

Requirements Engineering I

Chapter 7

Model-Based Requirements Specification

Motivation

Why do we model requirements?

- Gain an **overview** of a set of requirements
- **Understand relationships** and **inter-connections** between requirements
- **Focus** on some **aspect** of a system, abstracting from the rest



Primarily for **functional requirements**

Quality requirements and constraints are mostly specified in natural language

7.1 Models in RE

DEFINITION. **Model** – an abstract representation of an **existing** part of **reality** or a part of reality **to be created**.

The notion of **reality** includes **any conceivable set of elements**, phenomena or concepts, including other models.

With respect to a model, the modeled part of reality is called the **original**.

- Requirements models are **problem-oriented** models of the system to be built
- Architecture and design information is **omitted**

Requirements models can be used for

- **Specifying** requirements (as a means of replacing textually represented requirements)
- **Paraphrasing** textually represented requirements to improve understanding of complex structures and dependencies
- **Testing** textually represented requirements to uncover omissions, ambiguities and inconsistencies
- **Decomposing** a complex reality into comprehensible parts

Which aspects can be modeled?

○ Structure and Data

- Structural properties of a system, particularly of the **static data**
- Structure of a system's **domain**

○ Function and Flow

Sequence of actions and control / data flow for

- producing a required **result**
- describing a (business) **process**

○ State and Behavior

Behavior of a system or a domain component

- State-dependent **reactions to events**
- **Dynamics** of component **interaction**

Which aspects can be modeled? – 2

- Context and boundary
 - **Structural embedding** of system in its environment
 - **Interaction** between system and actors in the context
- Goals
 - Understanding the goals for a system
 - Goal **decomposition**
 - Goal-agent **networks**

7.2 Modeling structure and data

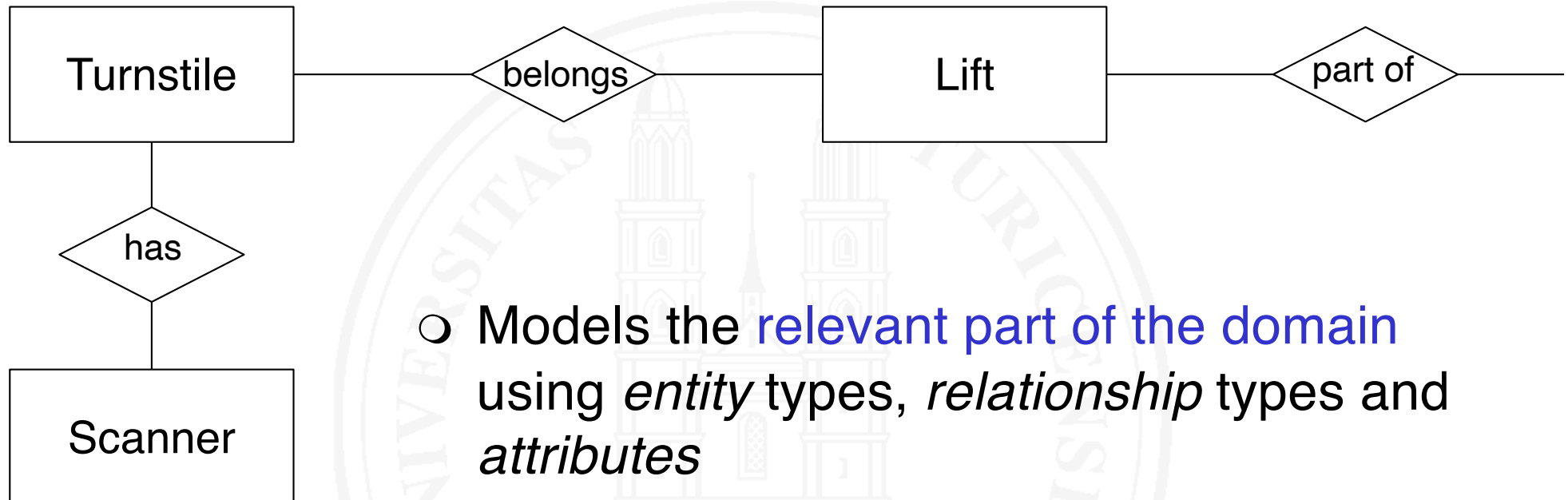
- Entity-relationship models
- Class and object models
- Component models

What to model

- **Static system models**: Information that a system needs to know and store persistently
- **Static domain models**: The (business) objects and their relationships in a domain of interest

Data modeling (entity-relationship models)

[Chen 1976]



- Models the **relevant part of the domain** using *entity* types, *relationship* types and *attributes*
- + Rather **easy** to model
- + Straightforward mapping to **relational database systems**
- **Ignores functionality** and **behavior**
- No means for system decomposition

Object and class modeling

[Booch 1986, Booch 1994, Glinz et al. 2002]

Idea

- Identify those **entities** in the **domain** that the system has to store and process
- Map this information to **objects/classes**, **attributes**, **relationships** and **operations**
- Represent requirements in a **static structural model**
- Modeling **individual objects does not work**: too specific or unknown at time of specification
 - *Classify* objects of the same kind to classes: **Class models**
 - or select an abstract *representative*: **Object models**

Terminology

Object – an individual entity which has an identity and does not depend on another entity.

Examples: Turnstile no. 00231, The Plauna chairlift

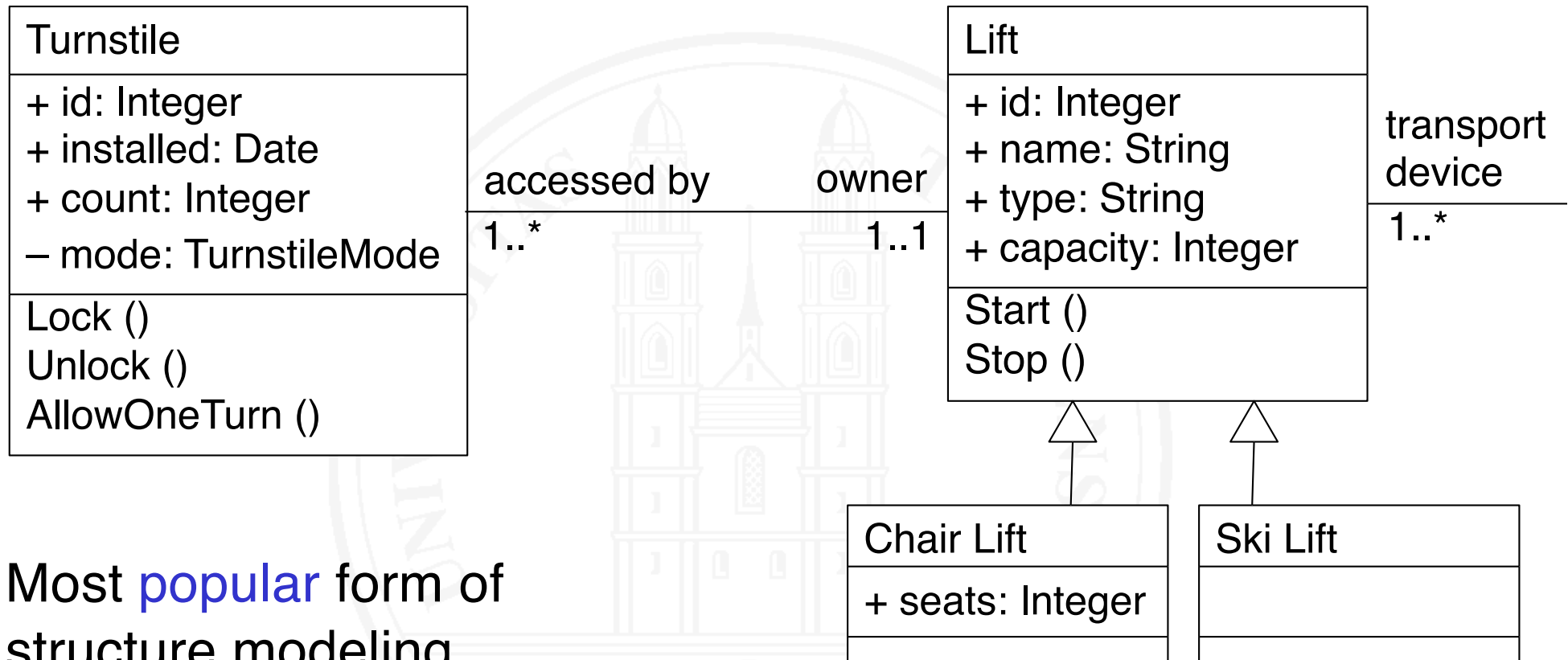
Class – Represents a set of objects of the same kind by describing the structure of the objects, the ways they can be manipulated and how they behave.

Examples: Turnstile, Lift

Abstract Object – an abstract representation of an individual object or of a set of objects having the same type

Example: A Turnstile

Class models / diagrams



Most **popular** form of structure modeling

Typically using **UML** class diagrams

Class diagram: a diagrammatic representation of a **class model**

Mini-Exercise: Class modeling

Assume that in our chairlift access control case study there is a requirement to keep an event log for every lift. Extend the class model from the previous slide such that the following information can be logged: A time stamp, the event name and event type (mode change, warning or failure), and (optionally) an action taken.

Class models are sometimes inadequate

- Class models don't work when **different objects of the same class** need to be **distinguished**
- Class models **can't be decomposed properly**: different objects of the same class may belong to different subsystems
- Subclassing is a **workaround**, but no proper solution

In such situations, we need **object models**

Object models: a motivating example

Example: Treating incidents in an emergency command and control system

Emergency command and control systems manage incoming emergency calls and support human dispatchers in reacting to incidents (e.g., by sending police, fire fighters or ambulances) and monitoring action progress.

When specifying such a system, we need to model

- Incoming incidents awaiting treatment
- The incident currently managed by the dispatcher
- Incidents currently under treatment
- Closed incidents

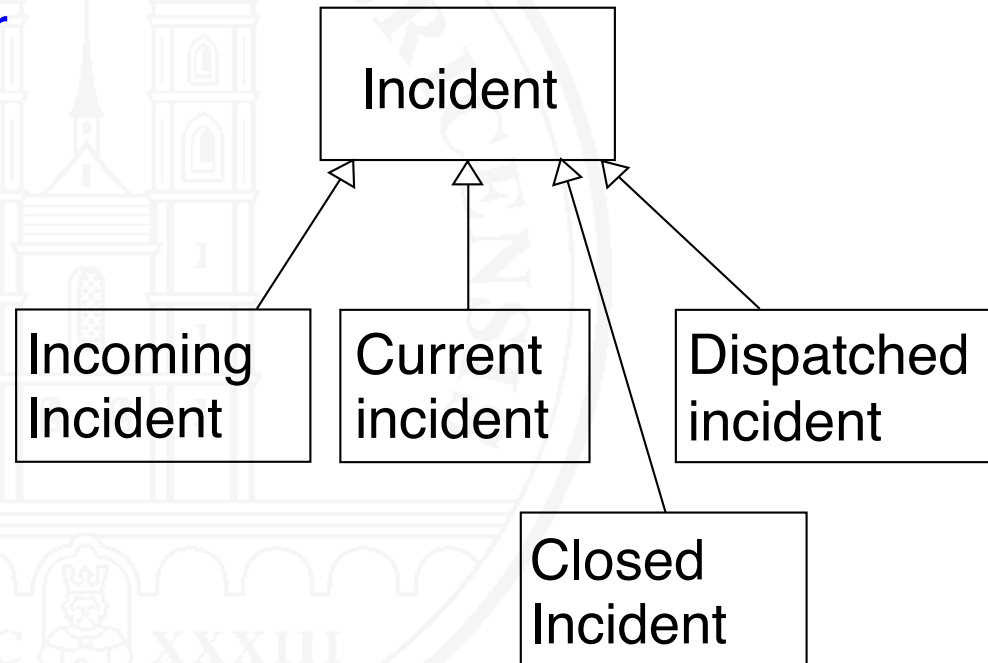
Class models are inadequate here

In a class model, incidents would have to be modeled as follows:

either



or

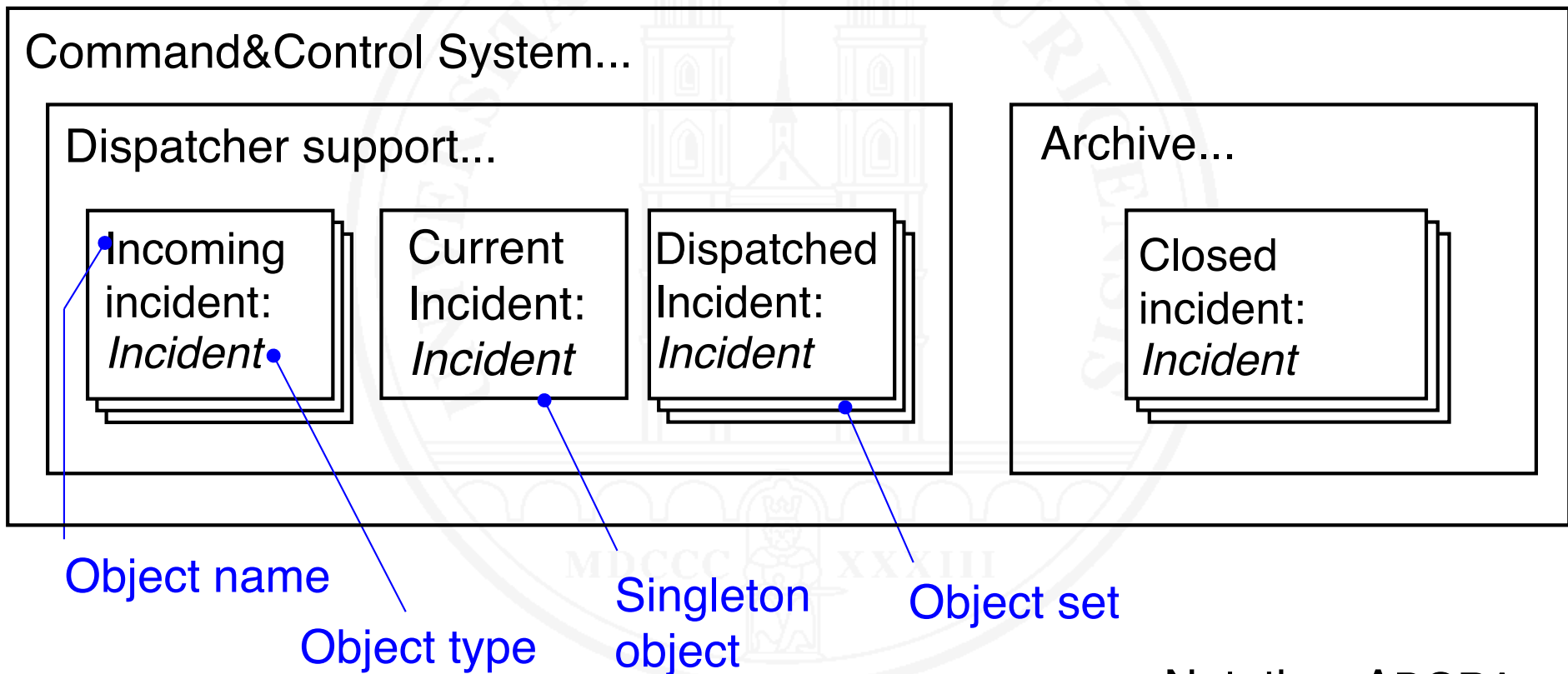


Bad: essential elements of the problem are not modeled

Unnatural: all subclasses are structurally identical

Object models work here

Modeling is based on a **hierarchy of abstract objects**



Notation: ADORA

- **ADORA** is a language and tool for object-oriented specification of software-intensive systems
- Basic concepts
 - Modeling with **abstract objects**
 - **Hierarchic decomposition** of models
 - **Integration** of object, behavior and interaction modeling
 - Model visualization in **context** with **generated views**
 - **Adaptable degree** of formality
- Developed in the REREG research group at UZH

Modeling with abstract objects in UML

- Not possible in the original UML (version 1.x)
- Introduced 2004 as an option in **UML 2**
- Abstract objects are modeled as **components** in UML
- The **component diagram** is the corresponding diagram
- **Lifelines** in UML 2 **sequence diagrams** are also frequently modeled as abstract objects
- In UML 2, **class diagrams** still dominate

What can be modeled in class/object models?

- **Objects** as *classes* or *abstract objects*
- **Local properties** as *attributes*
- **Relationships / non-local properties** as *associations*
- **Services** offered by objects as *operations* on objects or classes (called *features* in UML)
- **Object behavior**
 - Must be modeled in separate *state machines* in UML
 - Is modeled as an *integral part* of an object hierarchy in ADORA
- **System-context interfaces** and **functionality from a user's perspective** *can't* be modeled *adequately*

Object-oriented modeling: pros and cons

- + Well-suited for describing the **structure of a system**
- + Supports **locality of data** and **encapsulation of properties**
- + Supports **structure-preserving implementation**
- + **System decomposition** can be modeled
- **Ignores** functionality and behavior from a **user's perspective**
- UML **class models** don't support **decomposition**
- UML: **Behavior modeling** **weakly integrated**

Mini-Exercise: Classes vs. abstract objects

Specify a distributed **heating control system** for an office building consisting of a central boiler control unit and a room control unit in every office and function room.

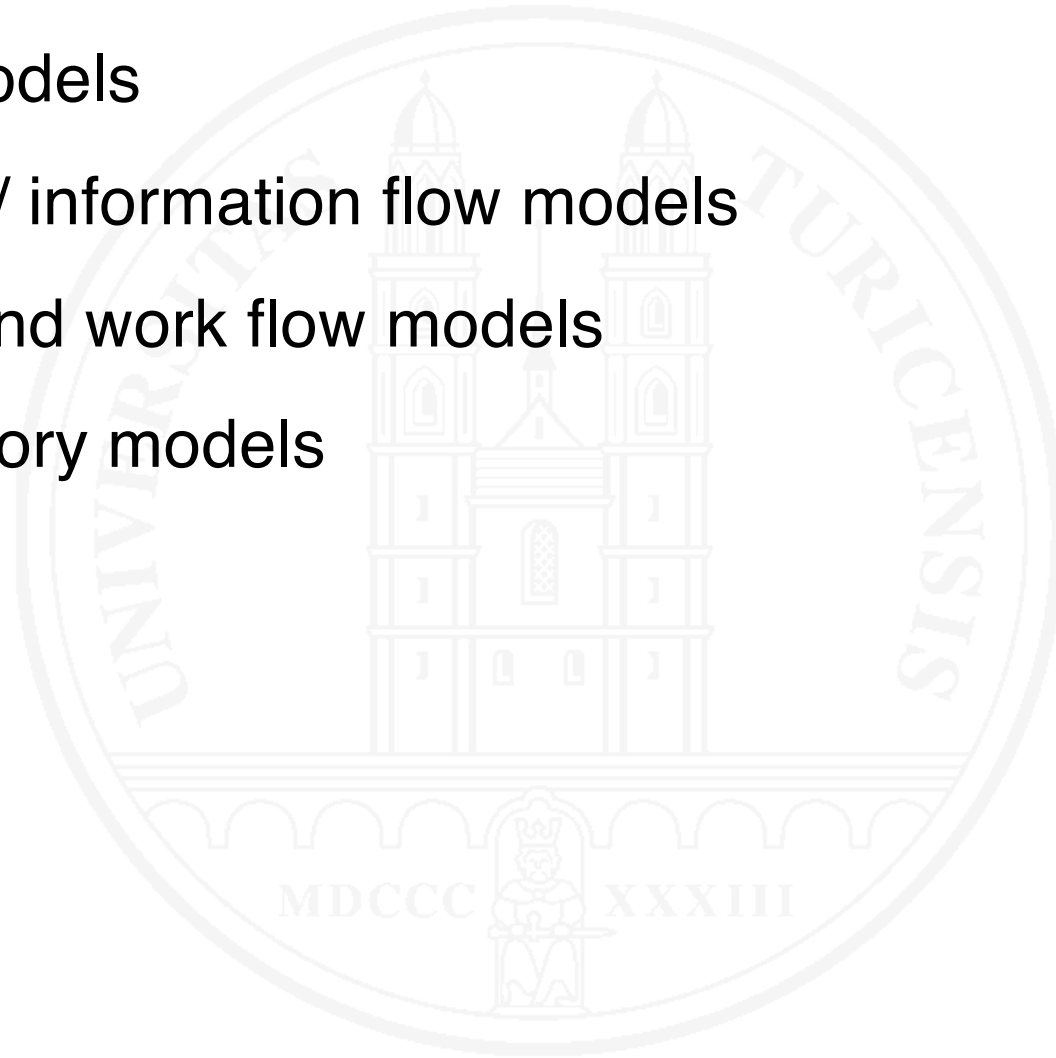
- The **boiler control unit** shall have a control panel consisting of a keyboard, a LCD display and on/off buttons.
- The **room control unit** shall have a control panel consisting of a LCD display and five buttons: on, off, plus, minus, and enter.

Model this problem using

- a. A class model
- b. An abstract object model.

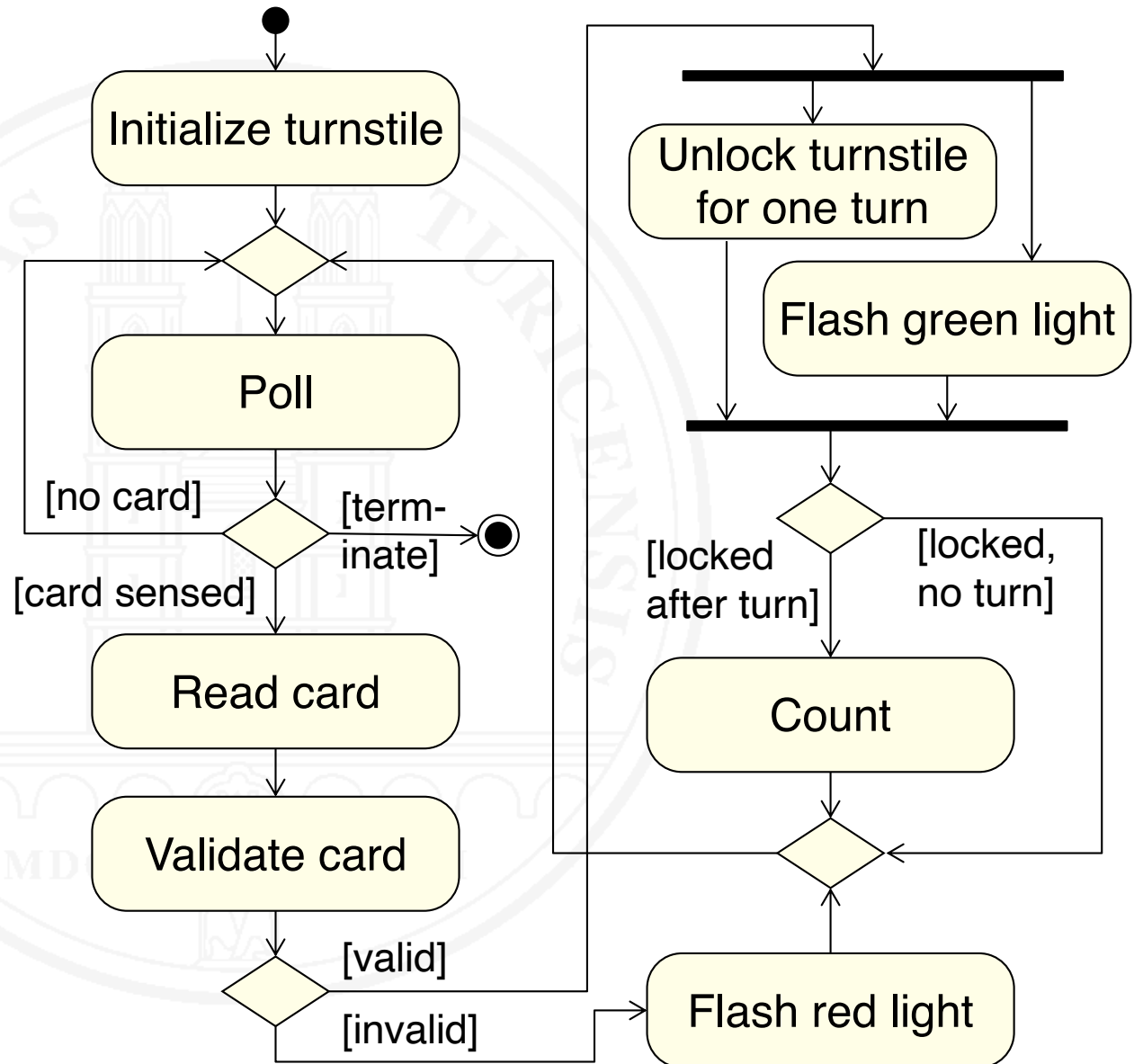
7.3 Modeling function and flow

- Activity models
- Data flow / information flow models
- Process and work flow models
- Domain story models



Activity modeling: UML activity diagram

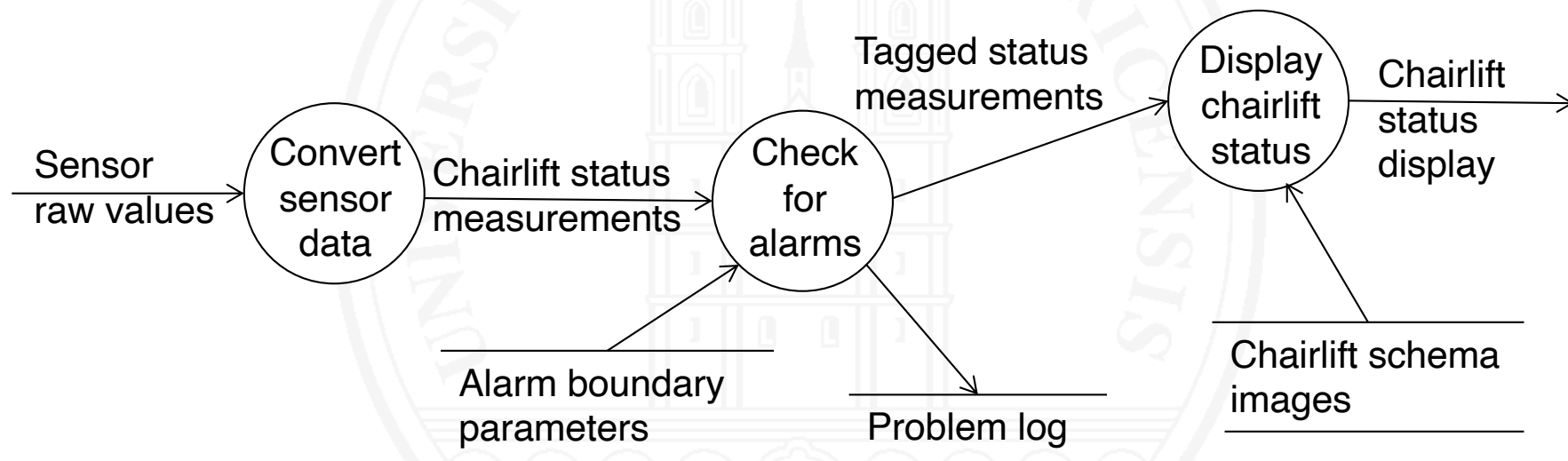
- Models process activities and control flow
- Can model data flow
- Model can be underpinned with execution semantics



Data and information flow

[DeMarco 1978]

- Models system functionality with **data flow diagrams**
- Once a dominating approach; **rarely used today**



- + Easy to understand
- + Supports system decomposition
- Treatment of data outdated: no types, no encapsulation

Process and workflow modeling

○ Elements

- Process steps / work steps
- Events influencing the flow
- Control flow
- Maybe data / information access and responsibilities

○ Typical languages

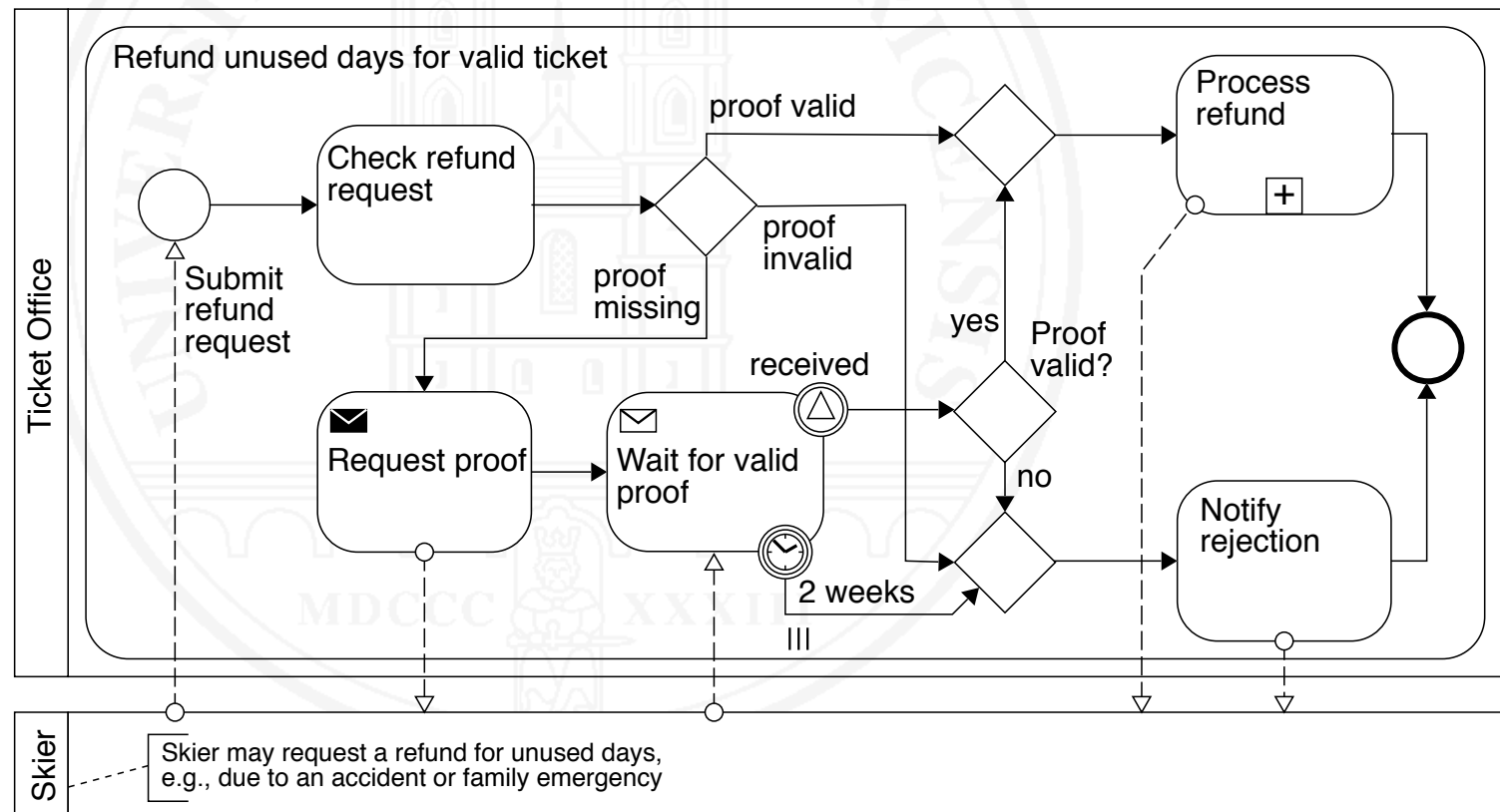
- UML activity diagrams
- BPMN
- Event-driven process chains

Process modeling: BPMN

[Object Management
Group 2013]

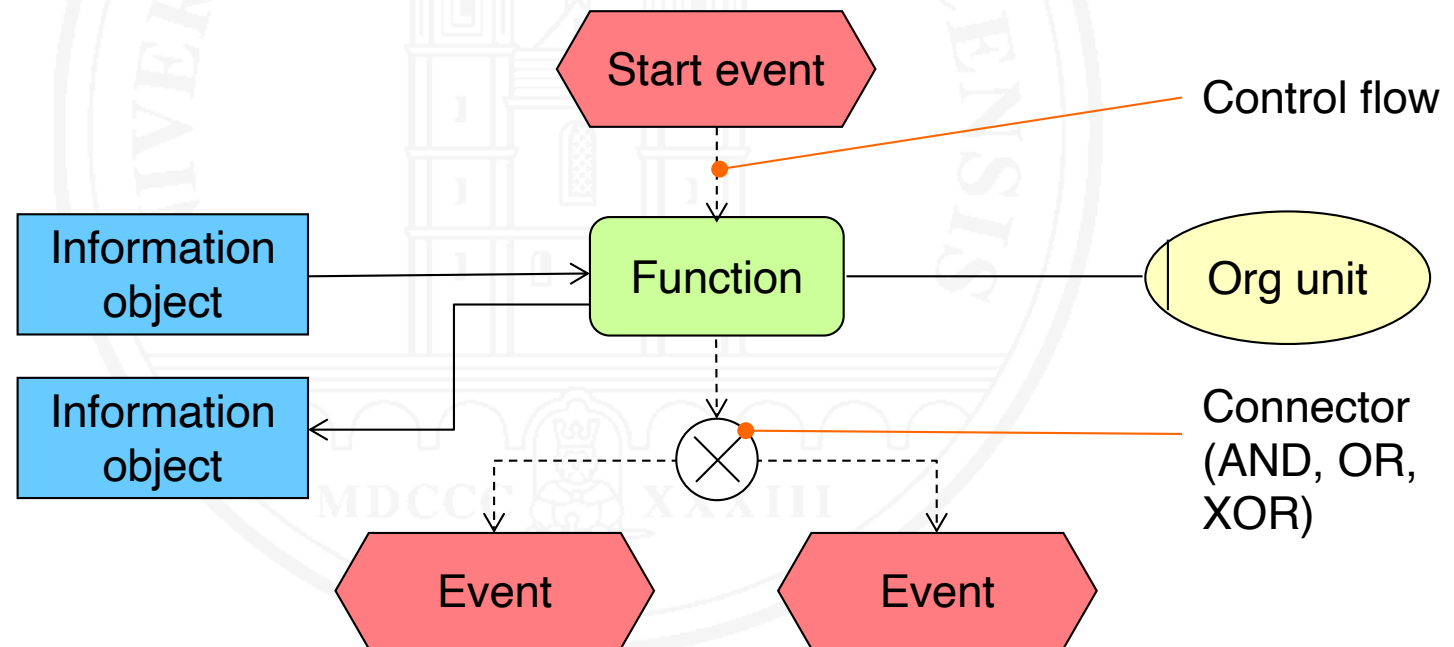
BPMN (Business Process Model and Notation)

- Rich language for describing business processes

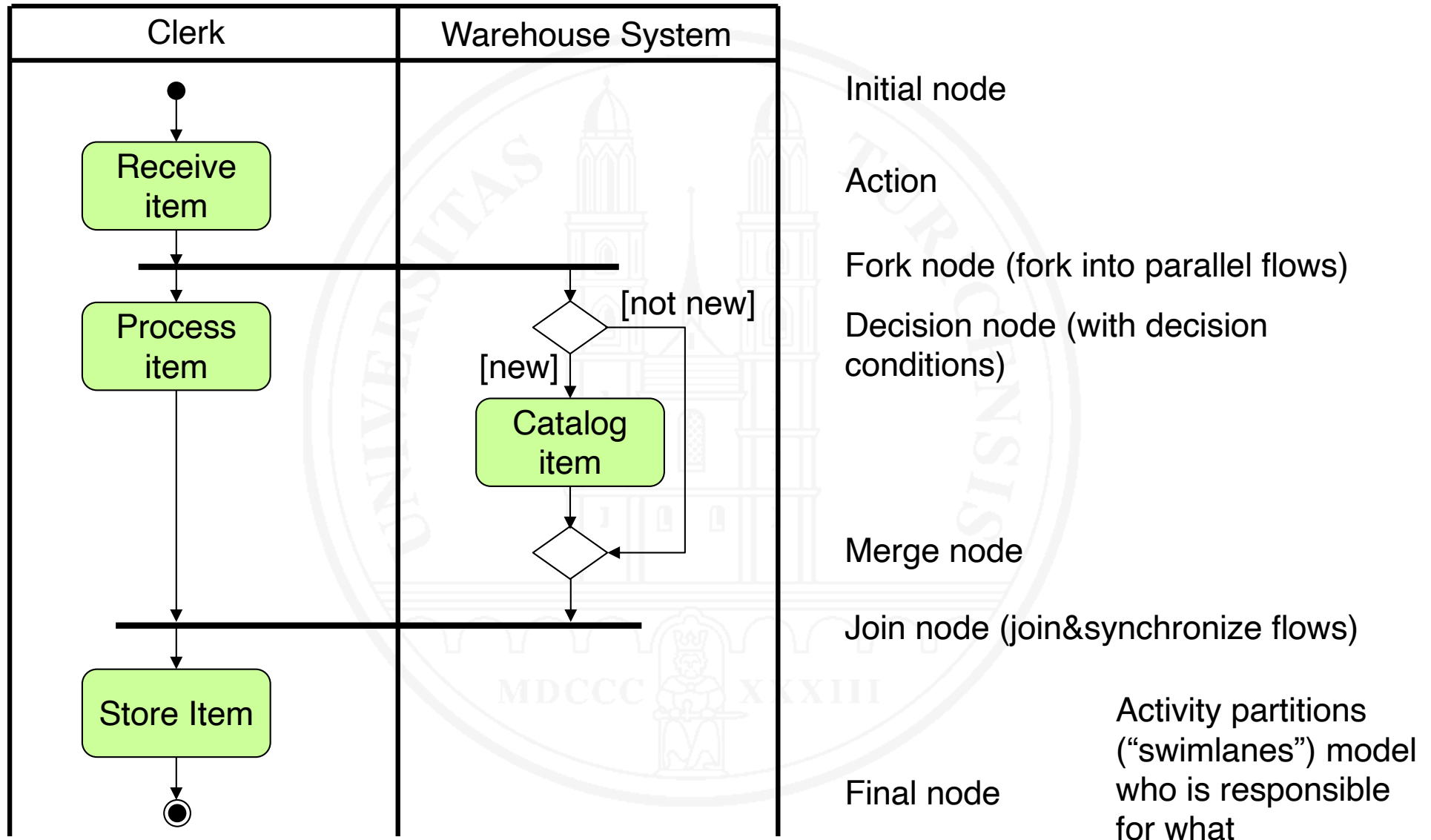


Process modeling: EPC

- Event-driven process chains (In German: ereignisgesteuerte Prozessketten, EPK)
- Adopted by SAP for modeling processes supported by SAP's ERP software

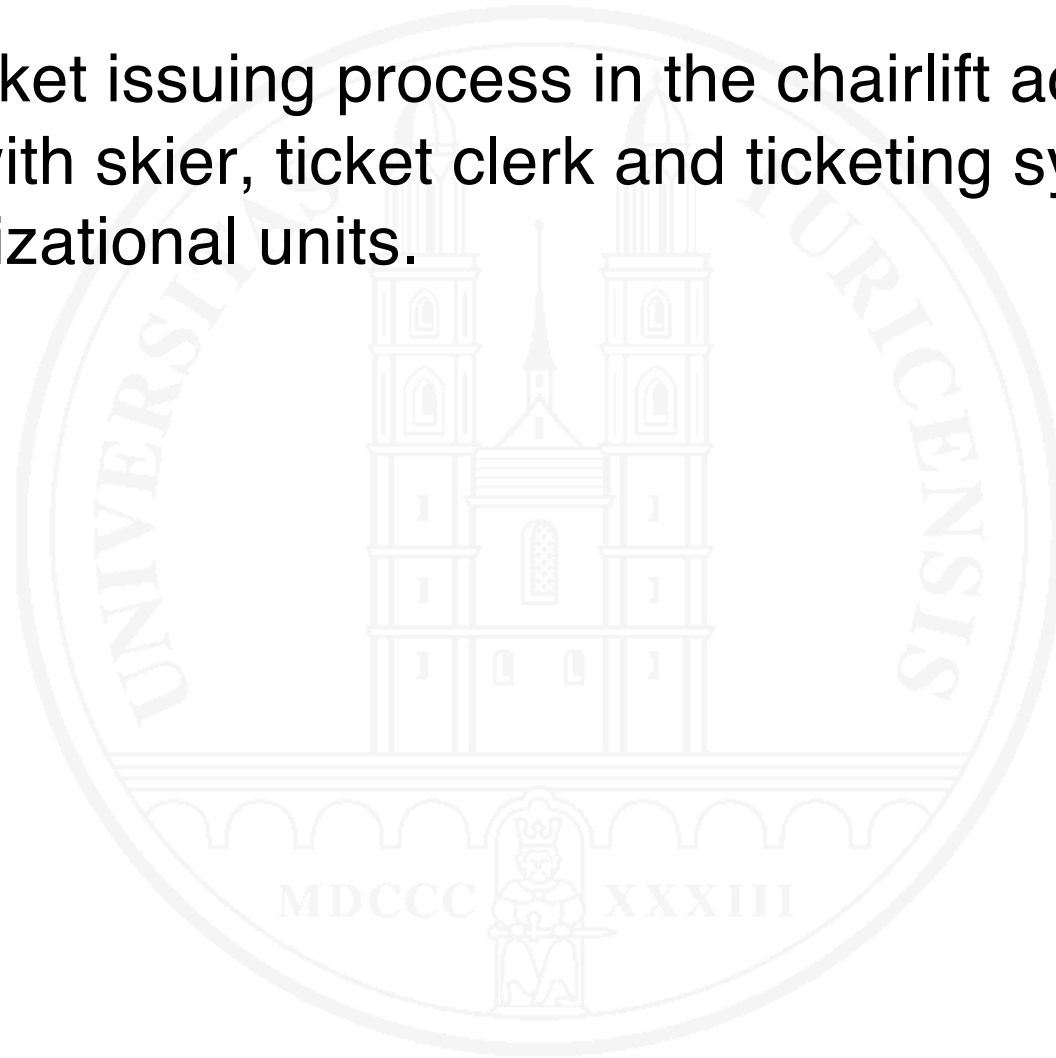


Process modeling: UML Activity Diagram



Mini-Exercise: Process modeling with UML

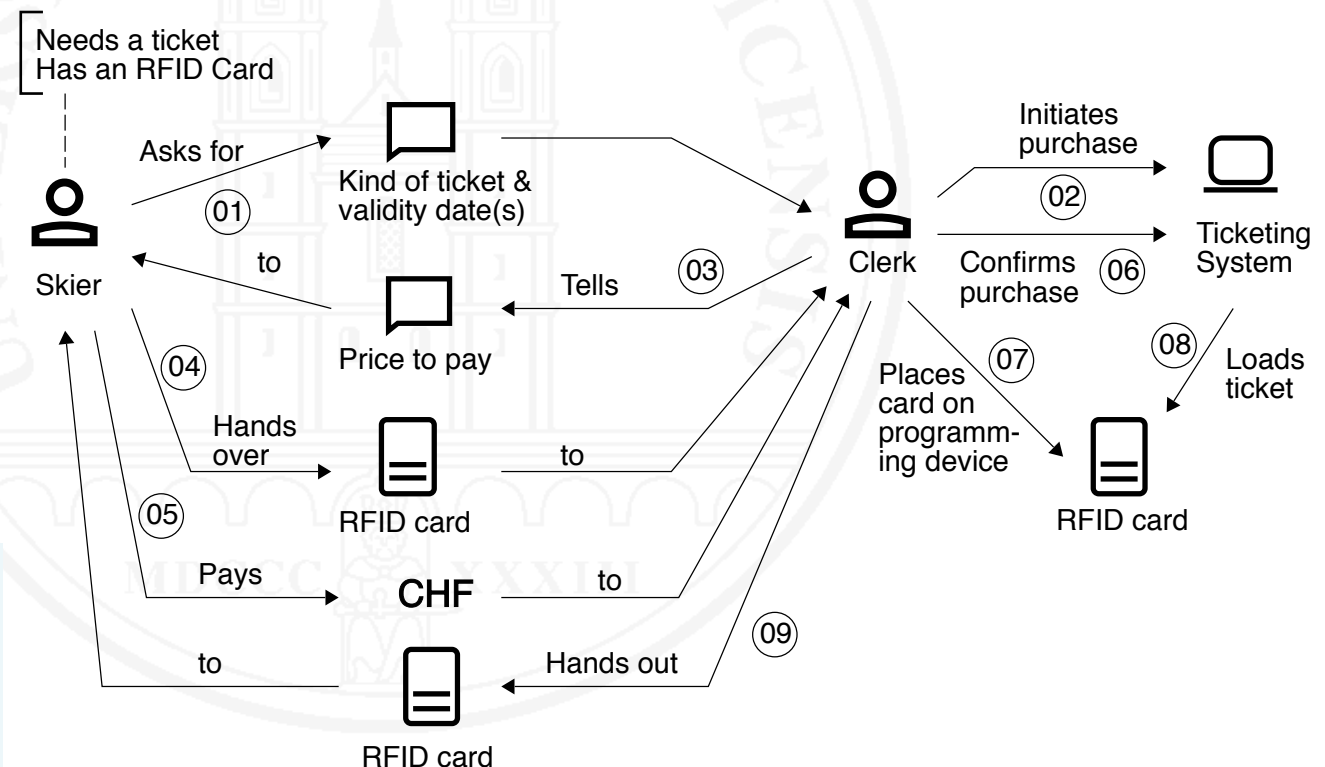
Model the ticket issuing process in the chairlift access control case study with skier, ticket clerk and ticketing system as actors/organizational units.



Domain story models

[Hofer&Schwendtner 2021]

- Visual stories about what stakeholders want to achieve
- Includes information about processes, system, people and organizations



The circled numbers indicate the order of steps in the story

7.4 Modeling state and behavior

Goal: describe dynamic system behavior

- How the system **reacts** to a sequence of external **events**
- How independent system components **coordinate** their work

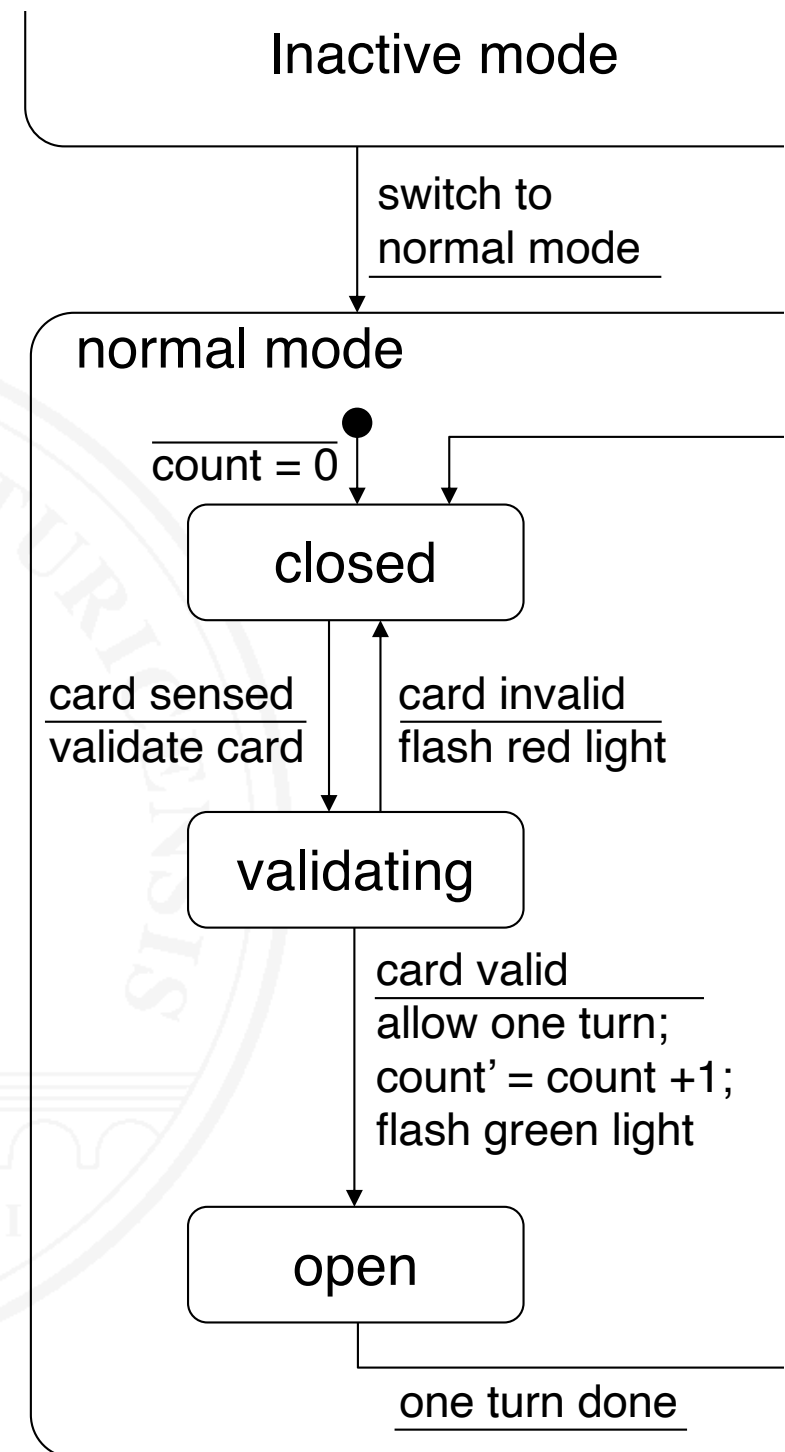
Means:

- **Finite state machines (FSMs)** – not discussed here
- **Statecharts / State machines**
 - Easier to use than FSMs (although theoretically equivalent)
 - State machines are the UML variant of statecharts
- **Sequence diagrams** (primarily for behavioral scenarios)
- **Petri nets** – not discussed in this course

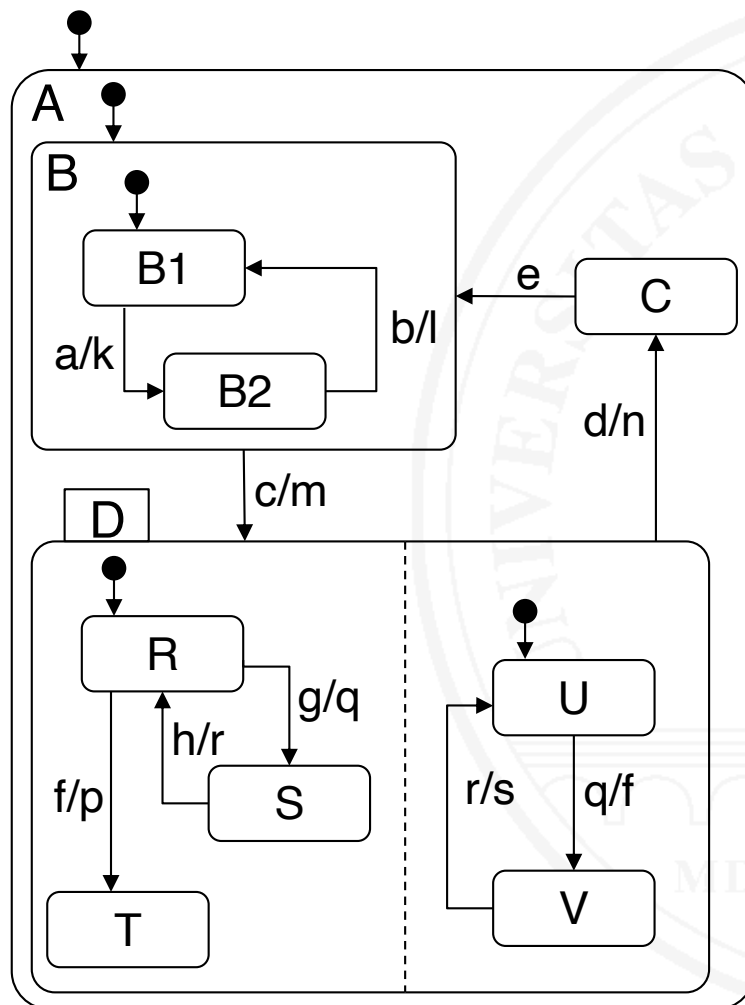
Statecharts

[Harel 1988]

- Models the *dynamic behavior*:
 - How the system reacts to **external events** in a given **state**
 - Reaction depends on actual state
 - States may be **hierarchically nested** and/or **orthogonal** (parallel)
- In UML: **state machine diagrams**
- + Global view of system behavior
- + Precise, but still readable
- Weak for modeling functionality and data



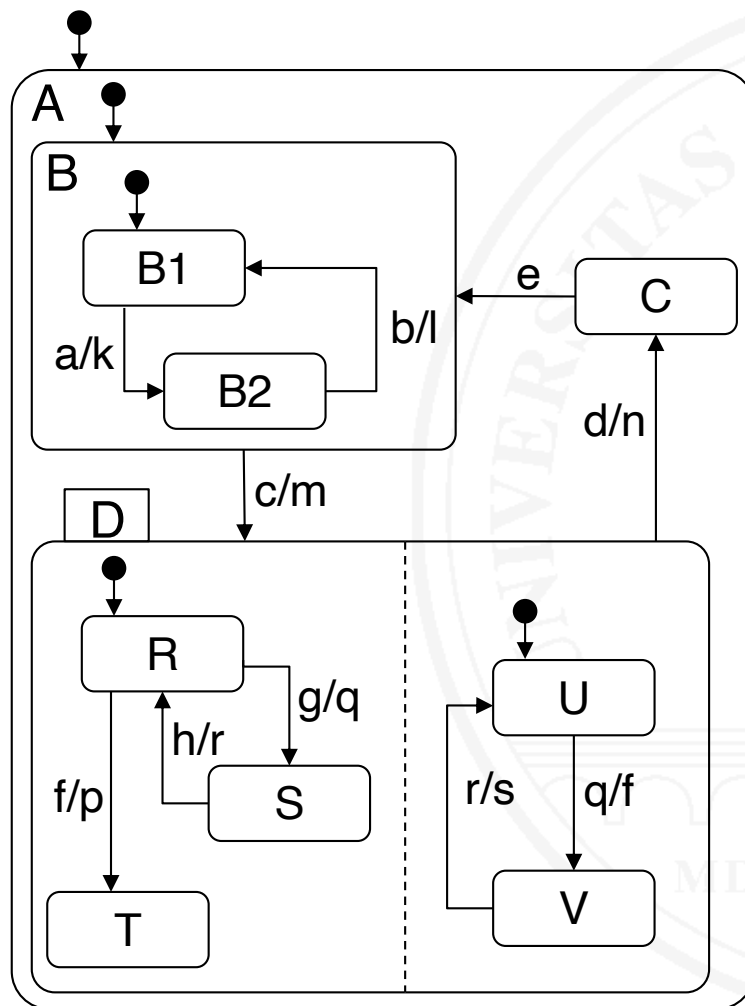
Interpretation of Statecharts



- Statecharts may have *composite states* with *substates* and *parallel regions*, for example:
 - B is a composite state, consisting of substates B1 and B2
 - D is a composite state with two parallel regions
- *Events* trigger *state transitions* and can trigger *actions* or *new events*, for example:

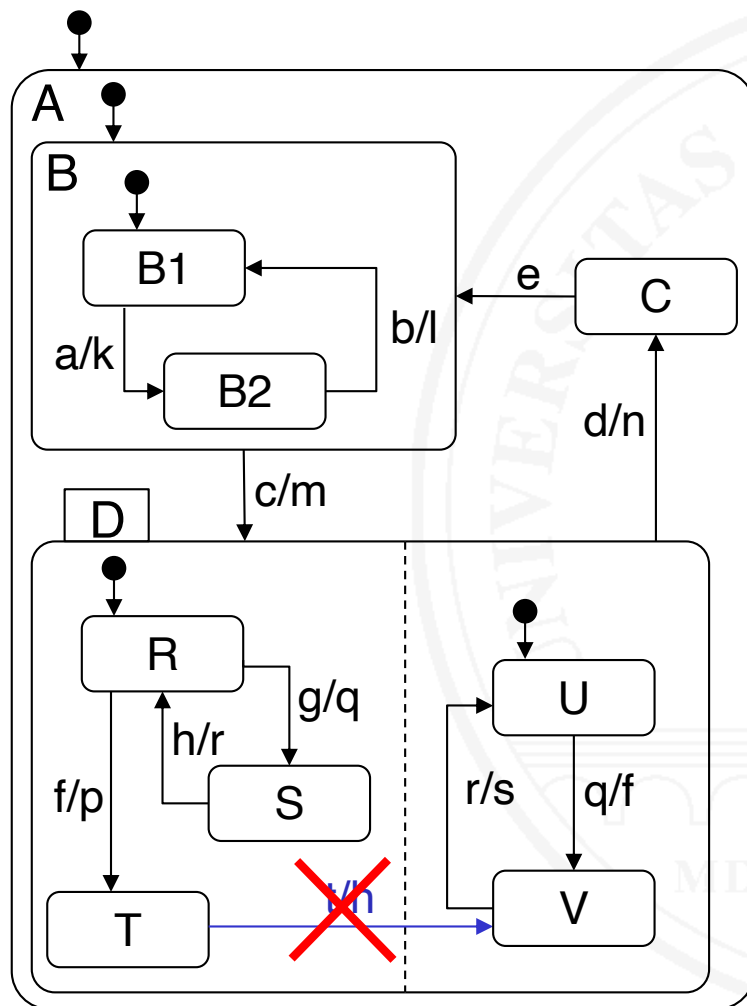
The occurrence of event c triggers the transition from state B to D, provided the system currently is in state B. The transition triggers m, which may be an action or an event.

Interpretation of Statecharts – 2



- The system is always in **exactly one** combination of states and nested substates, for example:
 - Statechart A initially is in state B and its substate B1
 - After the occurrence of event *c*, A is in state D and substates (R, U)
 - After the occurrence of event *f*, A still is in state D, but now in substates (T, U)
- Events are **ignored** when there is no transition for it in the current state: e.g., in state B2, event *f* is ignored

Interpretation of Statecharts – 3

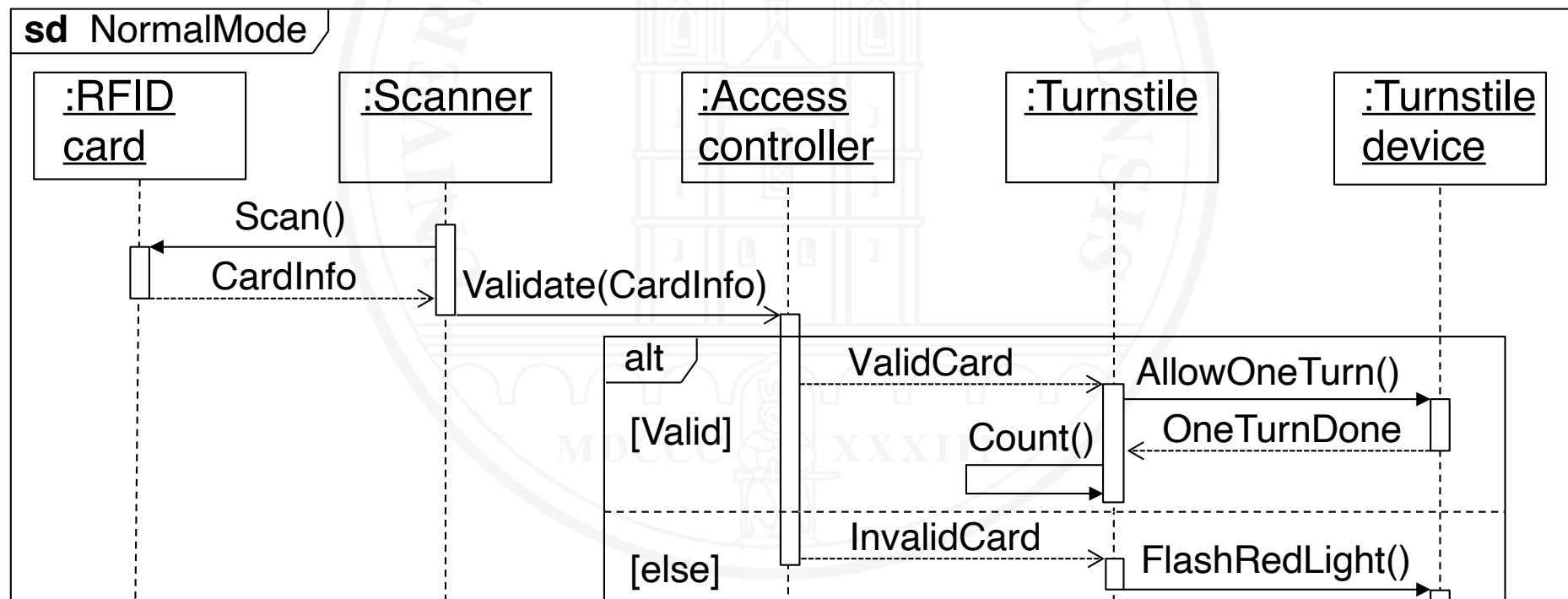


- State transitions into a composite state **also enter its substates**
- Leaving a state implies **leaving all its substates**
- Regions can **influence each other** via events, for example:
If the system is in R and U, the event g triggers a transition from R to S, producing q. Event q in turn triggers a transition from U to V.
- Transitions between regions are **forbidden**

Sequence diagrams / MSCs

Object Management Group (2011b)

- Models ...
 - ... **lifelines** of system components or objects
 - ... **messages** that the components exchange



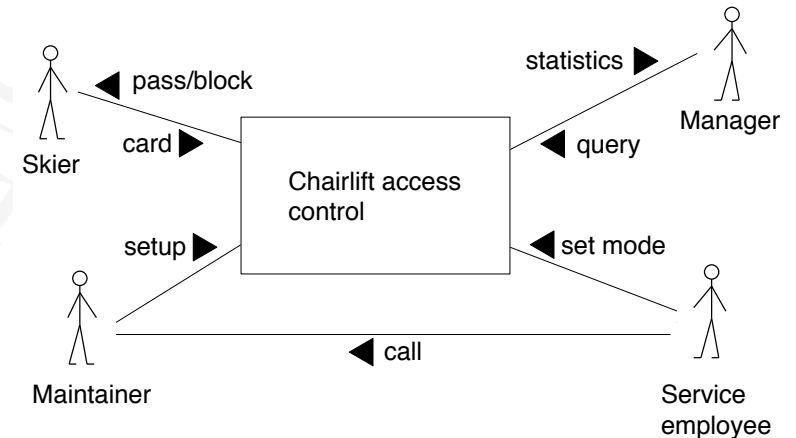
-
- Notation/terminology:
 - UML: Sequence diagram
 - Otherwise: Message sequence chart (MSC)
 - + Visualizes component collaboration on a **timeline**
 - In practice confined to the description of **required scenarios**
 - Design-oriented, can detract from modeling requirements

7.5 Modeling context and boundary

Structural embedding

- Context diagrams, modeling

- The system
- The actors in the system's context
- Information interfaces between actors and system
- Information interfaces among actors



→ Chapter 2.4

Dynamic interaction between system and context

- Scenarios
- Use cases

Dynamic interaction: modeling the users' view

Describing the functionality of a system from a **user's perspective**: How can a user interact with the system?

Two key terms:

- **Use case**
- **Scenario**

[Carroll 1995,
Glinz 1995,
Glinz 2000a,
Jacobson et al. 1992,
Sutcliffe 1998,
Weidenhaupt et al. 1998]

Use case

DEFINITION. **Use case** – A set of possible **interactions** between **external actors** and a **system** that provide a benefit for the actor(s) involved.

Use cases specify a system from a **user's** (or other **external actor's**) **perspective**: every use case describes some **functionality** that the system must provide for the actors involved in the use case.

- **Use case diagrams** provide an overview
- **Use case descriptions** provide the details

[Jacobson et al. 1992
Glinz 2013]

Scenario

DEFINITION. **Scenario** – 1. In general: A description of a potential **sequence of events** that lead to a desired (or unwanted) **result**.

2. In RE: An **ordered sequence of interactions** between partners, in particular between a **system** and **external actors**. May be a concrete sequence (**instance scenario**) or a set of potential sequences (**type scenario, use case**).

[Carroll 1995
Sutcliffe 1998
Glinz 1995]

Use case / scenario descriptions

Various representation options

- Free text in natural language
- Structured text in natural language
- Statecharts / UML state machines
- UML activity diagrams
- Sequence diagrams / MSCs

Structured text is most frequently used in practice

A use case description with structured text

USE CASE SetTurnstiles

Actor: Service Employee

Precondition: none

Normal flow:

- 1 Service Employee chooses turnstile setup.
System displays controllable turnstiles: locked in red, normal in green, open in yellow.
- 2 Service Employee selects turnstiles s/he wants to modify.
System highlights selected turnstiles.
- 3 Service Employee selects Locked, Normal, or Open.
System changes the mode of the selected turnstiles to the selected one, displays all turnstiles in the color of the current mode.

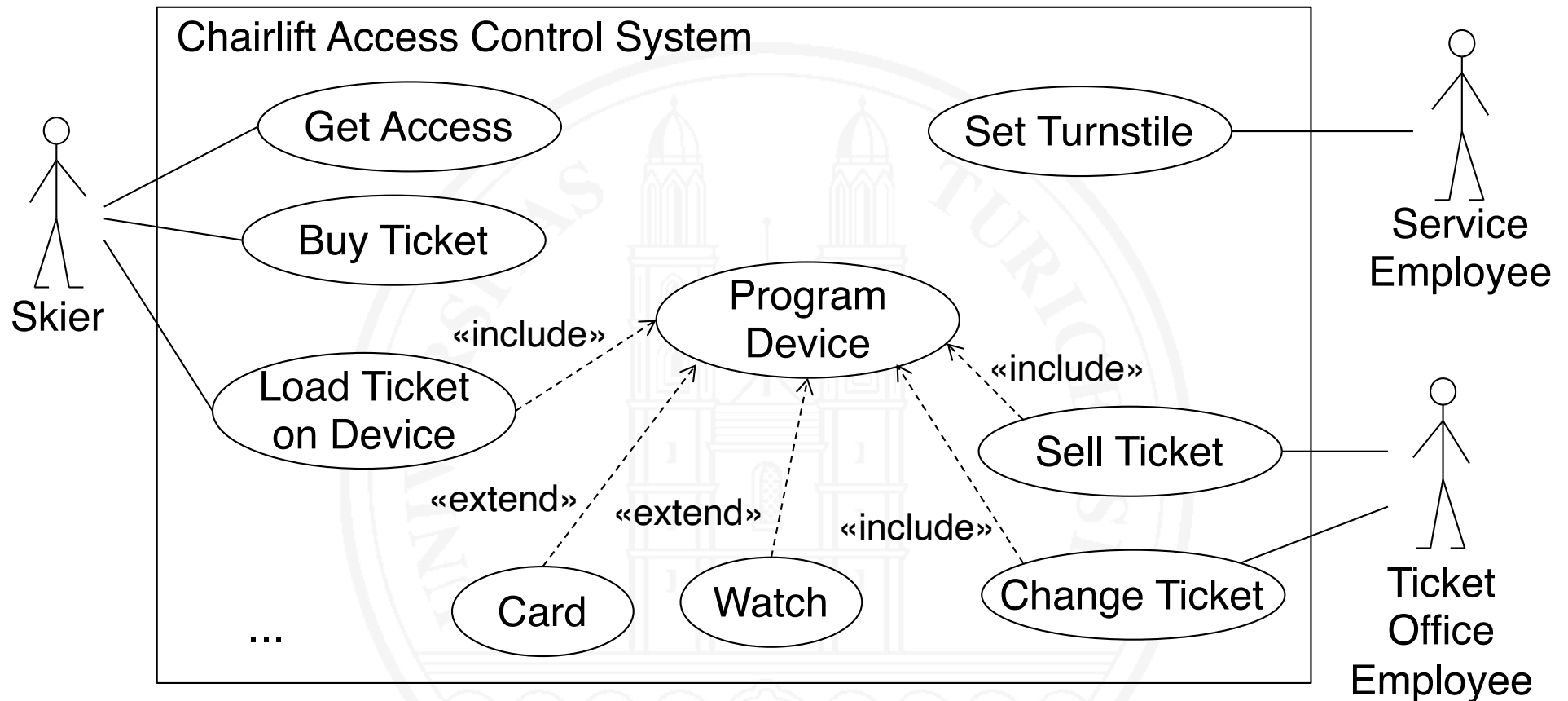
...

Alternative flows:

- 3a Mode change fails: System flashes the failed turnstile in the color of its current mode.

...

UML Use case diagram

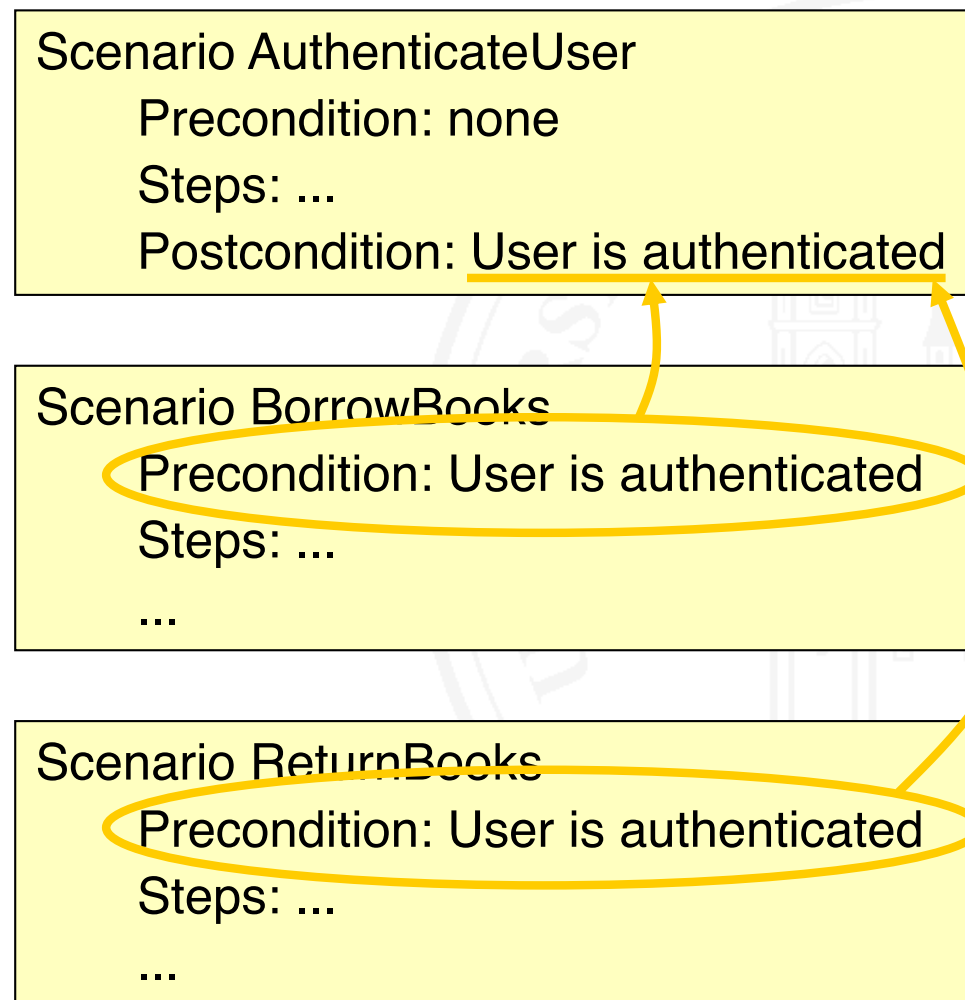


- + Provides abstract overview from actors' perspectives
- Ignores functions and data required to provide interaction
- Can't properly model hierarchies and dependencies

Dependencies between scenarios / use cases

- UML can only model inclusion, extension and generalization
- However, we need to model
 - Control flow dependencies (sequence, alternative, iteration)
 - Hierarchical decomposition
- Largely ignored in UML (Glinz 2000b)
- Options
 - Pre- and postconditions
 - Statecharts
 - Extended Jackson diagrams (in ADORA, Glinz et al. 2002)
 - Specific dependency charts (Ryser and Glinz 2001)

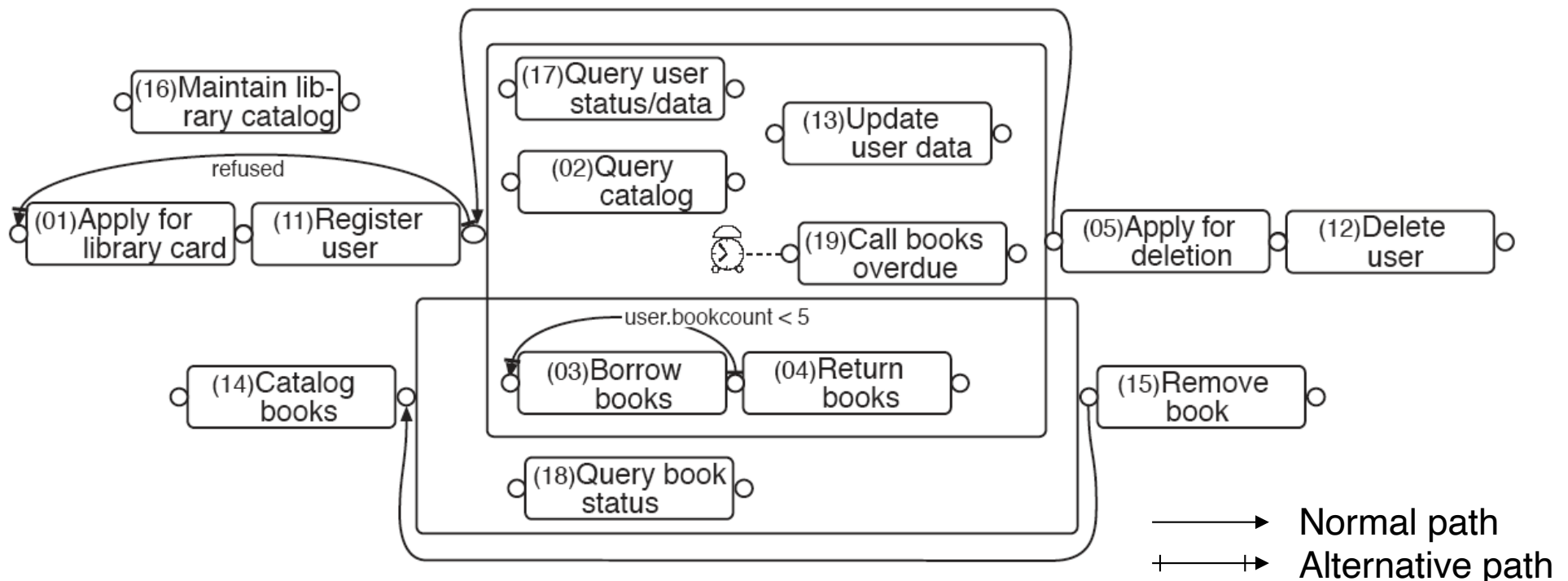
Dependencies with pre- and postconditions



- Simple dependencies of kind «B follows A» can be modeled
- Relationships buried in use case descriptions, no overview
- No hierarchical decomposition
- Modeling of complex relationships very complicated

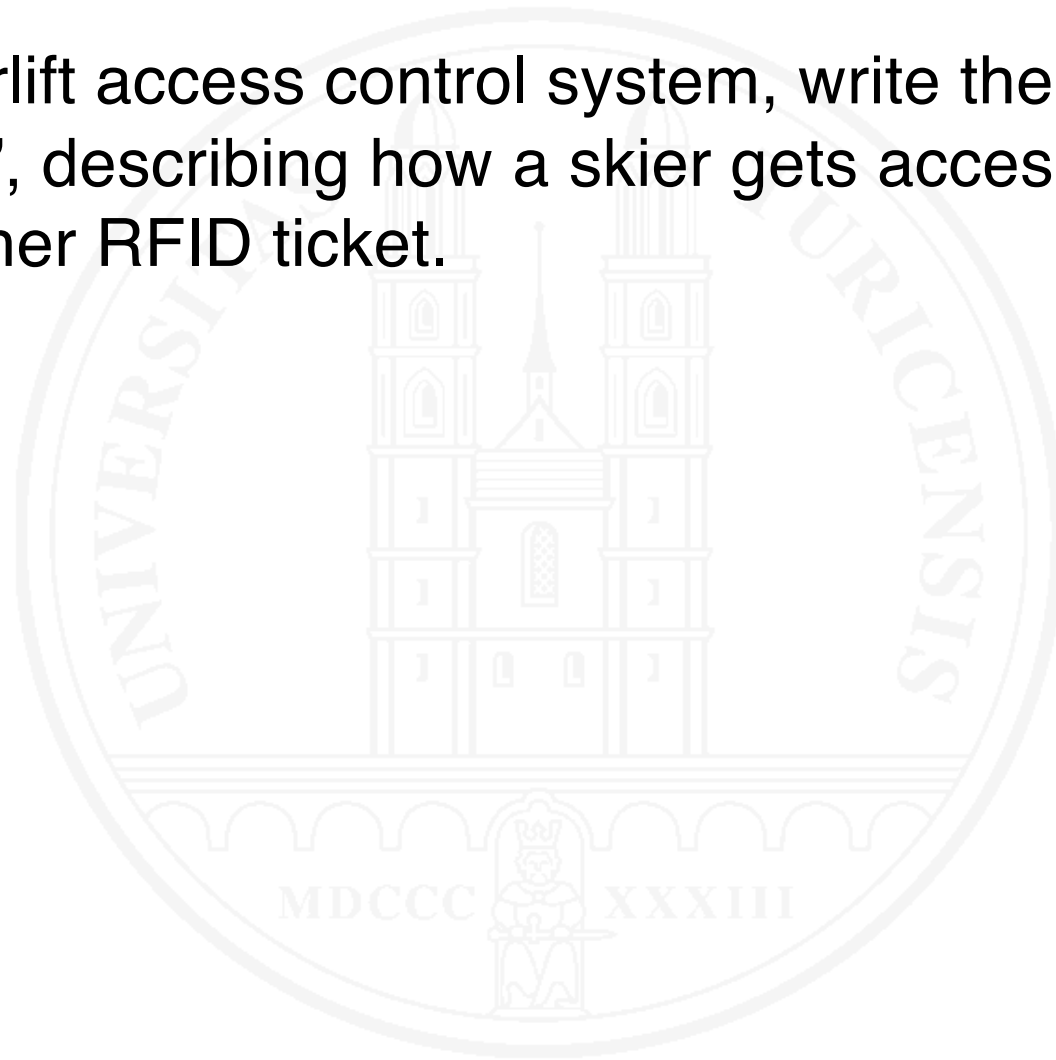
Dependency charts

- **Specific notation** for modeling of scenario dependencies (Ryser und Glinz 2001)
- **Research result**; not used in today's practice



Mini-Exercise: Writing a use case

For the Chairlift access control system, write the use case “Get Access”, describing how a skier gets access to a chairlift using his or her RFID ticket.



7.6 Modeling goals

- **Knowing the goals** of an organization (or for a product) is essential when specifying a system to be used in that organization (or product)
- Goals can be **decomposed** into **sub goals**
- Goal decomposition can be modeled with **AND/OR trees**
- Considering multiple goals results in a directed **goal graph**

[van Lamsweerde 2001, 2004
Mylopoulos 2006
Yu 1997]

AND/OR trees for goal modeling

goal

Reduce access control cost

AND-Decomposition

Reduce lift personnel

Simplify access control

OR-Decomposition

sub goals

Use RFID access cards

Use machine readable tickets

Use single point access

Install RFID enabled turnstiles

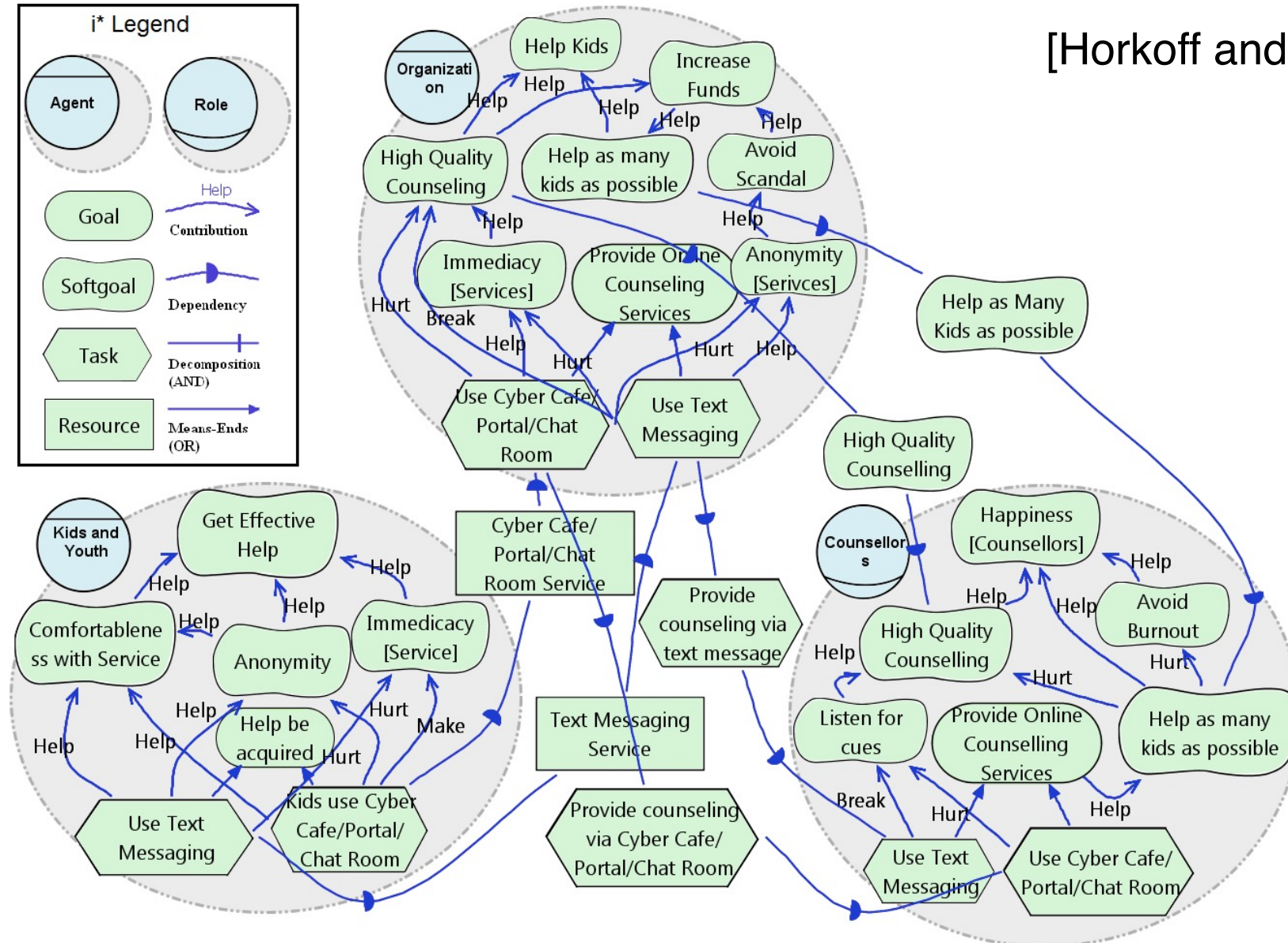
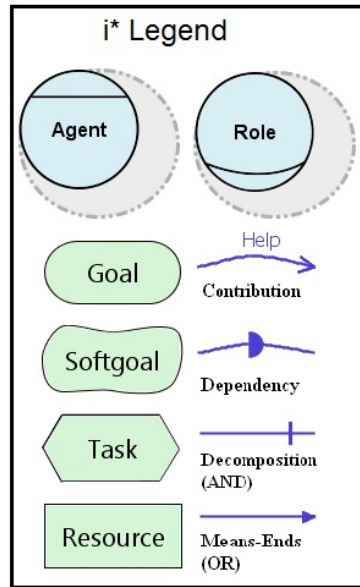
Install RFID enabled sales points

Goal-agent networks

- Explicitly models **agents** (stakeholders), their **goals**, **tasks** that achieve goals, **resources**, and **dependencies** between these items
- Many approaches in the RE literature
- **i*** is the most popular approach
- Rather **infrequently used** in practice

A real world i* example: Youth counseling

[Horkoff and Yu 2010]



7.7 UML (Unified Modeling Language)

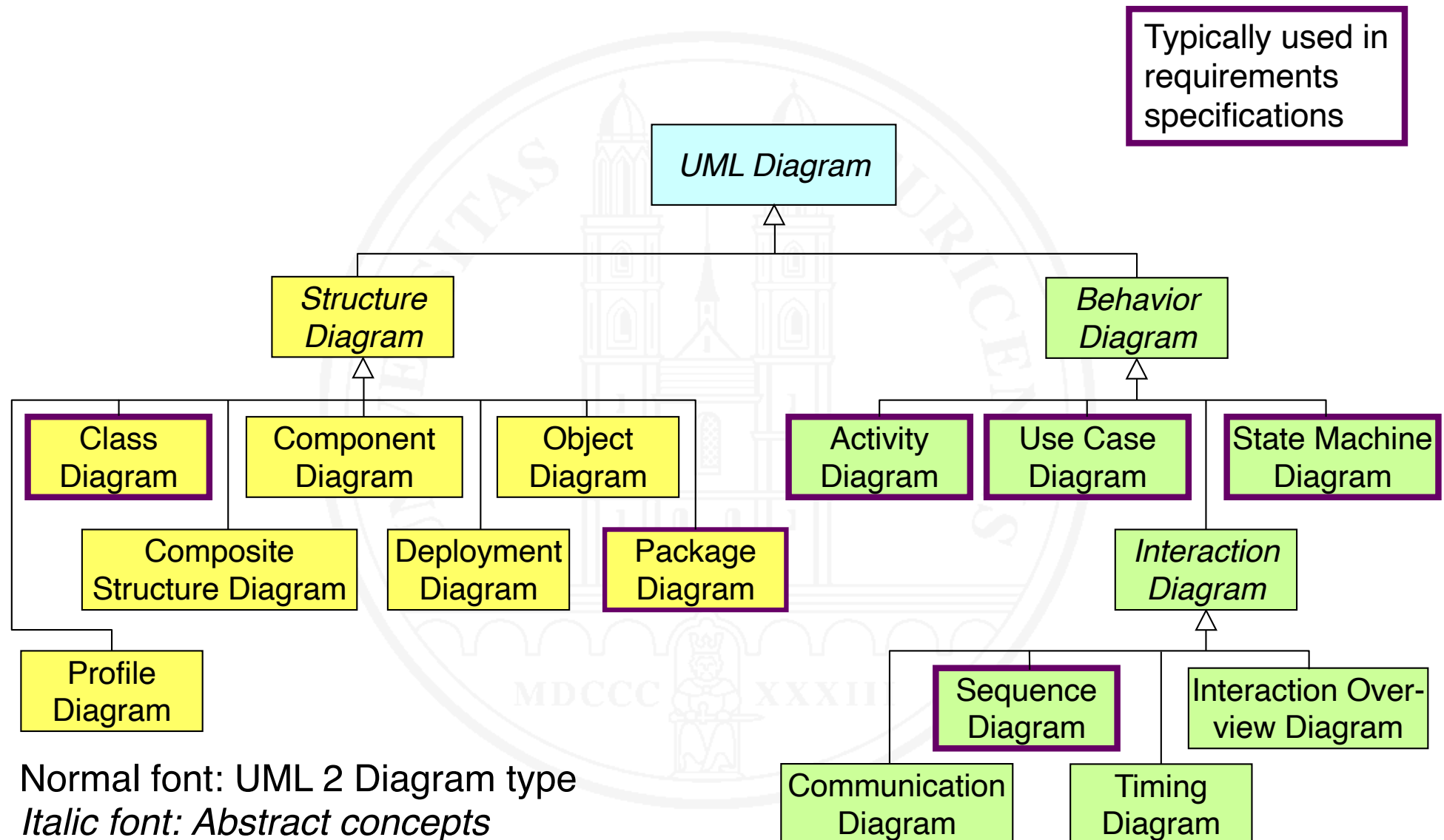


[Object Management Group 2017]

- UML is a collection of primarily graphic languages for expressing requirements models, design models, and deployment models from various perspectives
- A **UML specification** typically consists of a collection of loosely connected diagrams of various types
- Additional restrictions can be specified with the formal textual language **OCL** (Object Constraint Language)

[Object Management Group 2014]

UML – Overview of diagram types



Normal font: UML 2 Diagram type
Italic font: Abstract concepts

7.8 Lightweight, flexible modeling

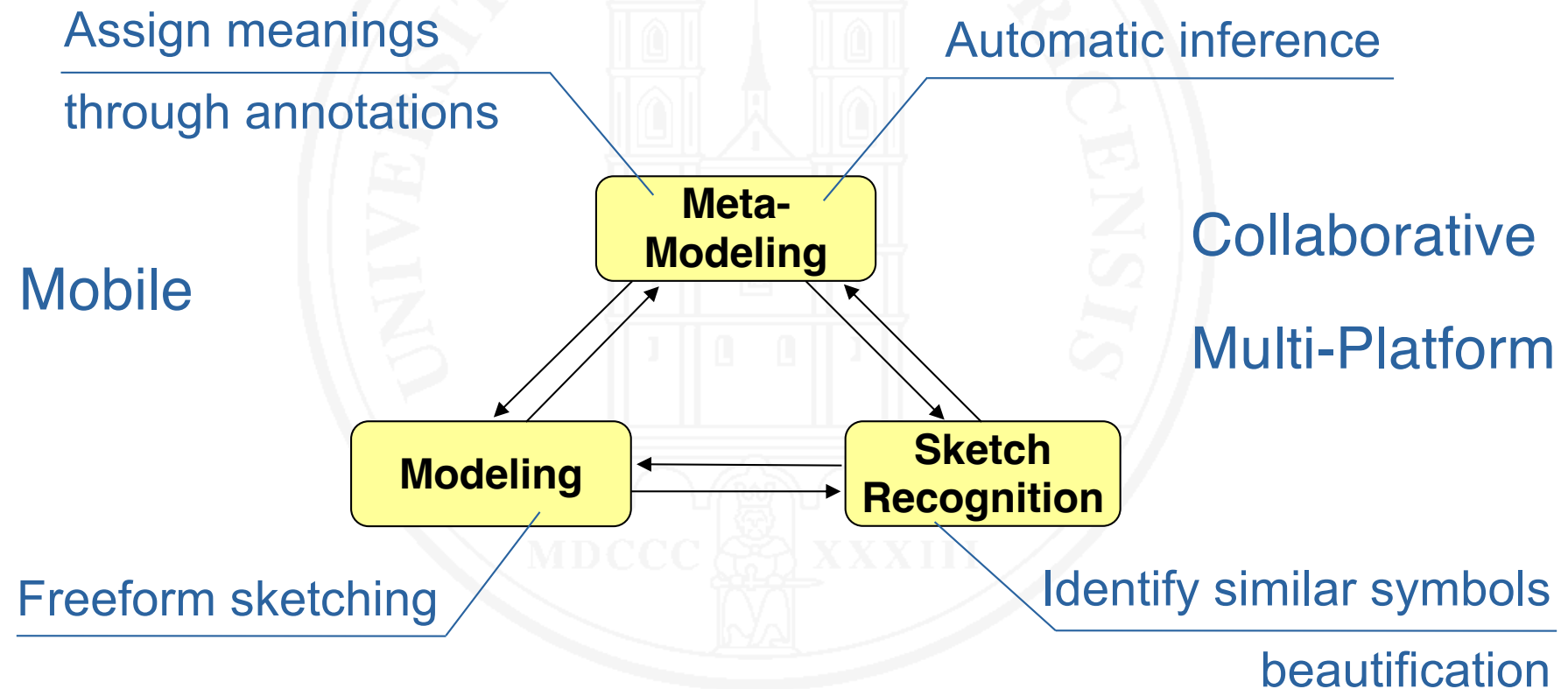
- Modeling languages – Have a predetermined syntax
 - Limited expressibility and flexibility
 - Too restrictive for sketching ideas or initial requirements
- Free-form sketching – Is fully flexible
 - Resulting sketches do not carry any structure or meanings
 - Too vague when sketches serve as a basis for further RE tasks
- Need for a middle-ground approach
 - High flexibility; no fixed set of language constructs
 - Co-evolution of models and model syntax & meanings
 - FlexiSketch

[Wüest, Seyff, Glinz 2019]

www.flexisketch.org

FlexiSketch – supporting flexible modeling

- Allow users to define their own notations & languages on the fly
- Co-evolve models and their metamodels



FlexiSketch Demo

