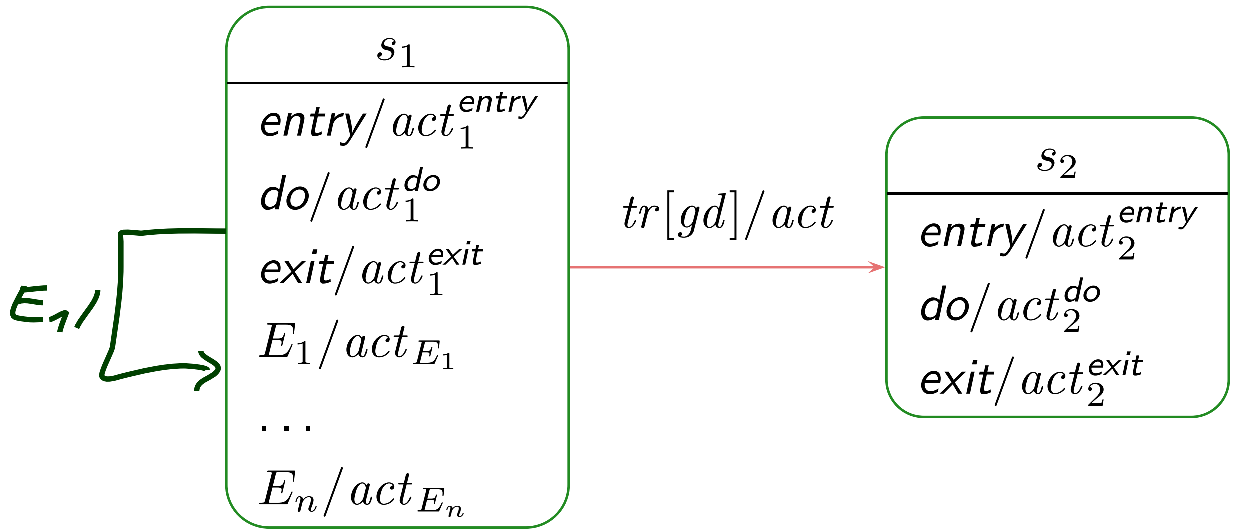
$$t_{act_{s_2}^{\text{entry}}} \circ t_{act} \circ t_{act_{s_1}^{\text{exit}}}(s) \quad \sim t_{s_2}^{\text{entry}}(t_{act}(t_{s_1}^{\text{exit}}(s)))$$

instead of only

$$t_{act}$$

$\rightsquigarrow$ adjust (2.), (3.) accordingly.

# *Internal Transitions*

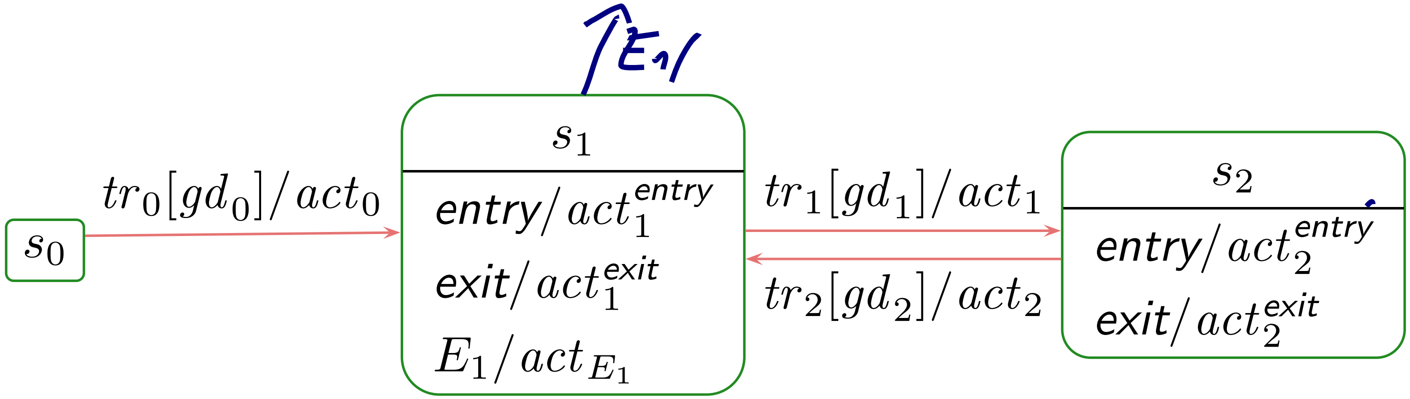



- For **internal transitions**, taking the one for $E_1$, for instance, still amounts to taking **only** $t_{act_{E_1}}$.
- Intuition: The state is neither left nor entered, so: no exit, no entry.

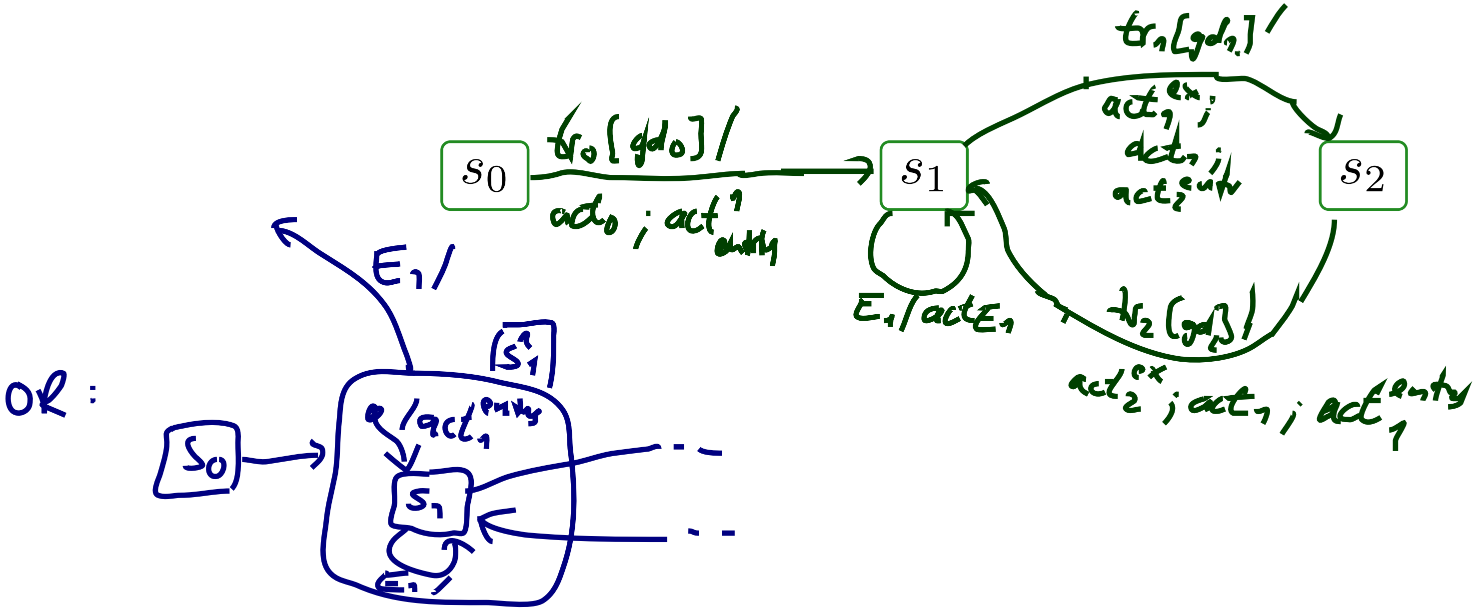
  $\rightsquigarrow$ adjust $(2.)$ accordingly.
- Note: internal transitions also start a run-to-completion step.
- Note: the standard seems not to clarify whether internal transitions have **priority** over regular transitions with the same trigger at the same state.

  Some code generators assume that internal transitions have priority!

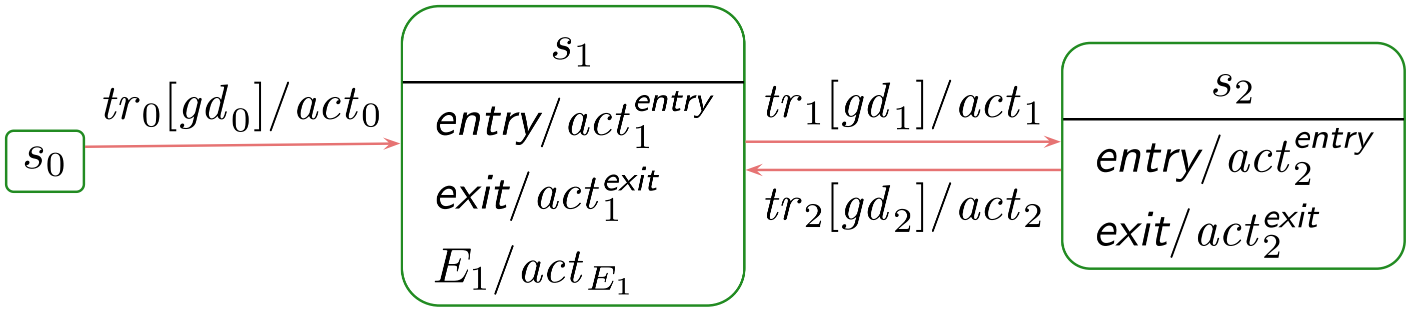
# Alternative View: Entry/Exit/Internal as Abbreviations



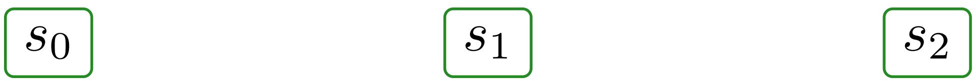

- ... as abbrevation for ...



# *Alternative View: Entry/Exit/Internal as Abbreviations*

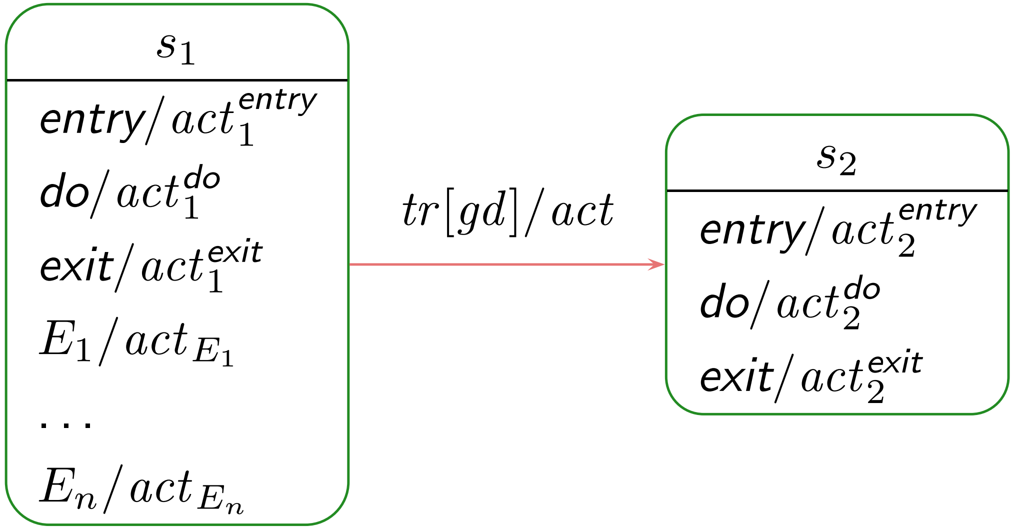



- ... as abbrevation for ...




- 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 (see later).
- Abbreviation may avoid confusion in context of hierarchical states (see later).

# Do Actions



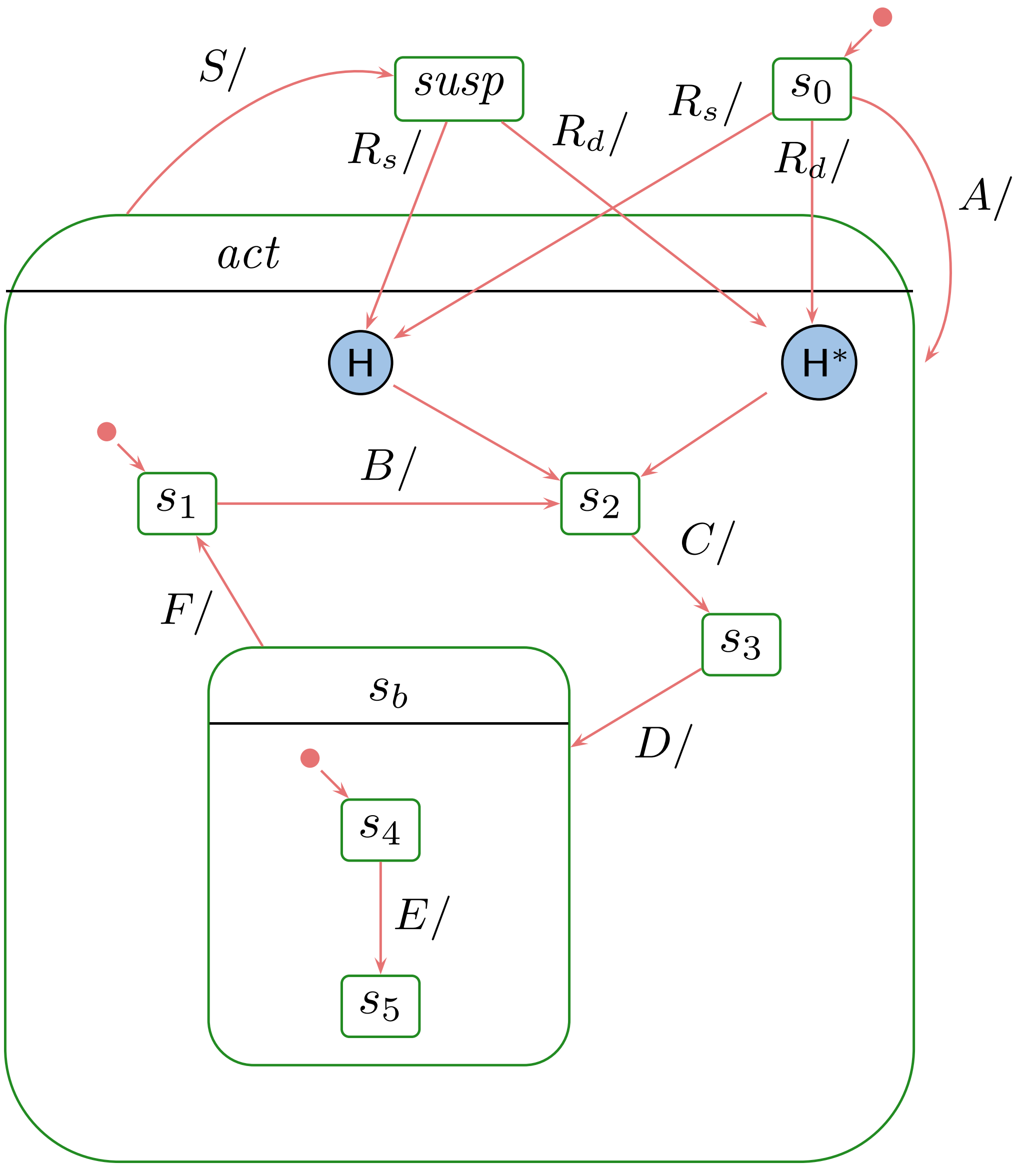

- **Intuition**: after entering a state, start its do-action.
- If the do-action terminates,
  - then the state is considered **completed**,
- otherwise,
  - if the state is left before termination, the do-action is stopped.

- 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

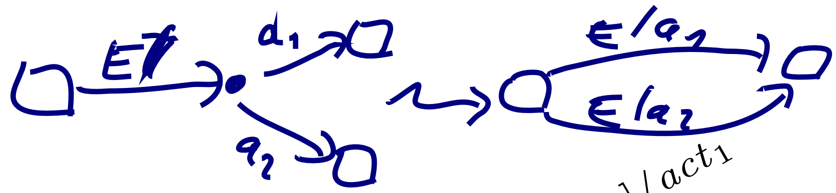


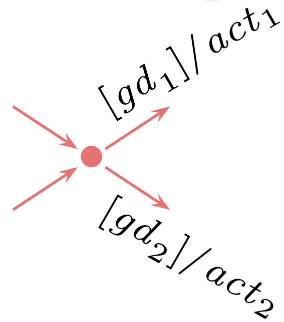

What happens on...

- $R_s$?
  $s_0, s_2$
- $R_d$?
  $s_0, s_2$
- $A, B, C, S, R_s$?
  $s_0, s_1, s_2, s_3, susp, s_3$
- $A, B, C, S, R_d$?
  $s_0, s_1, s_2, s_3, susp, s_3$
- $A, B, C, D, E, S, R_s$?
  $s_0, s_1, s_2, s_3, s_4, s_5, susp, s_4$
  E, S
- $A, B, C, D, R_d$?
  $s_0, s_1, s_2, s_3, s_4, s_5, susp, s_5$

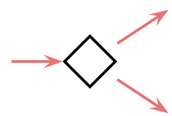
deep vs. shallow

# *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

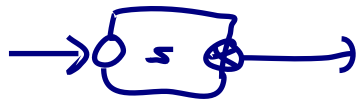


- Choice: (**"dynamic conditional branch"**)
  - **evil**: may get stuck
  - enters the transition **without knowing** whether there's an enabled path
  - at best, use "else" and convince yourself that it cannot get stuck
  - maybe even better: **avoid**

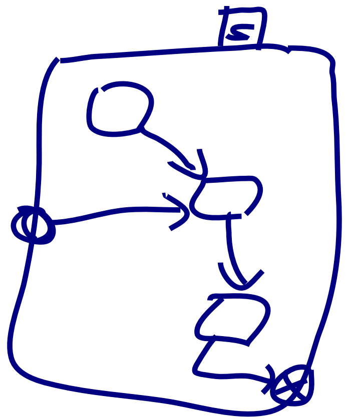
Note: not so sure about naming and symbols, e.g.,
**I'd guessed** it was just the other way round...

# 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. $\boxed{S : s}$
- **Entry/exit points** $\bigcirc$, $\otimes$
  - 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.

# *Contemporary UML Modelling Tools*

# *References*

# References

[Crane and Dingel, 2007] Crane, M. L. and Dingel, J. (2007). UML vs. classical vs. rhapsody statecharts: not all models are created equal. *Software and Systems Modeling*, 6(4):415–435.

[Damm et al., 2003] Damm, W., Josko, B., Votintseva, A., and Pnueli, A. (2003). A formal semantics for a UML kernel language 1.2. IST/33522/WP 1.1/D1.1.2-Part1, Version 1.2.

[Fecher and Schönborn, 2007] Fecher, H. and Schönborn, J. (2007). UML 2.0 state machines: Complete formal semantics via core state machines. In Brim, L., Haverkort, B. R., Leucker, M., and van de Pol, J., editors, *FMICS/PDMC*, volume 4346 of *LNCS*, pages 244–260. Springer.

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

[Harel and Kugler, 2004] Harel, D. and Kugler, H. (2004). The rhapsody semantics of statecharts. In Ehrig, H., Damm, W., Große-Rhode, M., Reif, W., Schnieder, E., and Westkämper, E., editors, *Integration of Software Specification Techniques for Applications in Engineering*, number 3147 in LNCS, pages 325–354. Springer-Verlag.

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