Software Engineering

System Modeling

Software & Systems Engineering | Prof. Dr. Andreas Vogelsang | 23.10.2023

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Learning Goals for Today

- Understand what modeling is and what it is good for
- Understand what the Unified Modeling Language (UML) is
- Understand what activity diagrams are and what they are used for
- Create activity diagrams to model flows of actions
- Understand what state machine diagrams are and what they are used for
- Create state machine diagrams to model states and their transitions

System Modeling: Why?

Motivation for Modeling

UML User Guide

"A successful software organization is one that consistently deploys **quality software** that meets the needs of its users. An organization that can develop such software in a **timely and predictable** fashion, with an **efficient and effective use of resources**, both human and material, is one that has a sustainable business. [...]
Modeling is a central part of all the activities that lead up to the deployment of good software. We build models to **communicate** the desired structure and behavior of our system. We build models to **visualize and control** the system's architecture. We build models to better **understand** the system we are building, often exposing opportunities for **simplification and reuse**. And we build models to **manage risk**."

UML User Guide

"We build models of complex systems because we cannot comprehend such a system in its entirety"

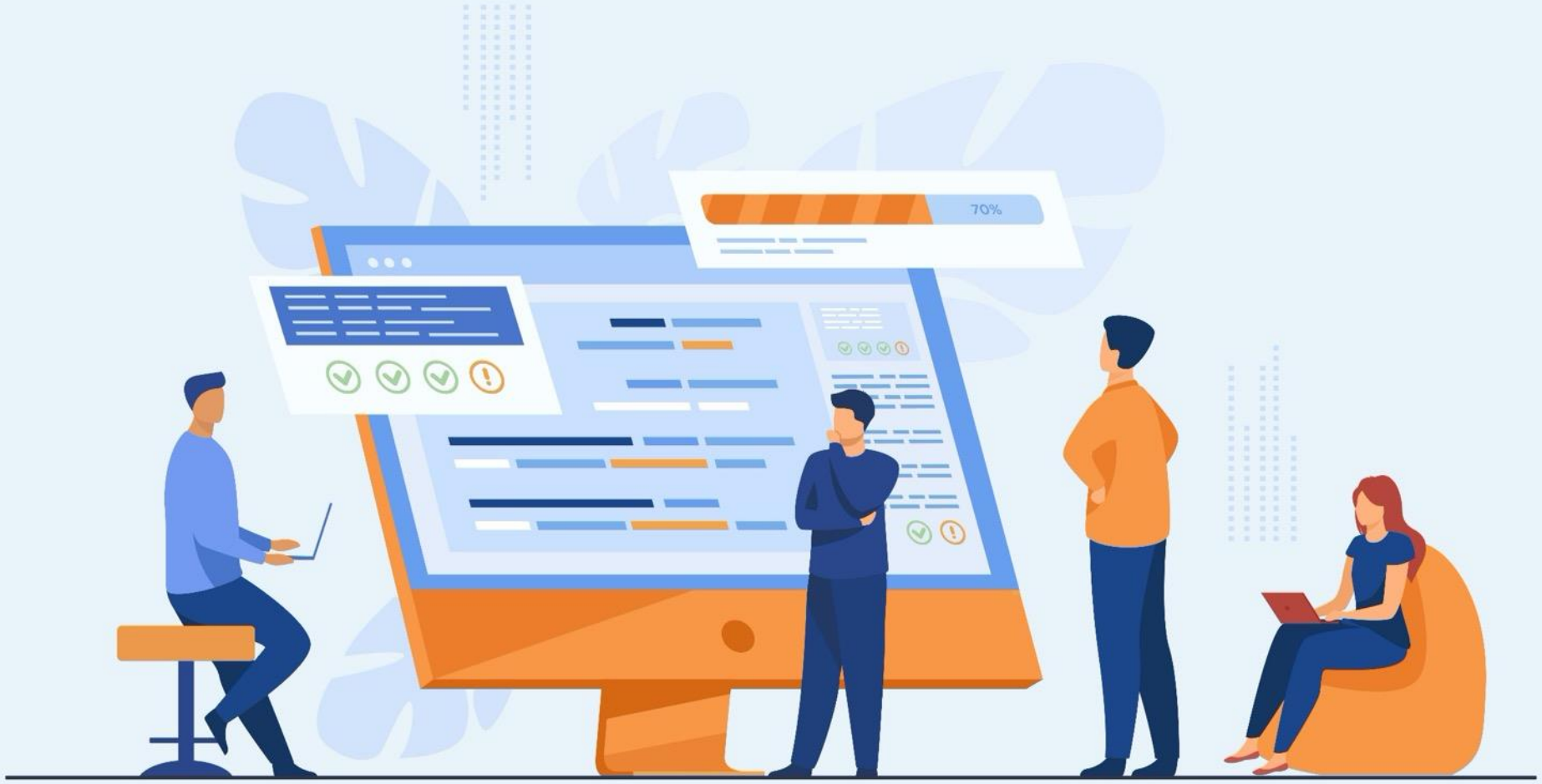
Recap: SE vs. Programming

What is System Modeling?

System Modeling

"**System modeling** is the process of developing abstract models of a system, with each model presenting a different view or perspective of that system. [...] Models are used during the requirements engineering process to help derive the **detailed requirements** for a system, during the design process to **describe the system to engineers** implementing the system, and after implementation to **document the system**'s structure and operation."

[Sommerville]



The Unified Modeling Language (UML)

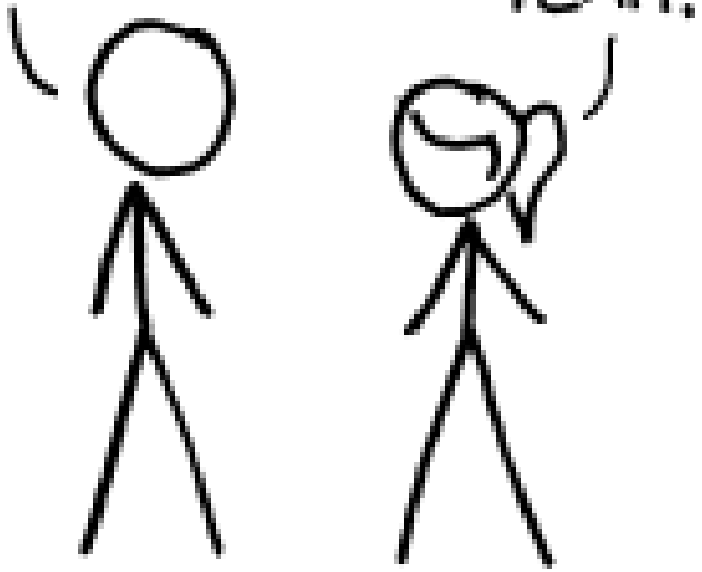
HOW STANDARDS PROLIFERATE:

(SEE: A/C CHARGERS, CHARACTER ENCODINGS, INSTANT MESSAGING, ETC.)

SITUATION:
THERE ARE
14 COMPETING
STANDARDS.

14?! RIDICULOUS!
WE NEED TO DEVELOP
ONE UNIVERSAL STANDARD
THAT COVERS EVERYONE'S
USE CASES.

YEAH!



SOON:

SITUATION:
THERE ARE
15 COMPETING
STANDARDS.

The Unified Modeling Language

UML

"The Unified Modeling Language (UML) is a general-purpose visual modeling language that is used to specify, visualize, construct, and document the artifacts of a software system."

[UML Reference Manual]

UML User Guide

"Modeling yields an understanding of a system. No one model is ever sufficient. Rather, you often need multiple models that are connected to one another [...]."

Different Kinds of UML Diagrams

Structure Diagrams (Strukturdiagramme)

"**Structure diagrams** show the static structure of the objects in a system. That is, they depict those elements in a specification that are irrespective of time. The elements in a structure diagram represent the meaningful concepts of an application, and may include abstract, real-world and implementation concepts."

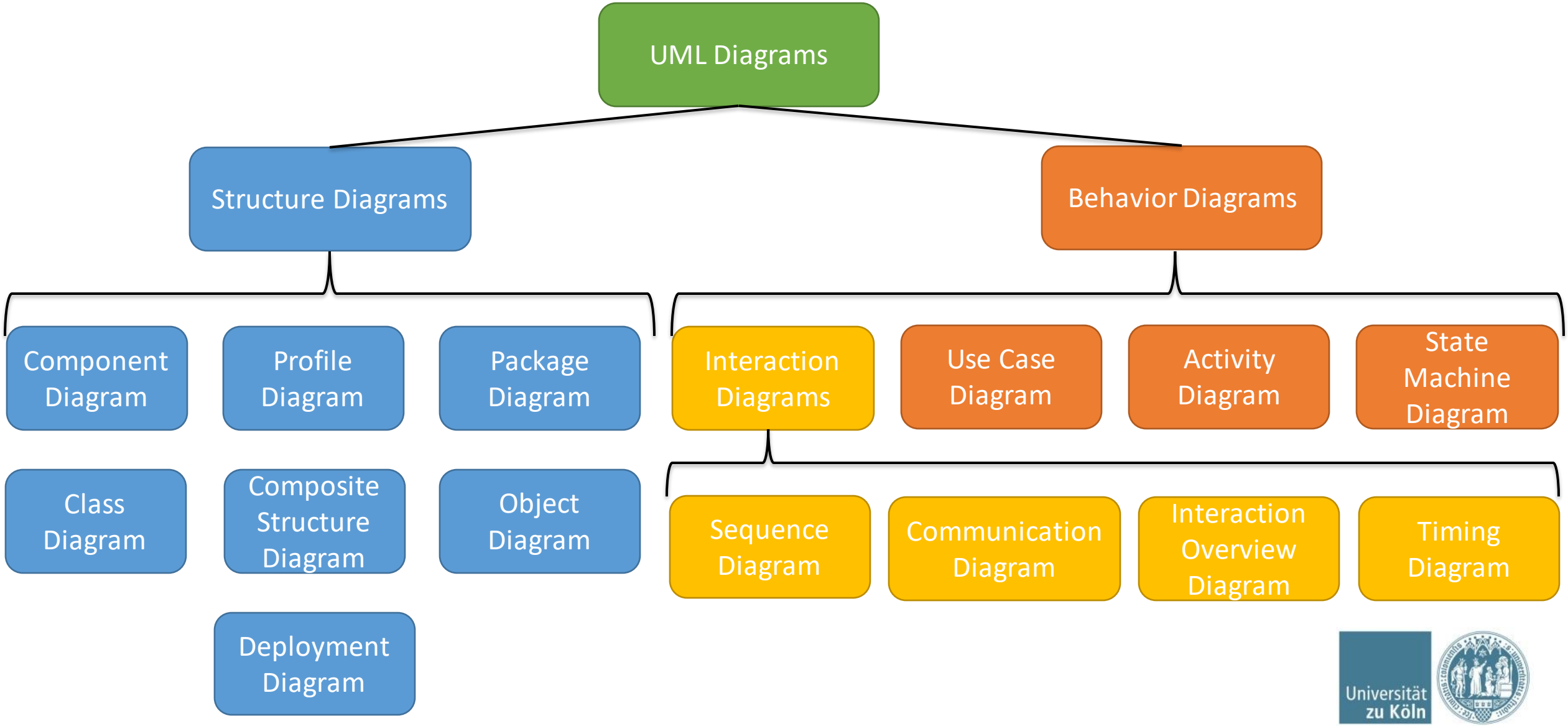
[UML 2.5.1]

Behavior Diagrams (Verhaltensdiagramme)

"**Behavior diagrams** show the dynamic behavior of the objects in a system, including their methods, collaborations, activities, and state histories. The dynamic behavior of a system can be described as a series of changes to the system over time."

[UML 2.5.1]

14 Types of UML Diagrams



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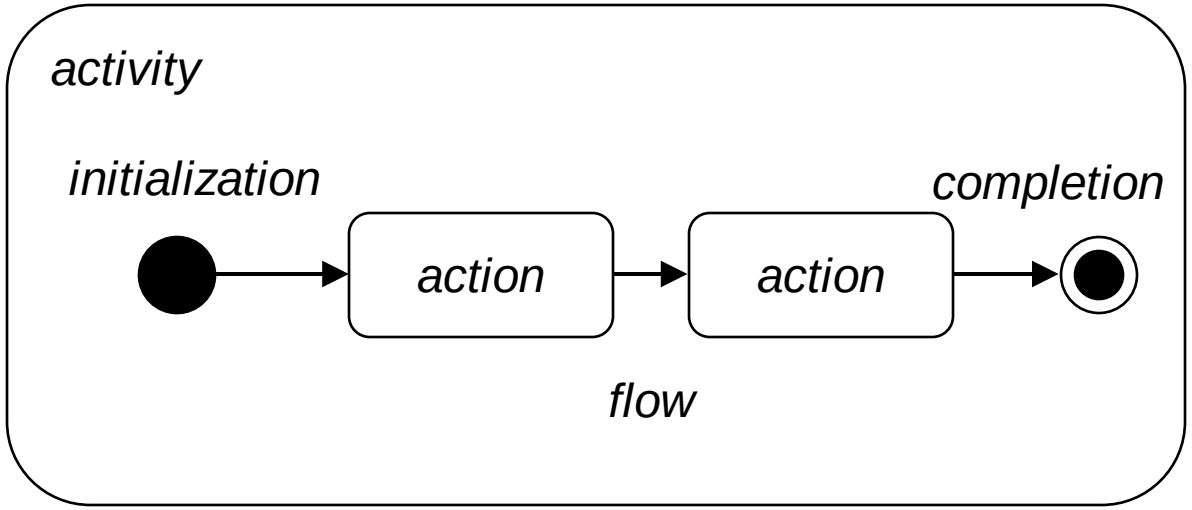
Activity Diagrams

Activity Diagrams

Activity Diagram (Aktivitätsdiagramm)

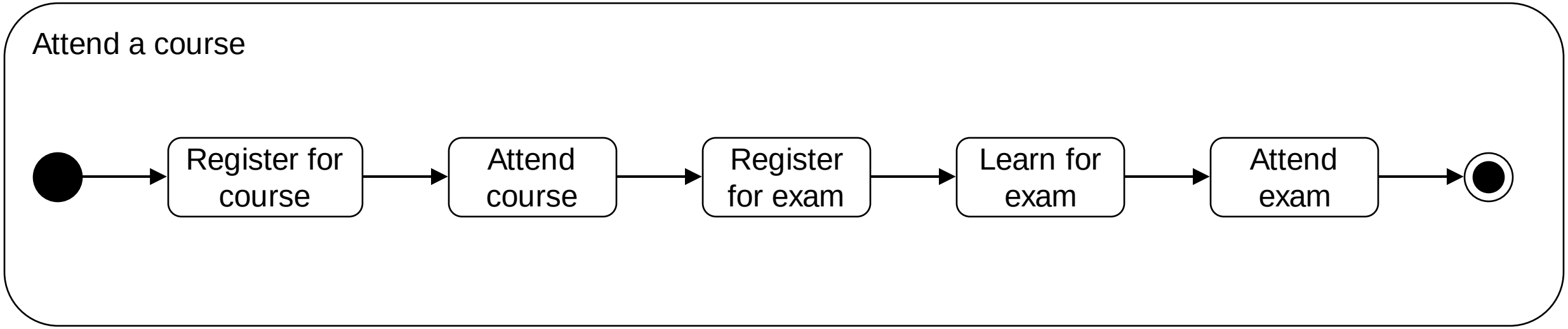
An **activity diagram** is a diagram visualizing **activities** and their order of execution. An activity contains **actions** (rounded box) that are connected by means of **flows** (solid arrows). The execution begins at the **initialization** (filled circle) and ends with the **completion** node (bull's eye).
(Aktivität, Fluss, Startzustand, Endzustand)



Rules for Activity Diagrams

- exactly one initialization/completion node
- at least one action
- every action has exactly one incoming and one outgoing flow
- every action is reachable from initialization
- completion is reachable from every action

Example of Sequential Activities



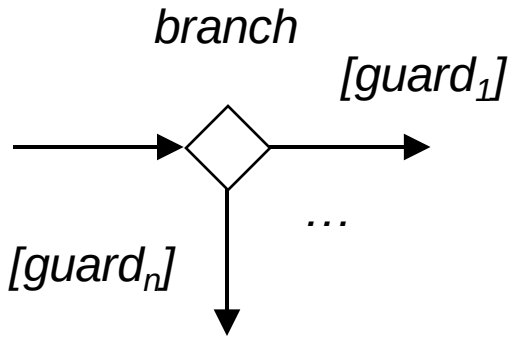
Branching and Merging in Activity Diagrams

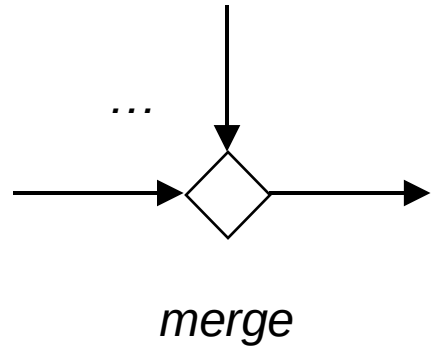
Branching and Merging [UML User Guide]

Motivation: model control flow that depends on certain conditions (i.e., actions that may happen)

Branching: A **branch** has exactly one incoming and two or more outgoing flows. Each outgoing flow has a Boolean expression called **guard**, which is evaluated on entering the branch. (Verzweigung)

Merging: A **merge** has two or more incoming and exactly one outgoing flow. (Zusammenführung)

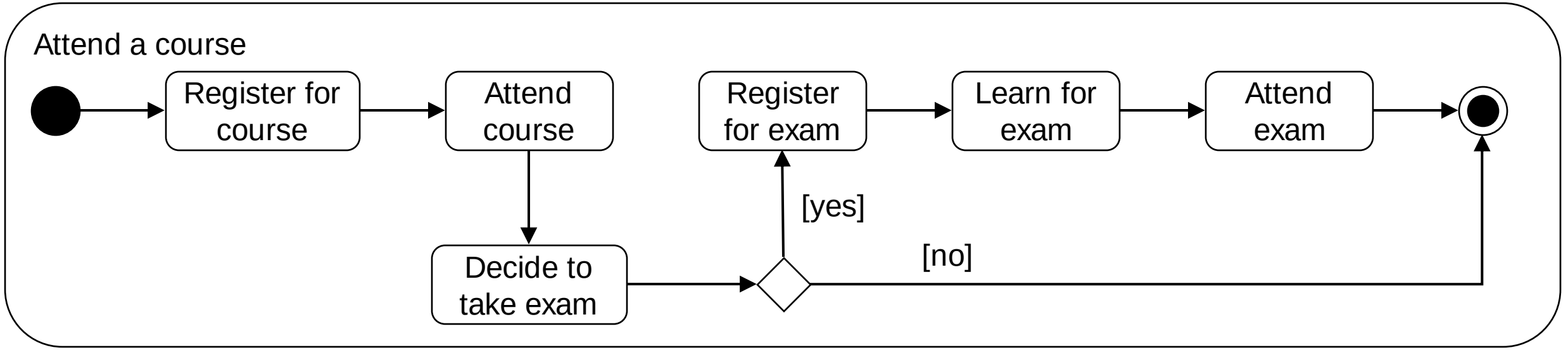




Further Rules for Activity Diagrams

- guards on outgoing flows should not overlap (flow of control is unambiguous)
- guards should cover all possibilities (flow of control does not freeze)
- keyword **else** possible for one guard (sonst)

Example of Conditional Activities



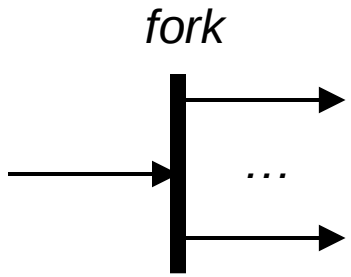
Forking and Joining in Activity Diagrams

Forking and Joining [UML User Guide]

Motivation: model concurrent control flows (i.e., activities that run in parallel)

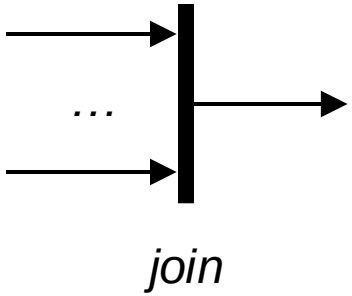
Forking: A **fork** (thick horizontal or vertical line) has exactly one incoming and two or more outgoing flows. (Gabelung)

Joining: A **join** (thick horizontal or vertical line) has two or more incoming and exactly one outgoing flow. (Vereinigung)

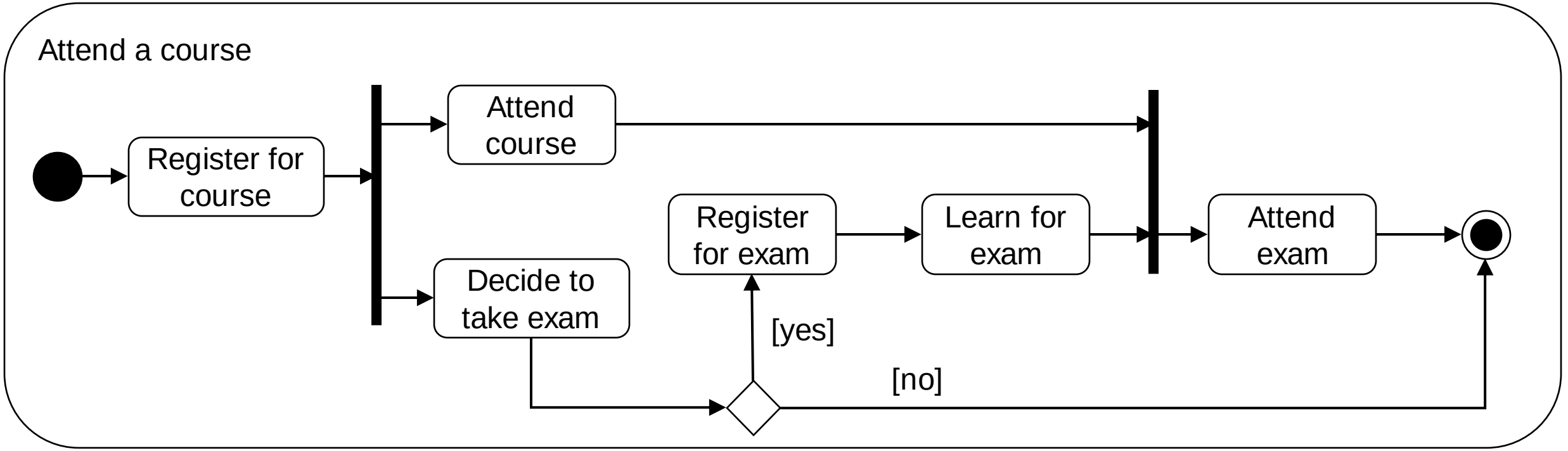


Further Rules for Activity Diagrams

- branched paths must be merged eventually (letztendlich)
- forked paths must be joined eventually
- only outgoing edges of branch nodes have guards



Example of Concurrent Activities



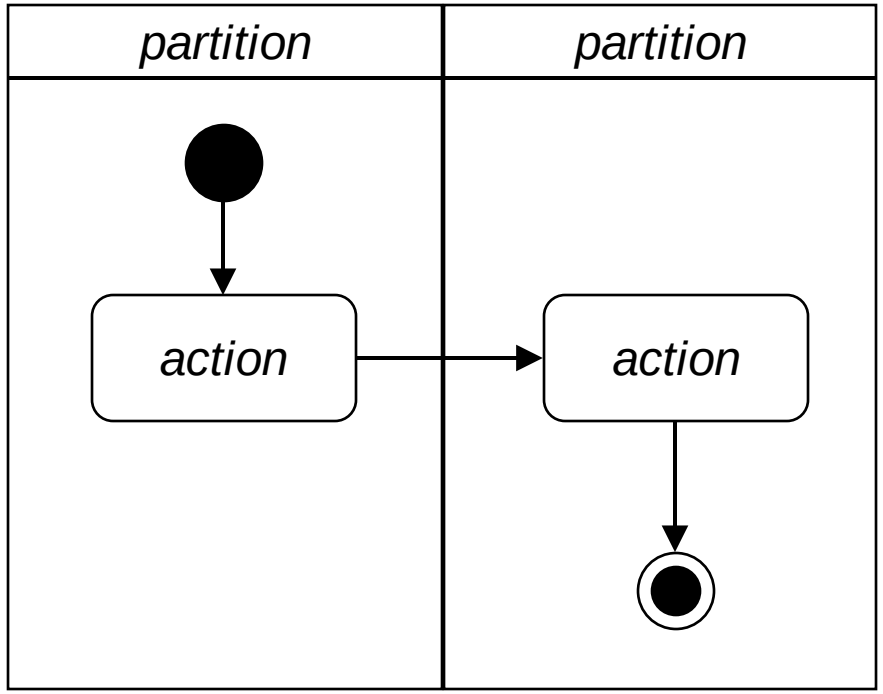
Swimlanes in Activity Diagrams

Swimlanes [UML User Guide]

Motivation: group activities according to responsibilities

Swimlane: An activity diagram may have no or at least two swimlanes. A **swimlane** (rectangle) represents a high-level responsibility activity within an activity diagram. (Verantwortlichkeitsbereiche)

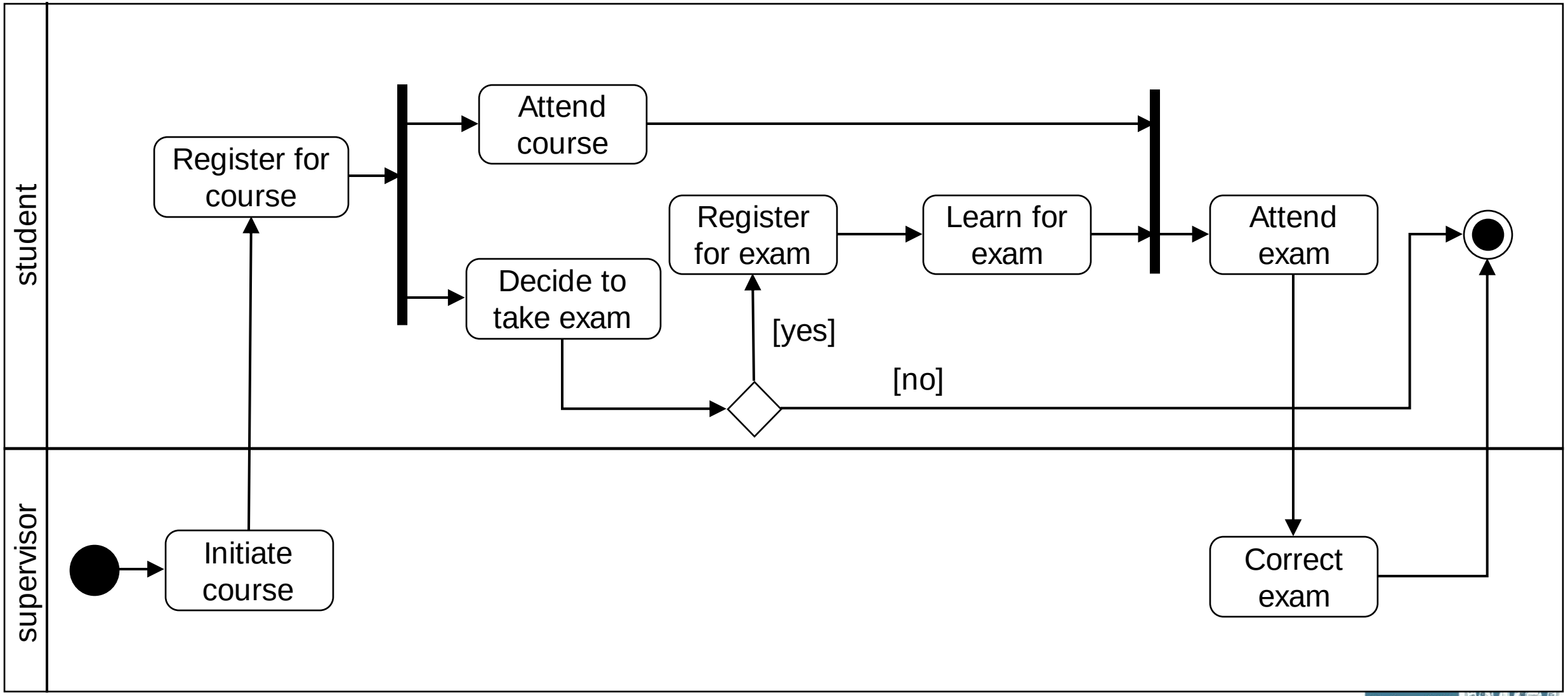
swimlanes



Further Rules for Activity Diagrams

- each swimlane has a name unique within its diagram
- every activity belongs to exactly one swimlane
- only flows may cross swimlanes

Example of Activities with Swimlanes



Activity Diagram Semantics

AD Semantics

Motivation: which behaviors are defined by an activity diagram?

Token-based Semantics: The possible flows in an activity diagram are defined by the possible token-flows. Elements of an activity diagram process tokens in different ways.

Token propagation rules

Init node: Produces exactly one token

Action: If the action receives a token, it also produces one token

Completion node: Consumes all tokens it gets (“sink”)

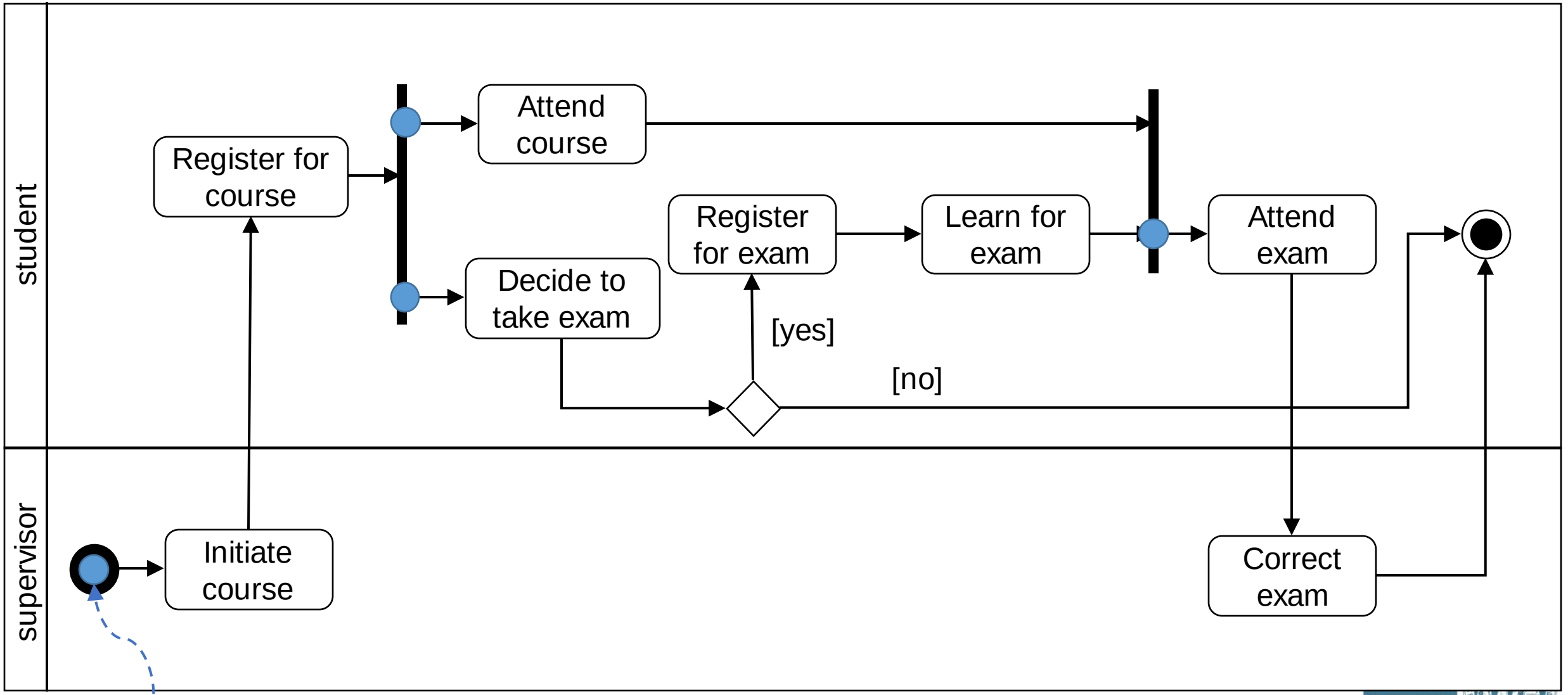
Branch node: If the branch node receives a token, it produces exactly one token on the flow where the guard evaluates to true.

Merge node: If the merge node receives a token on any of its incoming flows, it produces one token on the outgoing flow.

Fork node: If the fork node receives a token, it produces one token on all its outgoing flows.

Join node: If the join node has received a token on all its incoming flows, it produces one token on the outgoing flow.

Example of Token-based Semantics



Quick check

Which of the following statements match the diagram?

- *Initialize measuring device* must happen prior to *Register at server*.
- *Register at server* happens as soon as *Load certificates* is ready.
- *Initialize network connection* and *Load certificates* must finish at the same time.
- *Deactivate measuring device* is executed as soon as *Data receipt confirmed* is true.

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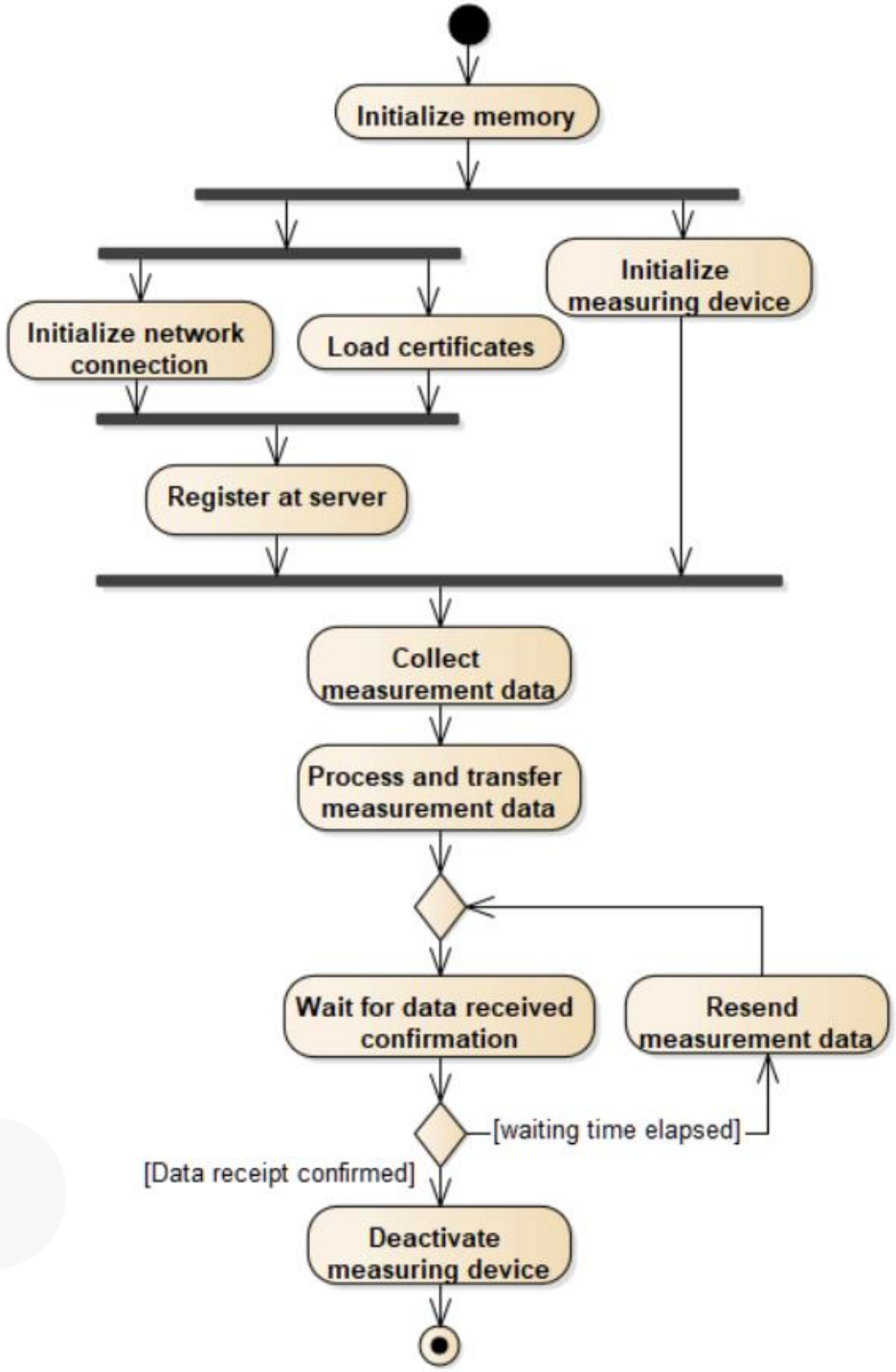

Quick check

Which of the following statements match the diagram?

- A route can be calculated without querying traffic information.
- A route can be calculated after querying traffic information.
- The system can ask for the desire to calculate the route dynamically without having to determine the GPS coordinates first.
- The order of *Enter destination* and *Determine GPS* coordinates is arbitrary.

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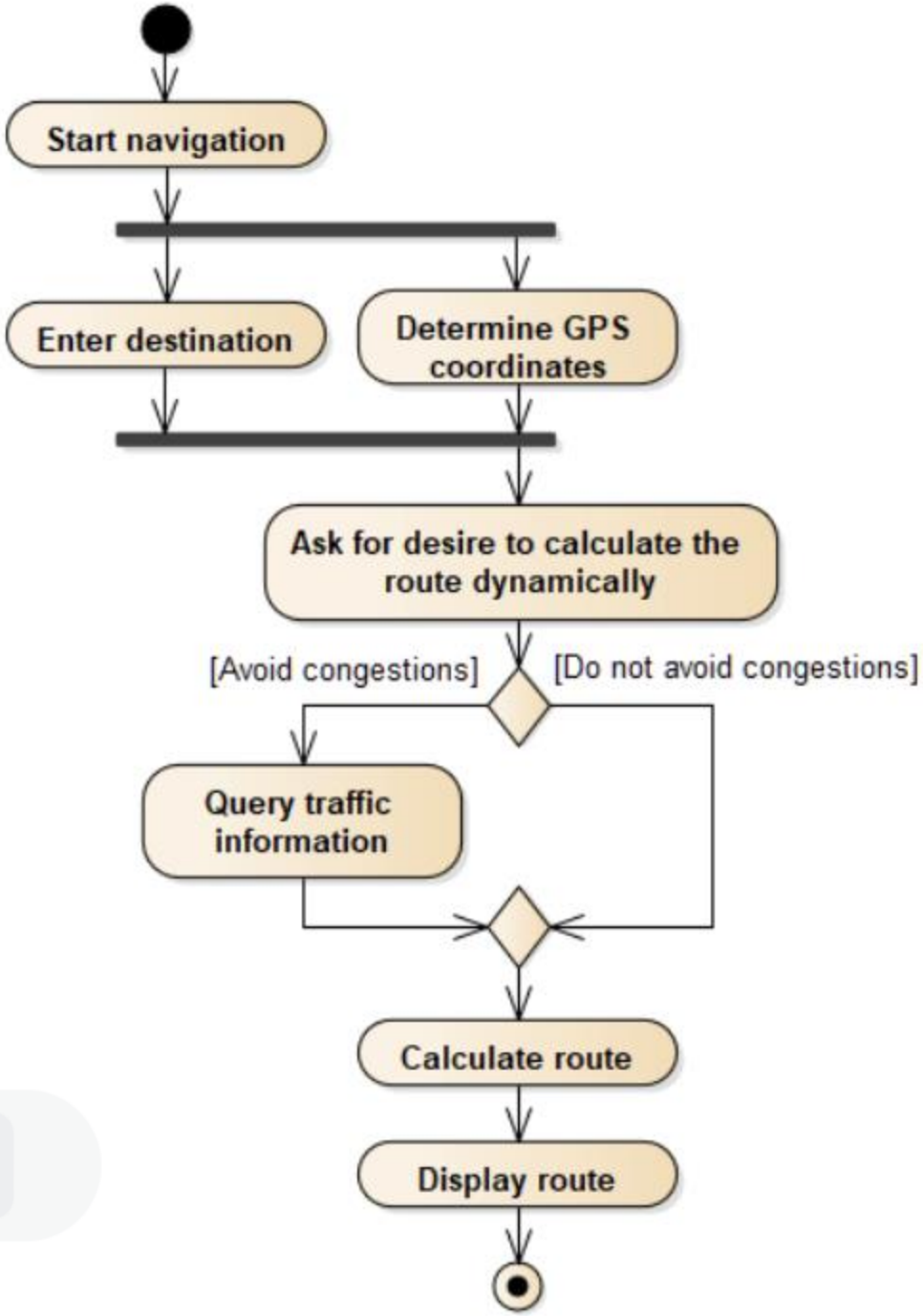
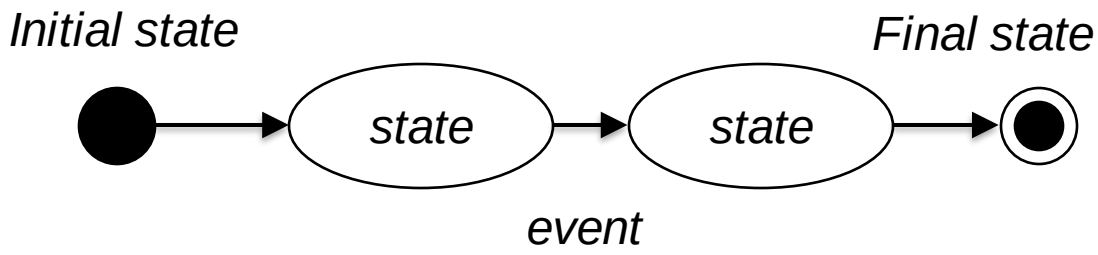


State Machine Diagrams

State Machine Diagrams

State Machine Diagram (Zustandsdiagramm)

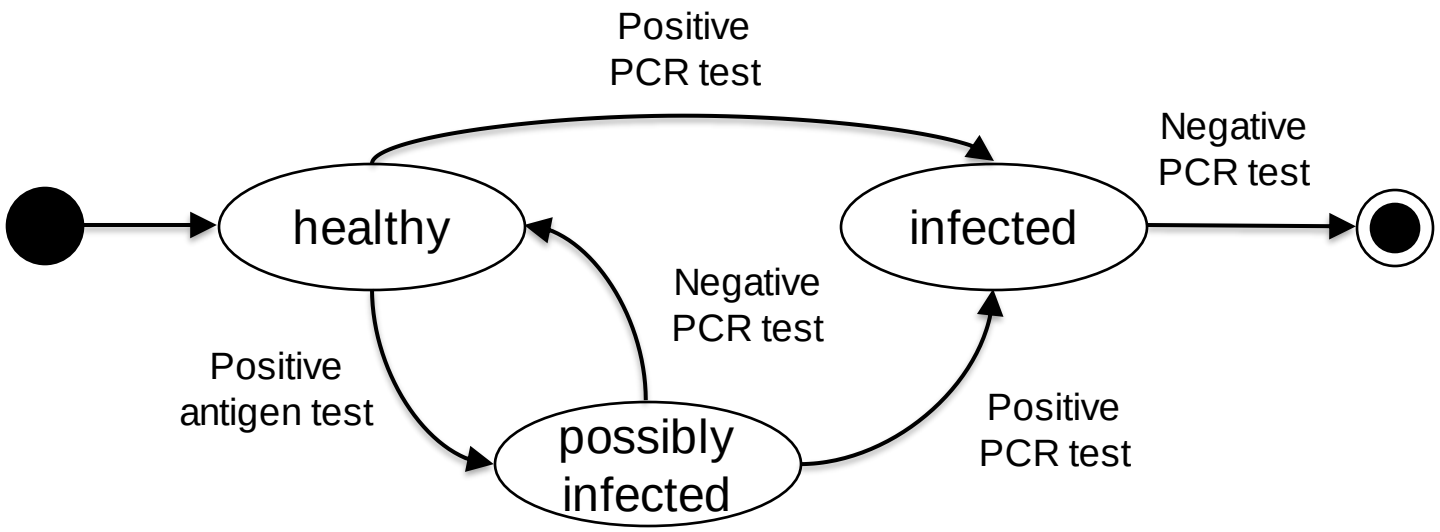
A **state machine diagram** specifies the sequences of states the (a part of) the system goes through during its lifetime in response to events, together with its responses to those events. Every **state** (oval) is characterized by a condition or situation. An **event** is an occurrence of a stimulus that can trigger a state transition. A **transition** (solid arrow) is a relationship between two states. (Zustand, Ereignis, Zustandsübergang)



Rules for State Machine Diagrams

there is a single **initial state** (filled circle) and a single **final state** (bull's eye) (Start- und Zielzustand) — see exception below

Example of a State Machine Diagram



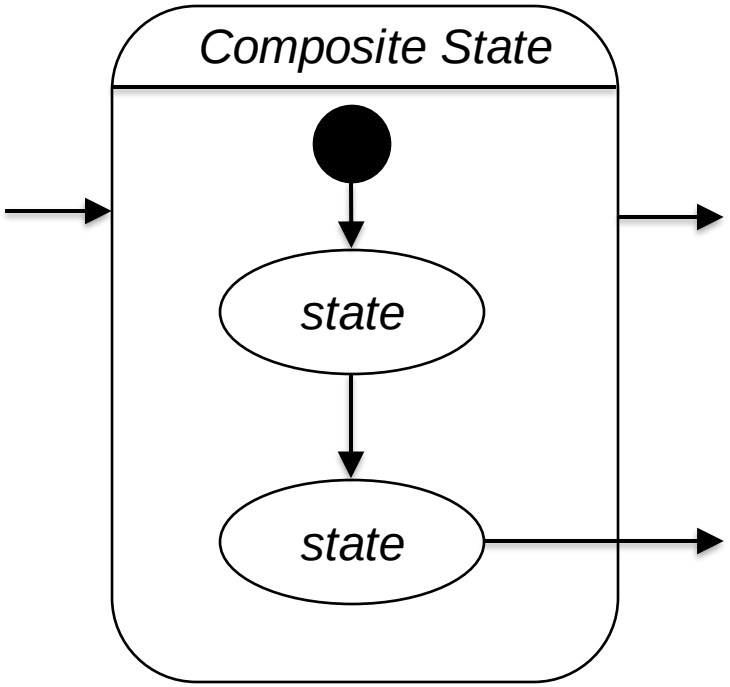
Hierarchical State Machine Diagrams

Single and Composite State [UML User Guide]

Motivation: avoid duplicated transitions, improve overview in complex state machine diagrams

Simple State: A simple state is a state that has no substructure. (einfacher Zustand)

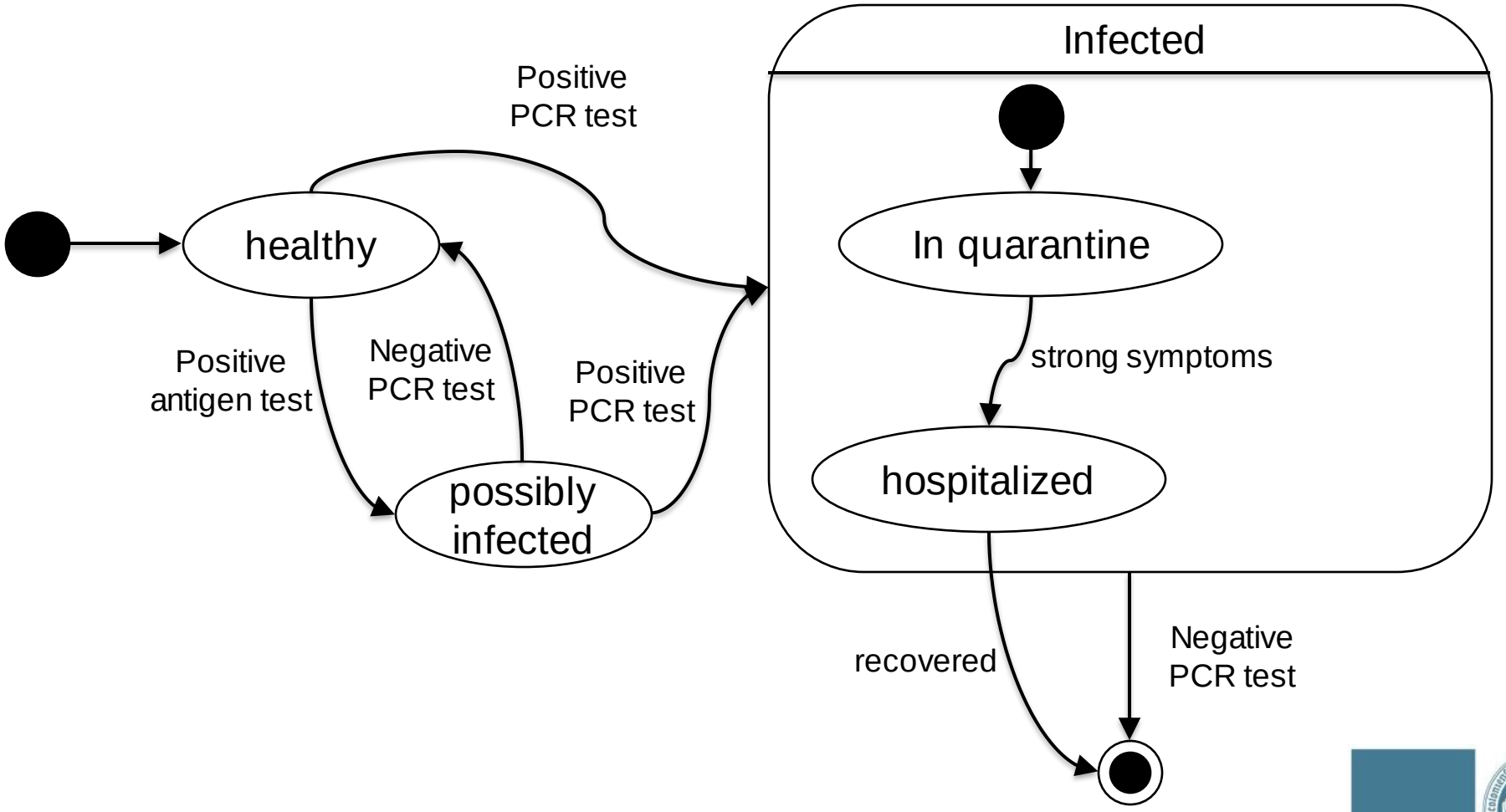
Composite State: A state that has substates (i.e., nested states) is called a composite state. (komplexer Zustand)



Rules for State Machine Diagrams

- every composite state has its own single initial state (Startzustand)
- substates may be nested to any level

Example of a State Machine Diagram



State Machine Diagram Semantics

SM Semantics

Motivation: which behaviors are defined by a state machine diagram?

Finite State Machine Semantics: The possible behavior induced by a state machine diagram is the set of event sequences that are accepted by a corresponding finite state machine

Accepting an event sequence

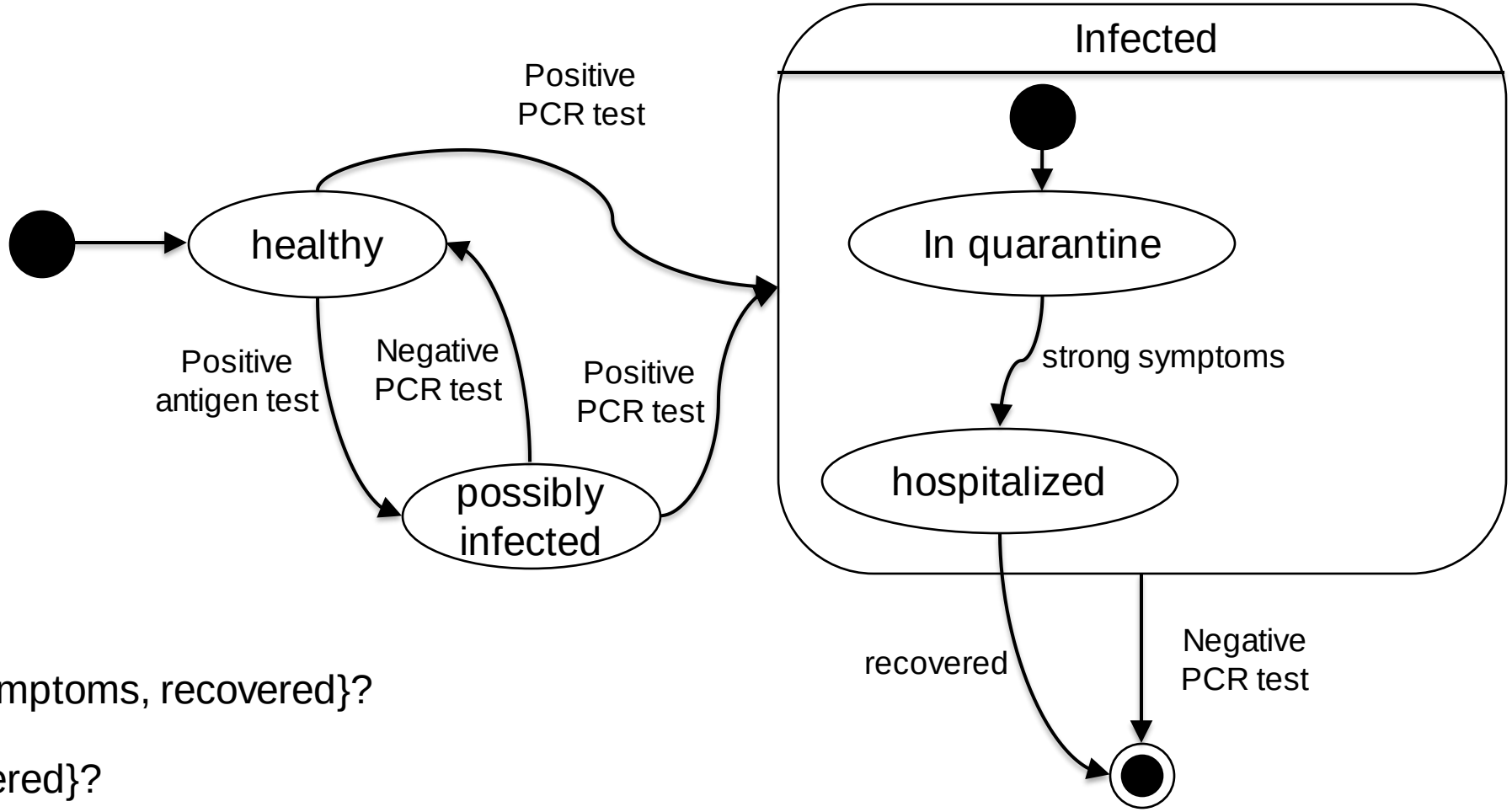
State: The outgoing state transitions of the current state define the possible transitions that can be taken

State transitions: Take the first event of the sequence and check if it matches any of the possible transitions. If a transition matches, take the transition, make the next state the current state, and remove the element from the sequence.

Final state: If the final state has been reached and the sequence is empty, the event sequence is accepted.

Non-acceptance: Event sequences are not accepted if
(1) the sequence is empty, but the final state has not been reached
(2) The final state has been reached but the event sequence is not yet empty
(3) No transition matches the current event in the sequence

Example of a FSM Semantics



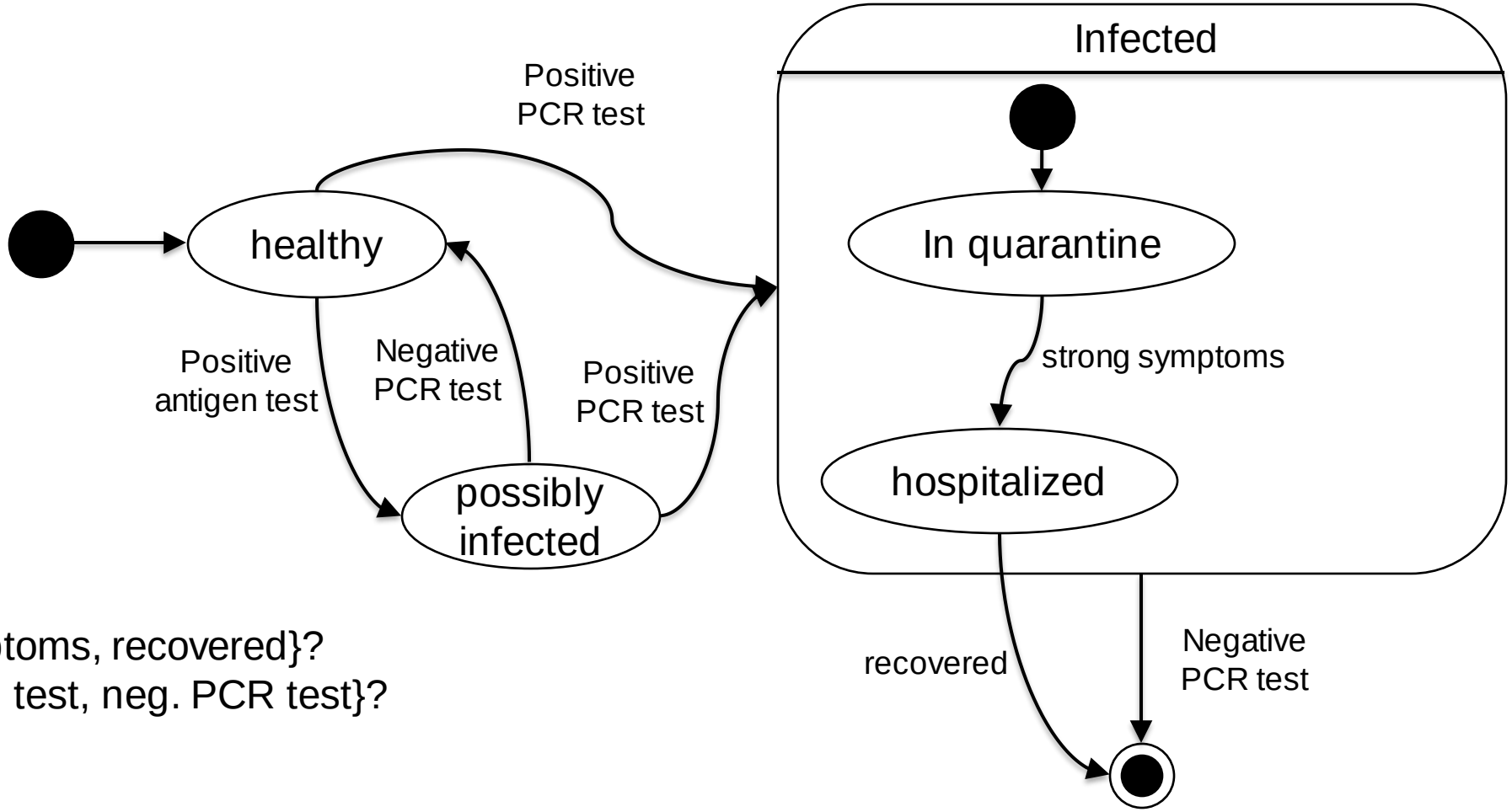
{pos. PCR test, strong symptoms, recovered}?

{strong symptoms, recovered}?

{recovered}?

{}

Example of a FSM Semantics



{pos. PCR test, strong symptoms, recovered}?
{pos. antigen test, pos. PCR test, neg. PCR test}?

…

(pos. antigen test, neg. PCR test)* (pos. PCR test | (pos. antigen test, pos. PCR test))
((strong symptoms, recovered | (strong symptoms, neg. PCR test) | neg. PCR test)

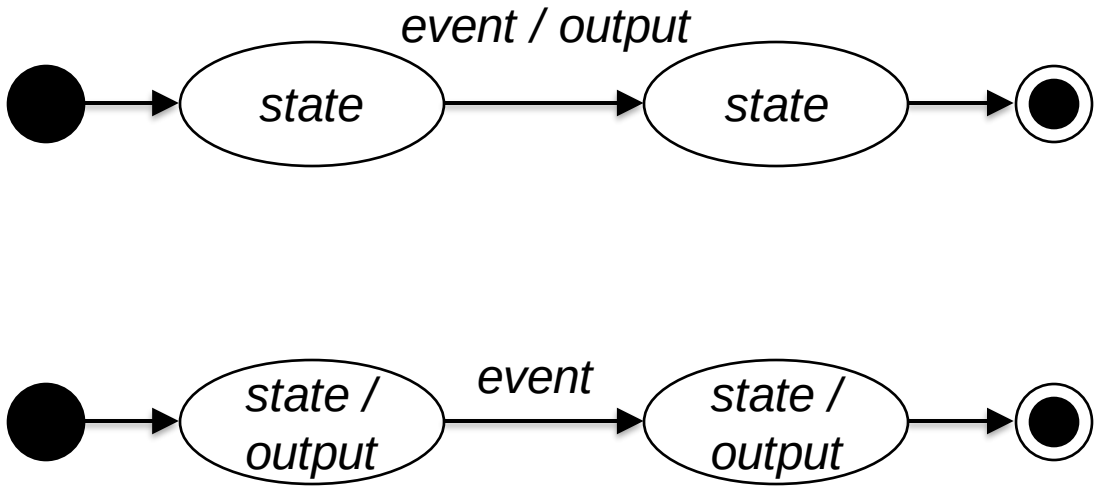
State Machine Diagrams with Output

Input/Output State Machines

Motivation: allow to attach output behavior to state machine diagrams

Output in transitions (Mealy Machines): While processing an input, the transition produces an output.

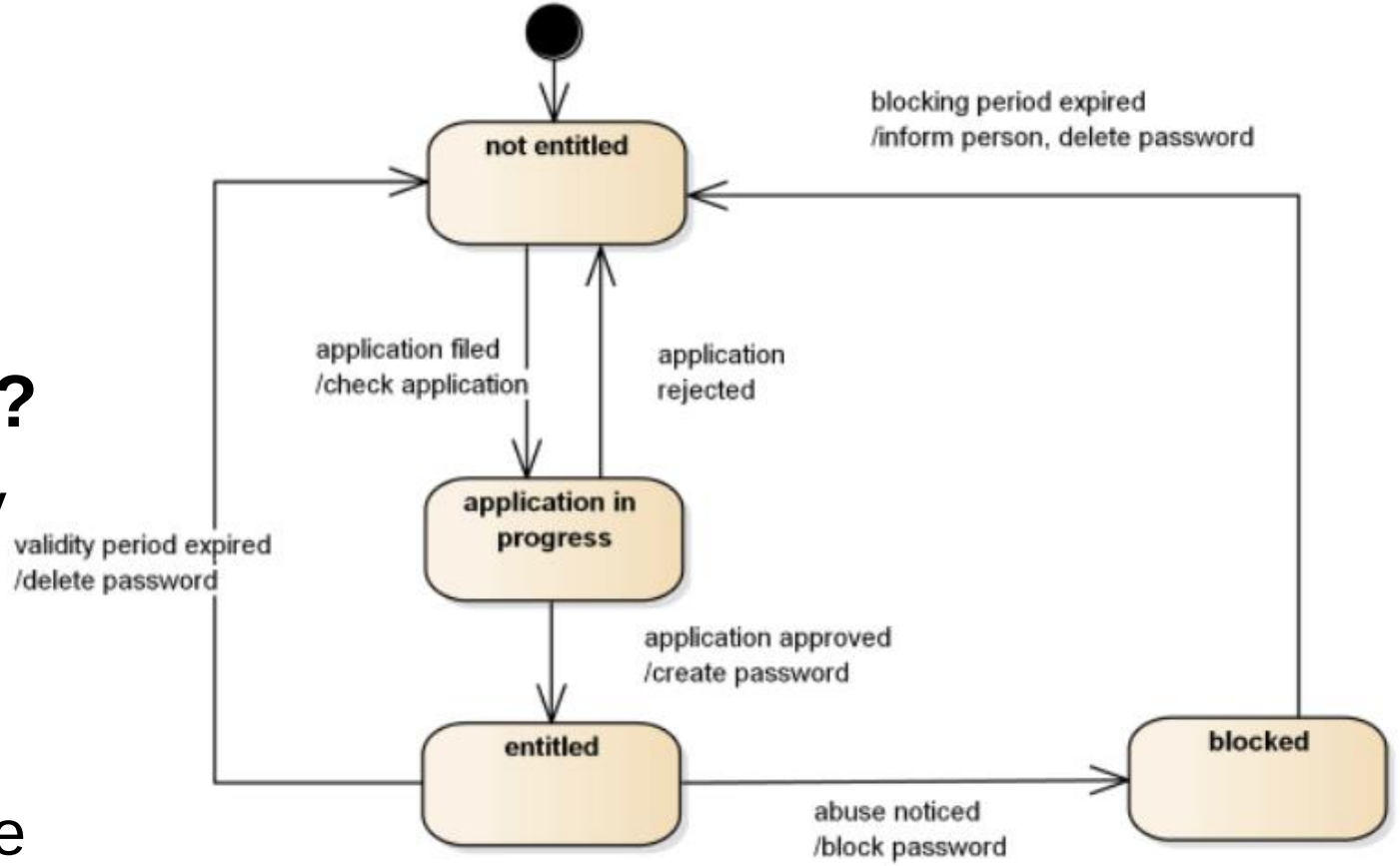
Output in states (Moore Machines): While entering/leaving a state, an output is produced.



Quick check

Which of the following requirements are modeled correctly in the state diagram?

- Blocked users can be unblocked by resetting the user's password.
- If abuse has been noticed, the password has to be blocked.
- If the validity period has expired, the password has to be deleted.
- If an application is approved, no new application can be created.



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Summary

Activity and State Machine Diagrams

We can visualize the dynamics of execution in two ways: by emphasizing the flow of control from activity to activity (**activity diagrams**) or by emphasizing the potential states and transitions among those states (**state machine diagrams**).