Software Design, Modelling and Analysis in UML

Lecture 15: Hierarchical State Machines I

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Contents & Goals

Last Lecture:

$(\sigma, \varepsilon) \xrightarrow[u]{\text{Sd,ccv}} (\sigma', \varepsilon')$

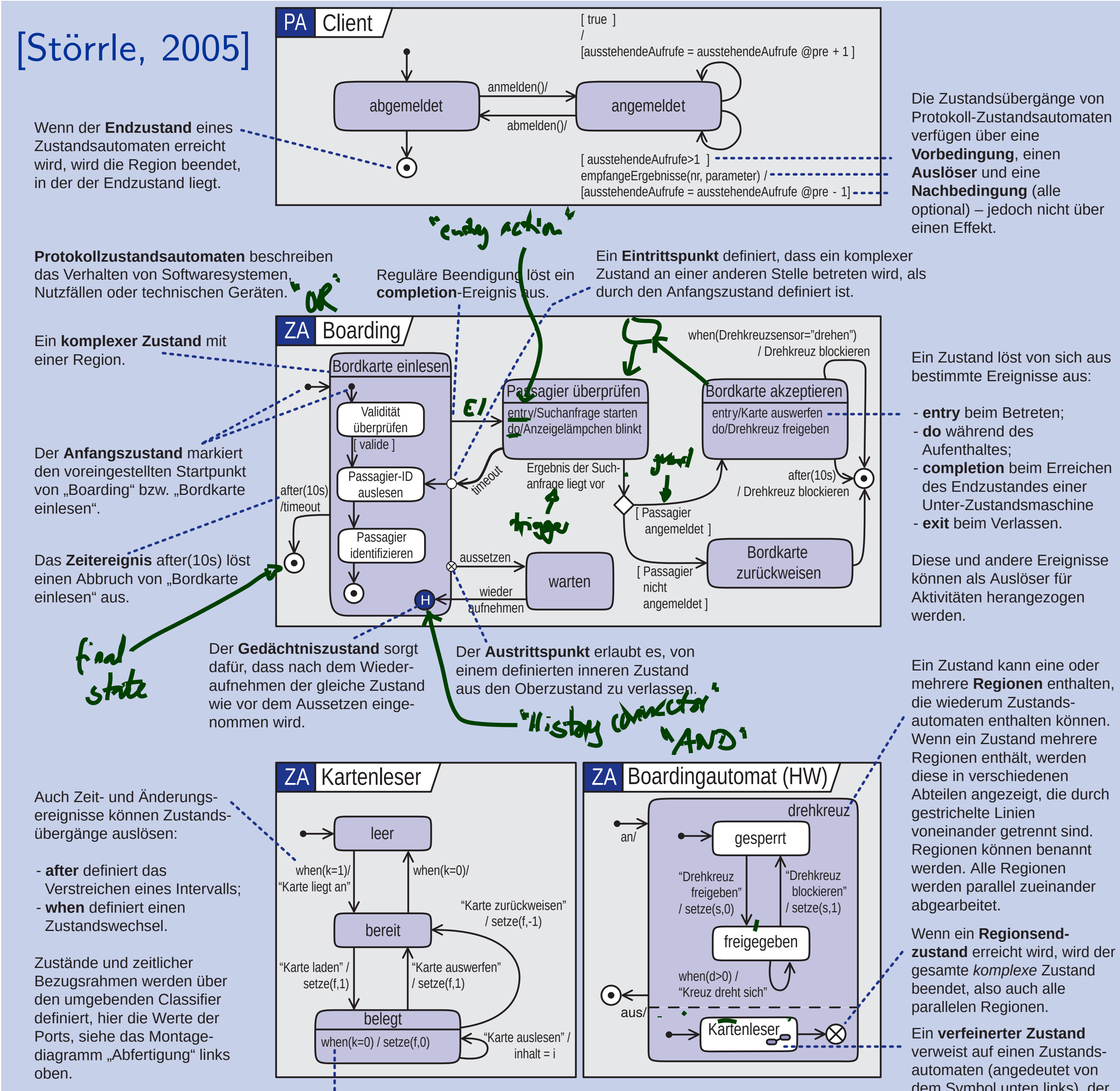
- RTC-Rules: Discard, Dispatch, Commence.
- Step, RTC, Divergence
- Putting It All Together – ODs for initial state
- Rhapsody Demo

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: initial state.
  - 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:**
  - Hierarchical State Machines Syntax

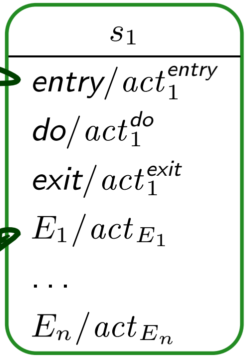
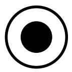
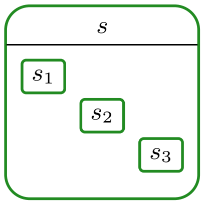
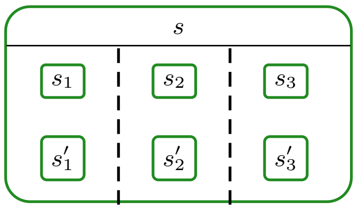
Hierarchical State Machines

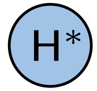
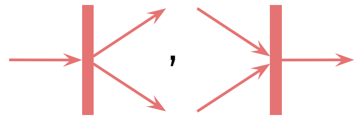
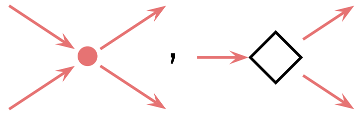
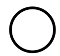
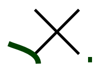
UML State-Machines: What do we have to cover?



The Full Story

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

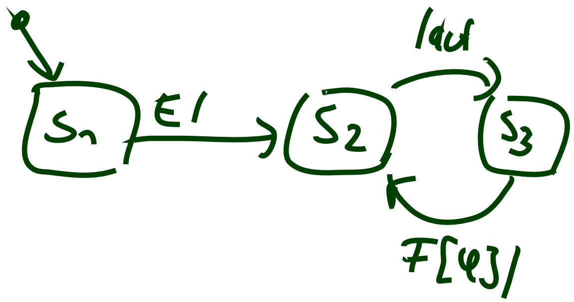
	example
simple state (as before)	
final state	
composite state	
OR	
AND	

	example
pseudo-state	
initial	
(shallow) history	
deep history	
fork/join	
junction, choice	
entry point	
exit point	
terminate	
submachine state	

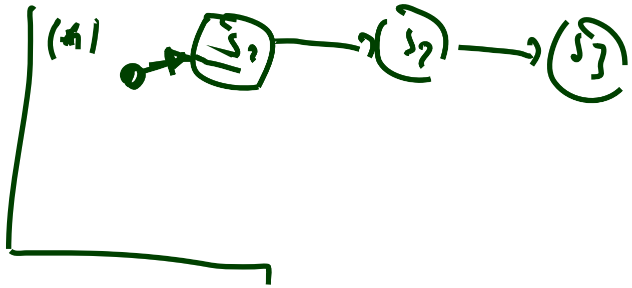
Representing All Kinds of States

- **Until now**:

$$(S, s_0, \rightarrow), \quad s_0 \in S, \rightarrow \; \subseteq S \times (\mathscr{E} \cup \{\_\}) \times Expr_{\mathscr{S}} \times Act_{\mathscr{S}} \times S$$



Representing All Kinds of States

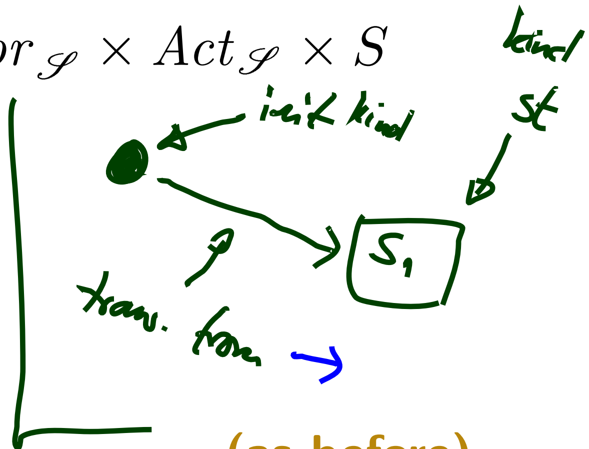


- **Until now**:

$$(S, s_0, \rightarrow), \quad s_0 \in S, \rightarrow\ \subseteq S \times (\mathscr{E} \cup \{\_\}) \times Expr_{\mathscr{S}} \times Act_{\mathscr{S}} \times S$$

- **From now on**: (**hierarchical**) **state machines**

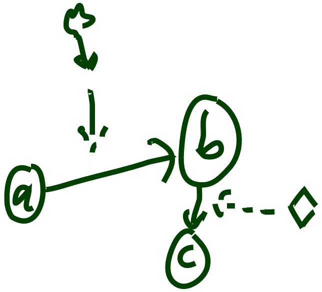
$$(S, kind, region, \rightarrow, \psi, annot)$$



where

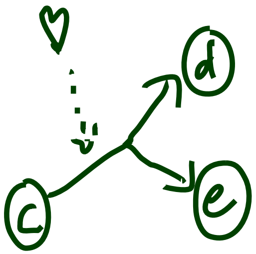
- $S \supseteq \{top\}$ is a finite set of states **(as before)**,
- $kind : S \rightarrow \{st, init, fin, shist, dhist, fork, join, junc, choi, ent, exi, term\}$ is a function which labels states with their **kind**, **(new)**
- $region : S \rightarrow 2^{2^S}$ is a function which characterises the **regions** of a state, **(new)**
- $\rightarrow$ is a set of transitions, **(changed)**
- $\psi : (\rightarrow) \rightarrow 2^S \times 2^S$ is an **incidence function**, and **(new)**
- $annot : (\rightarrow) \rightarrow (\mathscr{E} \cup \{\_\}) \times Expr_{\mathscr{S}} \times Act_{\mathscr{S}}$ provides an annotation for each transition. **(new)**

(s_0 is then redundant — replaced by proper state (!) of kind '*init*'.)

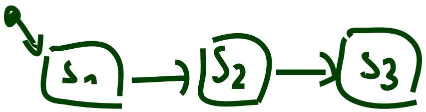


- $(\{a, b, c\}, \{(a,b), (b,c)\})$

- $(\{a, b, c\}, \{✿, \diamond\},$
  $\{✿ \mapsto (a,b), \diamond \mapsto (b,c)\})$



- $(\{c, d, e\}, \{\heartsuit\},$
  $\heartsuit \mapsto (\{c\}, \{d, e\}))$



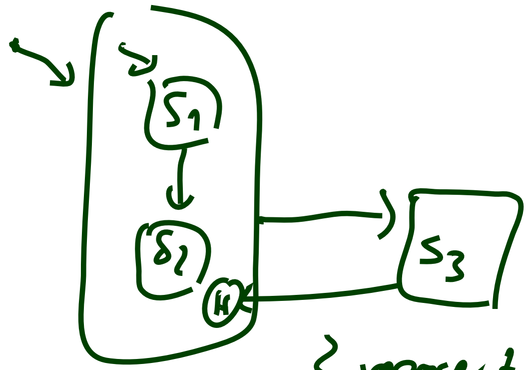
represent

$(S, s_0, \to)$

indices

transition system on $\Sigma_g^D \times Eth$, with

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



represent

$(S, kind, region, \to, \Psi, annot)$

indices

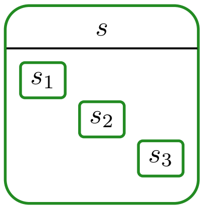
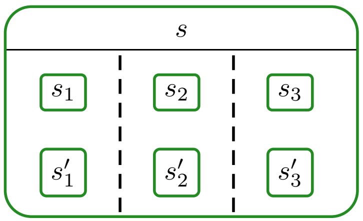
transition system on $\Sigma_g^D \times Eth$

now

later

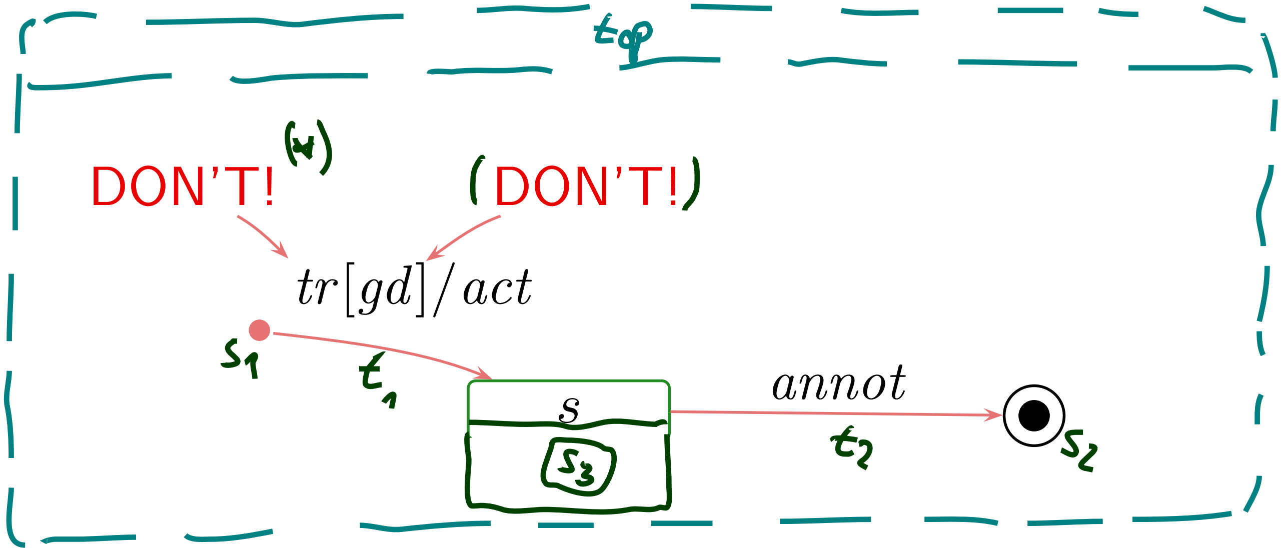
From UML to Hierarchical State Machines: By Example

$(S, kind, region, \rightarrow, \psi, annot)$

	example	$\in S$	$kind$	$region$
simple state (nothing nested)	s	s	st	$\emptyset$
final state	◉ (fresh name → q)	q	fin	$\emptyset$
composite state				
OR	 ,	s	st	$\{\{s_1, s_2, s_3\}\}$ (region)
AND		s	st	$\{\{s_1, s_1'\}, \{s_2, s_2'\}, \{s_3, s_3'\}\}$
submachine state	(later) –	–	–	
pseudo-state	●, (H), ...	q	$init$, $shist$, ...	$\emptyset$

$(s, kind(s))$ for short — e.g. (q, fin), (s, st)

From UML to Hierarchical State Machines: By Example



... translates to $(S, kind, region, \to, \psi, annot) =$ $(s_3, st),$

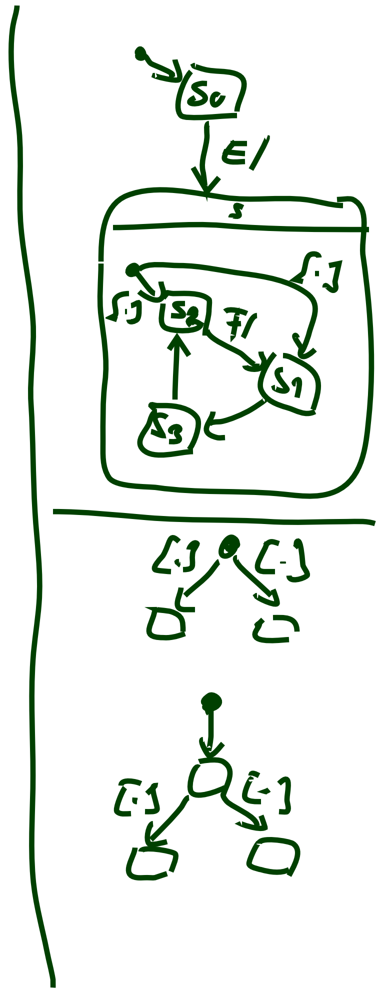
$$\underbrace{(\{(top, st), (s, st), (s_1, init), (s_2, fin)\},}_{S, kind}$$

$$\underbrace{\{top \mapsto \{\{s, s_1, s_2\}\}, s_1 \mapsto \emptyset, s_2 \mapsto \emptyset, s \mapsto \{\{s_3\}\},}_{region} s_3 \mapsto \emptyset\}$$

$$\underbrace{\{t_1, t_2\},}_{\to} \quad \underbrace{\{t_1 \mapsto (\{s_1\}, \{s\}), t_2 \mapsto (\{s\}, \{s_2\})\},}_{\psi}$$

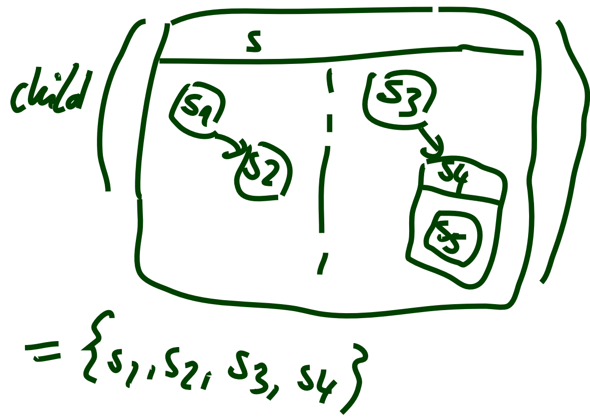
$$\underbrace{\{t_1 \mapsto (tr, gd, act), t_2 \mapsto annot\}}_{annot})$$

(*) because



Well-Formedness: Regions (follows from diagram)

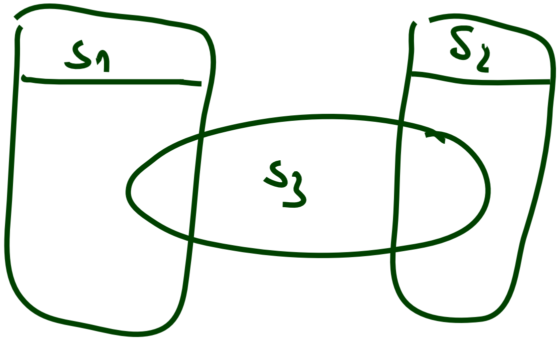
	$\in S$	$kind$	$region \subseteq 2^S, S_i \subseteq S$	$child \subseteq S$
simple state	s	*st*	$\emptyset$	$\emptyset$
final state	s	*fin*	$\emptyset$	$\emptyset$
composite state	s	*st*	$\{S_1, \dots, S_n\}, n \geq 1$	$S_1 \cup \dots \cup S_n$
pseudo-state	s	*init*, ...	$\emptyset$	$\emptyset$
implicit top state	top	*st*	$\{S_1\}$	S_1



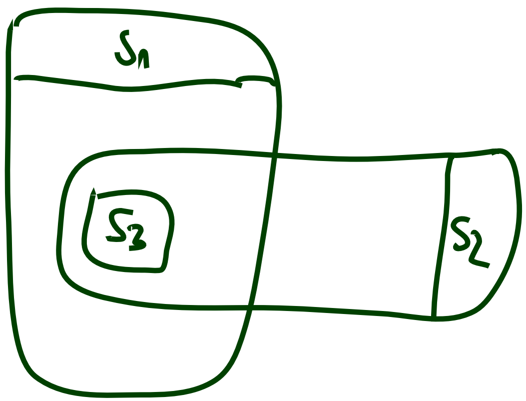
- Each state (except for top) lies in exactly one region,
- States $s \in S$ with $kind(s) =$ *st* **may comprise** regions.
  - No region: simple state.
  - One region: OR-state.
  - Two or more regions: AND-state.
- Final and pseudo states **don't comprise** regions.
- The region function induces a **child** function.

Each state (except for top) lies in exactly one region.

Follows from diagrams because we may not draw:



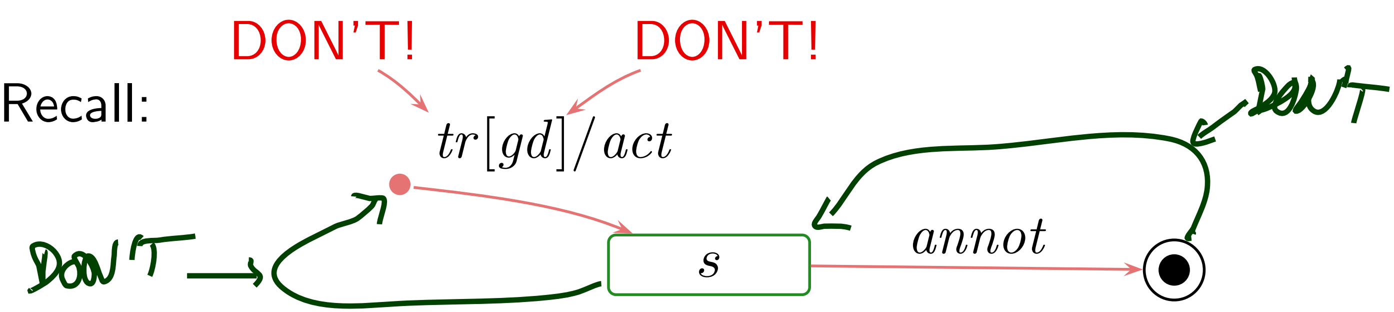
or



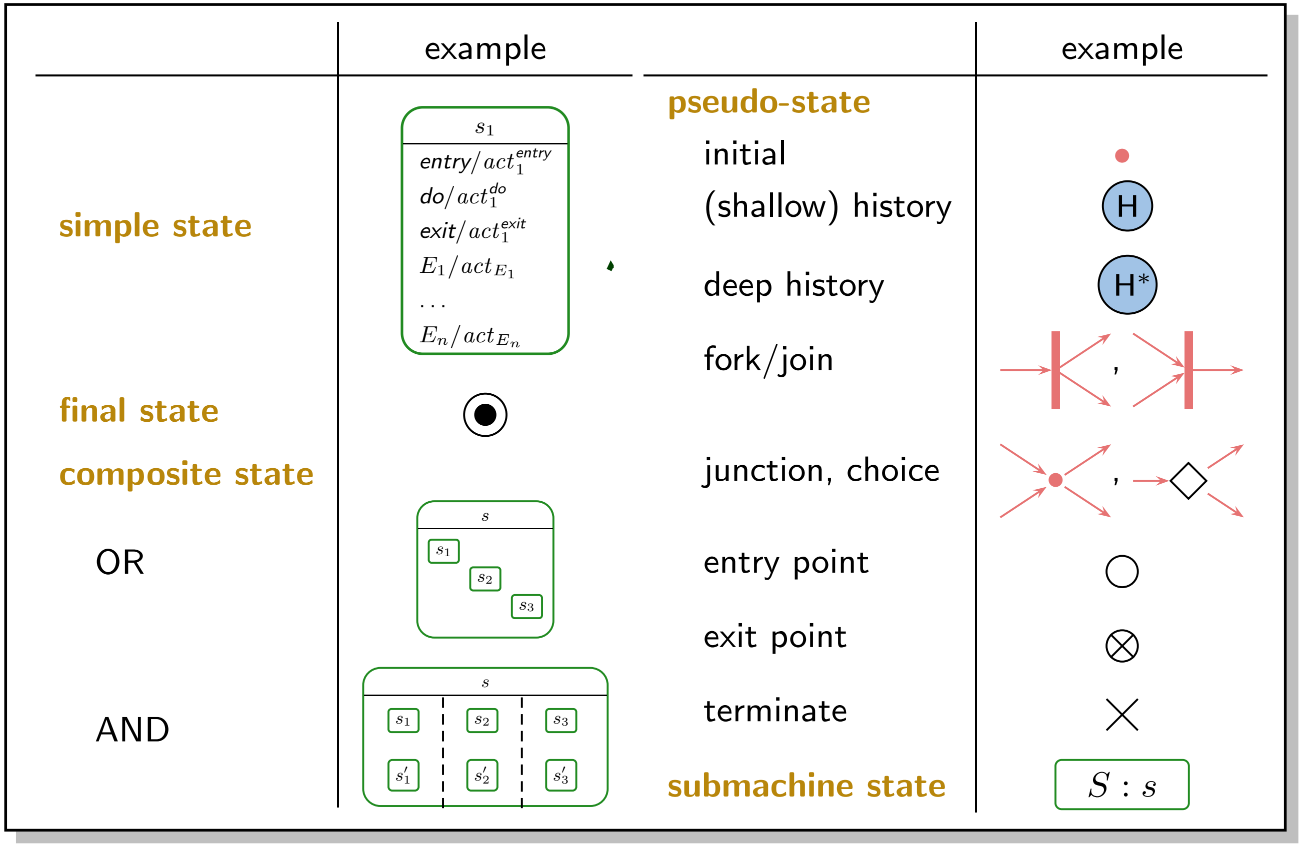
Well-Formedness: Initial State (requirement on diagram)

- Each non-empty region has a reasonable initial state and at least one transition from there, i.e.
  - for each $s \in S$ with $region(s) = \{S_1, \dots, S_n\}$, $n \geq 1$, for each $1 \leq i \leq n$,
  - there exists exactly one initial pseudo-state $(s_1^i, \textit{init}) \in S_i$ and at least one transition $t \in \longrightarrow$ with s_1^i as source,
  - and such transition's target s_2^i is in S_i, and (**for simplicity!**) $kind(s_2^i) = \textit{st}$, and $annot(t) = (\_, \textit{true}, act)$.
- No ingoing transitions to initial states.
- No outgoing transitions from final states.

- Recall:



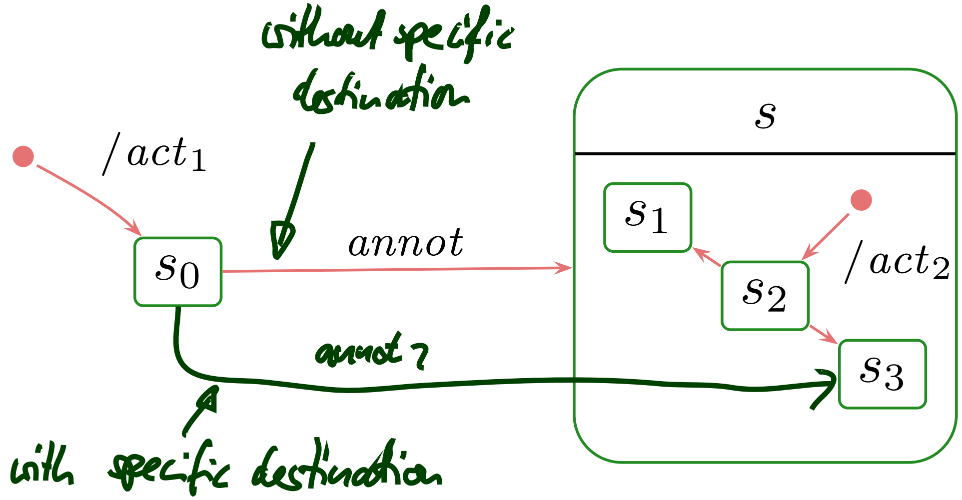
Plan



- Initial pseudostate, final state.
- Composite states.
- Entry/do/exit actions, internal transitions.
- History and other pseudostates, the rest.

Initial Pseudostates and Final States

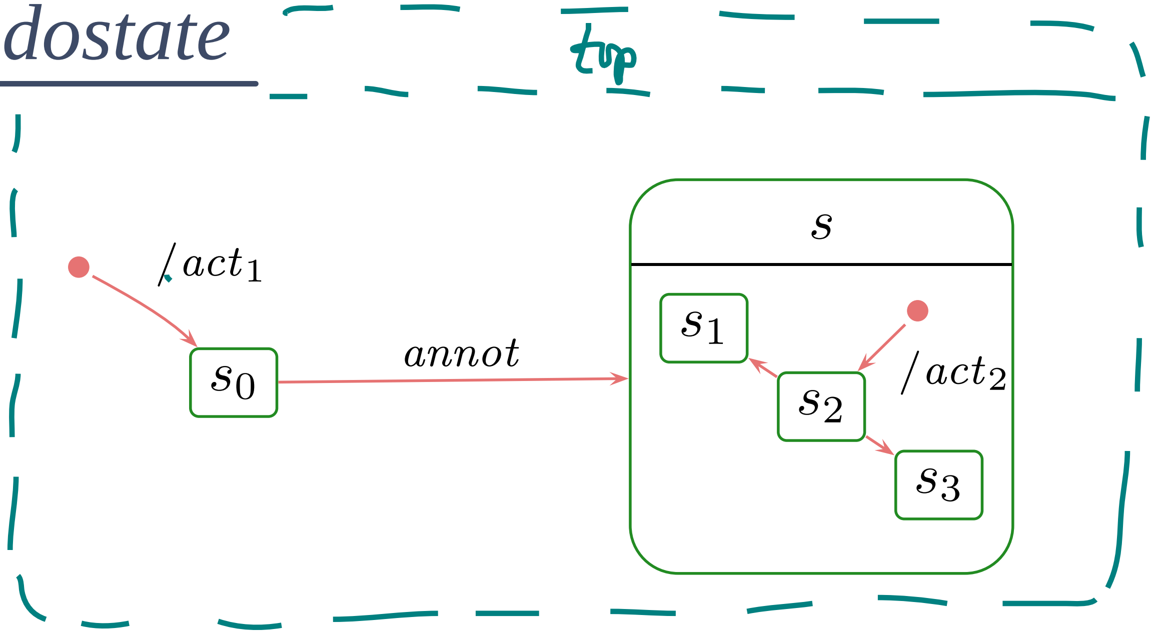
Initial Pseudostate



Principle:

- when entering a region **without** a specific destination state,
- then go to a state which is destination of an initiation transition,
- execute the action of the chosen initiation transitions **between** exit and entry actions. of source and destination (later).

Initial Pseudostate



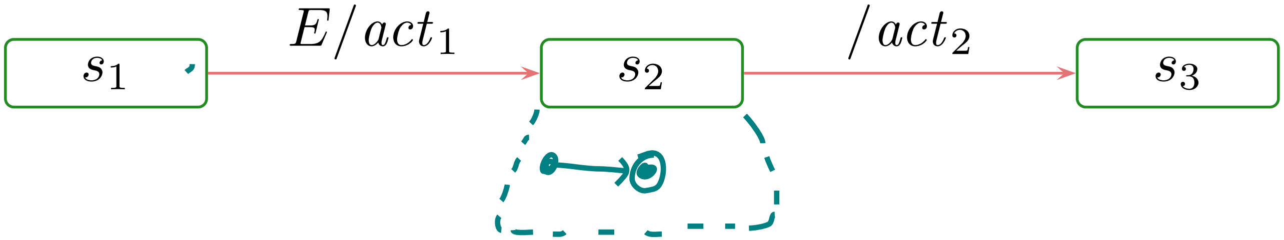
Principle:

- when entering a region **without** a specific destination state,
- then go to a state which is destination of an initiation transition,
- execute the action of the chosen initiation transitions **between** exit and entry actions.

Special case: the region of top.

- If class C has a state-machine, then "create-C transformer" is the concatenation of
  - the transformer of the "constructor" of C (here not introduced explicitly) and
  - a transformer corresponding to one initiation transition of the top region.

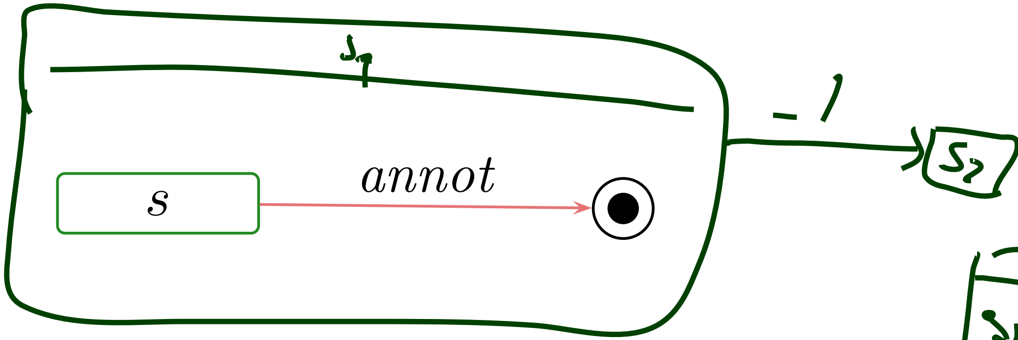
Towards Final States: Completion of States

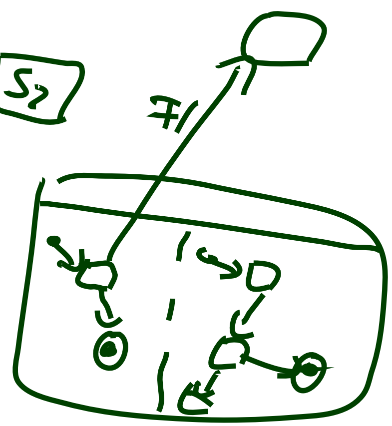


- Transitions without trigger can **conceptionally** be viewed as being sensitive for the "completion event".

- Dispatching (here: E) **can then alternatively** be **viewed** as
  - (i) fetch event (here: E) from the ether,
  - (ii) take an enabled transition (here: to s_2),
  - (iii) remove event from the ether,
  - (iv) after having finished entry and do action of current state (here: s_2) — the state is then called **completed** —,
  - (v) raise a **completion event** — with strict priority over events from ether!
  - (vi) if there is a transition enabled which is sensitive for the completion event,
    - then take it (here: (s_2, s_3)).
    - otherwise become stable.

Final States

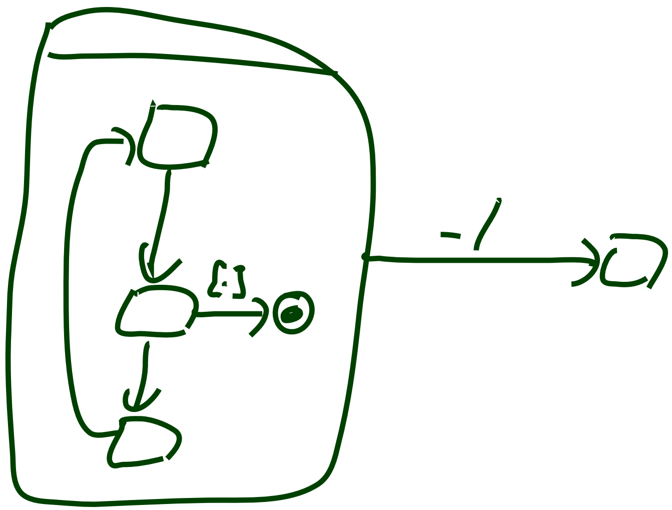




- If
  - a step of object u moves u into a final state $(s, \textit{fin})$, and
  - all sibling regions are in a final state,

  then (conceptionally) a completion event for the current composite state s is raised.
- If there is a transition of a **parent state** (i.e., inverse of $child$) of s enabled which is sensitive for the completion event,
  - then take that transition,
  - otherwise kill u

  $\rightsquigarrow$ adjust $(2.)$ and $(3.)$ in the semantics accordingly



Final States

- If
  - a step of object u moves u into a final state (s, fin), and
  - all sibling regions are in a final state,

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  - then take that transition,
  - otherwise kill u

  $\rightsquigarrow$ adjust $(2.)$ and $(3.)$ in the semantics accordingly

- **One consequence**: u never survives reaching a state (s, fin) with $s \in \mathit{child}(\mathit{top})$.

- **Now:** in Core State Machines, there is no parent state.
- **Later:** in Hierarchical ones, there may be one.

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.

[Störrle, 2005] Störrle, H. (2005). *UML 2 für Studenten*. Pearson Studium.