

# *Software Design, Modelling and Analysis in UML*

## *Lecture 7: Class Diagrams II*

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- **Rhapsody Demo I: Class Diagrams**

- **Visibility**

- **Intuition**
- **Context**, OCL with Visibility
- What is Visibility **Good For**?

- **Associations**

- Overview & Plan
- (Temporarily) **Extend Signature**
- From **Diagrams** to Signatures
  - What if Things are Missing?

## *Rhapsody Demo I: Class Diagrams*

RECALL, SEND US YOUR POOL-ACCOUNT NAME  
(meyer, NOT: mp124 (RZ))

## *Class Diagram Semantics Cont'd*

# Semantical Relevance

- The **semantics** (or meaning) of an extended object system signature  $\mathcal{S}$  wrt. a structure  $\mathcal{D}$  is **the set of system states**  $\Sigma_{\mathcal{D}}^{\mathcal{S}}$ .
- The **semantics** (or meaning) of an extended object system signature  $\mathcal{S}$  is **the set of sets of system states** wrt. some structure of  $\mathcal{S}$ , i.e. the set

$$\{\Sigma_{\mathcal{D}}^{\mathcal{S}} \mid \mathcal{D} \text{ is structure of } \mathcal{S}\}.$$

$$\mathcal{S}_1: \langle C, \emptyset, 0, 0 \rangle$$

$$\rightsquigarrow \Sigma_{\mathcal{S}_1}^{\mathcal{D}} =$$

$$\mathcal{S}_2: \langle C, \emptyset, 0, 1 \rangle \rightsquigarrow \Sigma_{\mathcal{S}_2}^{\mathcal{D}}$$

(only difference in  $\mathcal{S}_1, \mathcal{S}_2$  is activeness of  $C$ )

Which of the following aspects is **semantically relevant**, i.e. **does contribute** to the constitution of system states?

## A class

- has a set of **stereotypes**, ✗
- has a **name**, ✓
- belongs to a **package**,
- can be **abstract**, ✓
- can be **active**, ✗
- has a set of **attributes**, ✓
- has a set of **operations** (later).

## Each attribute has

- a **visibility**, ✗
- a **name**, a **type**, ✓
- a **multiplicity**, ✓, an **order**, ✗
- an **initial value**, and ✗
- a set of **properties**, (✗) such as **readOnly**, **ordered**, etc.

# What About The Rest?

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- **Classes:**

- **Stereotypes:** Lecture 6

- **Active:** not represented in  $\sigma$ .

**Later:** relevant for behaviour, i.e., how system states evolve over time.

- **Attributes:**

- **Initial value expression:** not represented in  $\sigma$ .

**Later:** provides an initial value as effect of “creation action”.

- **Visibility:** not represented in  $\sigma$ .

**Later:** viewed as additional **typing information** for well-formedness of OCL expressions and actions. *- typedness*

- **Properties:** such as `readOnly`, `ordered`, `composite` (**Deprecated** in the standard.)

- `readOnly` – can be treated **similar to visibility**.

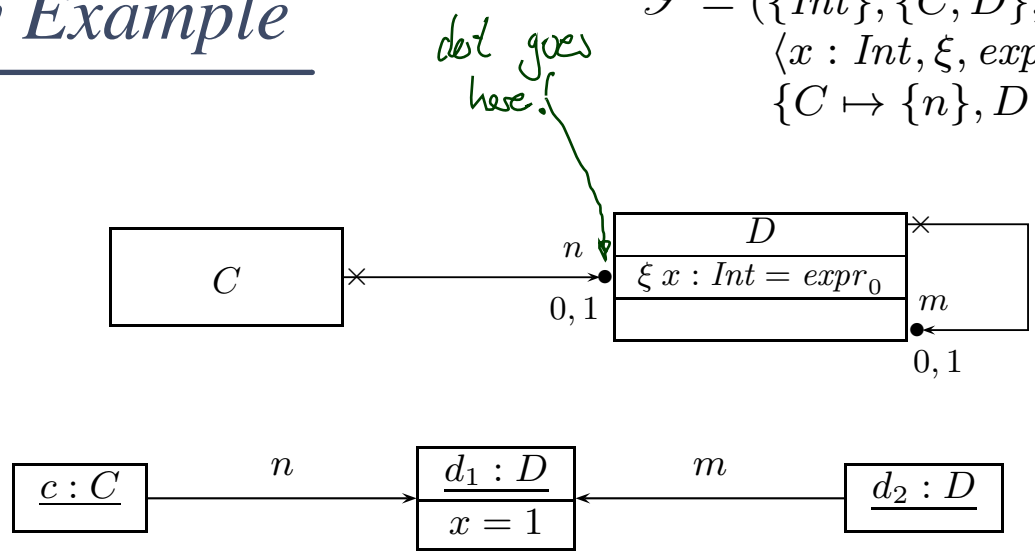
- `ordered` – not considered in our UML fragment ( $\rightarrow$  sets vs. sequences).

- `composite` – cf. lecture on associations.

# *Visibility*

# The Intuition by Example

$$\mathcal{S} = (\{\text{Int}\}, \{C, D\}, \{n : D_{0,1}, m : D_{0,1}, \langle x : \text{Int}, \xi, \text{expr}_0, \emptyset \rangle\}, \{C \mapsto \{n\}, D \mapsto \{x, m\}\})$$



Which of the following two **syntactically correct** (?) OCL expressions should we consider to be **well-typed**?

	$\xi = \text{public}$	$\xi = \text{private}$	$\xi = \text{protected}$	$\xi = \text{package}$
$\text{self}_C . n . x = 0$	✓ <del>   </del>     ✗ - ?	✓ - ✗ <del>   </del>     ?	later	not in lect.
$\text{self}_D . m . x = 0$	✓ <del>   </del>     ✗ - ?	✓     ✗     ?	later	not in lect.

*by class (C++, Java, ..)* (pointing to the private column for self\_C)

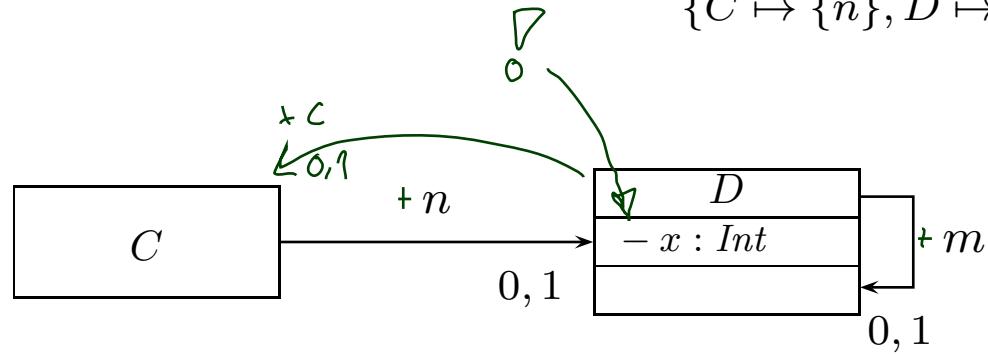
*by object* (pointing to the private column for self\_D)



# Context

$$\mathcal{S} = (\{Int\}, \{C, D\}, \{n : D_{0,1}, m : D_{0,1}, \\ \langle x : Int, \xi, expr_0, \emptyset \rangle\}, \\ \{C \mapsto \{n\}, D \mapsto \{x, m\}\})$$

- By example:



$$\underbrace{self_D}_{\tau_D} . x > 0 \quad \checkmark$$

$$\underbrace{self_D}_{\tau_D} . m . x > 0 \quad \checkmark$$

$$\underbrace{self_C}_{\tau_C} . n . x > 0 \quad \times$$

- That is, whether an expression involving attributes with visibility is well-typed **depends** on the class of the object which “tries to read out the value”.
- Visibility is ‘**by class**’ – **not** ‘by object’.

$$\underbrace{self_D}_{\tau_D} . c . n . x > 0 \quad \checkmark$$

$$\underbrace{self_C}_{\tau_C} . n . c . n . x > 0 \quad \times$$

# Attribute Access in Context

**Recall:** attribute access in OCL Expressions,  $C, D \in \mathcal{C}$ .

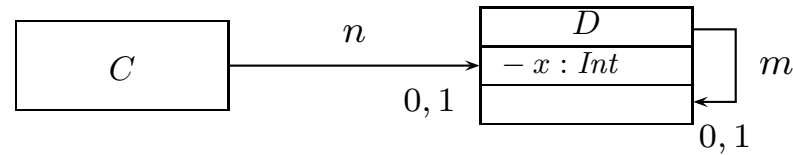
- |               |                                    |   |
|---------------|------------------------------------|---|
| $v(expr_1)$   | $: \tau_C \rightarrow \tau(v)$     | • $v : T \in atr(C), T \in \mathcal{T}$ , |
| $r_1(expr_1)$ | $: \tau_C \rightarrow \tau_D$      | • $r_1 : D_{0,1} \in atr(C)$ ,            |
| $r_2(expr_1)$ | $: \tau_C \rightarrow Set(\tau_D)$ | • $r_2 : D_* \in atr(C)$ ,                |

## New rules for well-typedness considering visibility:

- |  |                                    |   |
|--|------------------------------------|---|
| • $v(w)$   | $: \tau_C \rightarrow T$           | $w : \tau_C, v : T \in atr(C), T \in \mathcal{T}$   |
| • $r_1(w)$   | $: \tau_C \rightarrow \tau_D$      | $w : \tau_C, r_1 : D_{0,1} \in atr(C)$  |
| • $r_2(w)$   | $: \tau_C \rightarrow Set(\tau_D)$ | $w : \tau_C, r_2 : D_* \in atr(C)$  |
| • $v(\underbrace{expr_1(w)}_{\underbrace{\omega_1(\dots(\omega_n(w))\dots)}})$   | $: \tau_C \rightarrow T$           | $\langle v : T, \xi, expr_0, P \rangle \in atr(C), T \in \mathcal{T},$<br>$\underbrace{expr_1(w) : \tau_C, w : \tau_{C_1} \text{ and } C_1 = C, \text{ or } \xi = +}$ |
| • $r_1(\underbrace{expr_1(w)}_{\underbrace{\omega_1(\dots(\omega_n(w))\dots)}})$ | $: \tau_C \rightarrow \tau_D$      | $\langle r_1 : D_{0,1}, \xi, expr_0, P \rangle \in atr(C),$<br>$expr_1(w) : \tau_C, w : \tau_{C_1} \text{ and } C_1 = C, \text{ or } \xi = +$                         |
| • $r_2(\underbrace{expr_1(w)}_{\underbrace{\omega_1(\dots(\omega_n(w))\dots)}})$ | $: \tau_C \rightarrow Set(\tau_D)$ | $\langle r_2 : D_*, \xi, expr_0, P \rangle \in atr(C),$<br>$expr_1(w) : \tau_C, w : \tau_{C_1} \text{ and } C_1 = C, \text{ or } \xi = +$                             |

# Example

(i) $v(w)$	$: \tau_C \rightarrow T$	$w : \tau_C, v : T \in atr(C), T \in \mathcal{I}$
(ii) $r_1(w)$	$: \tau_C \rightarrow \tau_D$	$w : \tau_C, r_1 : D_{0,1} \in atr(C)$
(iii) $v(expr_1(w))$	$: \tau_C \rightarrow T$	$\langle v : T, \xi, expr_0, P \rangle \in atr(C), T \in \mathcal{I},$ $expr_1(w) : \tau_C, w : \tau_{C_1}$ and $C_1 = C$ , or $\xi = +$
	$\downarrow v(\omega_1(\dots(\omega_n(w))\dots))$	
(iv) $r_1(expr_1(w))$	$: \tau_C \rightarrow \tau_D$	$\langle r_1 : D_{0,1}, \xi, expr_0, P \rangle \in atr(C),$ $expr_1(w) : \tau_C, w : \tau_{C_1}$ and $C_1 = C$ , or $\xi = +$



•  $self_D . x > 0 \rightsquigarrow x(self_D) > 0$  OK, by (i)

•  $self_D . m . x > 0 \rightsquigarrow x(m(self_D)) > 0$  OK, by (iii)  
 $\underbrace{\quad}_{:\tau_D} =$

•  $self_C . n . x > 0 \rightsquigarrow x(n(self_C)) > 0$  NOT OK  
 $\underbrace{\quad}_{:\tau_C} \neq$   
 $\underbrace{\quad}_{:\tau_D} \xi = -$

# The Semantics of Visibility

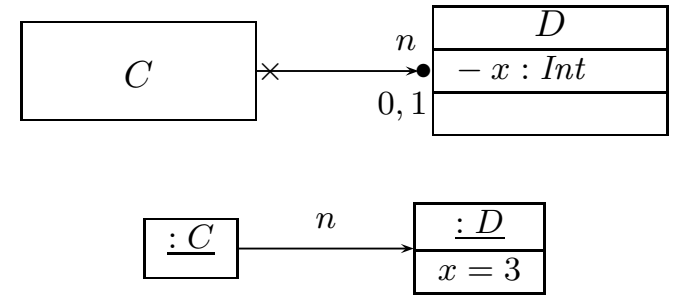
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- **Observation:**
    - Whether an expression **does** or **does not** respect visibility is **a matter of well-typedness only**.
    - We only evaluate (= apply  $I$  to) **well-typed** expressions.
- We **need not** adjust the interpretation function  $I$  to support visibility.

Just decide: should we take visibility into account yes / no,  
and check well-typedness by the new / old rules.

# What is Visibility Good For?

- Visibility is a property of attributes – is it useful to consider it in OCL?
- In other words: given the diagram above, **is it useful** to state the following invariant (even though  $x$  is private in  $D$ )



context  $C$  inv :  $n.x > 0$  ?

**It depends.**

(cf. [OMG \(2006\)](#), Sect. 12 and 9.2.2)

- **Constraints and pre/post conditions:**
  - Visibility is **sometimes not** taken into account. To state “global” requirements, it may be adequate to have a “global view”, i.e. be able to “look into” all objects.
  - But: visibility supports “narrow interfaces”, “information hiding”, and similar **good design practices**. To be more robust against changes, try to state requirements only in the terms which are visible to a class.

**Rule-of-thumb:** if attributes are important to state requirements on design models, leave them public or provide get-methods (later).

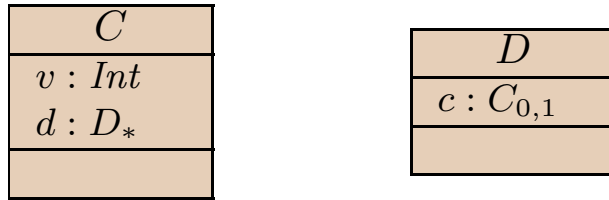
- **Guards and operation bodies:**
  - If in doubt, **yes** (= do take visibility into account).

Any so-called **action language** typically takes visibility into account.

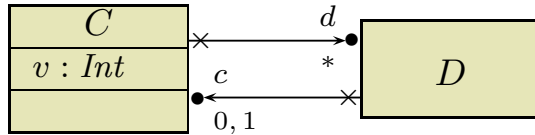
# *Associations*

# Overview

- **Class diagram:**



Alternative presentation:



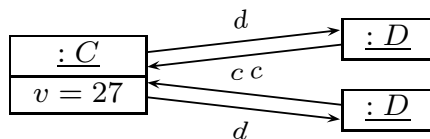
- **Signature:**

$$\mathcal{S} = (\{Int\}, \{C, D\}, \{v : Int, d : D_*, c : C_{0,1}\}, \{C \mapsto \{v, d\}, D \mapsto \{c\}\})$$

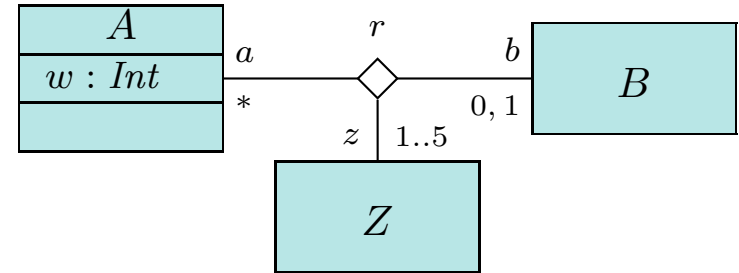
- **Example system state:**

$$\sigma = \{1_C \mapsto \{v \mapsto 27, d \mapsto \{5_D, 7_D\}\}, 5_D \mapsto \{c \mapsto \{1_C\}\}, 7_D \mapsto \{c \mapsto \{1_C\}\}\}$$

- **Object diagram:**



- **Class diagram (with ternary association):**



- **Signature:** extend again to represent

- **association**  $r$  with

- **association ends**  $a, b,$  and  $z$  (each with multiplicity, visibility, etc.)

- **Example system state:**  $(\sigma, \lambda)$

$$\sigma = \{1_A \mapsto \{w \mapsto 13\}, 1_B \mapsto \emptyset, 1_Z \mapsto \emptyset\}$$

$$\lambda = \{r \mapsto \{(1_A, 1_B, 1_Z), (1_A, 1_B, 2_Z)\}\}$$

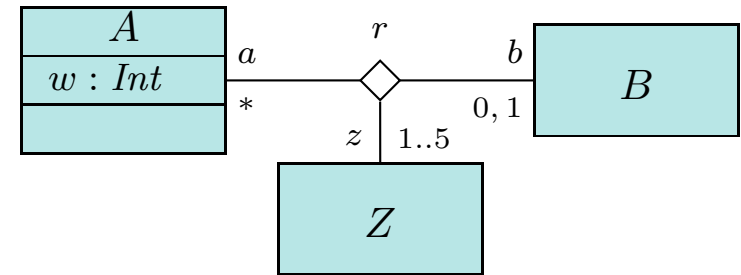
		$z$
$1_A$	$1_B$	$1_Z$
$1_A$	$1_B$	$2_Z$

- **Object diagram:** No...

# Plan

- (i) Study association **syntax**.
- (ii) Extend **signature** accordingly.
- (iii) Define  $(\sigma, \lambda)$  **system states** with
  - **objects** in  $\sigma$   
(instances of classes),
  - **links** in  $\lambda$   
(instances of associations).
- (iv) Change **syntax** of OCL to refer to **association ends**.
- (v) Adjust **interpretation**  $I$  accordingly.
- (vi) ... go back to the special case of  $C_{0,1}$  and  $C_*$  attributes.

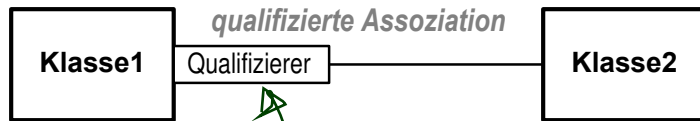
- **Class diagram** (with ternary association):



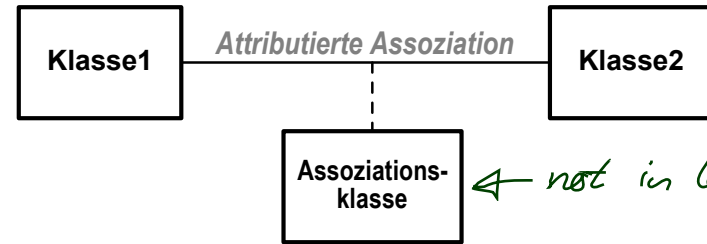
- **Signature**: extend again to represent
  - **association**  $r$  with
    - **association ends**  $a$ ,  $b$ , and  $z$   
(each with multiplicity, visibility, etc.)
- **Example system state**:
$$\sigma = \{1_A \mapsto \{w \mapsto 13\}, 1_B \mapsto \emptyset, 1_Z \mapsto \emptyset\}$$
$$\lambda = \{r \mapsto \{(1_A, 1_B, 1_Z), (1_A, 1_B, 2_Z)\}\}$$
- **Object diagram**: No...



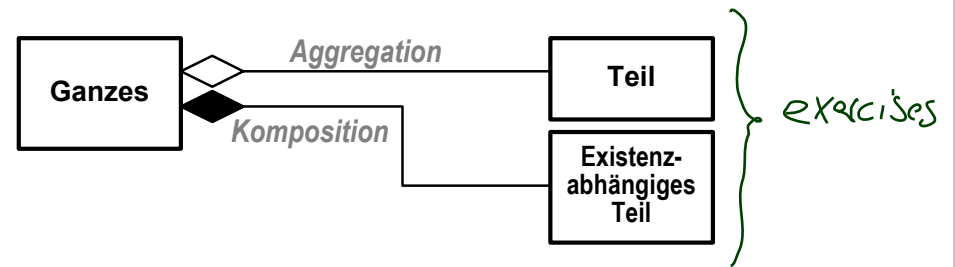
# *Associations: Syntax*



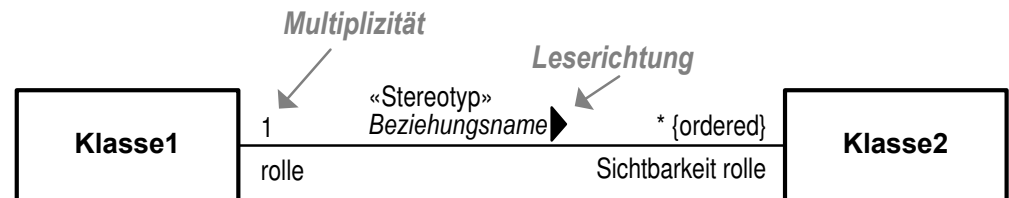
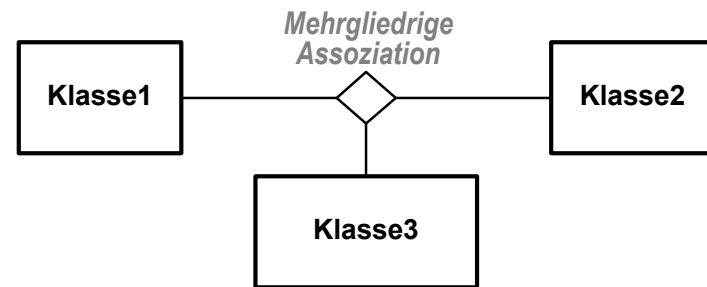
*not in lect.*



*not in lect.*



*exercises*



# More Association Syntax (OMG, 2011b, 61;43)

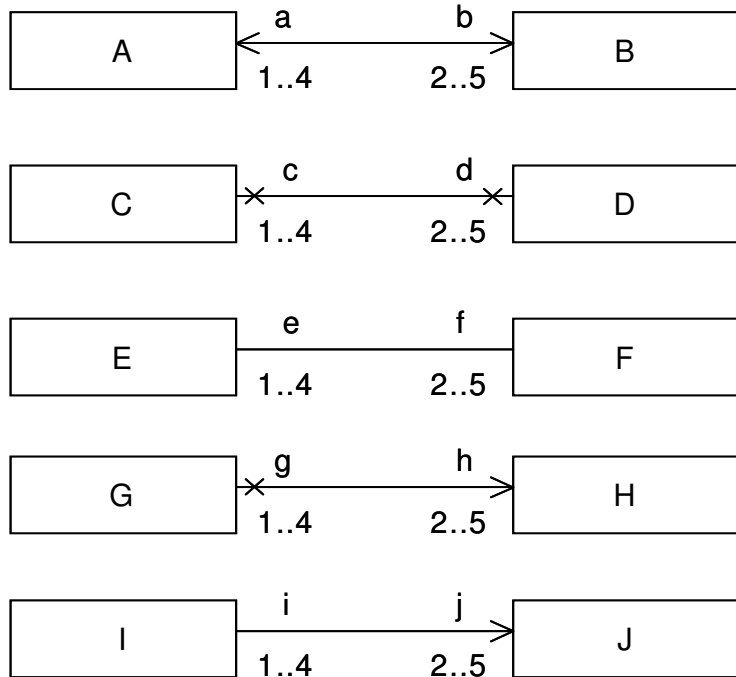


Figure 7.23 - Examples of navigable ends

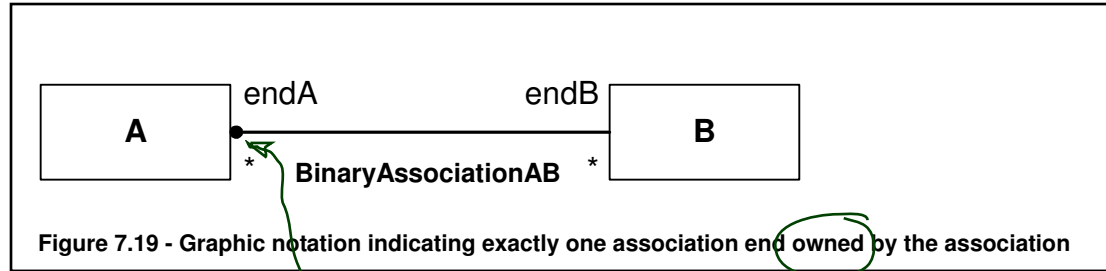


Figure 7.19 - Graphic notation indicating exactly one association end owned by the association

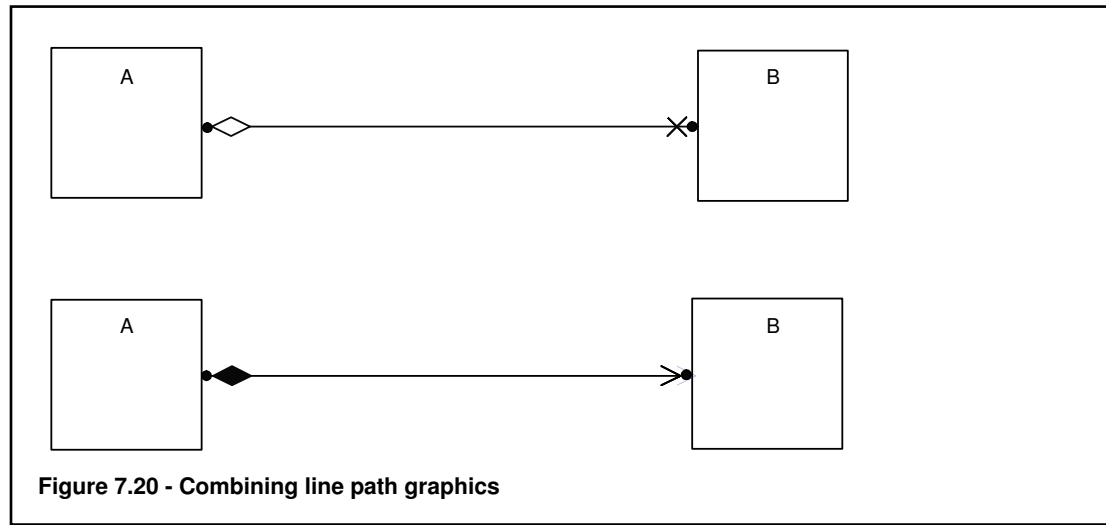


Figure 7.20 - Combining line path graphics

# So, What Do We (Have to) Cover?

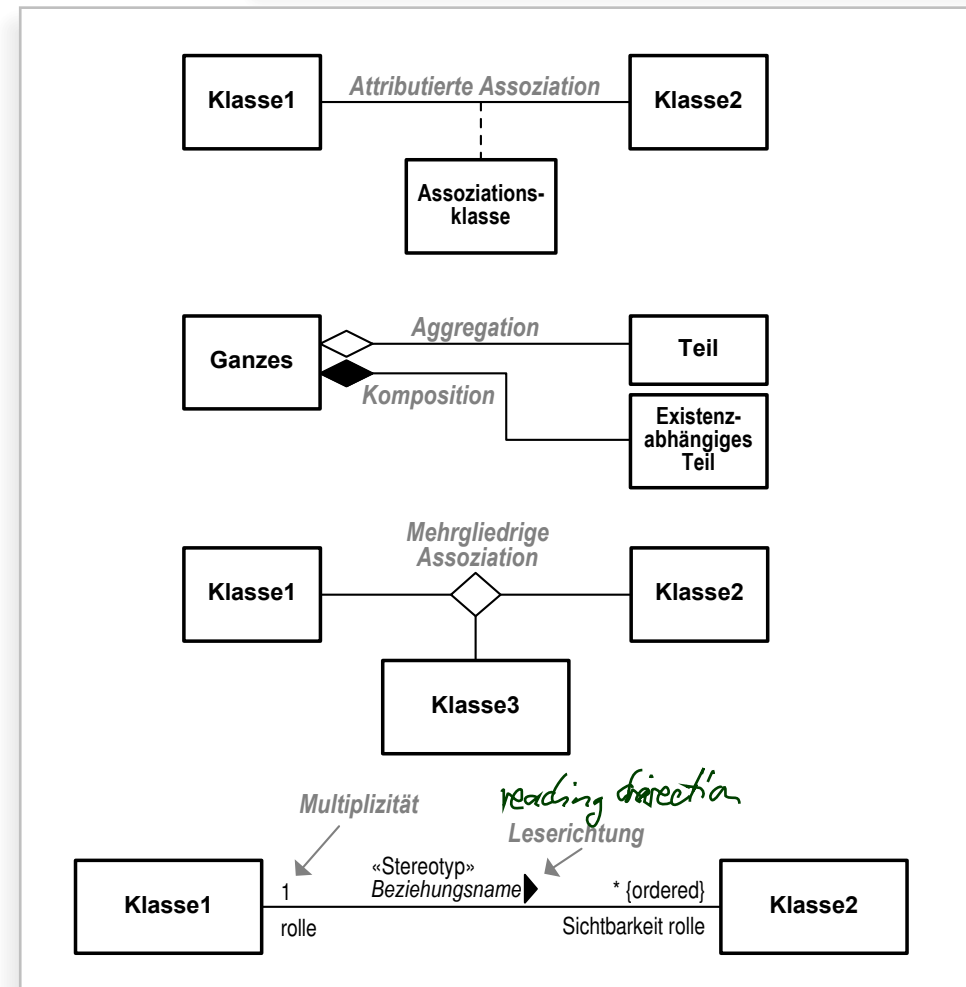
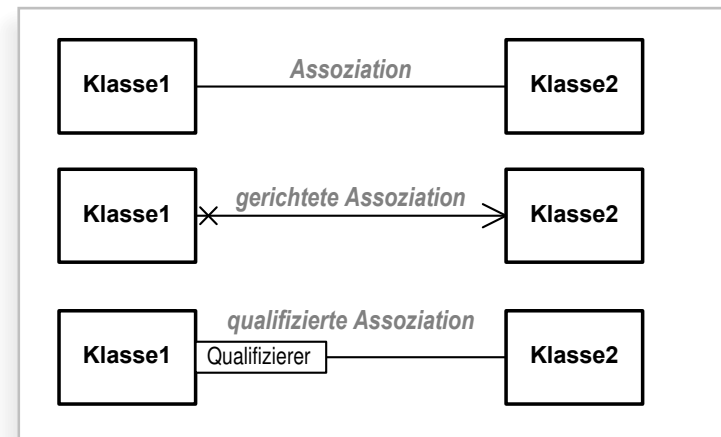
An **association** has

- a **name**,
- a **reading direction**, and
- at least two **ends**.

Each **end** has

- a **role name**,
- a **multiplicity**,
- a set of **properties**, such as **unique**, **ordered**, etc.
- a **qualifier**, (not in lect.)
- a **visibility**,
- a **navigability**,
- an **ownership**,
- and possibly a **diamond**.

**Wanted:** places in the signature to represent the information from the picture.



# (Temporarily) Extend Signature: Associations

Only for the course of Lectures 7 – 9 we assume that each element in  $V$  is

- either a **basic type attribute**  $\langle v : T, \xi, expr_0, P_v \rangle$  with  $T \in \mathcal{T}$  (as before),
- or an **association** of the form

$$\langle r : \begin{array}{l} \langle role_1 : C_1, \mu_1, P_1, \xi_1, \nu_1, o_1 \rangle, \\ \vdots \\ \langle role_n : C_n, \mu_n, P_n, \xi_n, \nu_n, o_n \rangle \end{array} \rangle$$

- $n \geq 2$  (at least two ends),
- $r, role_i$  are just **names**,  $C_i \in \mathcal{C}, 1 \leq i \leq n$ ,
- the **multiplicity**  $\mu_i$  is an expression of the form

$$\mu ::= N..M \mid N..* \mid \mu, \mu \quad \begin{array}{l} 0..1 \checkmark \\ 10..27, 30..81 \checkmark \\ 3..3 \checkmark \\ 0..* \checkmark \end{array} \quad (N, M \in \mathbb{N})$$

- $P_i$  is a set of **properties** (as before),
- $\xi \in \{+, -, \#, \sim\}$  (as before),
- $\nu_i \in \{\times, -, >\}$  is the **navigability**,
- $o_i \in \mathbb{B}$  is the **ownership**.

- $N$  for  $N..N$ ,
- $*$  for  $0..*$  (use with care!)

# (Temporarily) Extend Signature: Associations

Only for the course of Lectures 7 – 9 we assume that each element in  $V$  is

- either a **basic type attribute**  $\langle v : T, \xi, expr_0, P_v \rangle$  with  $T \in \mathcal{T}$  (as before),
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- $n \geq 2$  (at least two ends),
- $r, role_i$  are just **names**,  $C_i \in \mathcal{C}, 1 \leq i \leq n$ ,
- the **multiplicity**  $\mu_i$  is an expression of the form

$$\mu ::= N..M \mid N..* \mid \mu, \mu \quad (N, M \in \mathbb{N})$$

- $P_i$  is a set of **properties** (as before),
- $\xi \in \{+, -, \#, \sim\}$  (as before),
- $\nu_i \in \{\times, -, >\}$  is the **navigability**,
- $o_i \in \mathbb{B}$  is the **ownership**.

## Multiplicity abbreviations:

- $N$  for  $N..N$ , e.g.  $3$  for  $3..3$
- $*$  for  $0..*$  (use with care!)

# Temporarily (Lecture 7 – 9) Extended Signature

**Definition.** An (Extended) Object System **Signature** (with Associations) is a quadruple  $\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, atr)$  where

- ...
- each element of  $V$  is
  - **either** a **basic type attribute**  $\langle v : T, \xi, expr_0, P_v \rangle$  with  $T \in \mathcal{T}$
  - **or** an **association** of the form

$$\langle r : \begin{array}{l} \langle role_1 : C_1, \mu_1, P_1, \xi_1, \nu_1, o_1 \rangle, \\ \vdots \\ \langle role_n : C_n, \mu_n, P_n, \xi_n, \nu_n, o_n \rangle \end{array} \rangle$$

(ends with multiplicity  $\mu_i$ , properties  $P_i$ , visibility  $\xi_i$ , navigability  $\nu_i$ , ownership  $o_i$ ,  $1 \leq i \leq n$ )

- ...
- $atr : \mathcal{C} \rightarrow 2^{\{v \in V \mid v:T, T \in \mathcal{T}\}}$  maps classes to **basic type** (!) attributes.

In other words:

- only **basic type attributes** “belong” to a class (may appear in  $atr(C)$ ),
- **associations** are not “owned” by a class (not in any  $atr(C)$ ), but “live on their own”.

# *Tell Them What You've Told Them...*

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- Class Diagrams in the **Rhapsody** Tool
- **Visibility** of attributes contributes to the well-typedness of (among others) OCL expressions.
  - Well-typedness depends on the **context**.
  - We only interpret (= apply  $I$  to) **well-typed** OCL constraints.
  - Sometimes we **consider** visibility, sometimes we don't.
- **Associations** can have any number ( $\geq 2$ ) of **Association Ends**.



# *References*

# References

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Oestereich, B. (2006). *Analyse und Design mit UML 2.1, 8. Auflage*. Oldenbourg, 8. edition.

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