Course "Softwaretechnik"
Book Chapter 2

Modeling with UML

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- Modeling, models and UML
- Static view:
  - Class diagrams
- Dynamic view:
  - Sequence diagrams
  - State machine diagrams
  - Activity diagrams
- Other UML diagram types
  - component d., collaboration use d., deployment d., communication d., interaction overview d.
- UML Metamodel, Profiles
- Some notation details
  - Classes, associations, interfaces, states

What is modeling?

- Modeling consists of building an abstraction of reality
  - Models ignore irrelevant details (i.e., they simplify)
  - and only represent the relevant details
- What is *relevant* or *irrelevant* depends on the purpose of the model. We typically want to
  - draw complicated conclusions about reality with simple steps in the model in order to
  - get insights into the past or presence or make predictions

- Reality R:
  - Real things, people, etc.
  - Processes happening during some time
  - Relationships between things etc.
- Model M:
  - Abstractions of any or all of the above

What is a "good" model?

- In a good model, relationships which are valid in reality R are also valid in model M (if they exist in M at all).
  - I : Mapping of reality R to the model M (abstraction)
  - f_M: relationship between abstractions in M
  - f_R: equivalent relationship between real things in R

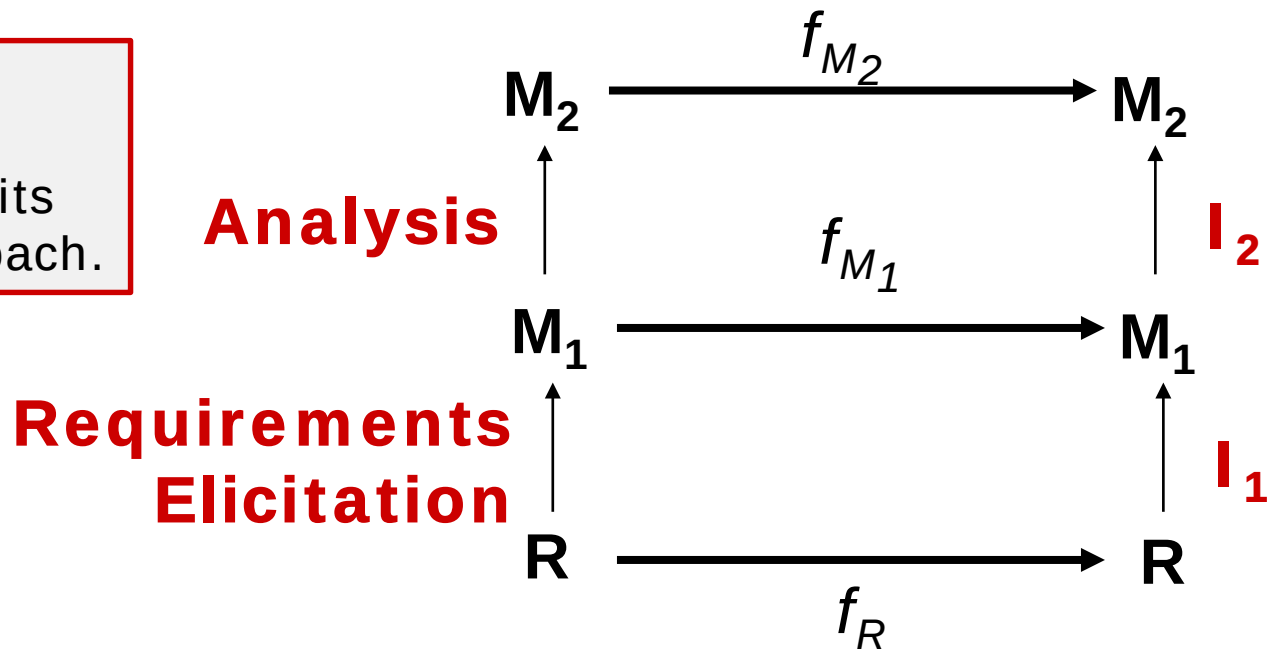
- In a good model, the following diagram is commutative:

$$\begin{tikzcd}
m_a \arrow[r, "f_M"] & m_b \\
r_a \arrow[u, "I"] \arrow[r, "f_R"'] & r_b \arrow[u, "I"']
\end{tikzcd}$$

Models of models of models...

- **We can think of a model as reality and can build another model from it (with additional abstractions)**
  - The development of software systems is a transformation of models:
    Requirements elicitation (→ req's document M_1),
    Requirements analysis (→ analysis model M_2),
    Design (→ design model M_3),
    Implementation (→ source code M_4)
    ....

"Model-Driven Development" uses this idea for its engineering approach.



Systems, models and views

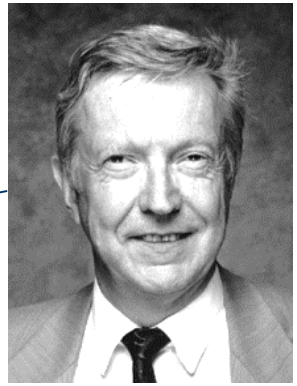
- A ***model*** is an abstraction describing relevant aspects of a system
- A ***view*** ("Sicht") depicts selected aspects of a model
  - Any view is a model itself
  - Calling a model a view makes clear it is part of a larger model
  - Complex models are often shown as many views only
    - never as a whole
- A ***notation*** is a set of rules for depicting models
  - graphically or textually

- Example:
  - System: Aircraft
  - Models: Flight simulator, scale model, construction plan, …
  - Views: All blueprints (e.g. electrical wiring, fuel system)

What is UML?

UML (**Unified Modeling Language**):

- The most-used standard for software modeling
  - For both requirements modeling (application domain)
  - and software modeling (solution domain)
- A set of related notations
  - Quite complex, we will use a subset only
- Resulted from the convergence of notations from three leading object-oriented methods:
  - OMT (James Rumbaugh)
  - OOSE (Ivar Jacobson)
  - Booch method (Grady Booch)
  - The authors are known as *"The Three Amigos"*



- Supported by CASE tools
  - http://de.wikipedia.org/wiki/UML-Werkzeug

Common UML diagram types

- Use Case diagrams (functional view)
  - Catalog scenarios that describe the functional behavior of the system as seen by the user [see lecture "use cases"]
- Class diagrams / Object diagr. (static view and examples)
  - Describe the static structure of the system: Classes, attributes, object associations (class diagram) or snapshots of possible resulting configurations (object diagram)
- Sequence diagrams (dynamic view examples)
  - Describe *examples* of the dynamic behavior between objects of the system (and possibly actors)
- State machine diagrams (dynamic view)
  - Describe some aspects of the dynamic behavior of the individual object of a class by a finite state automaton
- Activity diagrams (dynamic view)
  - Model the dynamic behavior of a system, in particular the workflow (essentially a flowchart, but with concurrency)

Less common UML diagram types

Hardly covered in this course:

- Implementation diagrams
  - Component diagrams
  - Deployment diagrams
- Communication diagrams
  - Equivalent to sequence diagrams, but embedded in an object diagram (shows both static structure and dynamic interaction)
- Interaction overview diagrams
  - Related to activity diagrams, for describing control flow

There is also a non-graphical language for expressing conditions:

- Object constraint language (OCL)
  - Introduced in lecture on Object Design

UML core conventions

- Diagrams are mostly graphs
  - Nodes are entities
  - Edges are relationships between entities

- Rectangles are classes or instances
- Ovals are functionalities or use cases

- An instance is denoted with an underlined name
  - <u>myWatch:SimpleWatch</u> or with no classifier: <u>myWatch:</u>
  - <u>Jane:Firefighter</u> or with no name: <u>:Firefighter</u>
  - (Anonymous instance of unnamed classifier: <u>:</u>
    - Please don't use this …)
- A classifier is denoted with a non-underlined name
  - SimpleWatch
  - Firefighter

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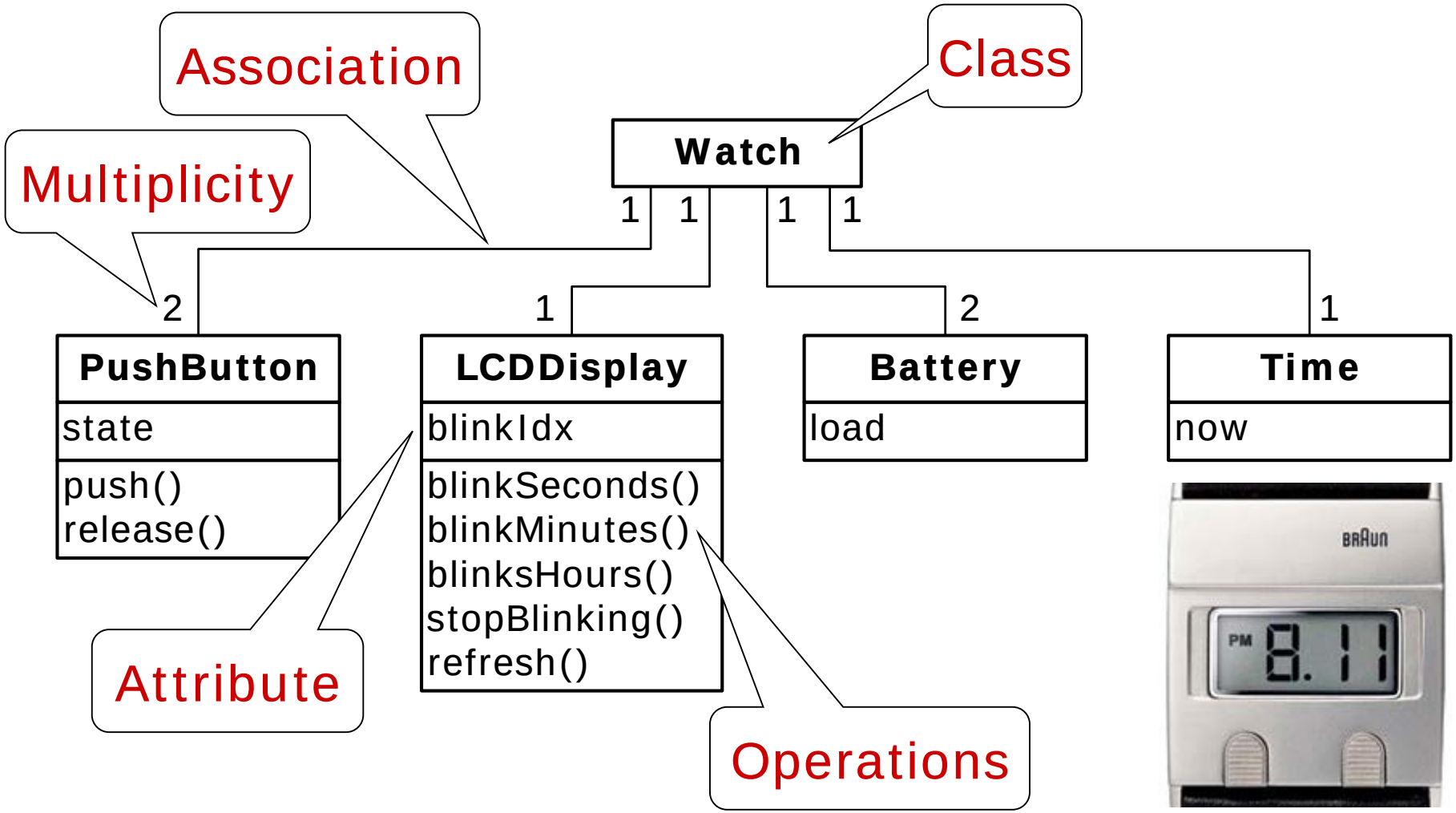
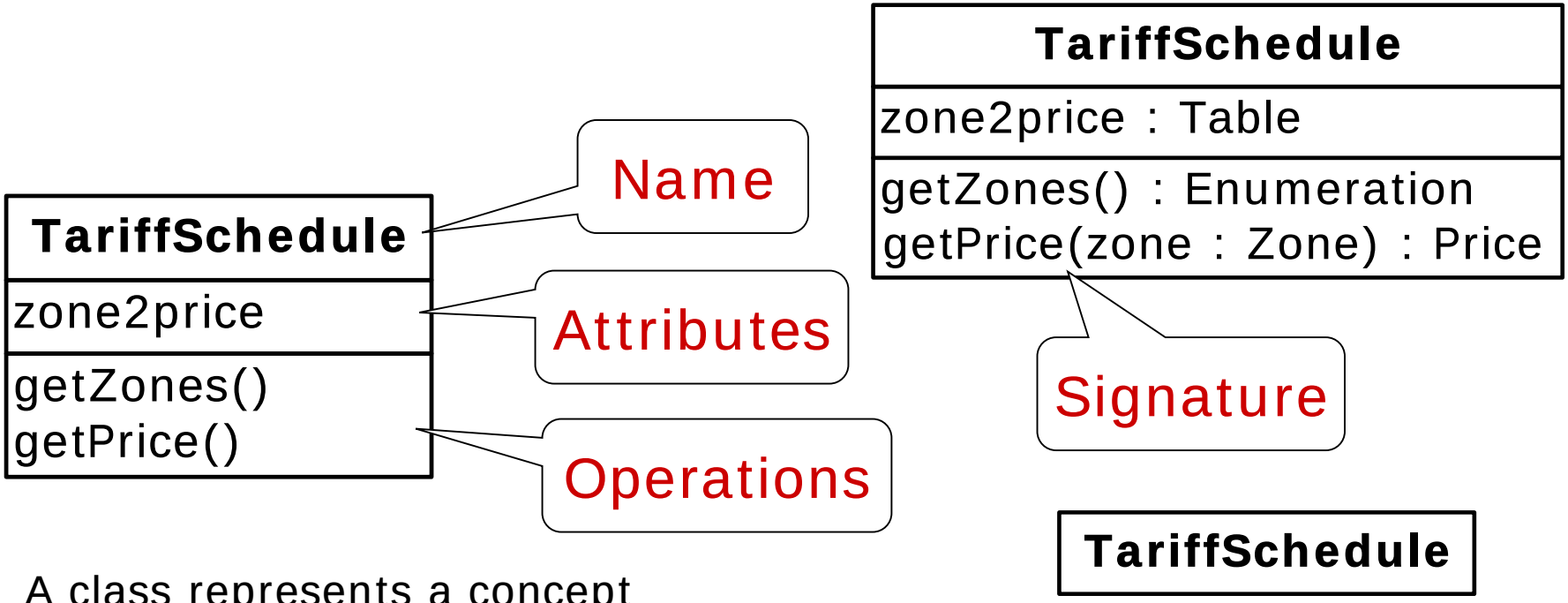
Class diagrams represent the structure of the system

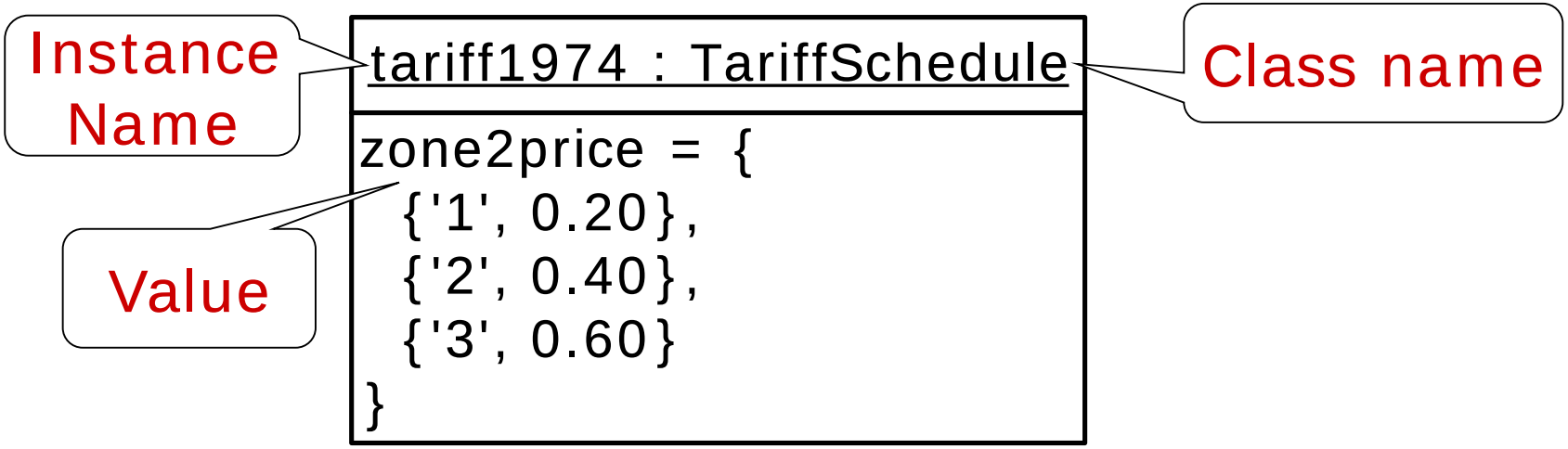


Class diagrams: Classes



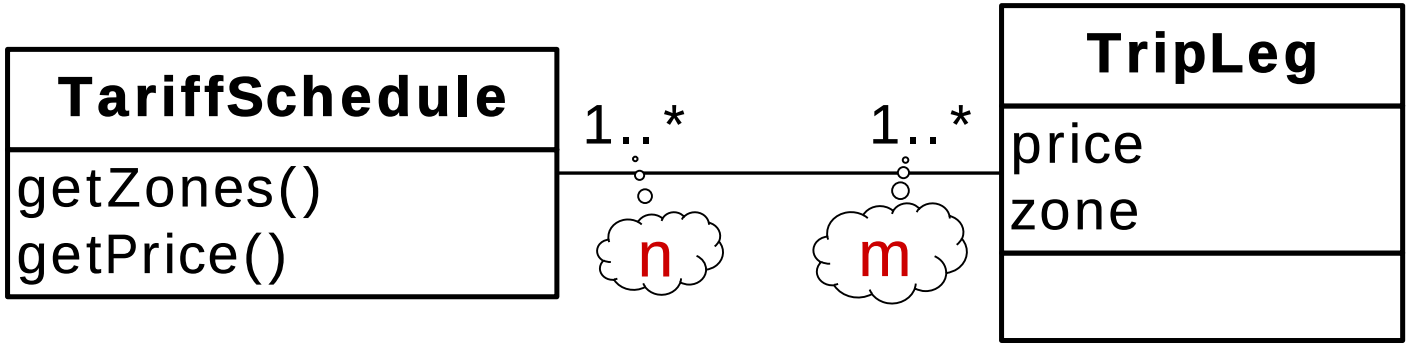
- A class represents a concept
- A class encapsulates state (attributes) and behavior (operations)
- Each attribute has a type
- Each operation has a signature
- But the class name is the only mandatory information in a UML class description

Instances ("Exemplare", "Objekte")



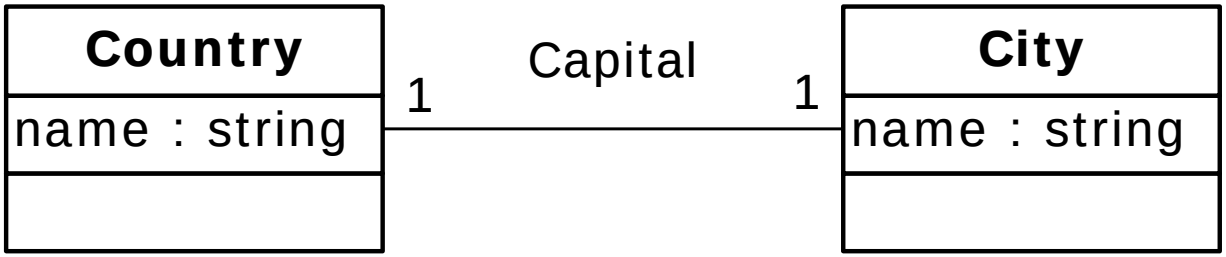
- An instance represents a phenomenon
- The name of an instance is underlined and may indicate the class of the instance
  - May indicate instance name or class or both
- Attributes may be represented with their values

Associations



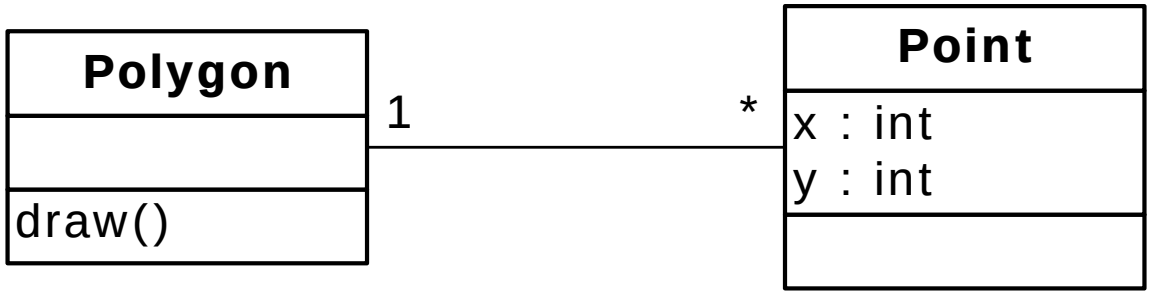
- Associations denote relationships between classes
- The multiplicity of an association end denotes how many objects the source object can legitimately reference:
  - Any one TariffSchedule object is associated with at least one TripLeg object
  - Any one TripLeg object is associated with at least one TariffSchedule object
  - **n** and **m** can be numbers ("5") or ranges (closed/open: "1..5" or "2..*")
  - A missing annotation means "1"
    - Except if there are no annotations anywhere, then it means "unspecified"
  - "*" alone means "arbitrarily many" (zero, one, or several)

1-to-1 and 1-to-many associations



(Too restrictive?: Some countries have a separate seat of government)

One-to-one association

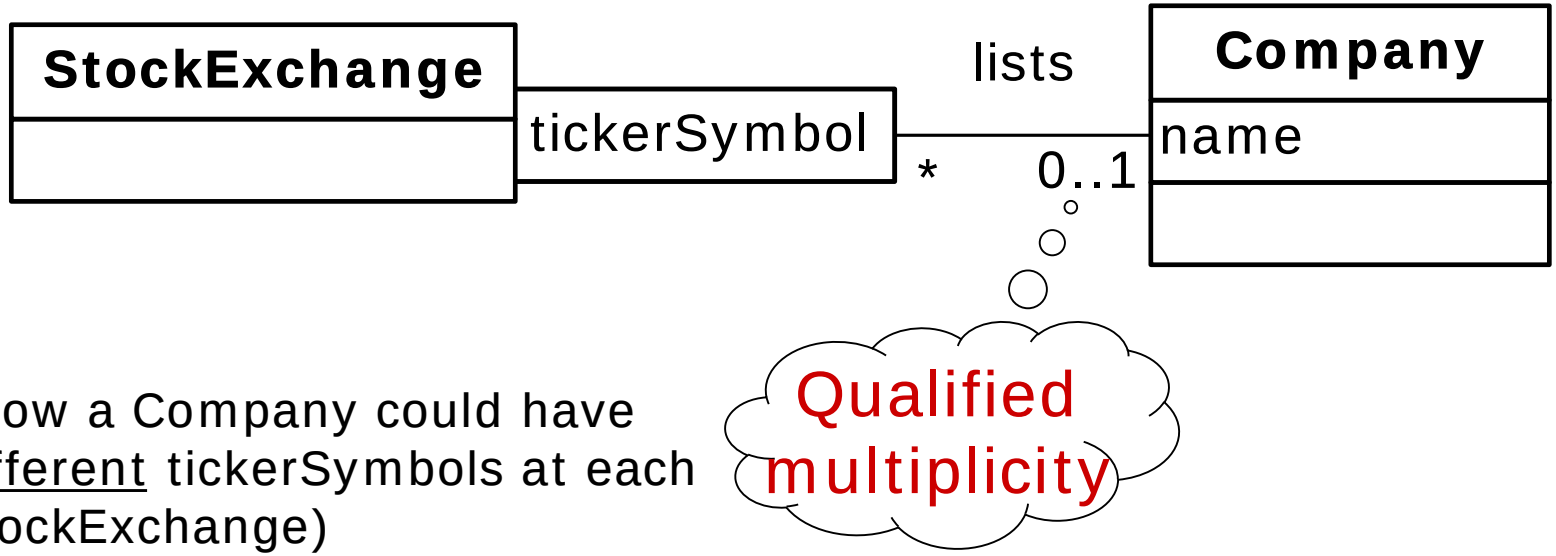


(Too flexible?: Does a Polygon with 0, 1, or 2 Points really make sense?)

One-to-many association

Many-to-many associations

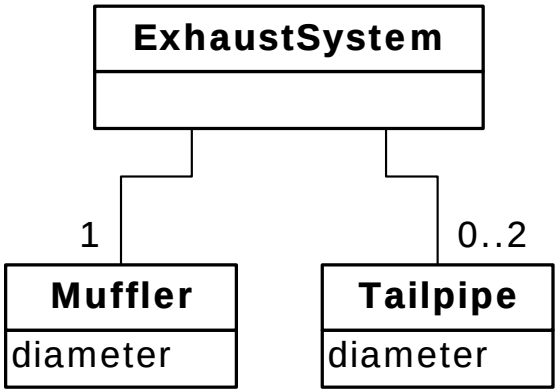
Problem Statement: "A stock exchange lists many companies. Each company is uniquely identified by a ticker symbol."

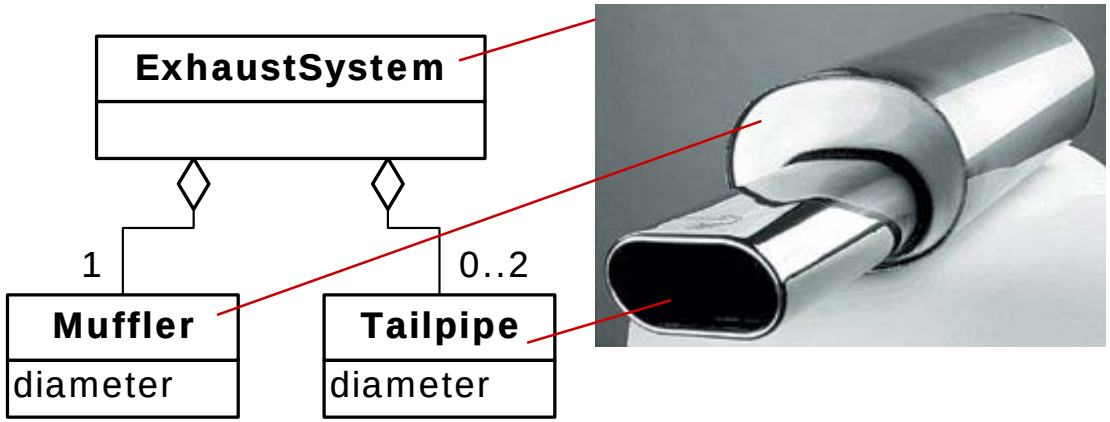


(Now a Company could have <u>different</u> tickerSymbols at each StockExchange)

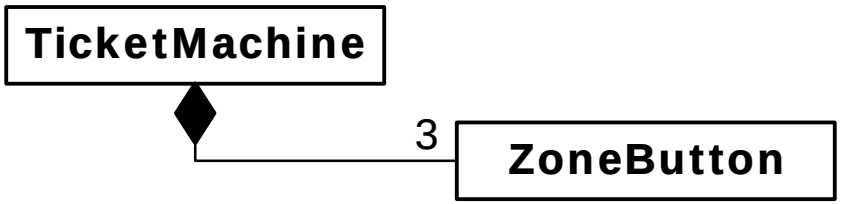
Aggregation

- An ***aggregation*** is a special case of association denoting a "consists of"/"is part of" hierarchy
- The object representing the whole is called the ***aggregate,*** the objects representing the parts are called ***components***

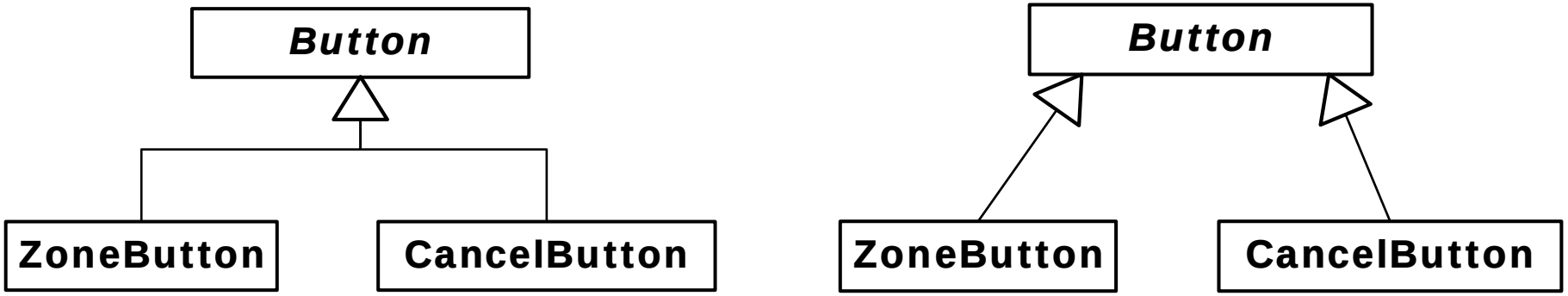




- A solid diamond denotes ***composition***, a strong form of aggregation where the parts never exist without the composite
  - The association is in force throughout the life of the parts objects

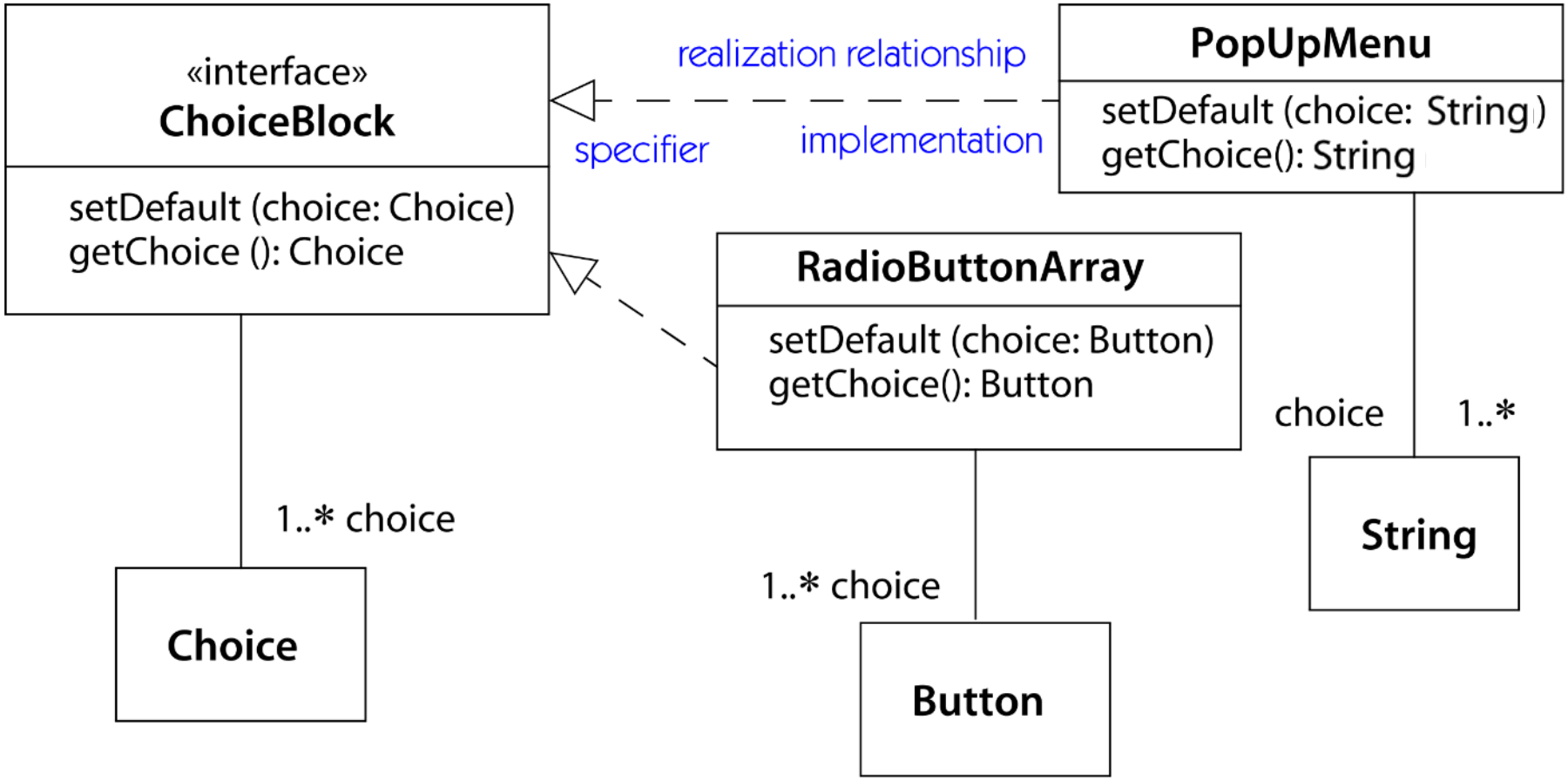


Inheritance (Java: "extends")

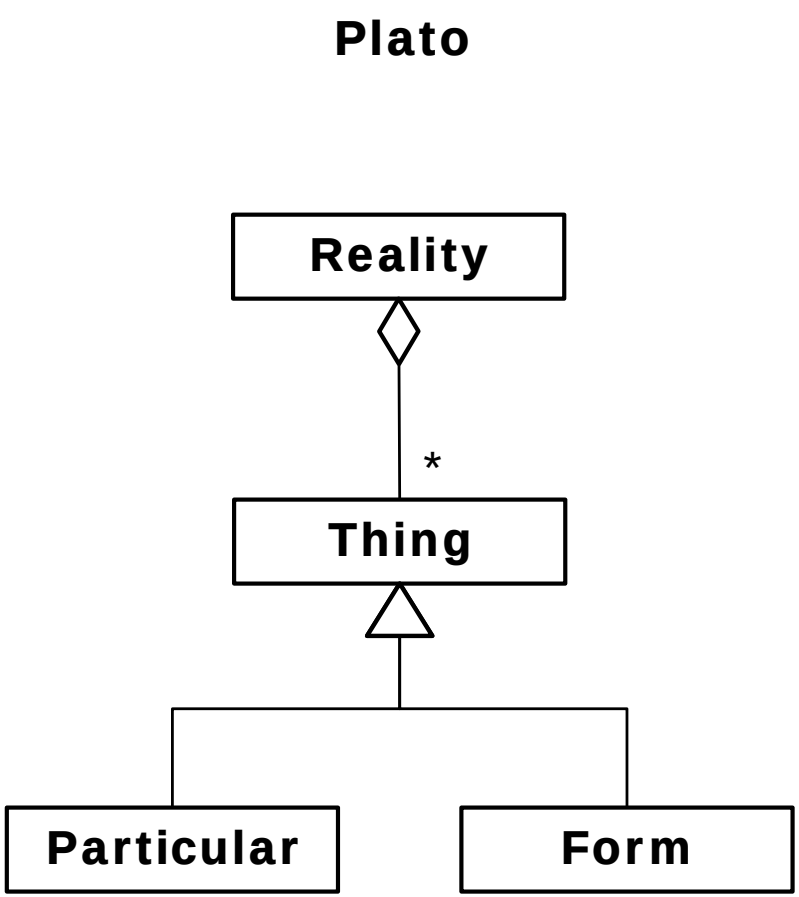


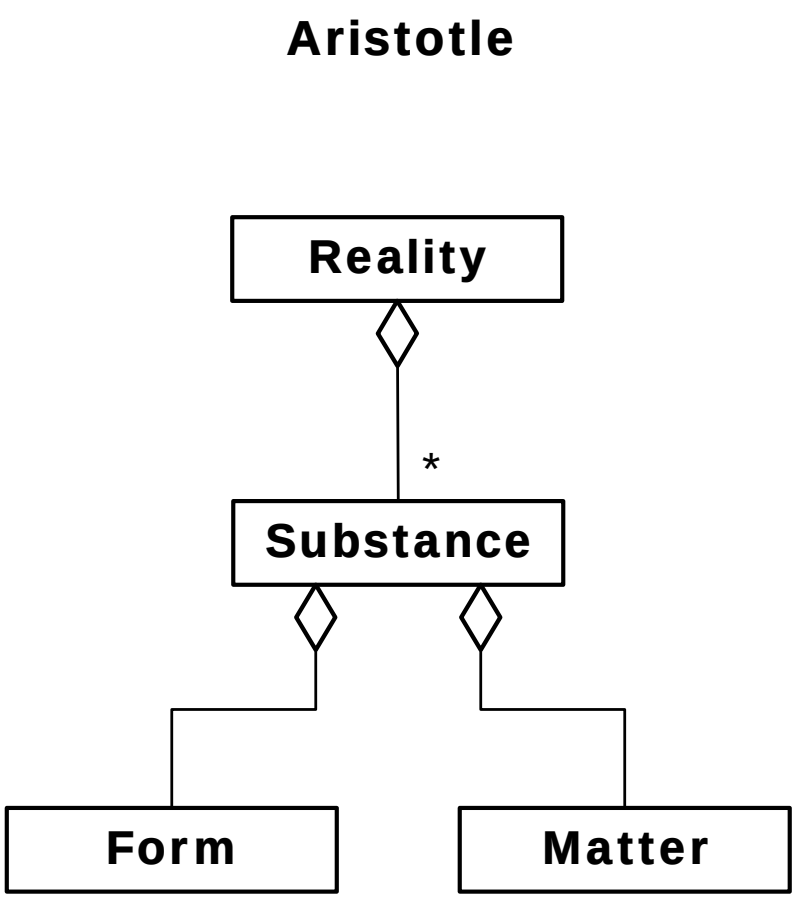
- The **children classes** inherit the attributes and operations of the **parent class**
- Read the triangle as an arrowhead, meaning "inherits from"
  - *CancelButton* inherits from *Button*
  - *ZoneButton* inherits from *Button*

Realization (Java: "implements")



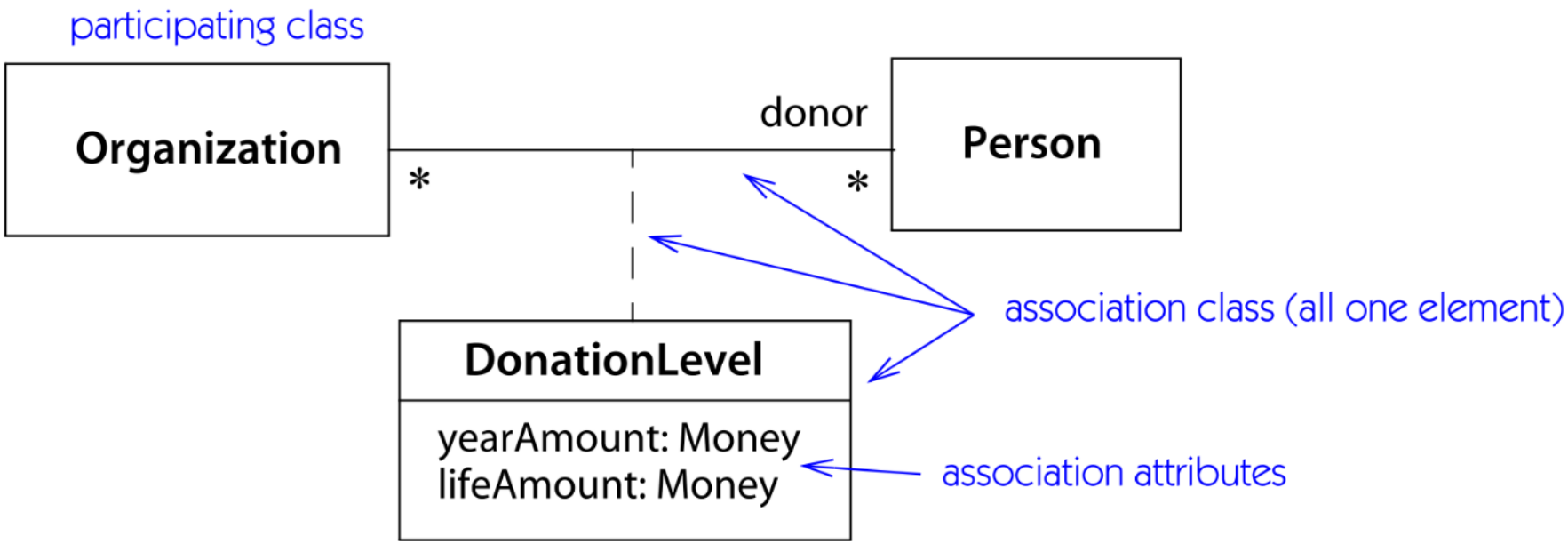
Example:
Plato's and Aristotle's world views





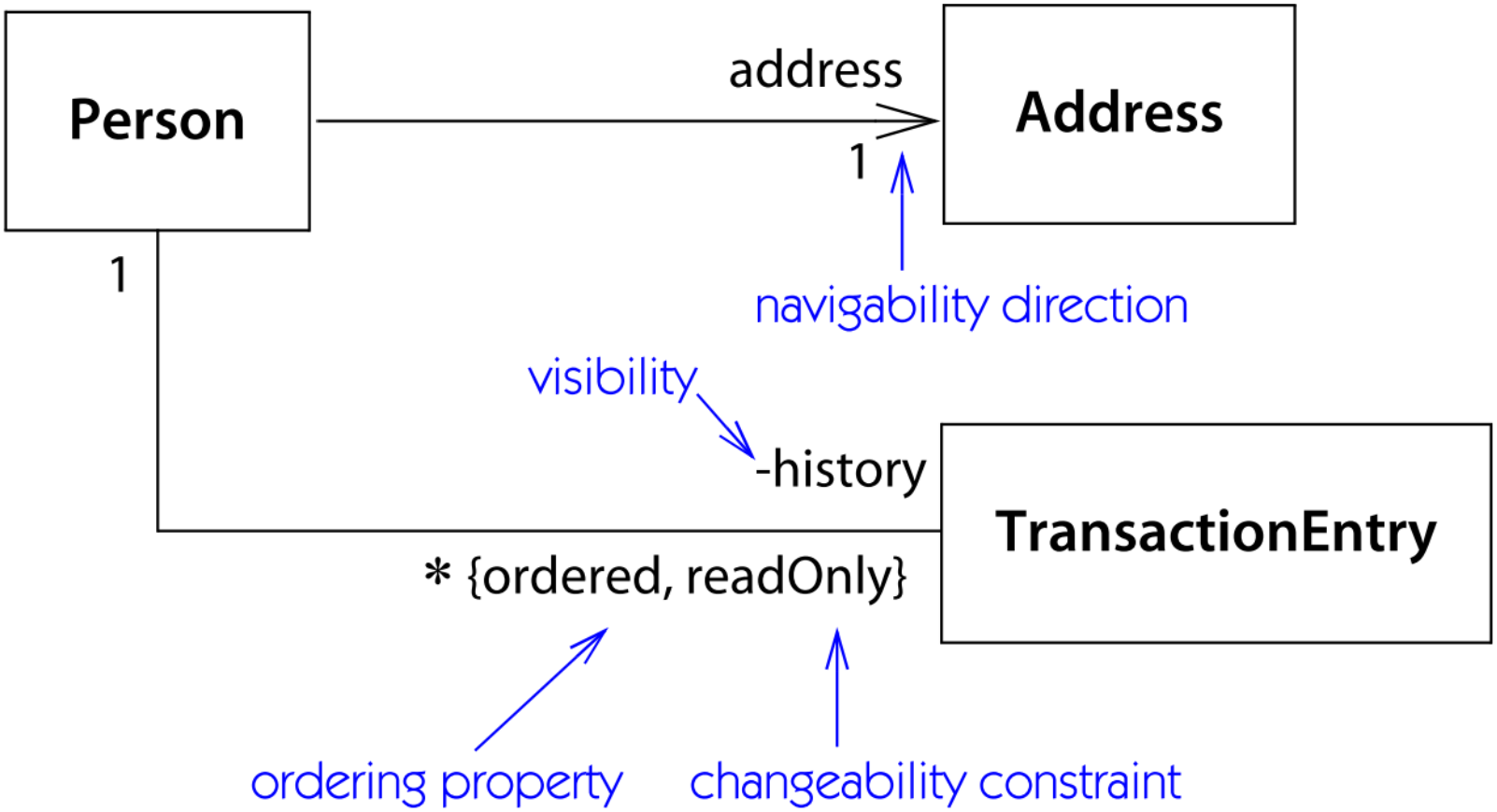
Association classes

- Individual associations between objects can have attributes
  - Described by an association class



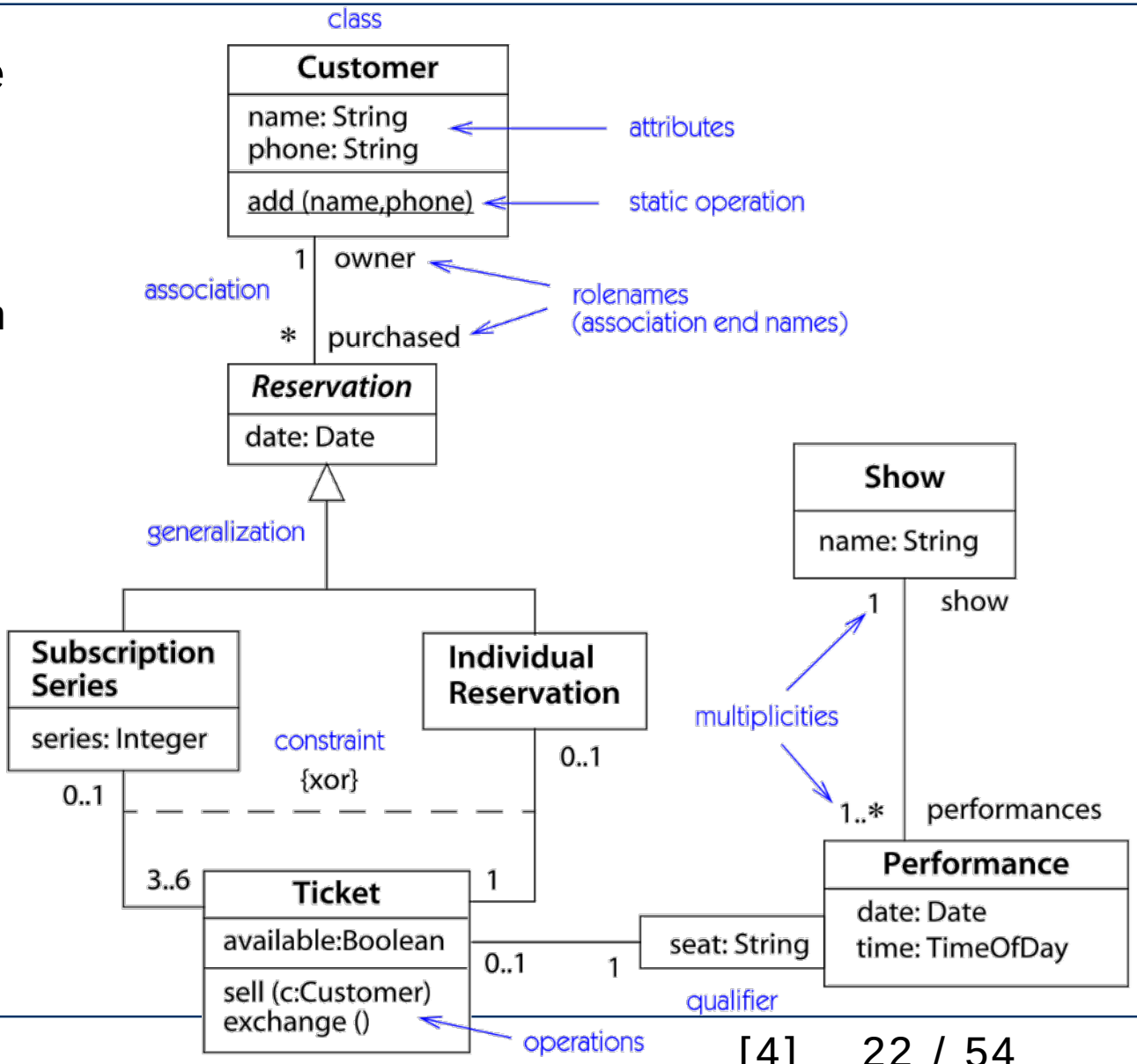
Association constraints

- Associations can be described by further details:



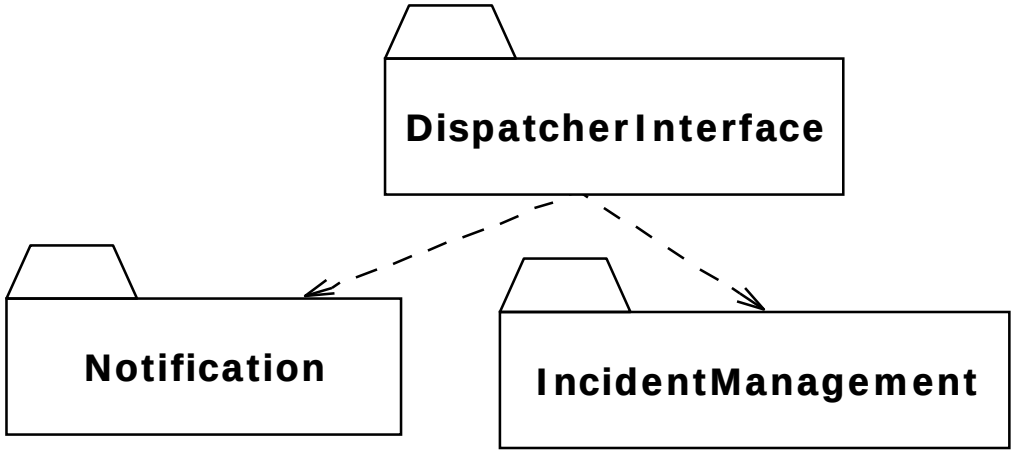
Class diagrams: theater example

- ..and some more notation details:
  - role name
  - XOR constraint
  - static operation



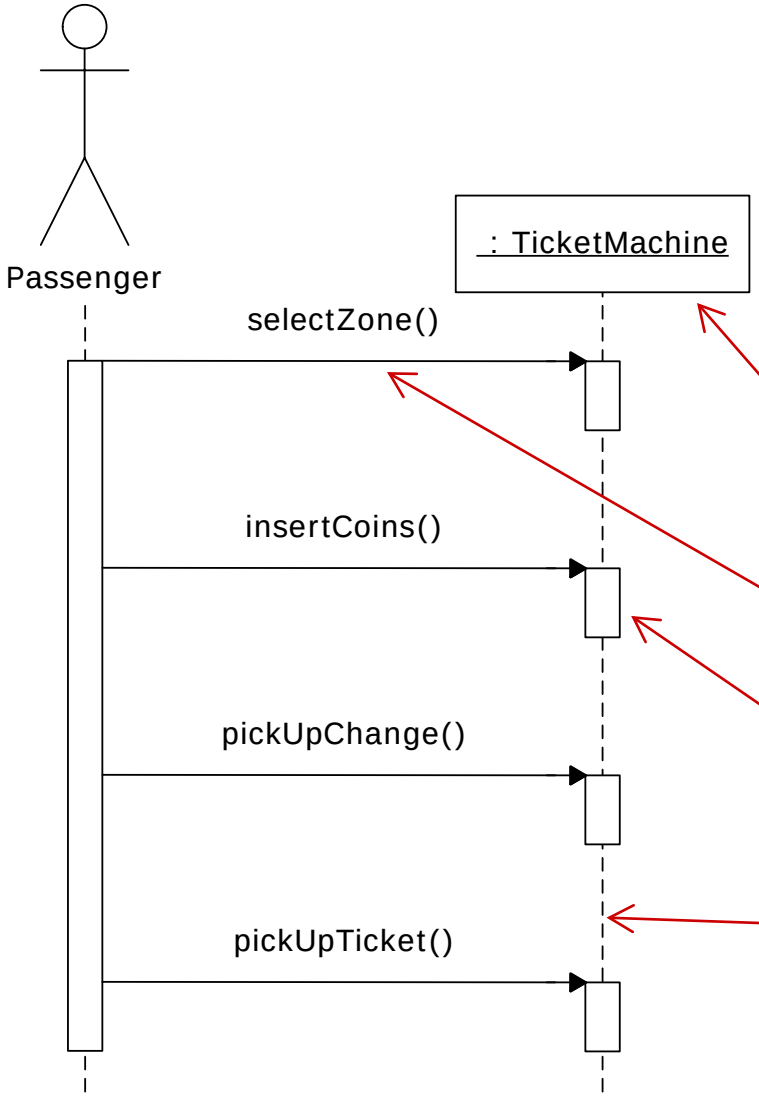
Packages

- A package is a UML mechanism for organizing elements (e.g. classes or whole class diagrams) into groups
  - Does not usually represent an application domain concept
- Packages are the basic grouping construct with which you may organize UML models to increase their readability



- A complex system can be decomposed into subsystems, where each subsystem is modeled as a package

UML sequence diagrams



- Used during requirements analysis
  - To refine use case descriptions
  - to find additional objects ("participating objects")
- Used during system design
  - to refine subsystem interfaces

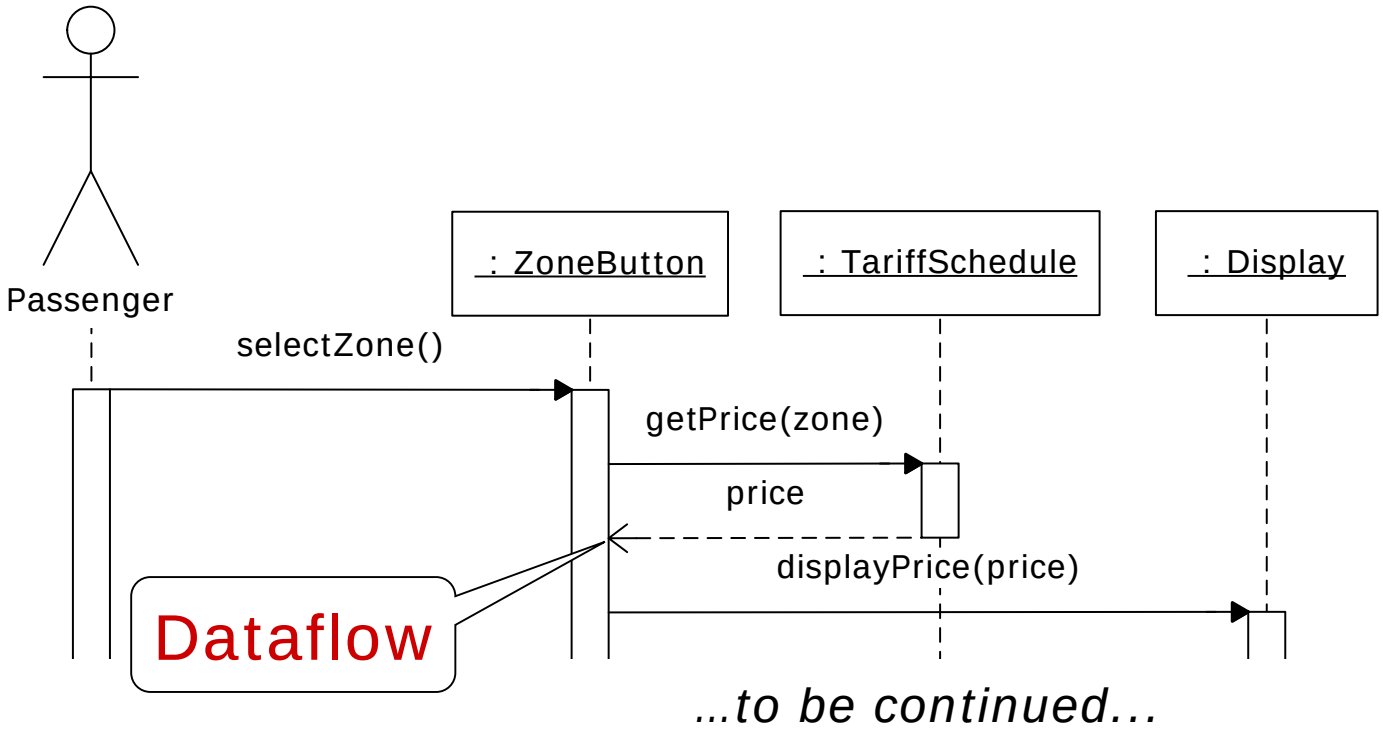
Objects are represented by columns (*objname:classname*)

Messages are represented by arrows

Activations are represented by narrow rectangles

Lifelines are represented by dashed lines

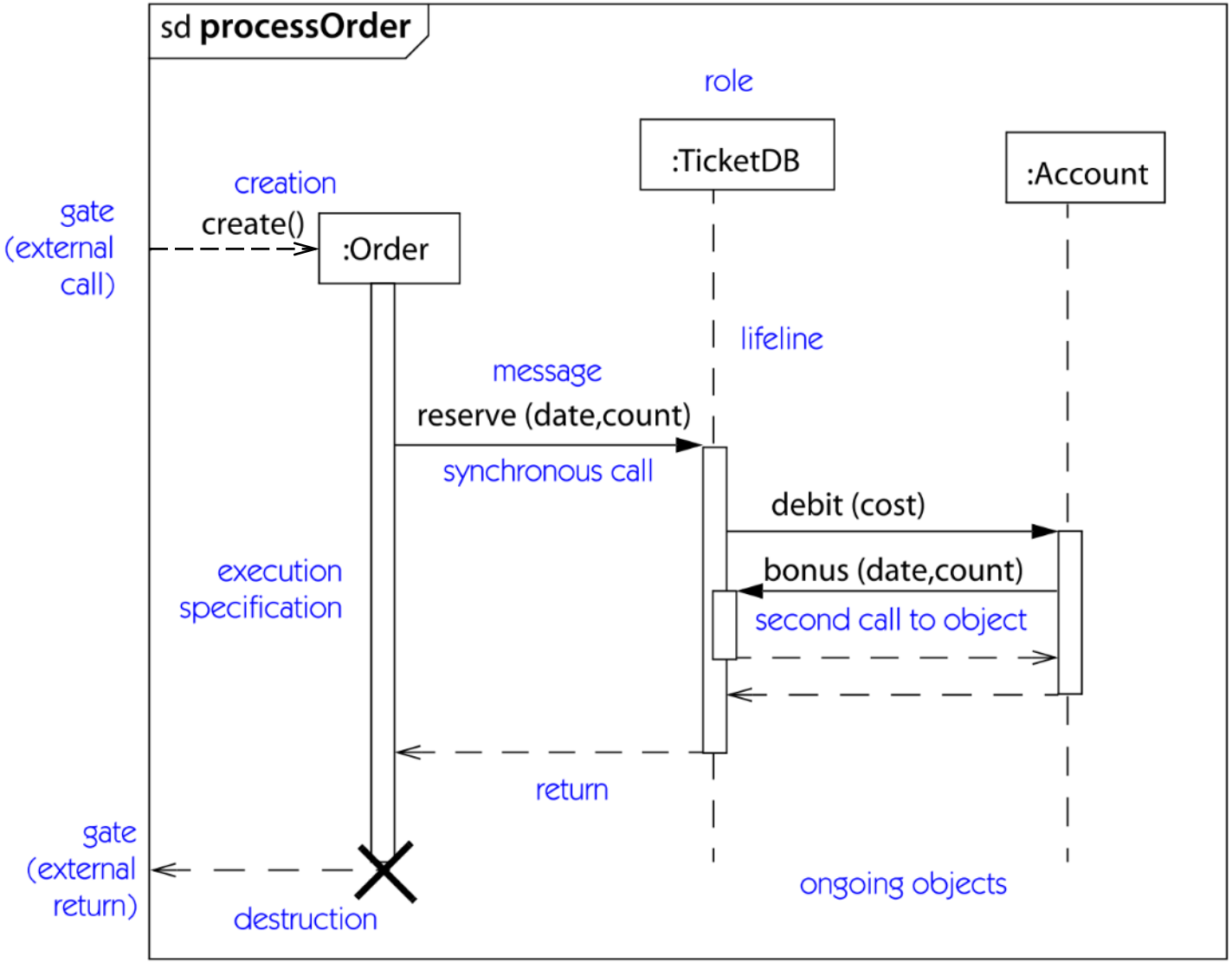
Nested messages



- The source of an arrow indicates the activation which sent the message
- An activation is as long as all nested activations (for normal calls)
- Horizontal dashed arrows indicate data flow
- Vertical dashed lines indicate lifelines

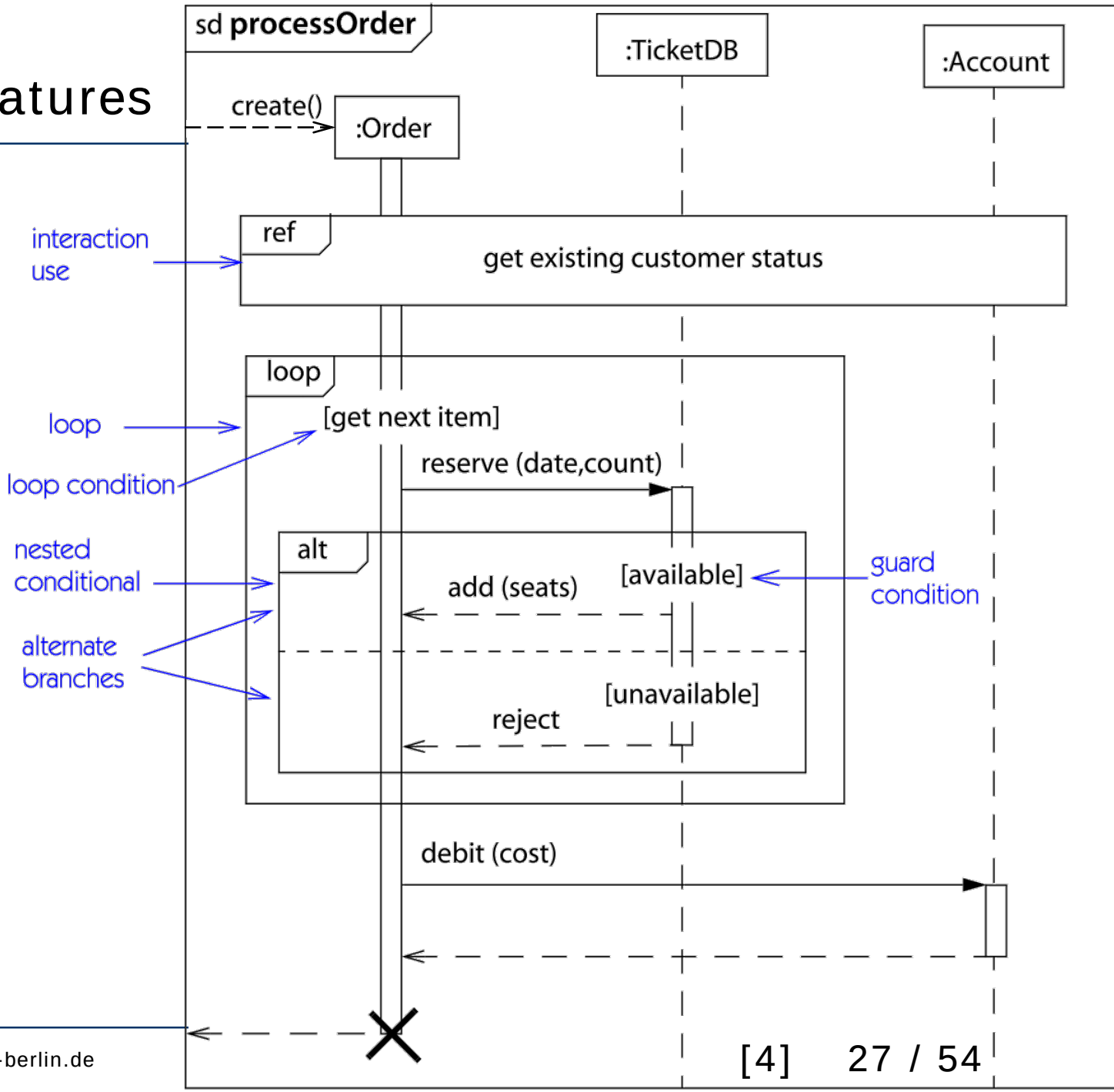
Sequence diagram: theater example

external call,
external return



Advanced features

- creation
- nesting
- iteration
- conditions, branching
- destruction



Sequence diagram summary

- UML sequence diagrams represent behavior in terms of object interactions
  - Useful to find missing objects
  - Useful for explaining design ideas
    - Describes examples only, no general specification

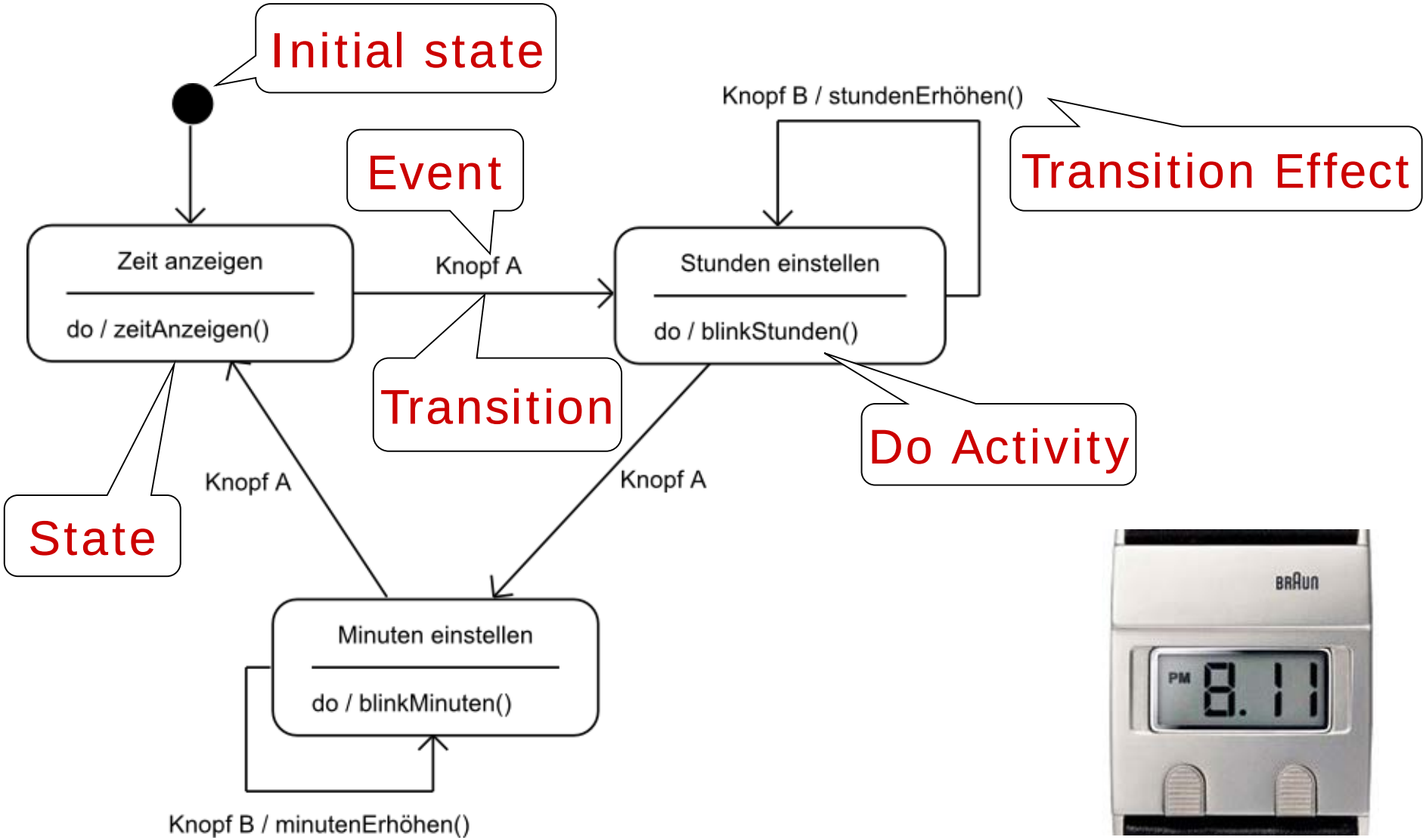
dynamic view

- Time-consuming to build, but may be worth it

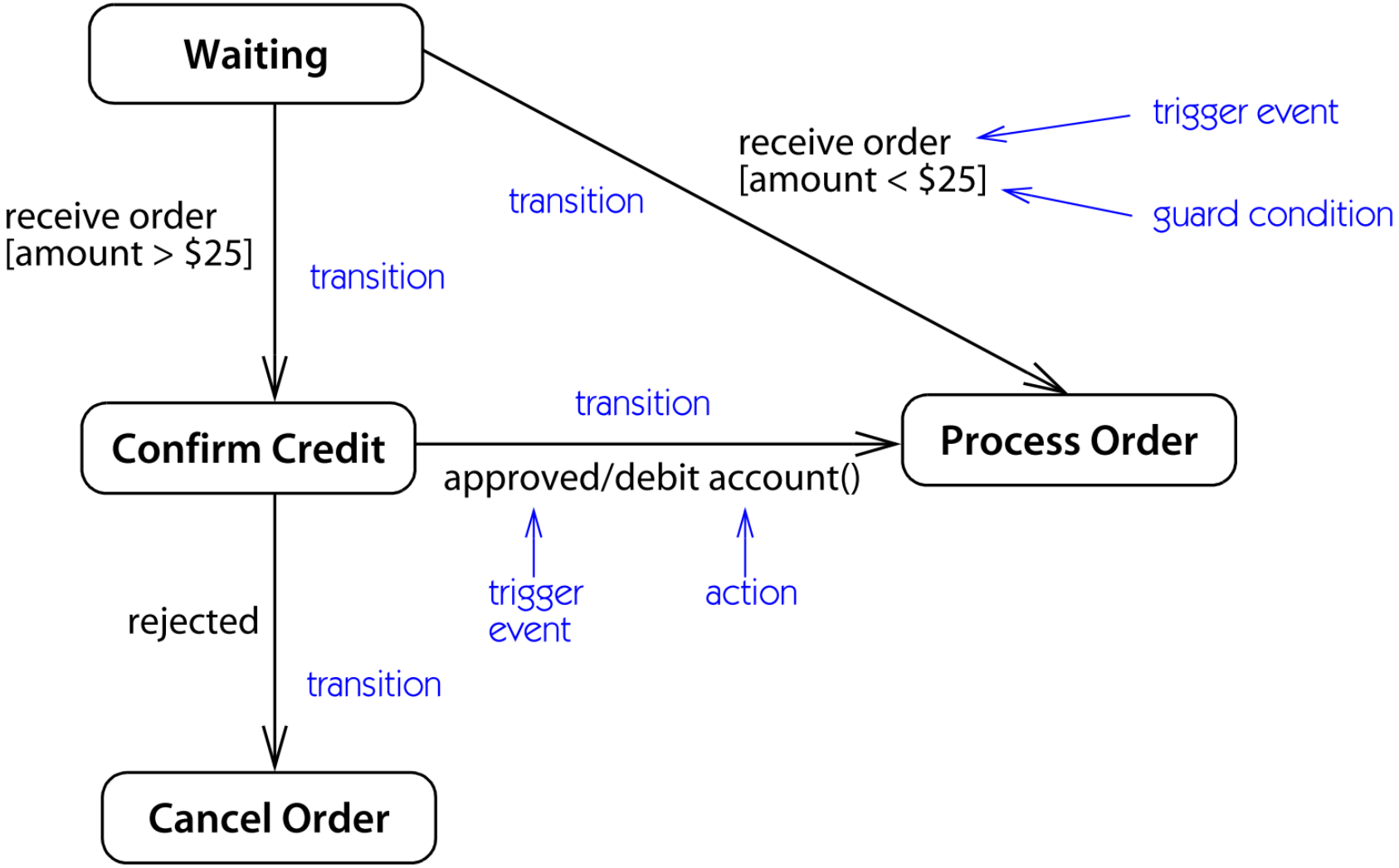
static view

- Complement the class diagrams (which represent structure)

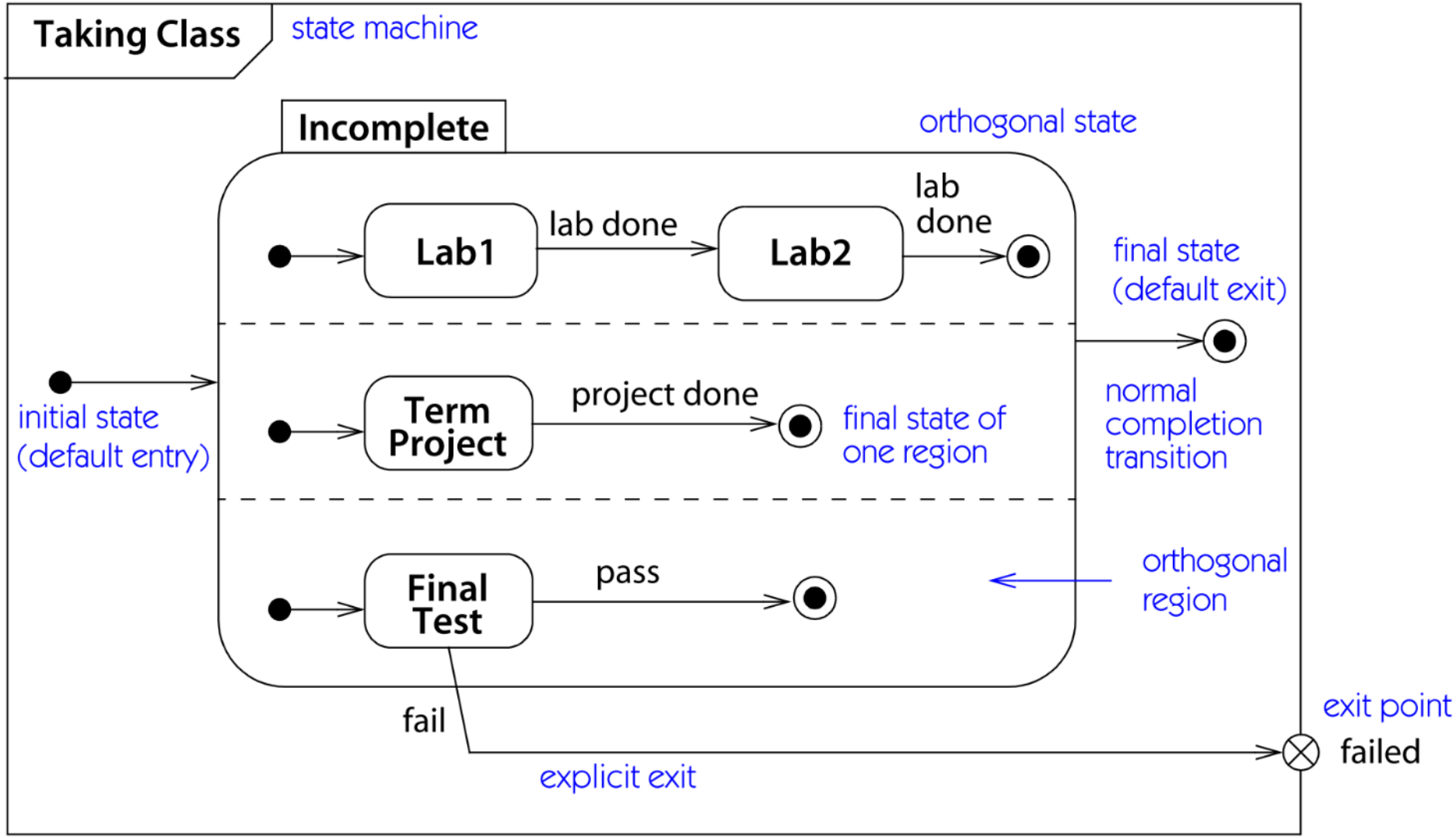
State machine diagrams



Transitions can be subject to guard conditions



Parallel (orthogonal) states, explicit exits

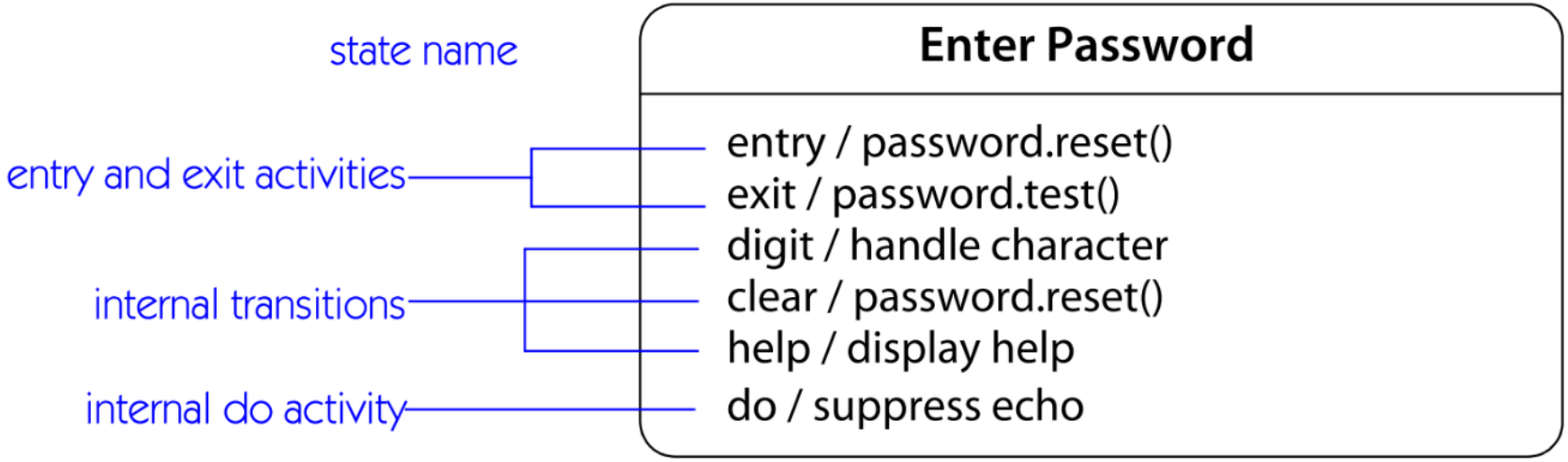


A transition is the consequence of an event

Event Type	*Description*	*Syntax*
call event	Receipt of an explicit synchronous call request by an object	op (a:T)
change event	A change in value of a Boolean expression	**when** (exp)
signal event	Receipt of an explicit, named, asynchronous communication among objects	sname (a:T)
time event	The arrival of an absolute time or the passage of a relative amount of time	**after** (time)

There can be multiple transitions at one state

- Internal transitions don't leave the state
- Entry and Exit Activities can be annotated inside the state box
  - to avoid redundancy and encapsulate the state



- also: do / some_activity
  - for a concurrent, abortable, potentially long-running activity occuring throughout the state

Activity Diagrams

- An activity diagram shows flow control (and optionally data flow) within a system

- Two types of (executable) nodes:
  - Action node:
    - Basic activity, cannot be decomposed any further
    - Predefined in UML, e.g. object creation/destruction, accessing/modifying attributes or links, calling operations
  - Activity node:
    - Can be decomposed further
    - The activity is modeled by another activity diagram

State machine diagram vs. activity diagram

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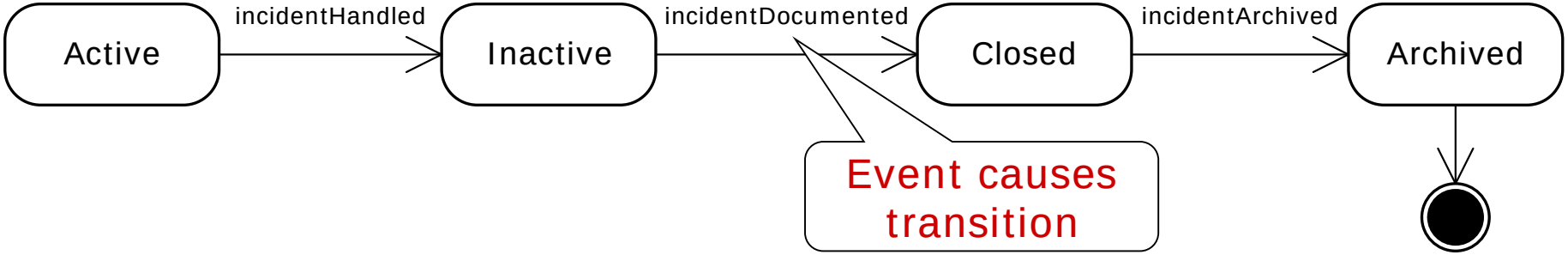
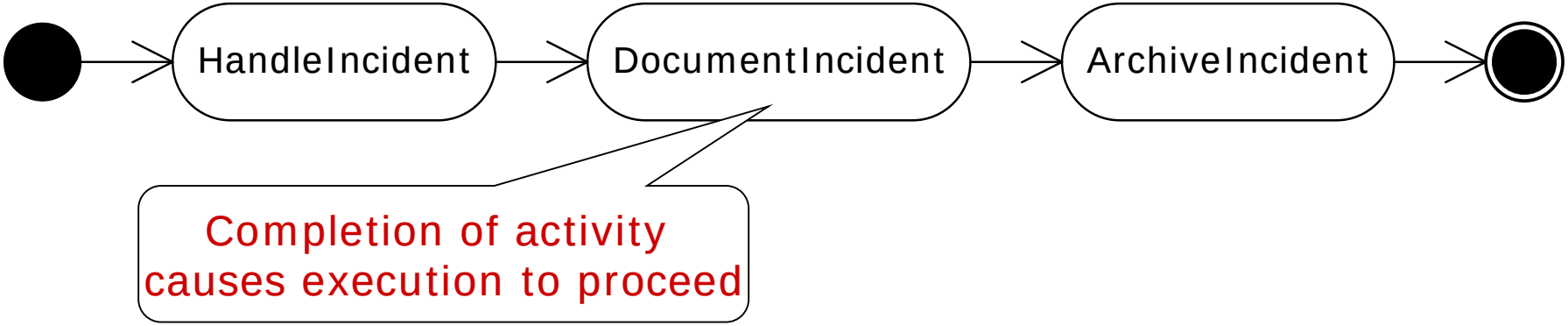
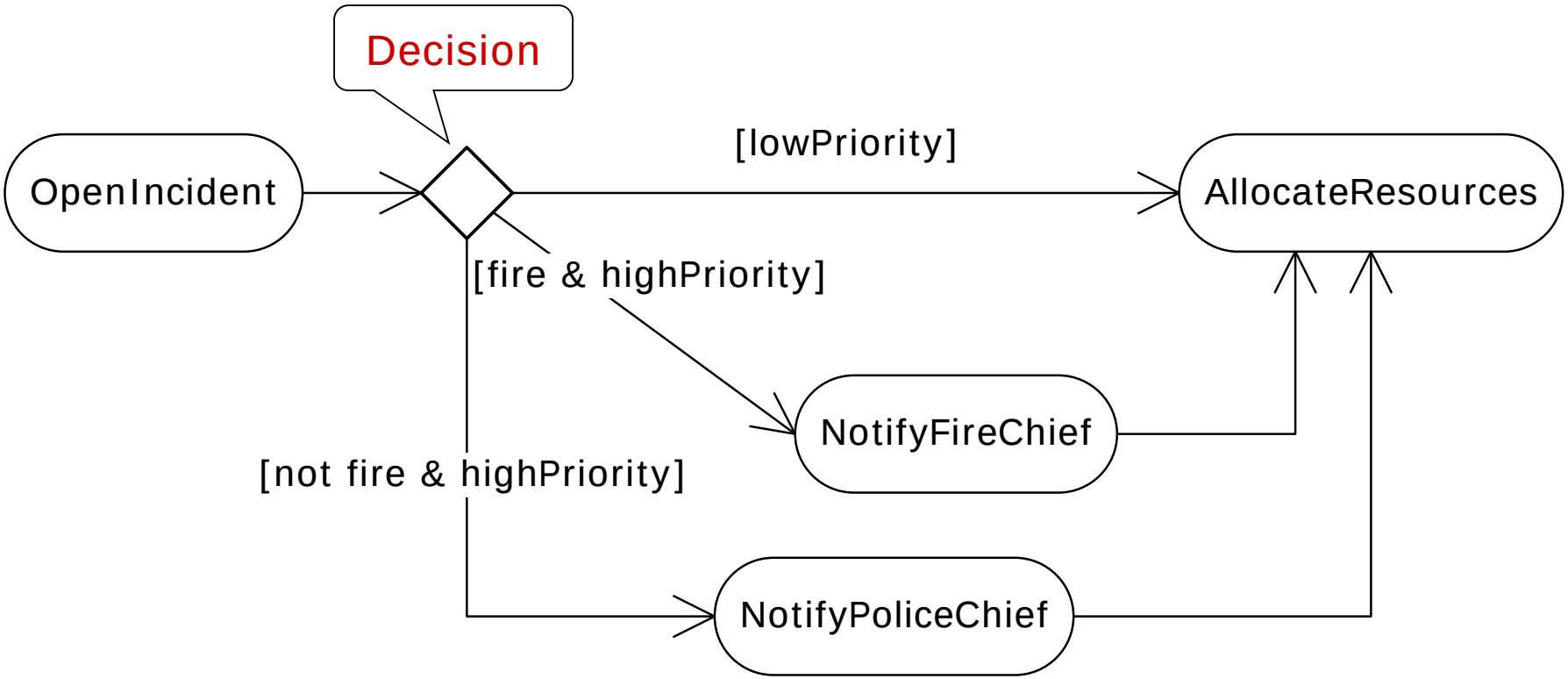
State machine diagram for Incident
(Node represents some set of attribute values)



Activity diagram for Incident handling
(Node represents some collection of operations)

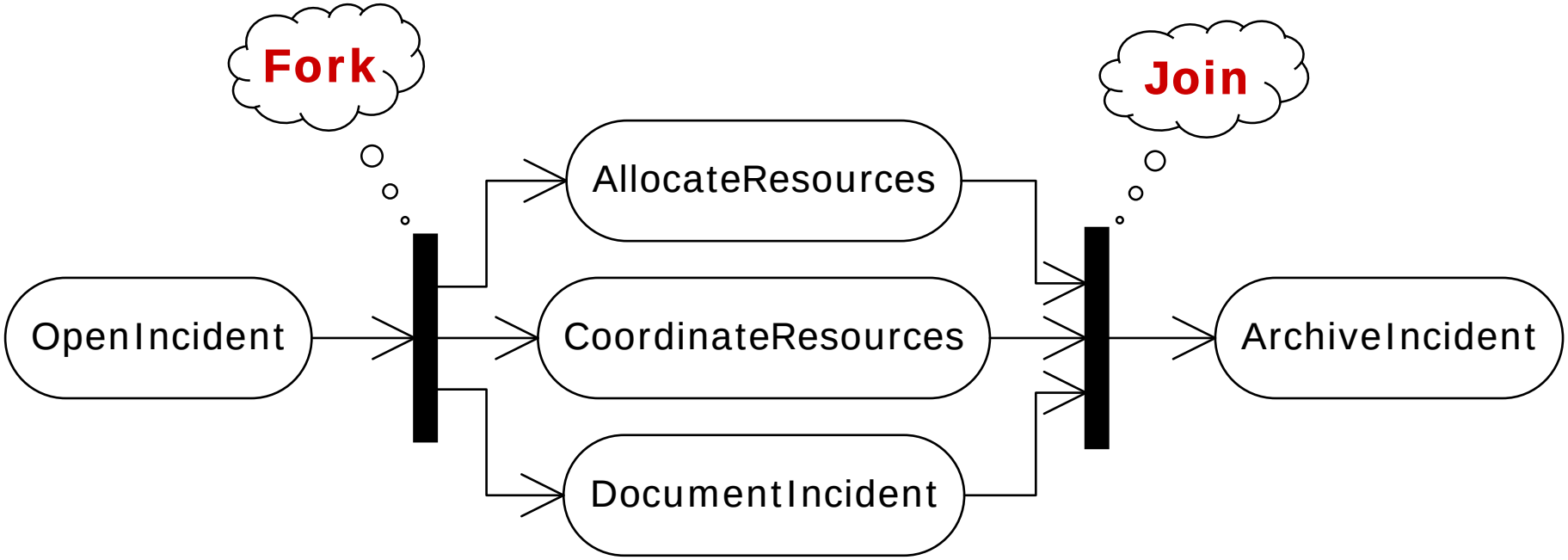


Activity diagram: decisions

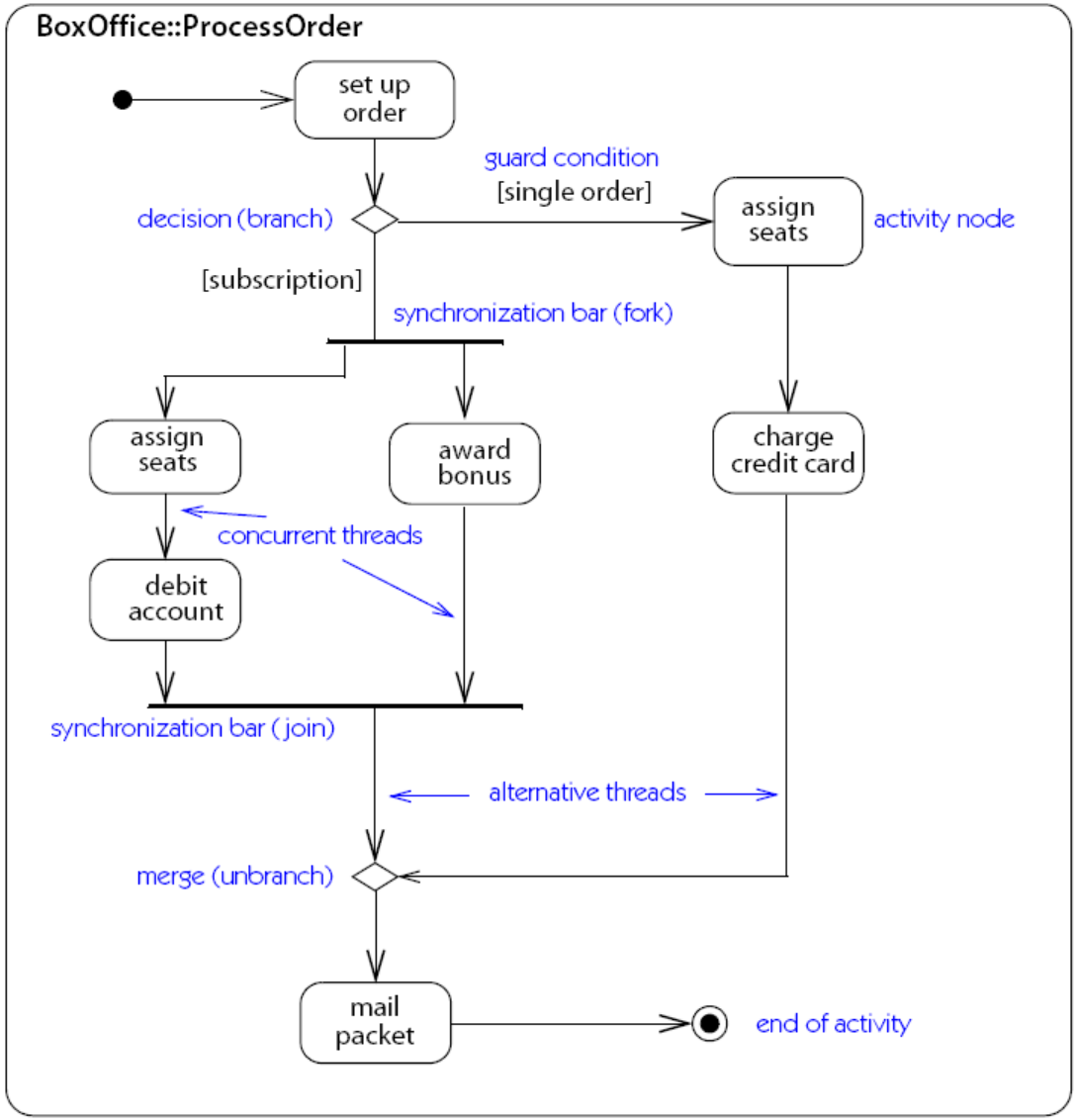


Activity diagrams: concurrency

- Synchronization of multiple activities
- Splitting the flow of control into multiple threads



Activity diagrams: theater example



Further UML diagram types

Static view:

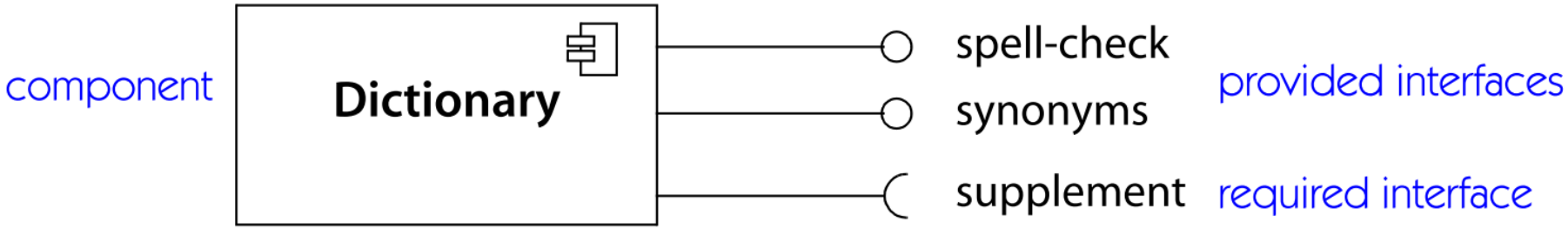
- Component diagrams, internal structure diagrams
  - Subsystems (components) and their interfaces
- Collaboration use diagram
  - A part of a structure that collaborates for a specific purpose
- Deployment diagrams
  - Computers and which part of the system runs on which

Dynamic view:

- Communication diagrams
  - Equivalent to sequence diagrams, but embedded in an object diagram (shows both static structure and dynamic interaction)
- Interaction overview diagrams
  - Related to activity diagrams, for describing control flow

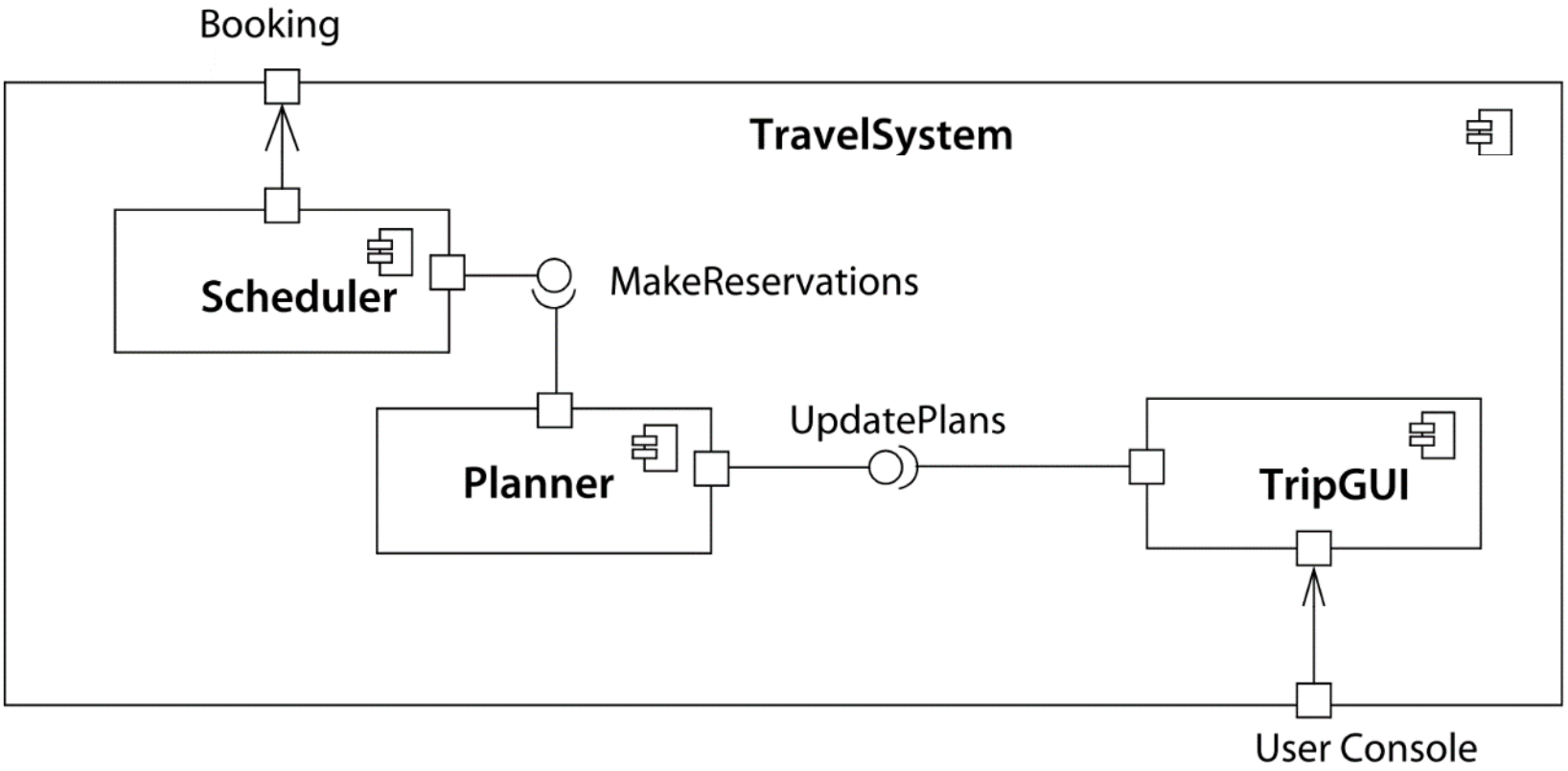
Components

- Components represent classes or subsystems (multiple classes)
  - The focus is on their interfaces



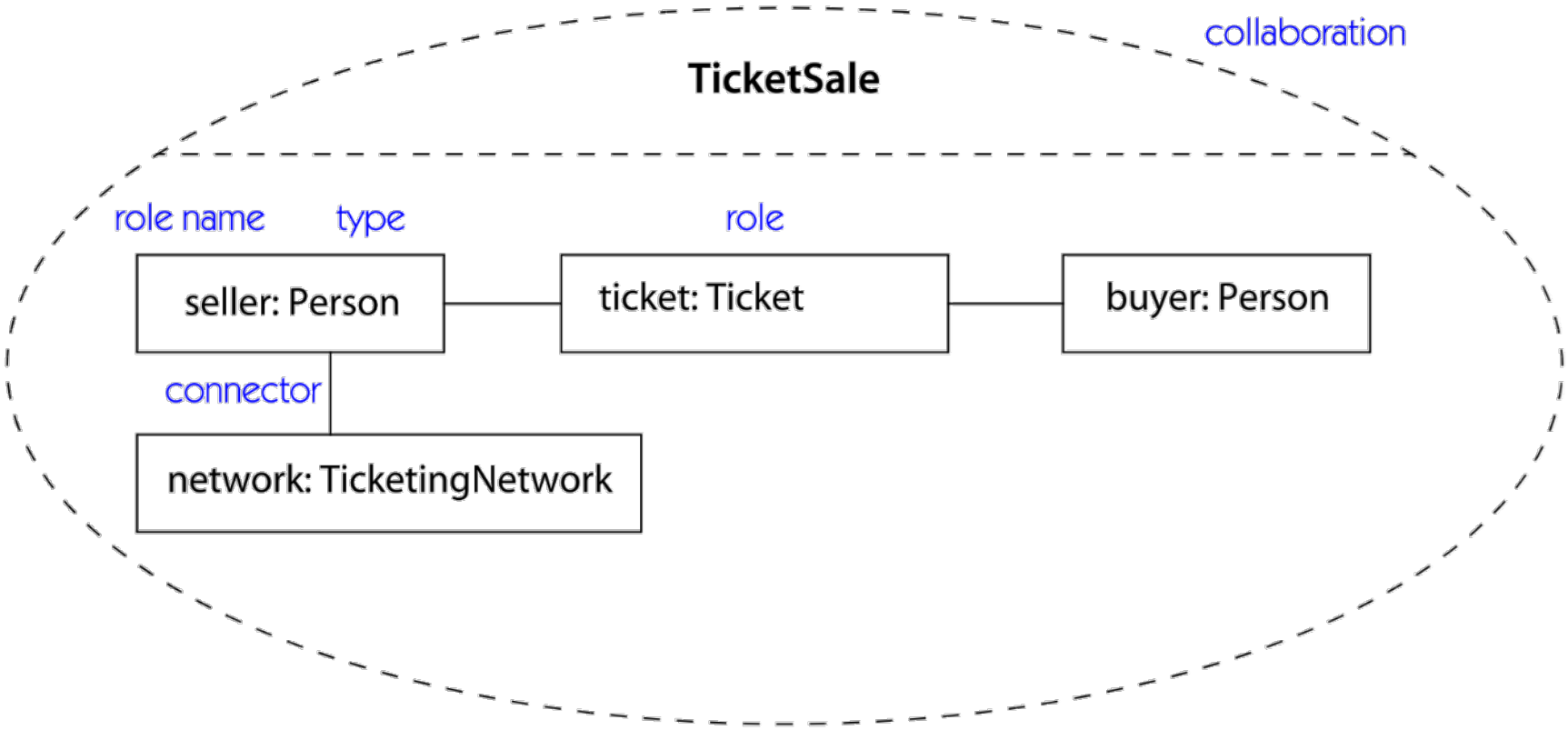
Component diagram, internal structure diagram

- Compositions of components
  - Component diagram: relationships between components
  - Internal structure diagram: structure of a component (as below) or any other classifier

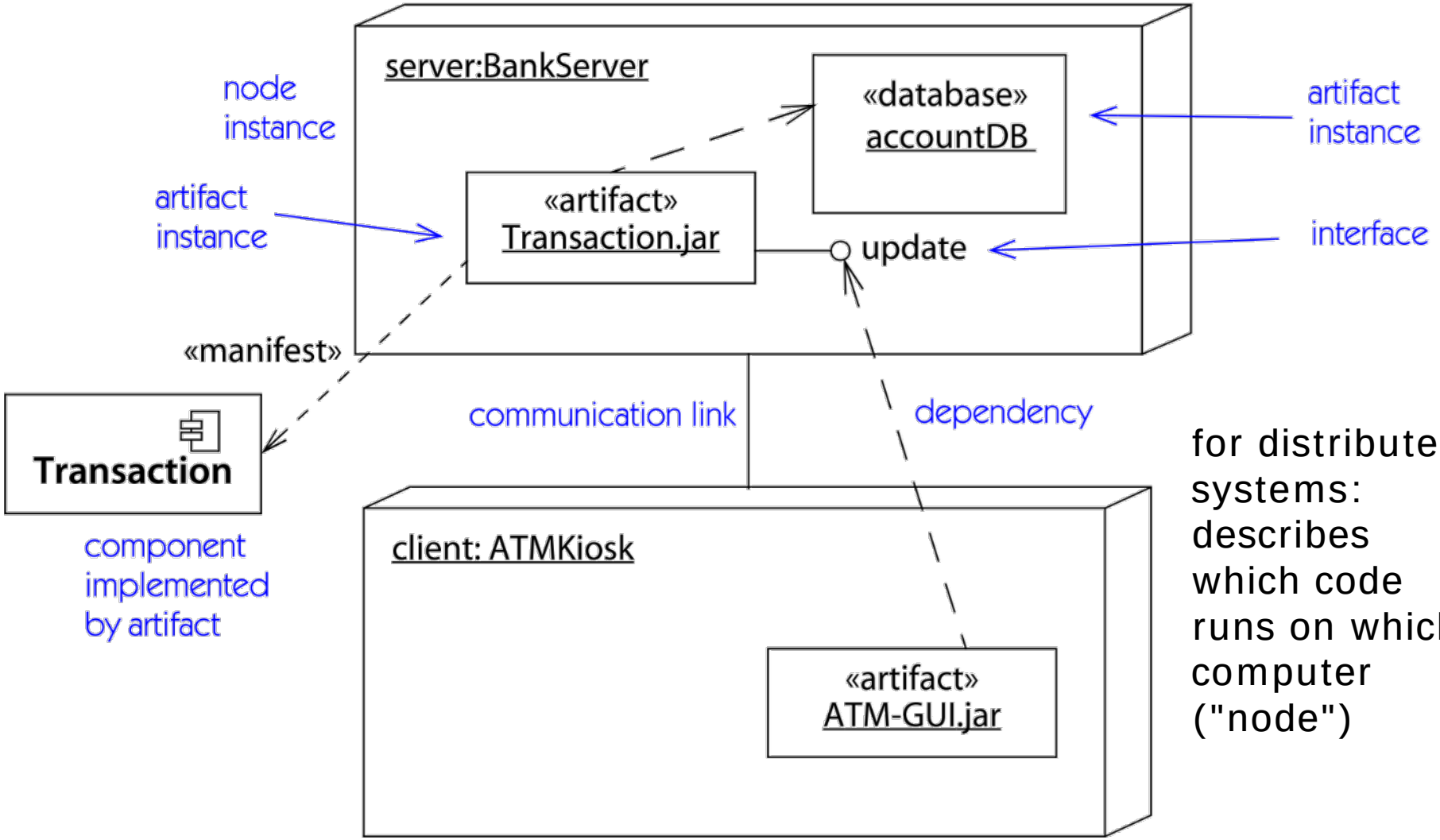


Collaboration use diagram

- A view describing the roles different parts play for one specific purpose
  - Can be on class level (as below) and on instance level



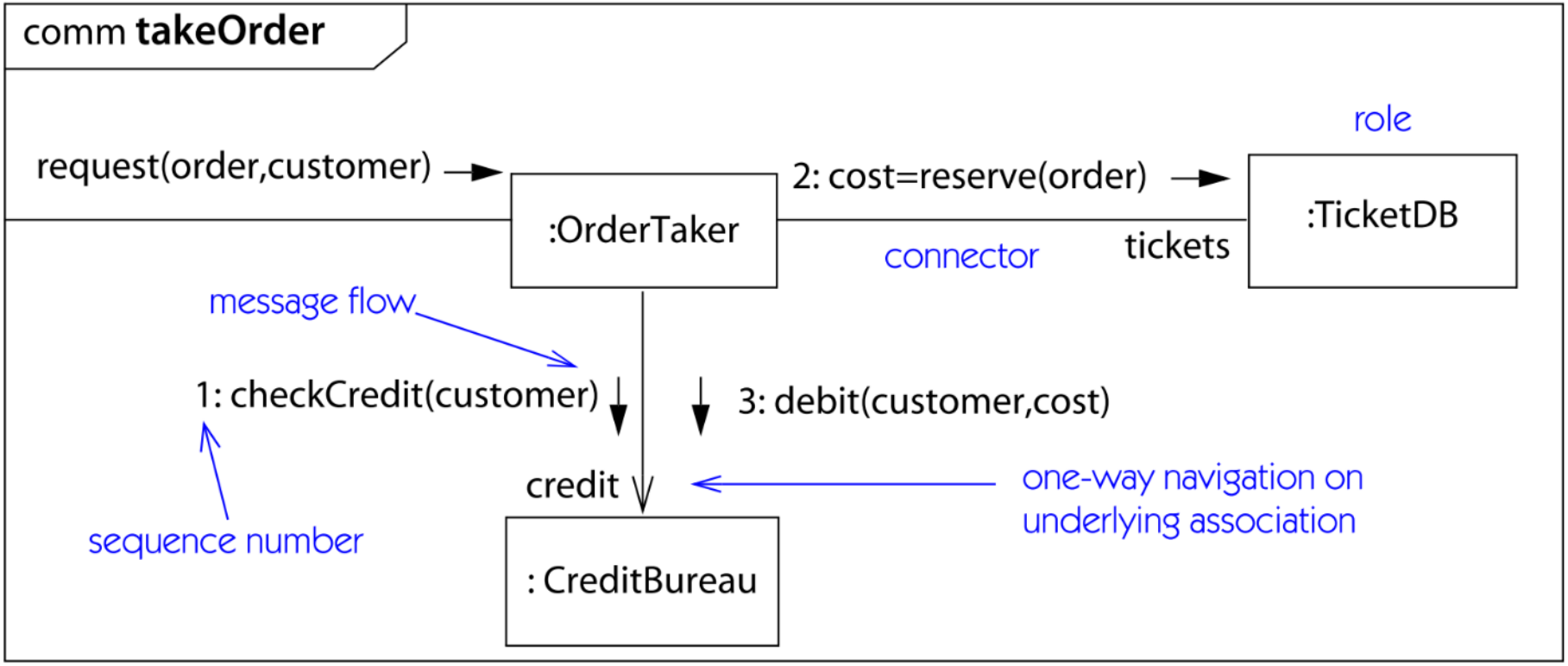
Deployment diagram



for distributed systems: describes which code runs on which computer ("node")

Communication diagram

- An object diagram with interaction annotations
  - Indicates interactions (like a sequence diagram) as well as object relationships (by the object diagram)



Interaction overview diagram

- A combination of activity diagram and sequence diagram:
  - activities may be sequence diagram fragments

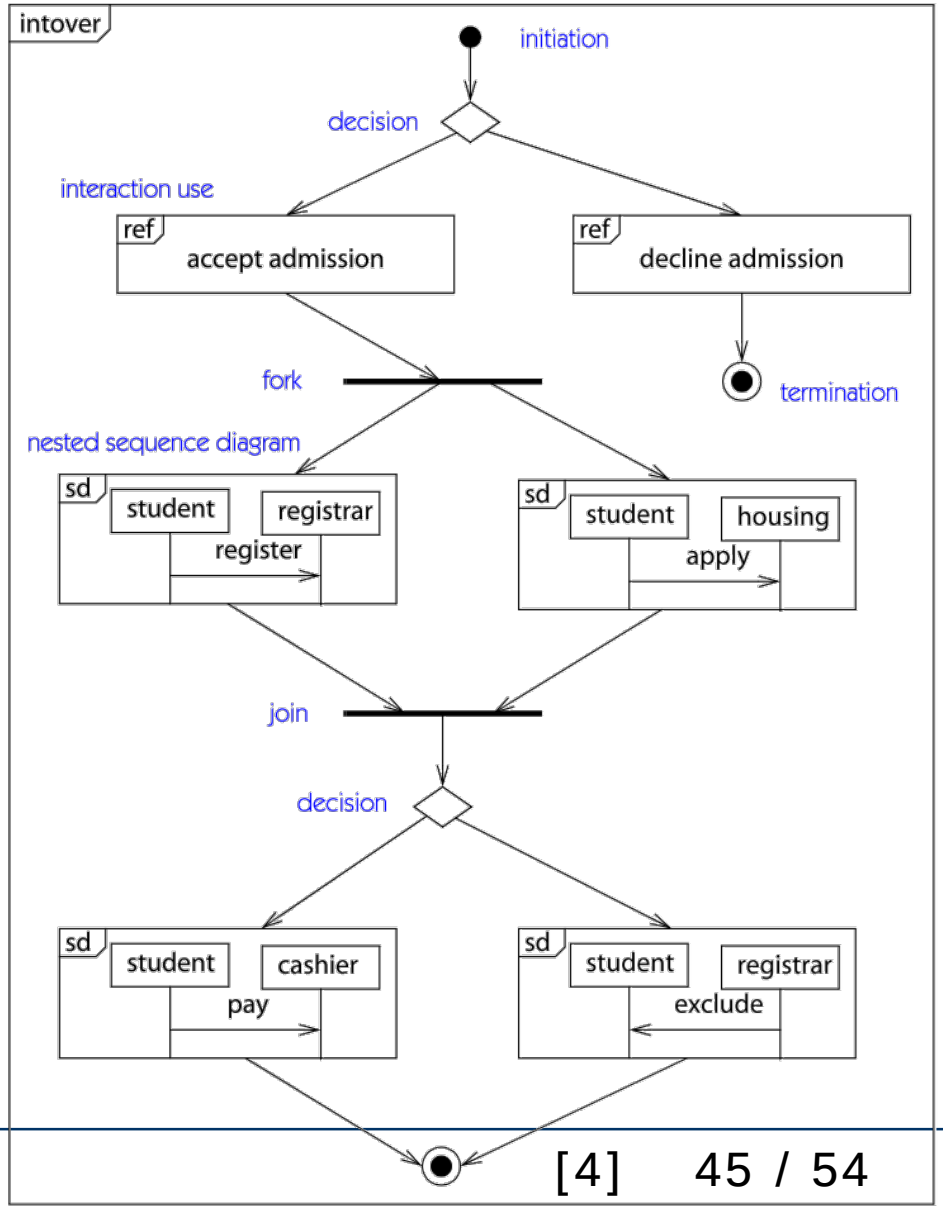
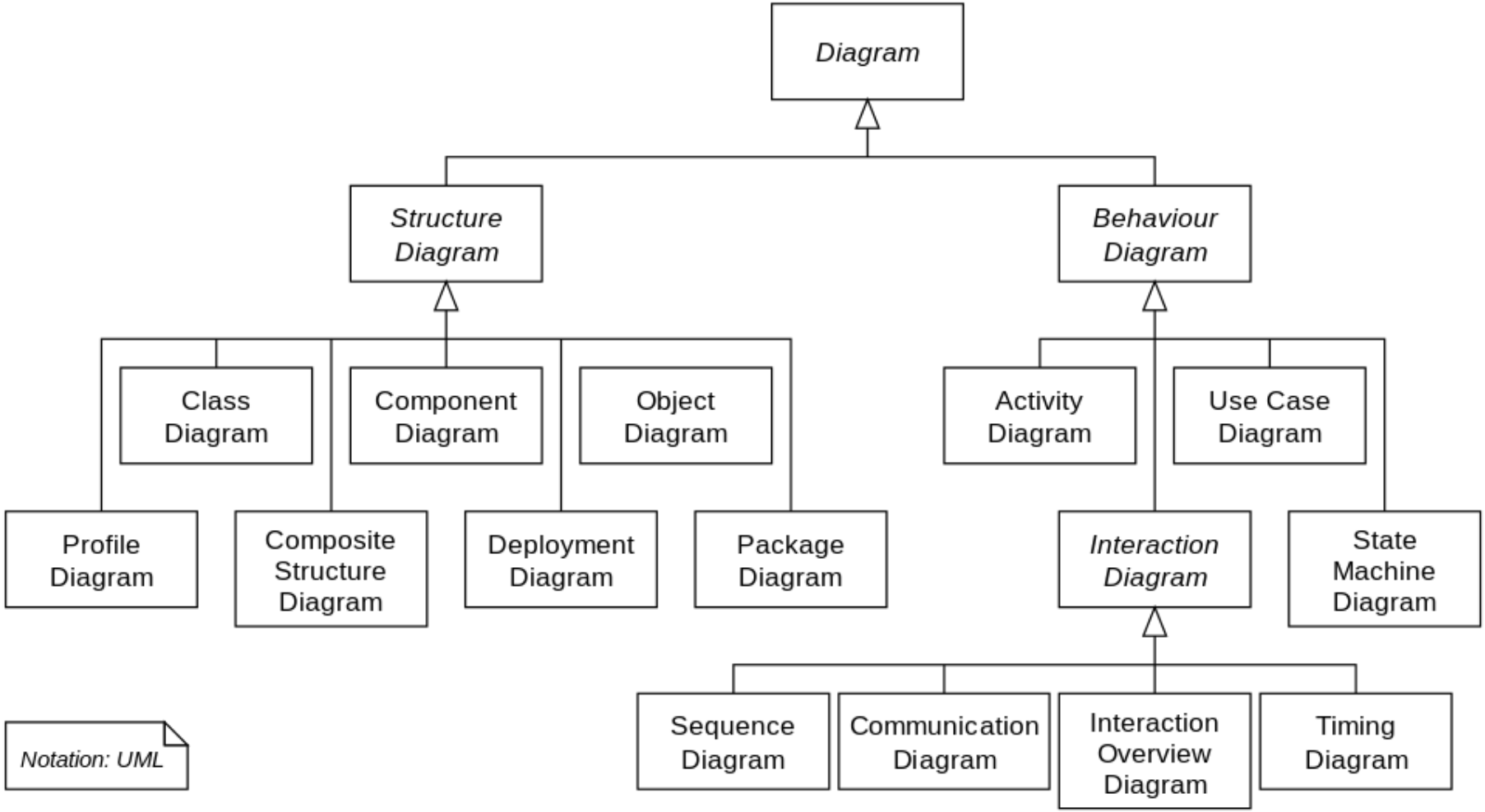


Diagram types overview (UML 2.2)



source: Wikimedia Commons

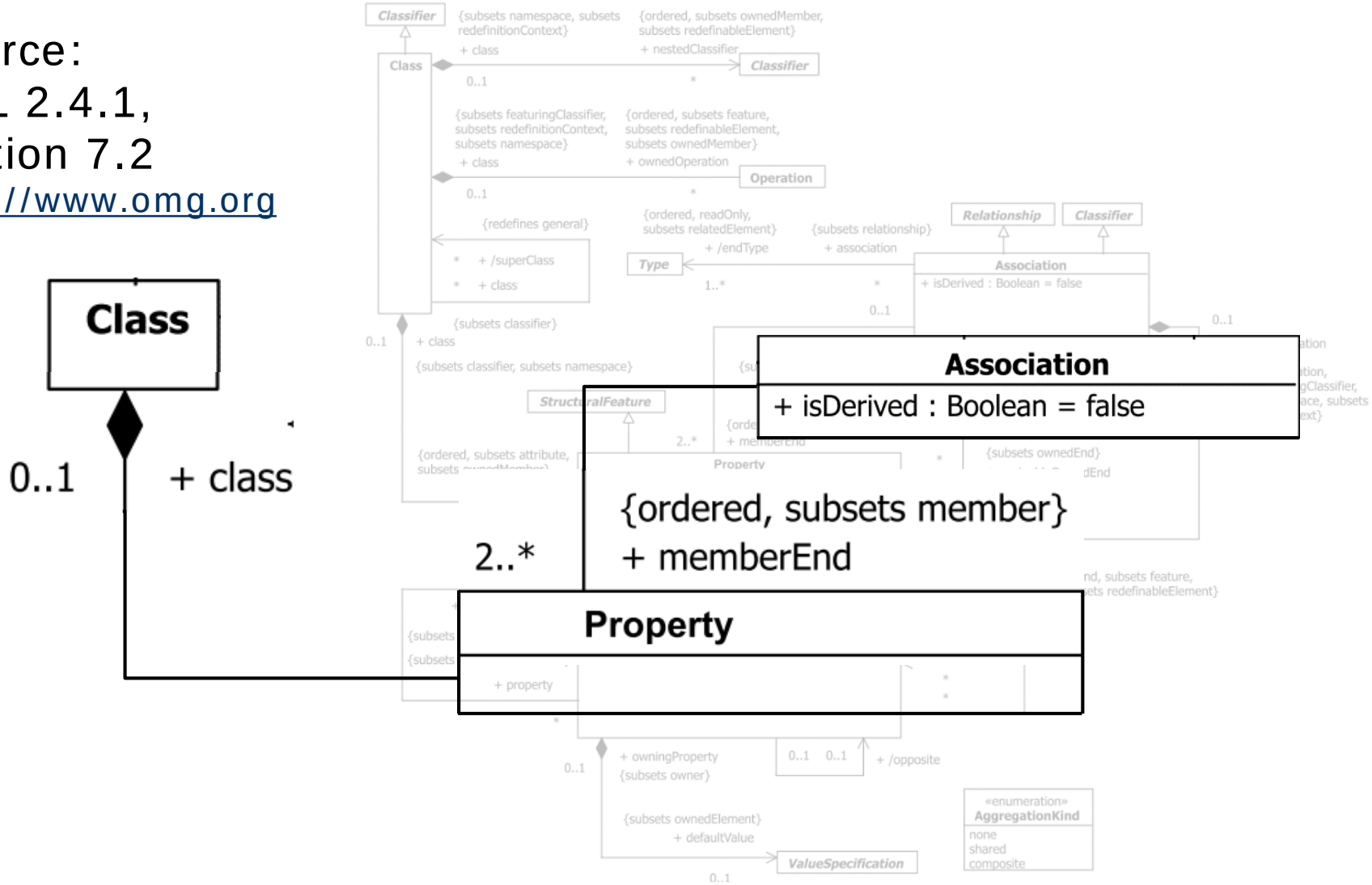
UML is described in UML itself

- The UML model describing UML is called the **UML metamodel**
  - It consists of UML class diagrams plus descriptive text

- Class level: Every kind of UML element (e.g. *"association"*) is a class in that metamodel
  - The characteristics are described by attributes or associated classes
  - e.g. the UML metamodel contains a class *Association*
- Instance level: Every association in a specific UML model can be interpreted as an instance of the *Association* class in the UML metamodel
  - But actually there is much more than just one class:

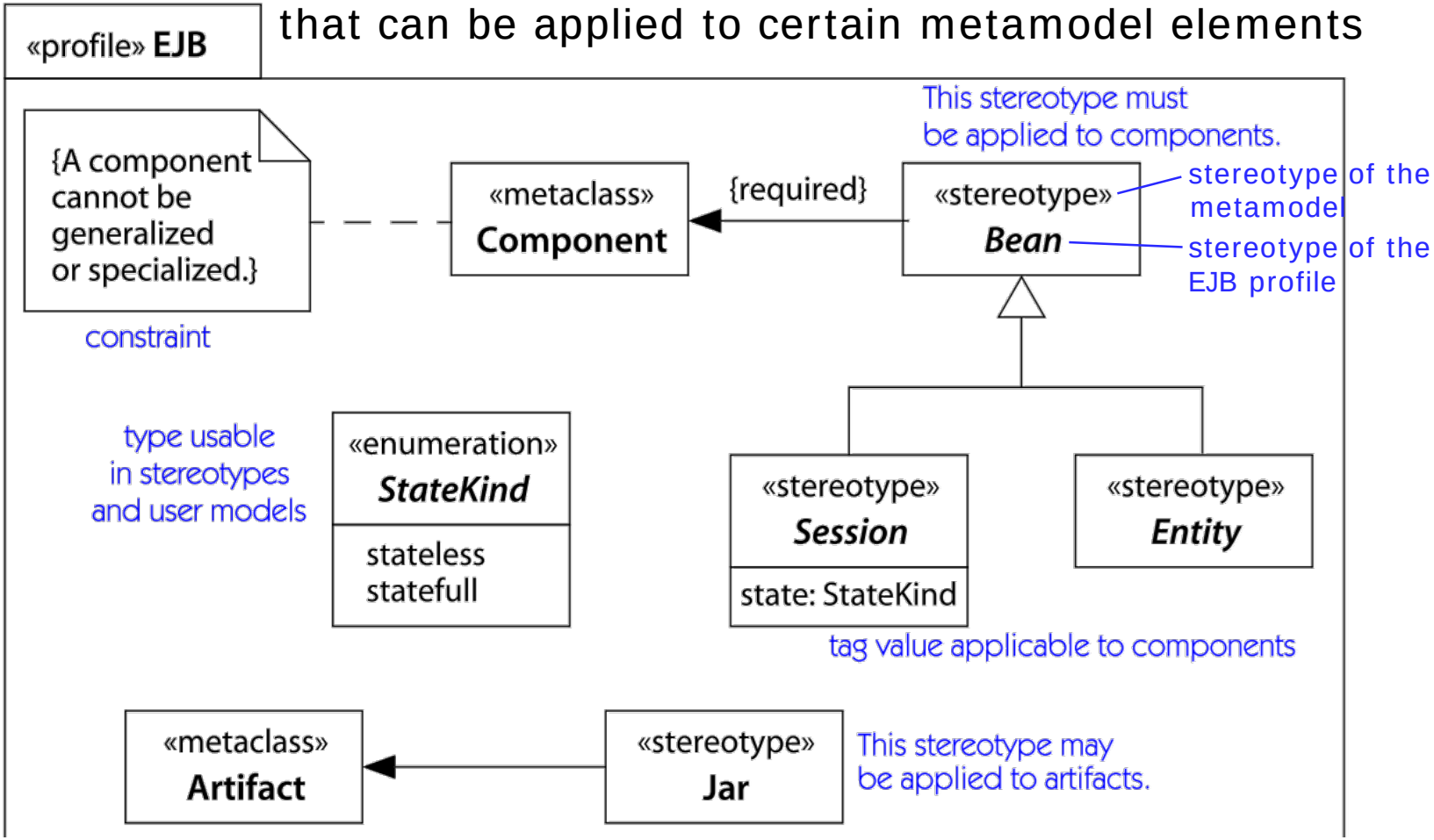
The UML Metamodel of associations

Source:
UML 2.4.1,
section 7.2
http://www.omg.org



UML is extensible

- **Profiles** add elements to the UML metamodel
  - A profile is a package that defines «stereotypes» and constraints that can be applied to certain metamodel elements



UML is fairly precise

- In this course, we will be using UML in a rather informal and imprecise manner
  - Our models are usually not very detailed
  - They leave many things unspecified (i.e., they are incomplete)
- However, one can produce fairly precise UML models
  - Such models have a reasonably well-defined meaning, as UML itself is specified in a semi-formal manner
    - No complete semantics have been specified for UML overall, though
  - There is **<u>much</u>** more to UML than can be said here
    - UML 2.4 Infrastructure + Superstructure: 200 + 800 pages
    - UML 2.5, rewritten in one document: 800 pages
- Precise UML usage is relevant for automatic code generation from the UML model
  - In some domains, such as telecommunication, complete subsystems are sometimes code-generated from UML models today

What should you know about UML?

- For all application domains:
  - Learn as much as you can about class diagrams (object diagrams help in doing this)
    - (soon maybe also component diagrams)
  - Learn the basics of use case, sequence, communication, state machine, and activity diagrams
- For realtime and formally specifiable (sub)domains:
  - Also learn a lot about state machine diagrams
- If you want to make full use of UML CASE tools:
  - Learn a lot about packages and about profiles
- If you want to build UML CASE tools:
  - Learn about the UML metamodel (Warning: tough!)

UML summary

- UML provides a wide variety of notations for representing many aspects of software development
  - Powerful, but complex language
  - Can be misused to generate unreadable models
  - Can be misunderstood when using too many exotic features
  - Many people who claim to "know UML" actually know very little

- For now we concentrate on a few notations:
  - Functional model: Use case diagram
  - Object model: class diagram
  - Dynamic model: sequence diagrams, state machine and activity diagrams

Literature

- James Rumbaugh, Ivar Jacobson, Grady Booch: *"The Unified Modeling Language Reference Manual",* Second Edition (UML 2.0), Addison-Wesley 2005.
  - this is also the source of the figures with blue annotations

- James Rumbaugh, Ivar Jacobson, Grady Booch: *"The Unified Modeling Language User Guide",* Second Edition (UML 2.0), Addison-Wesley 2005.
  - actually teaches how to *use* the UML
    - this lecture did not do this, but some of the rest of the course will
  - less misleading than some other books on the topic

The current version of UML is 2.5 (June 2015).

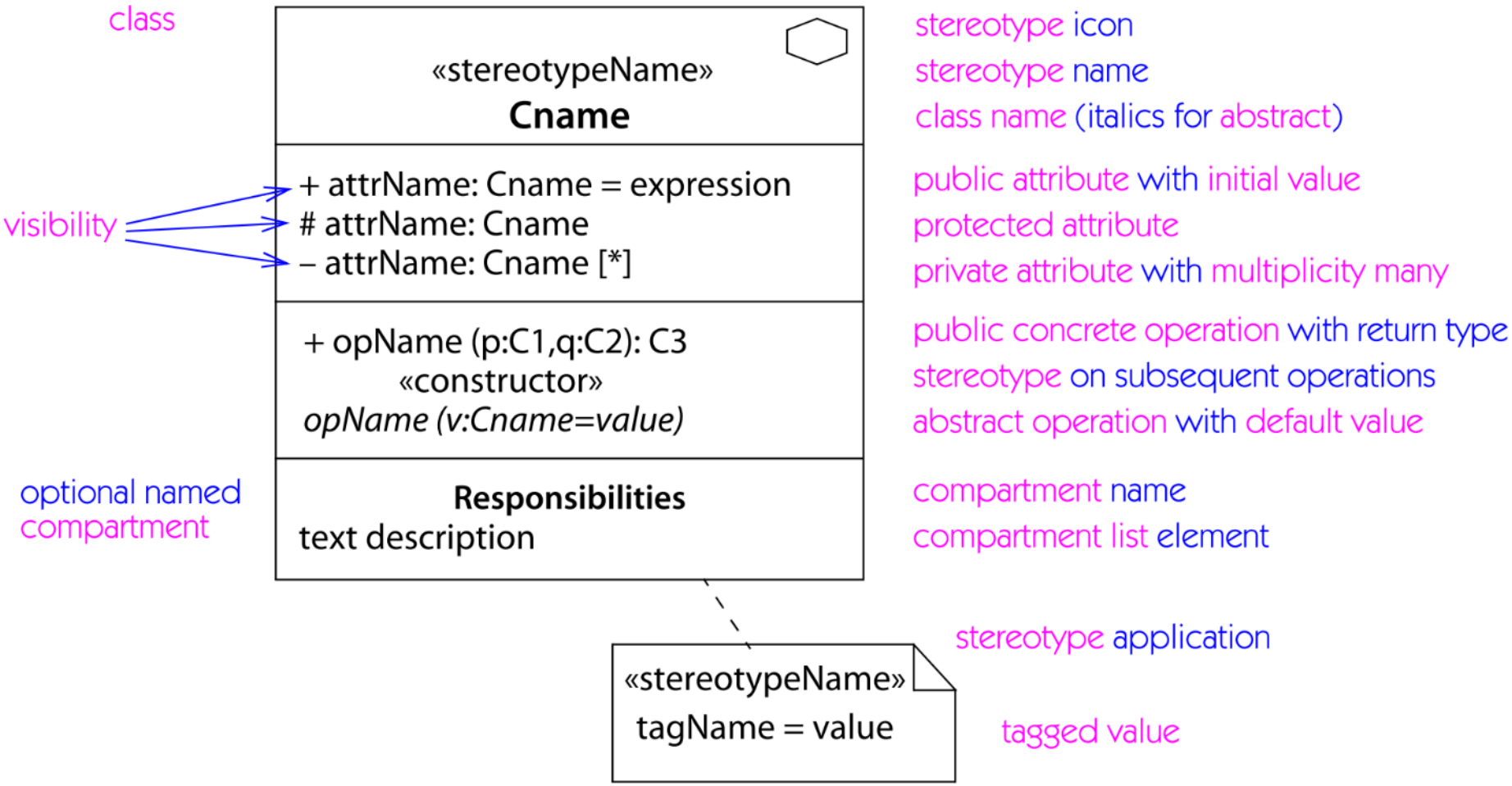
- http://www.omg.org/spec/UML/2.5/PDF/

Thank you!

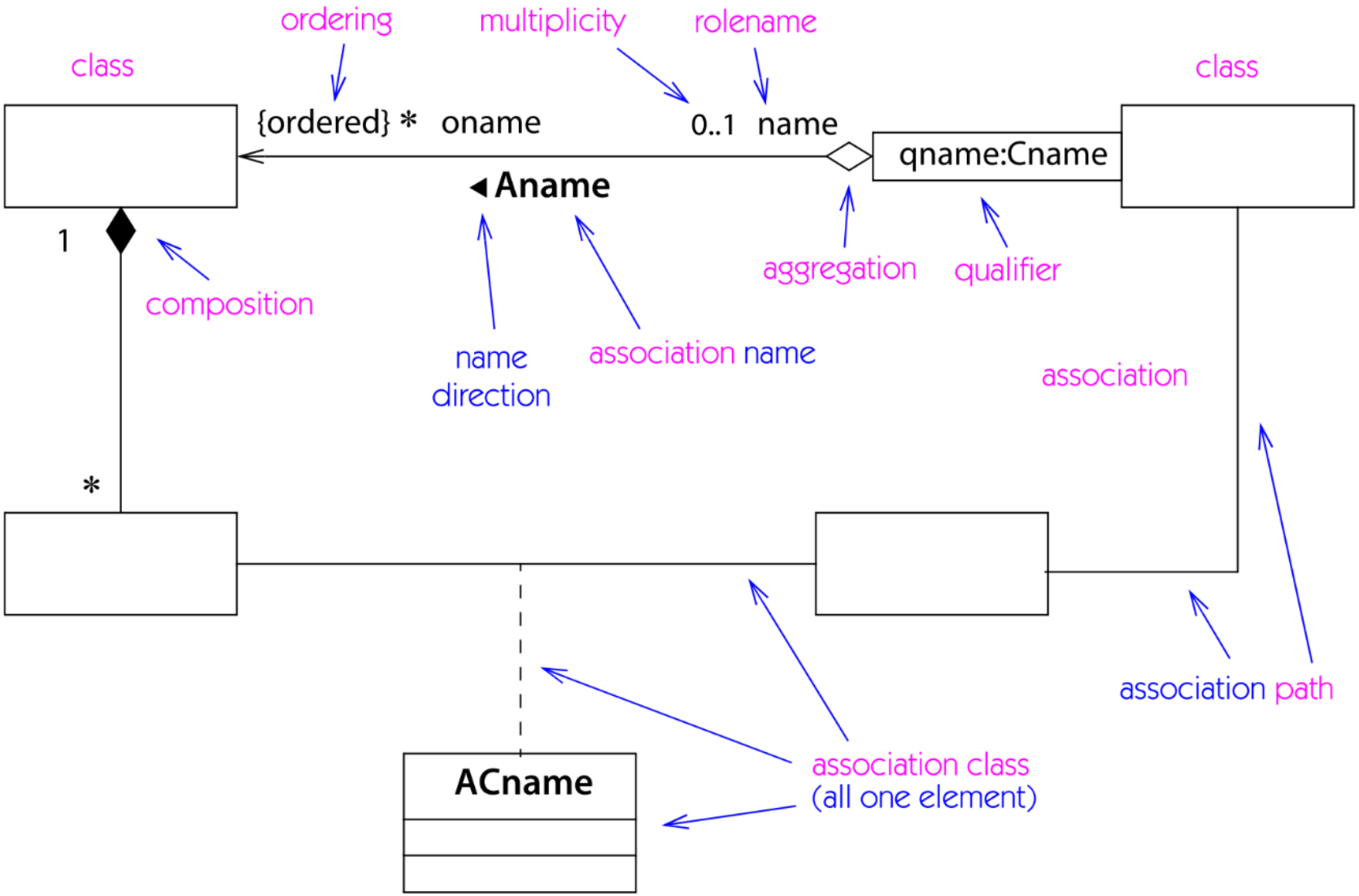
UML language elements details

- The next few slides present a number of details in the notation of
  - Classes (Class diagrams)
  - Associations (Class diagrams)
  - Interfaces (Class diagrams)
  - States (State machine diagrams)

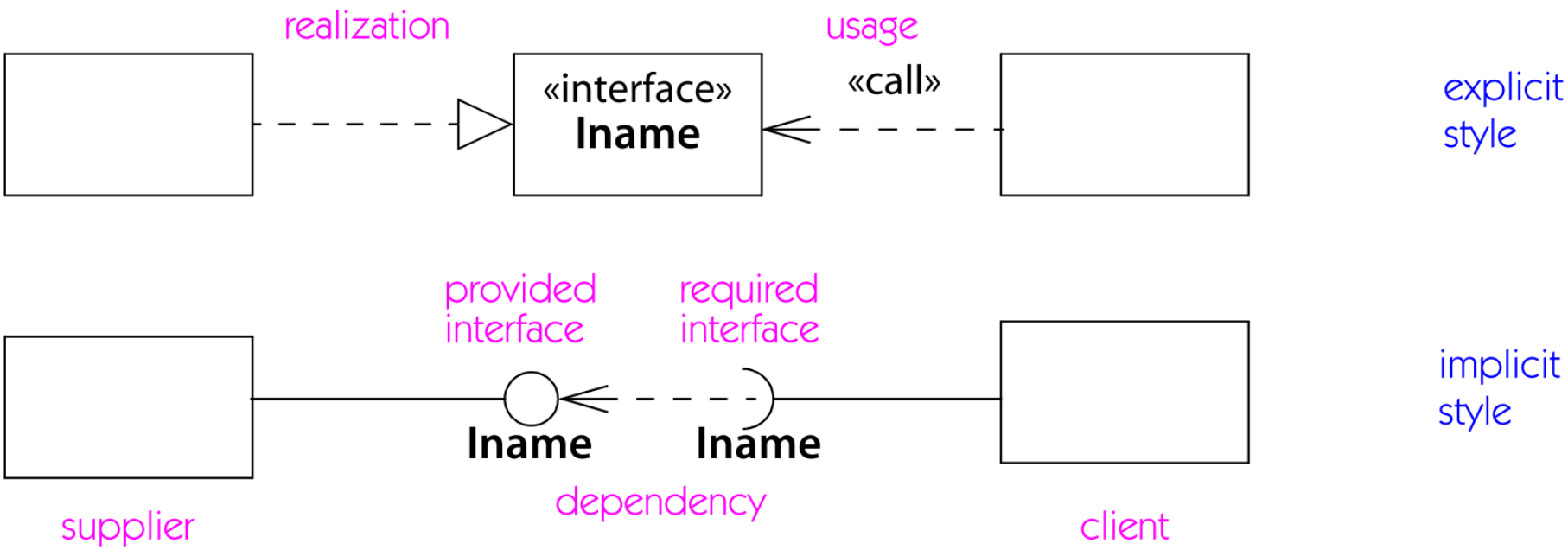
Details: Class



Details: Association



Details: Interfaces



Details: States