Software Design, Modelling and Analysis in UML

Lecture 9: Class Diagrams IV

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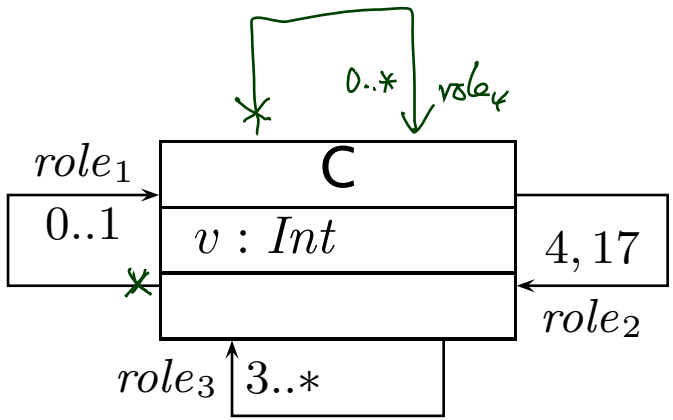
Content

- **Associations**: **The Rest**
  - **Visibility**, **Navigability**, **Properties**,
  - **Ownership**, "**Diamonds**",
  - **Multiplicity**
- **Back to the Main Track**
- **OCL in (Class) Diagrams**
- What makes a class diagram a **good class diagram**?
  - Web-Shop Examples
  - The Elements of UML 2.0 Style
  - Example: Game Architecture

Associations: The Rest

Multiplicities

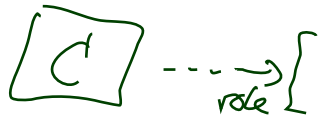
$\mathcal{CD}$:



context C inv: $role_3 \rightarrow size \geq 3$

Multiplicities as Constraints

Recall: Multiplicity is a term of the form $N_1..N_2, \ldots, N_{2k-1}..N_{2k}$
where $N_i \leq N_{i+1}$ for $1 \leq i \leq 2k$, $\quad N_1, \ldots, N_{2k-1} \in \mathbb{N}$, $\quad N_{2k} \in \mathbb{N} \cup \{*\}$.



Define $\mu^C_{\mathsf{OCL}}(role) :=$

$$\text{context } C \text{ inv} : (N_1 \leq role \text{ -> size}() \leq N_2) \text{ or } \ldots \text{ or } (N_{2k-1} \leq role \text{ -> size}() \underbrace{\leq N_{2k}}_{\text{omit if } N_{2k} = *})$$

for each $\langle r : \ldots, \langle role : D, \mu, _, _, _, _\rangle, \ldots, \langle role' : C, _, _, _, _, _\rangle, \ldots\rangle \in V$ or

$$\langle r : \ldots, \langle role' : C, _, _, _, _, _\rangle, \ldots, \langle role : D, \mu, _, _, _, _\rangle, \ldots\rangle \in V,$$

with $role \neq role'$, if $\mu \neq 0..1$, $\mu \neq 1..1$, and

$$\mu^C_{\mathsf{OCL}}(role) := \text{context } C \text{ inv} : \text{not}(\text{oclIsUndefined}(role))$$

if $\mu = 1..1$.

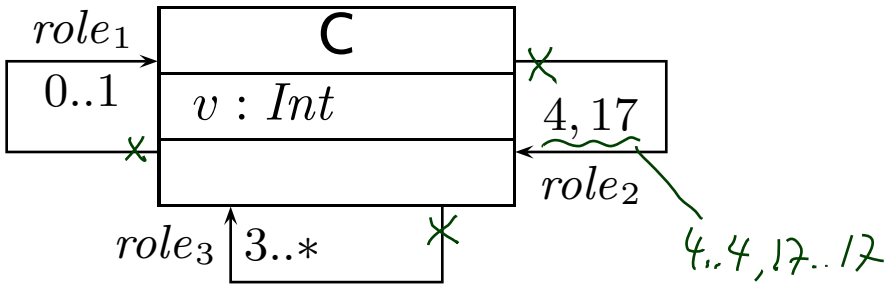
Note: in n-ary associations with $n > 2$, there is redundancy.

Multiplicities as Constraints Example

$$\mu^C_{\mathsf{OCL}}(role) = \text{context } C \text{ inv : } (N_1 \leq role \text{ -> size()} \leq N_2) \text{ or } \ldots \text{ or } (N_{2k-1} \leq role \text{ -> size()} \leq N_{2k})$$

$$\mu^C_{\mathsf{OCL}}(role) = \text{context } C \text{ inv : not(oclIsUndefined}(role))$$

$\mathcal{CD}$:



- context C inv : $3 \leq role_3 \text{ -> size()}$
- context C inv : $4 \leq role_2 \text{ -> size()} \leq 4$ or $17 \leq role_2 \text{ -> size()} \leq 17$

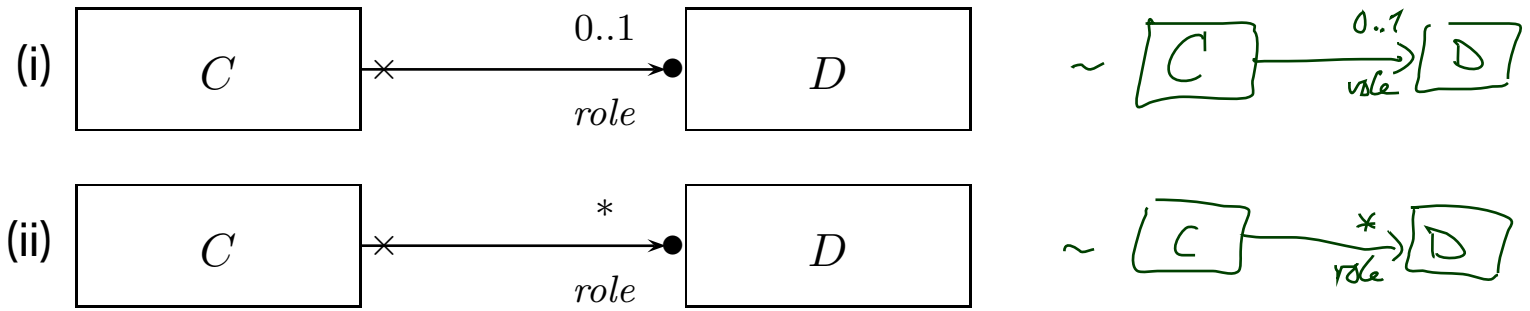
Back to the Main Track

Back to the main track:

Recall: on some earlier slides we said, the extension of the signature is **only** to study associations in "full beauty".
For the remainder of the course, we should look for something simpler...

Proposal:

- **from now on**, we only use associations of the form



(And we may omit the non-navigability and ownership symbols.)

- Form (i) introduces $role : \mathscr{D}_{0,1}$, and form (ii) introduces $role : \mathscr{D}_{*}$ in the set of attributes V.
- In both cases, $role \in atr(C)$.
- We drop λ and go back to our nice σ with $\sigma(u)(role) \subseteq \mathscr{D}(D)$.

OCL Constraints in (Class) Diagrams

Where Shall We Put OCL Constraints?

Three options:

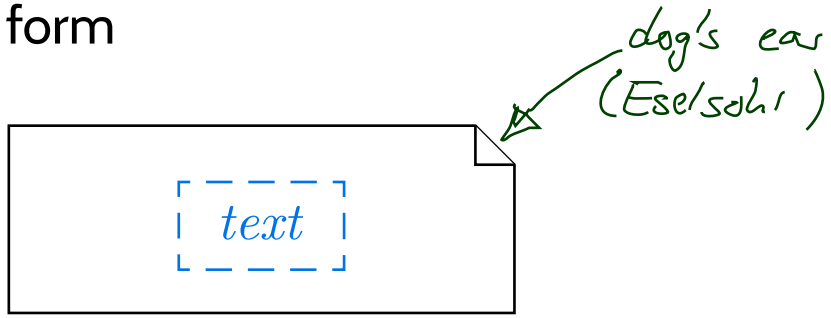
(o) Separate document.

(i) Notes.

(ii) Particular dedicated places.

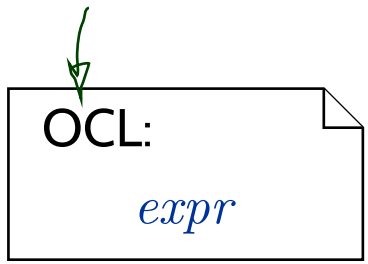
(i) **Notes**:

A UML **note** is a picture of the form

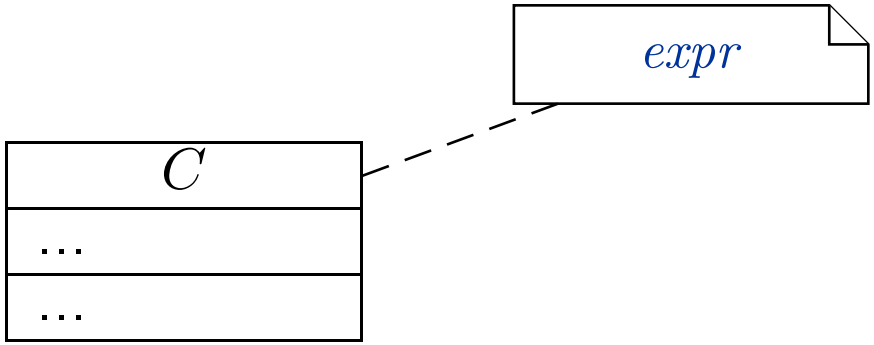


$text$ can principally be **everything**, in particular **comments** and **constraints**.

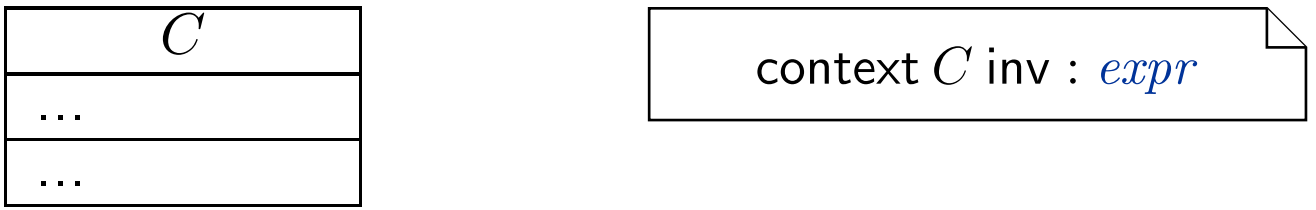
Sometimes, content is **explicitly classified** for clarity:



OCL in Notes: Conventions

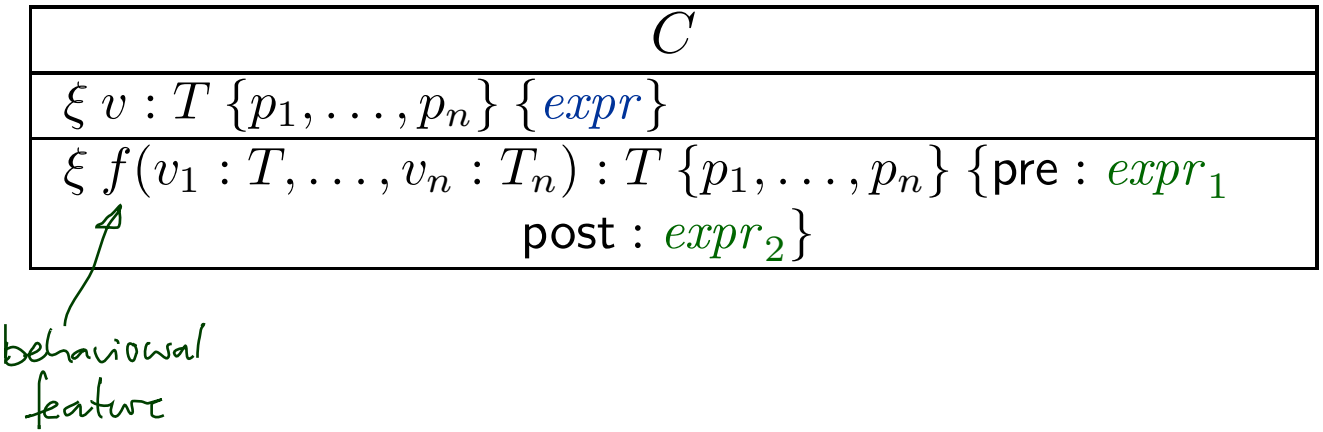


stands for

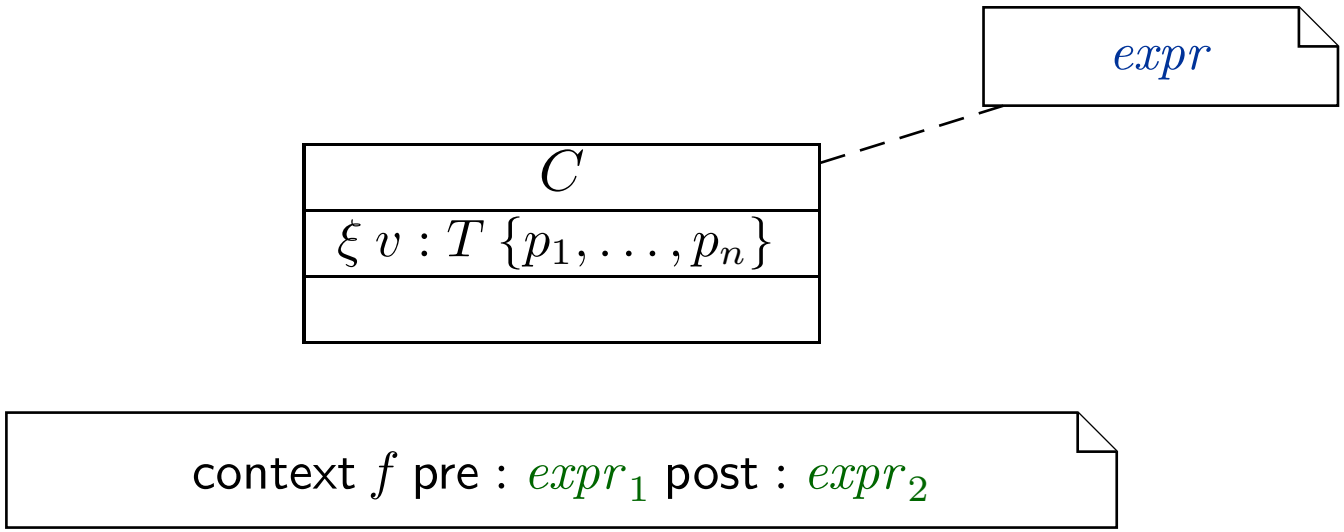


Where Shall We Put OCL Constraints?

(ii) **Particular dedicated places** in class diagrams: (behavioural features: later)



For simplicity, we view the above as an abbreviation for



Invariants of a Class Diagram

- Let $\mathcal{CD}$ be a class diagram.
- We are (now) able to recognise OCL constraints when we see them, so define

$$\mathit{Inv}(\mathcal{CD})$$

as the set $\{\varphi_1, \ldots, \varphi_n\}$ of OCL constraints **occurring** in notes in $\mathcal{CD}$ – after **unfolding** all **graphical** abbreviations (cf. previous slides).

- **As usual**: consider all invariants in all notes in any class diagram – plus implicit multiplicity-induced invariants.

$$\mathit{Inv}(\mathscr{CD}) = \bigcup_{\mathcal{CD} \in \mathscr{CD}} \mathit{Inv}(\mathcal{CD}) \cup$$

only applies in the general setting for associations

$$\{\mu^C_{\mathsf{OCL}}(role) \mid \langle r : \ldots, \langle role : D, \mu, _, _, _, _\rangle, \ldots, \langle role' : C, _, _, _, _, _\rangle, \ldots\rangle \in V \text{ or}$$
$$\langle r : \ldots, \langle role' : C, _, _, _, _, _\rangle, \ldots, \langle role : D, \mu, _, _, _, _\rangle, \ldots\rangle \in V\}.$$

- **Analogously**: *Inv*(·) for any kind of diagram (like **state machine diagrams**).

Semantics of a Class Diagram

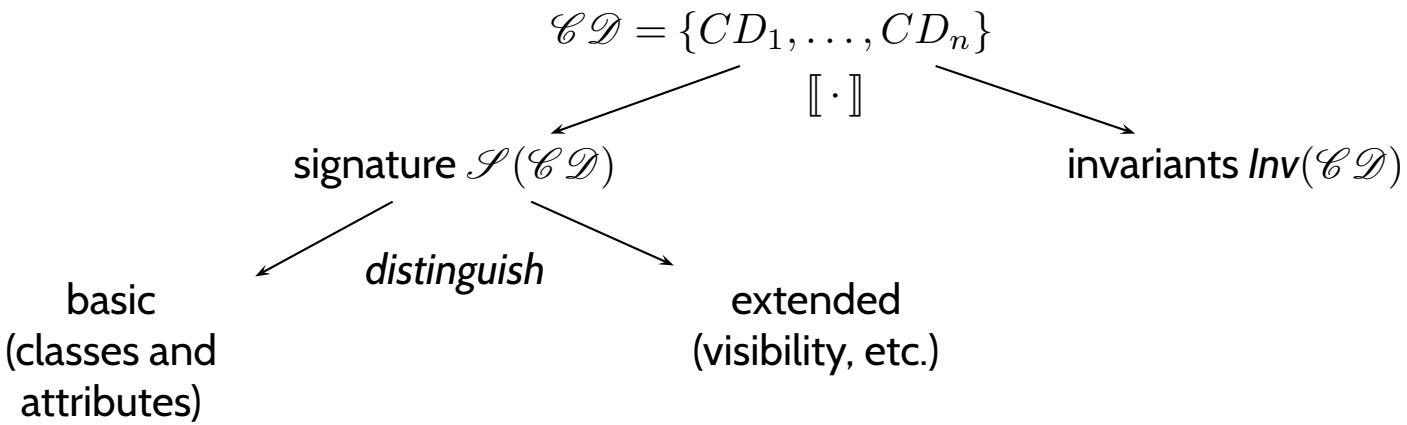
Definition. Let $\mathscr{CD}$ be a set of class diagrams.

We say, the semantics of $\mathscr{CD}$ is the signature it induces and the set of OCL constraints occurring in $\mathscr{CD}$, denoted

$$[\![\mathscr{CD}]\!] := \langle \mathscr{S}(\mathscr{CD}), \mathit{Inv}(\mathscr{CD}) \rangle.$$

Given a structure $\mathscr{D}$ of $\mathscr{S}$ (and thus of $\mathscr{CD}$), the class diagrams describe the system states $\Sigma^{\mathscr{D}}_{\mathscr{S}}$, of which **some** may satisfy $\mathit{Inv}(\mathscr{CD})$.

In pictures:



Pragmatics

Recall: a UML **model** is an image or pre-image of a software system.

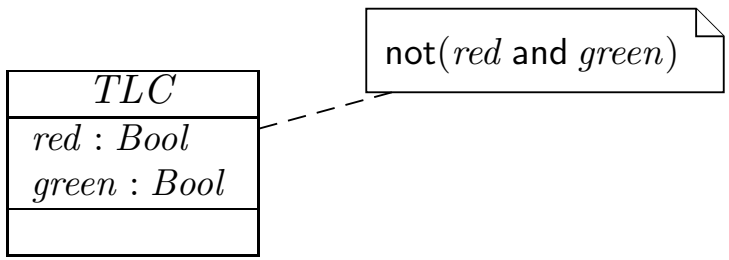
A set of class diagrams $\mathscr{CD}$ describes the **structure** of system states.

Together with the invariants *Inv*$(\mathscr{CD})$ it can be used to state:

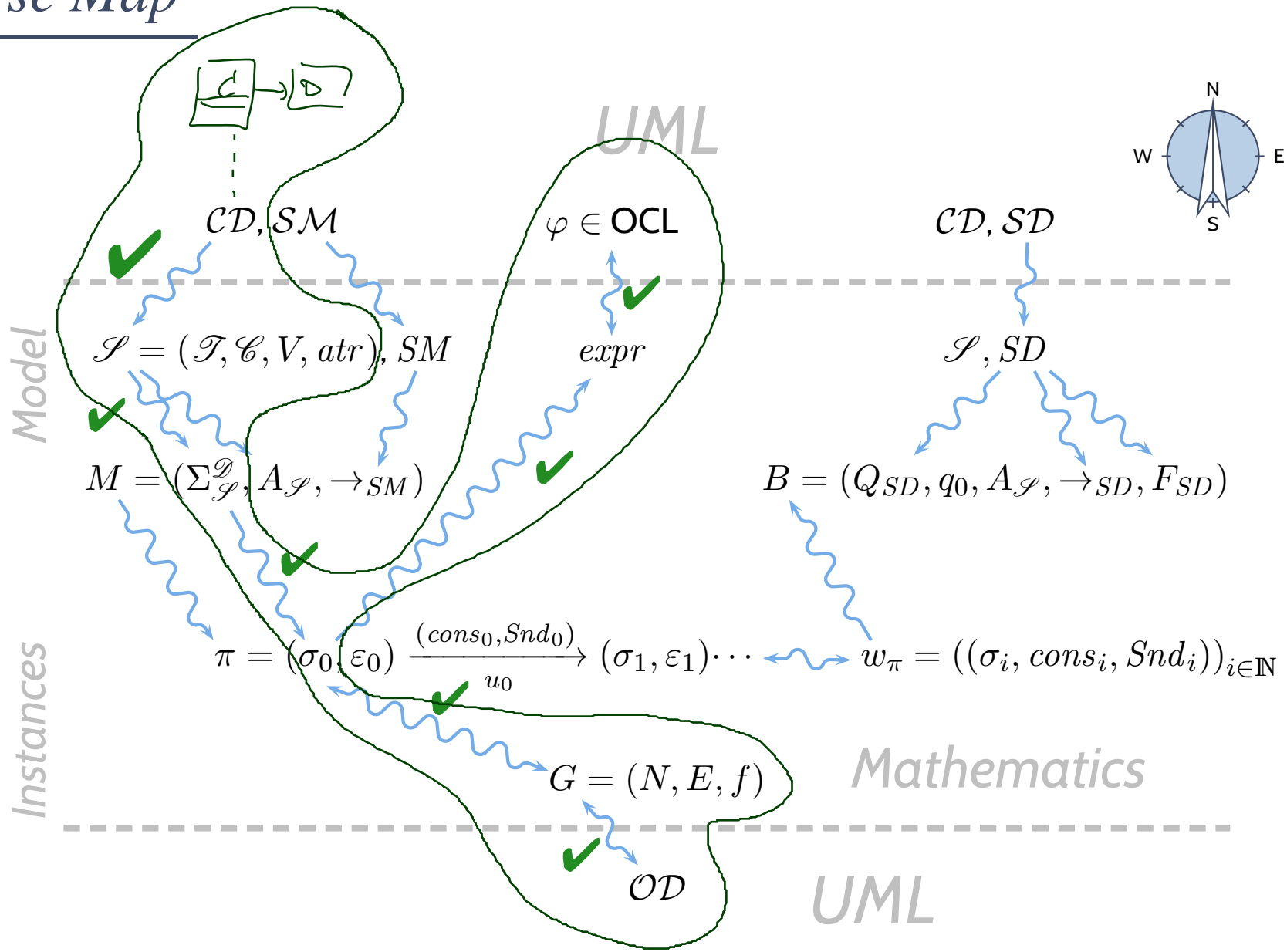
- **Pre-image**: Dear programmer, please provide an implementation which **uses** only system states that satisfy *Inv*$(\mathscr{CD})$.
- **Post-image**: Dear user/maintainer, in the existing system, only system states which satisfy *Inv*$(\mathscr{CD})$ are **used**.

(The exact meaning of "**use**" will become clear when we study behaviour – intuitively: the system states that are reachable from the initial system state(s) by calling methods or firing transitions in state-machines.)

Example: highly abstract model of traffic lights controller.



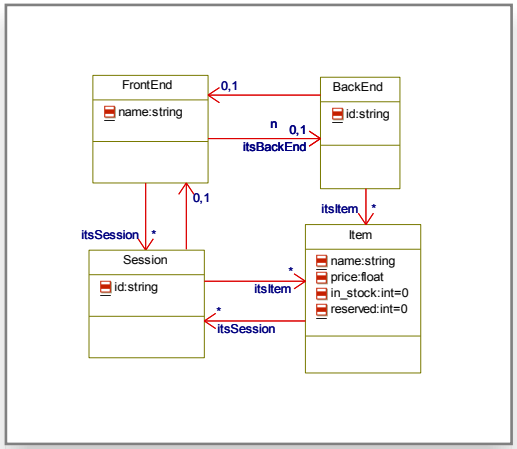
Course Map

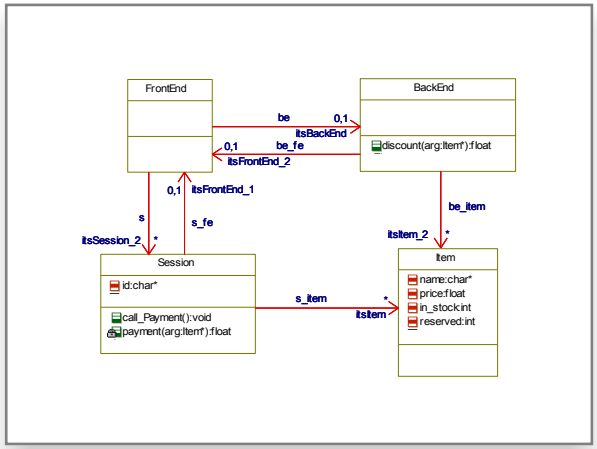

UML
N
W
E
S
$\mathcal{CD}, \mathcal{SM}$
$\varphi \in \mathsf{OCL}$
$\mathcal{CD}, \mathcal{SD}$
Model
$\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr), SM$
$expr$
$\mathscr{S}, SD$
$M = (\Sigma^{\mathscr{D}}_{\mathscr{S}}, A_{\mathscr{S}}, \rightarrow_{SM})$
$B = (Q_{SD}, q_0, A_{\mathscr{S}}, \rightarrow_{SD}, F_{SD})$
$\pi = (\sigma_0, \varepsilon_0) \xrightarrow[u_0]{(cons_0, Snd_0)} (\sigma_1, \varepsilon_1) \cdots$
$w_\pi = ((\sigma_i, cons_i, Snd_i))_{i \in \mathbb{N}}$
Instances
$G = (N, E, f)$
Mathematics
$\mathcal{OD}$
UML

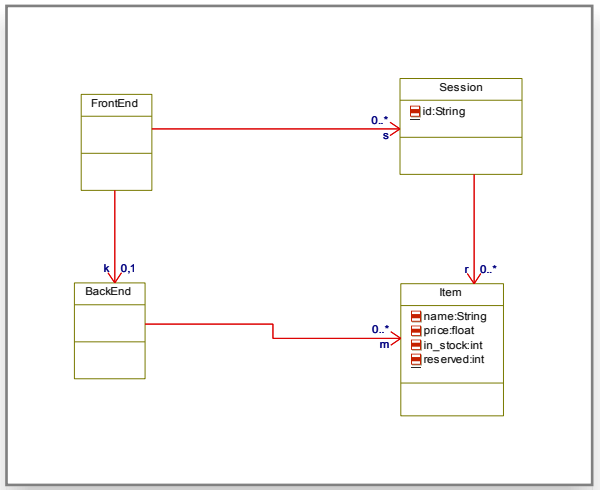
Design Guidelines for (Class) Diagram

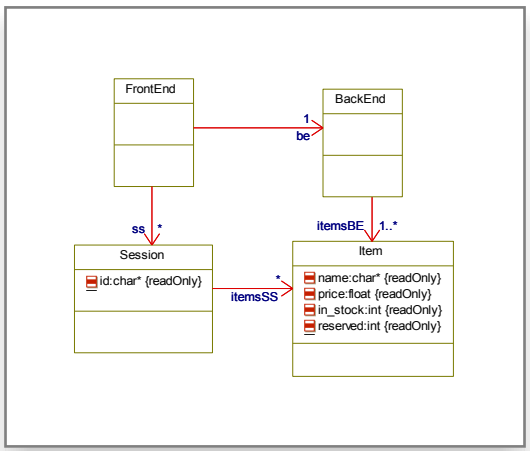
(partly following Ambler (2005))

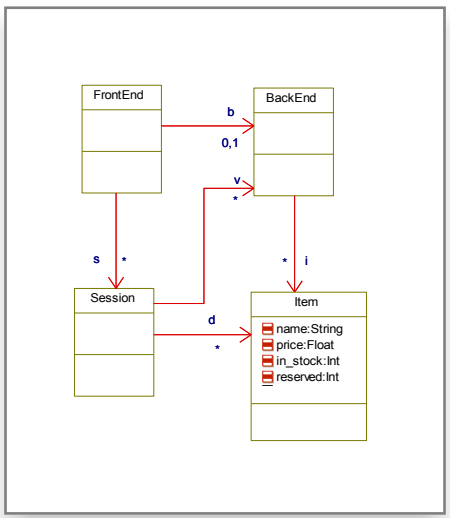
Some Web-Shop Class Diagrams

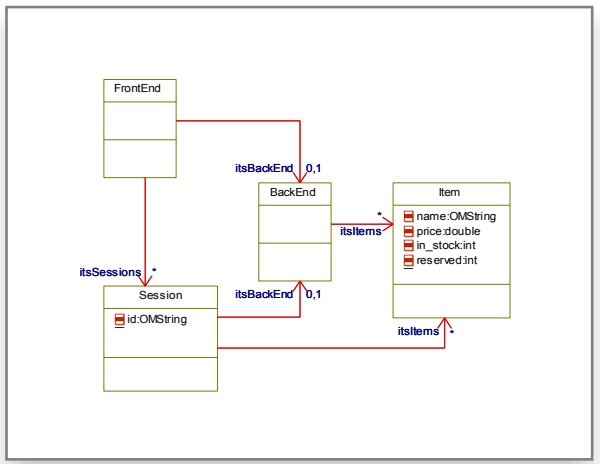




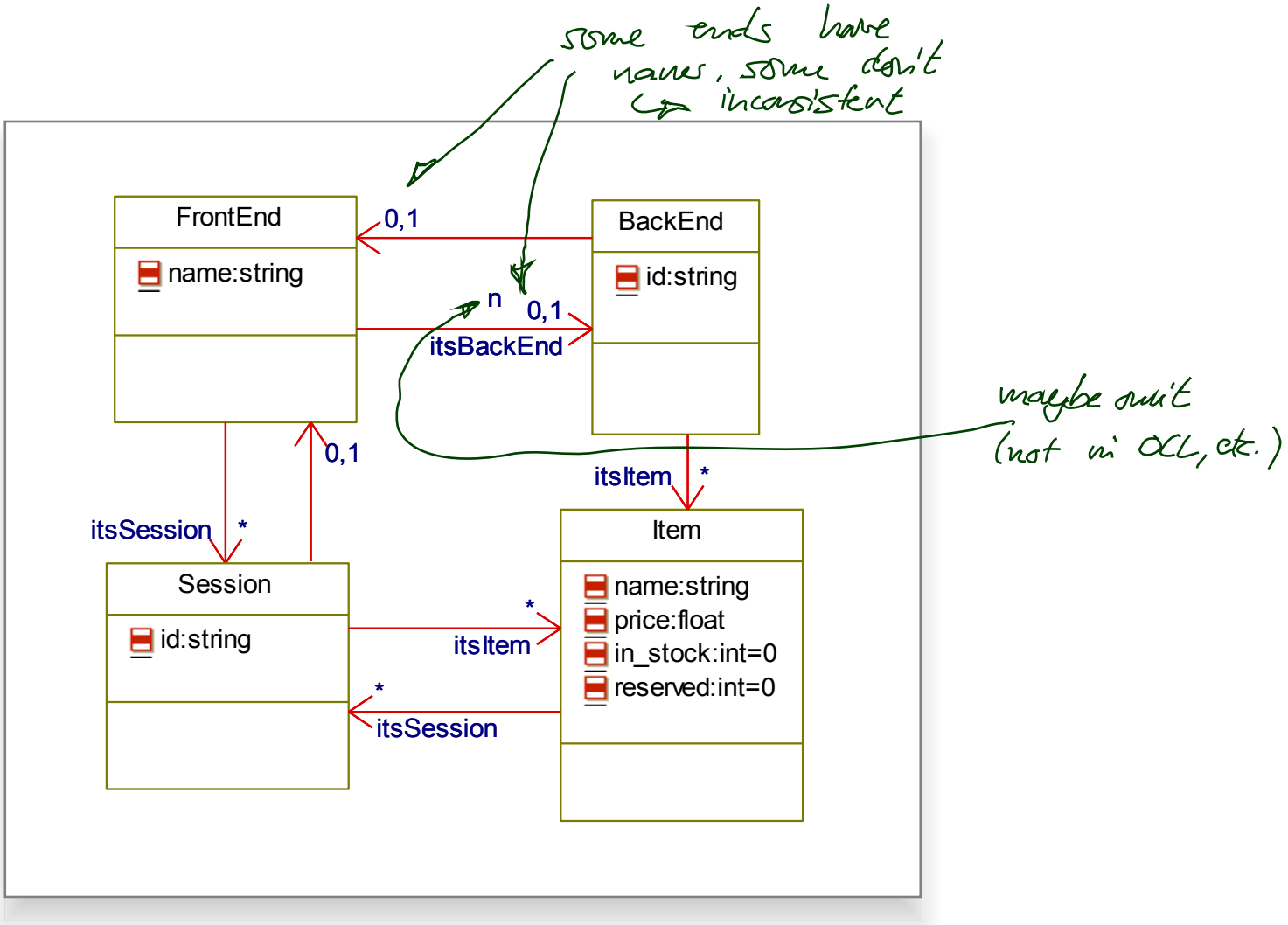






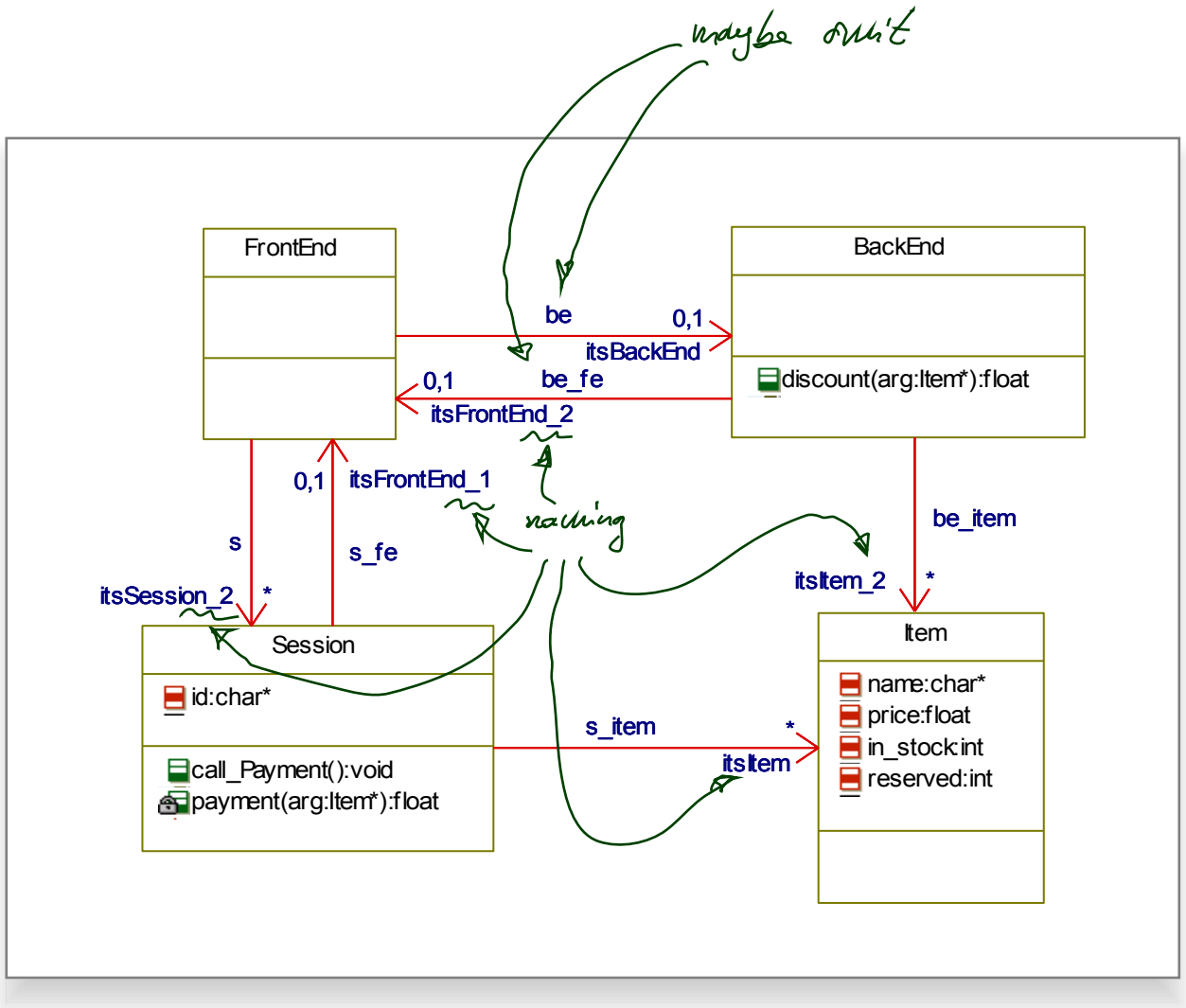


A Closer Look



V = <n : <itsBackEnd : BackEnd, +, ... >, < ... >>

A Closer Look



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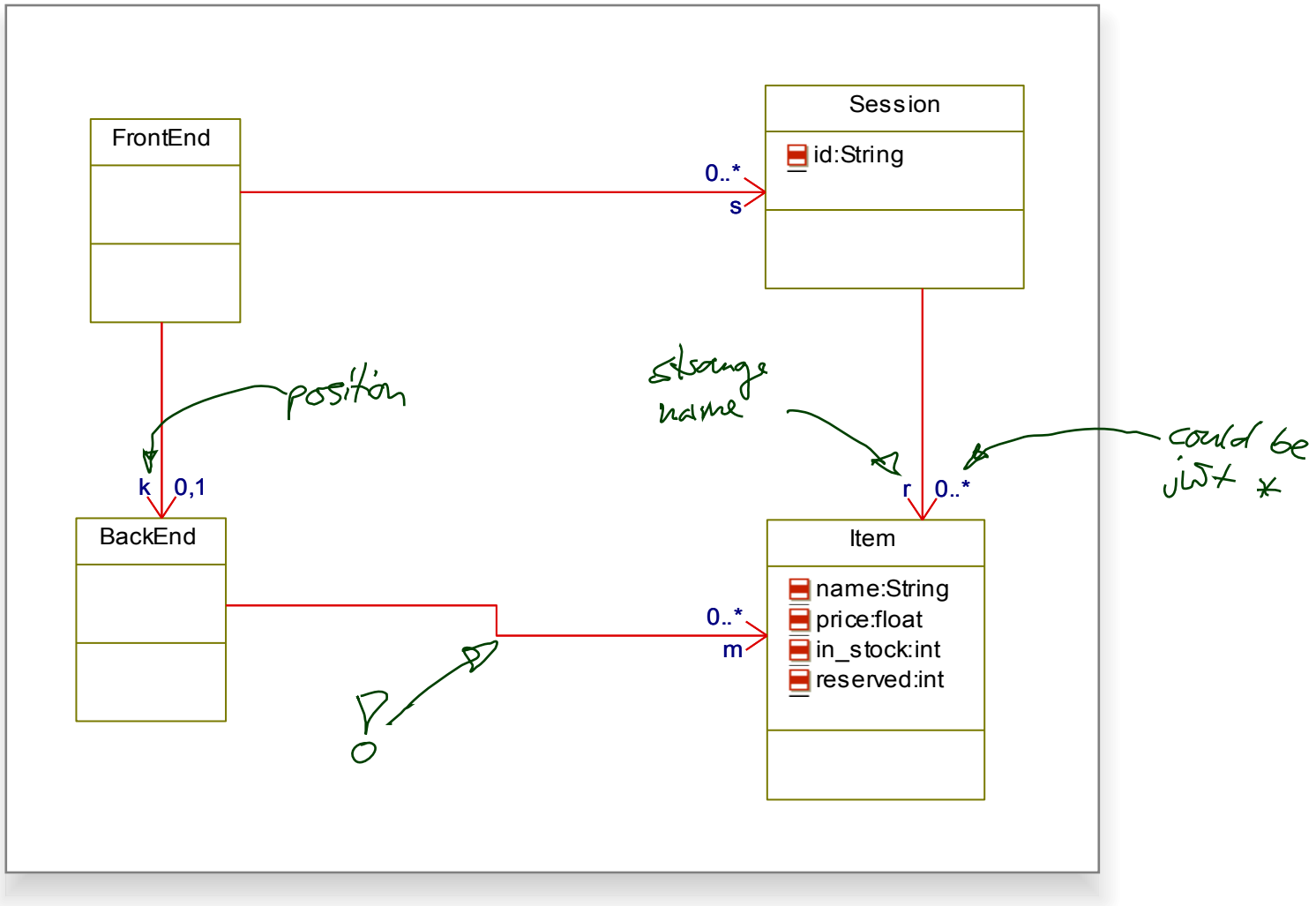

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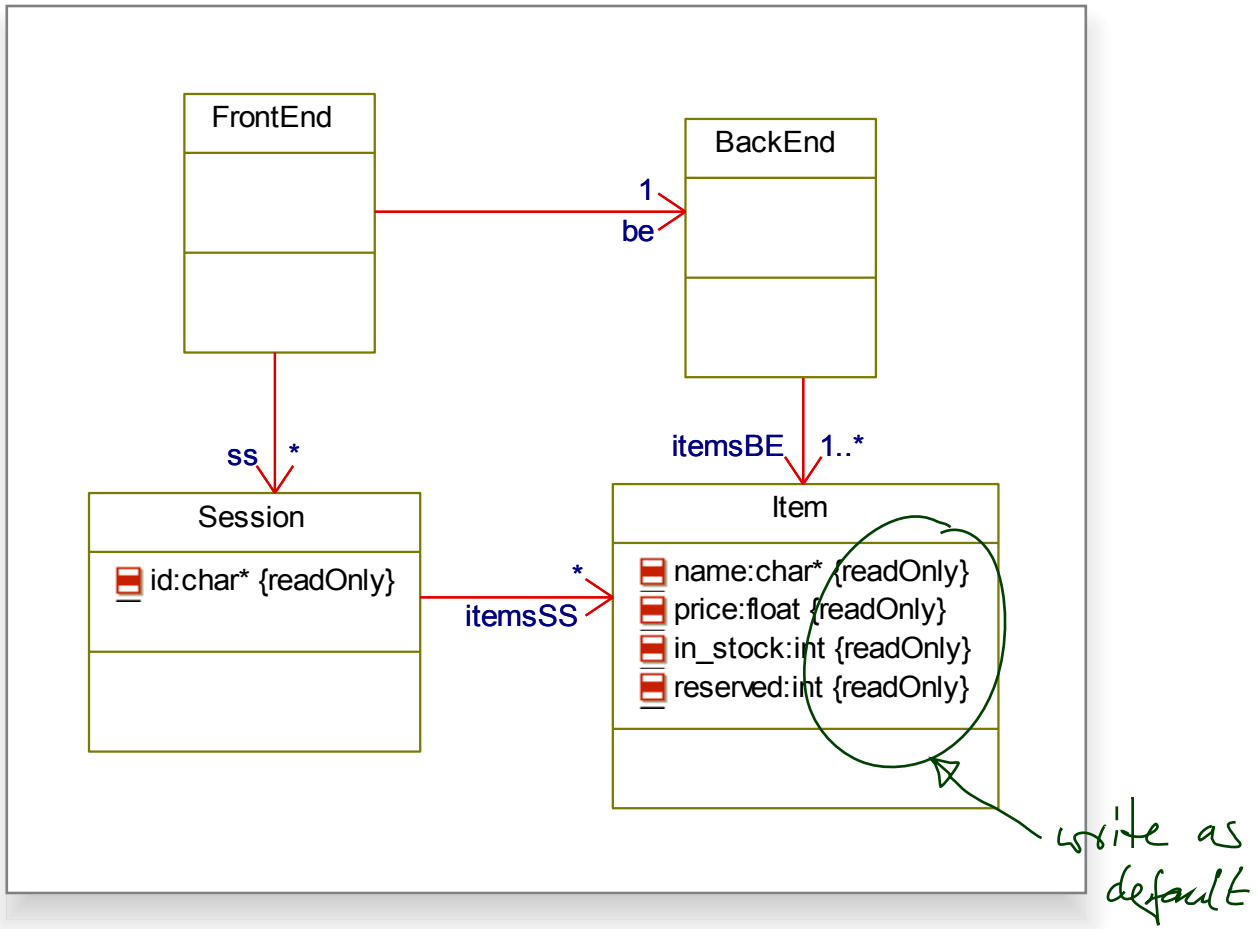

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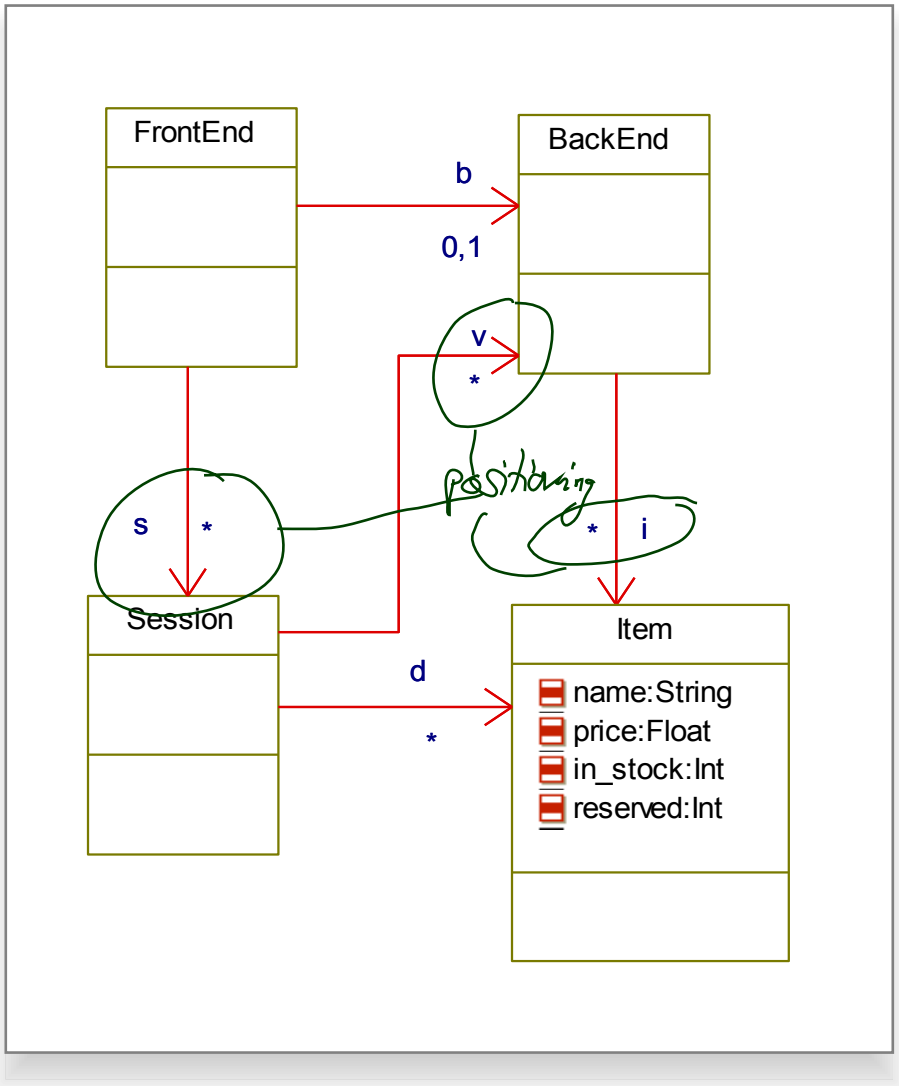

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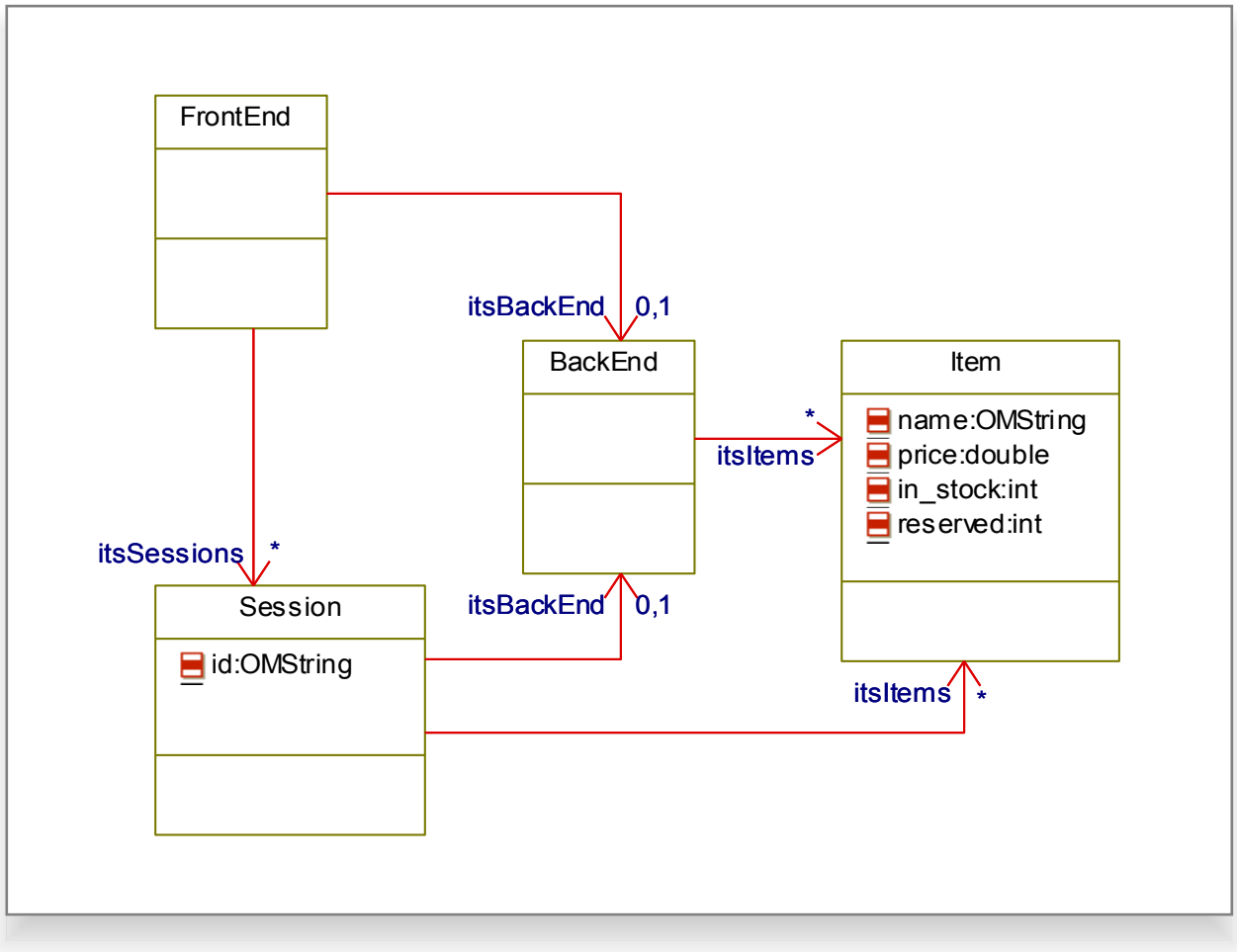
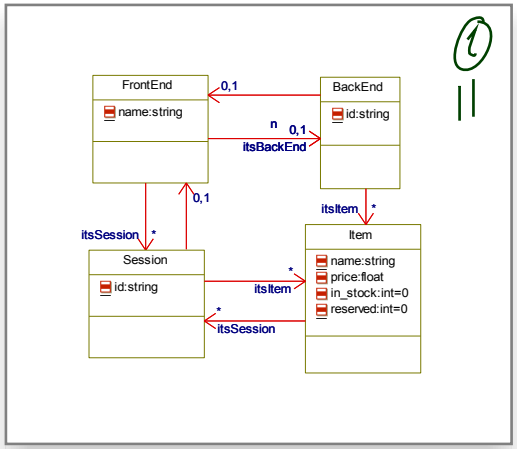
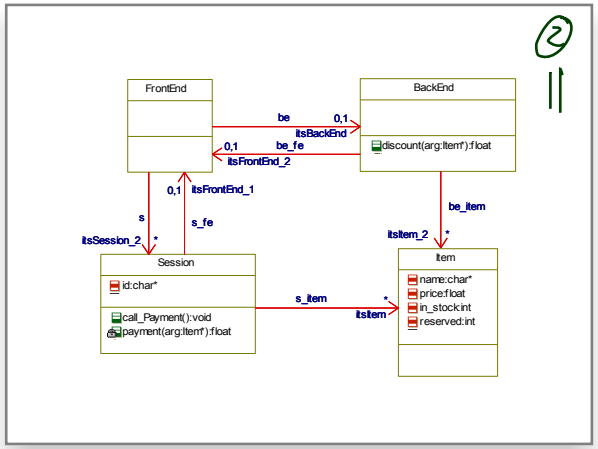
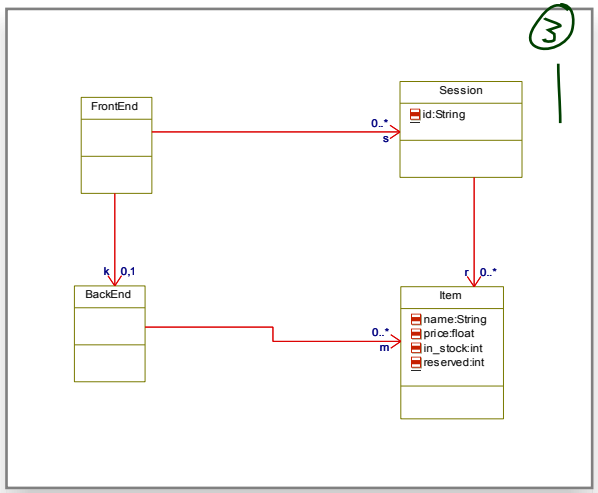
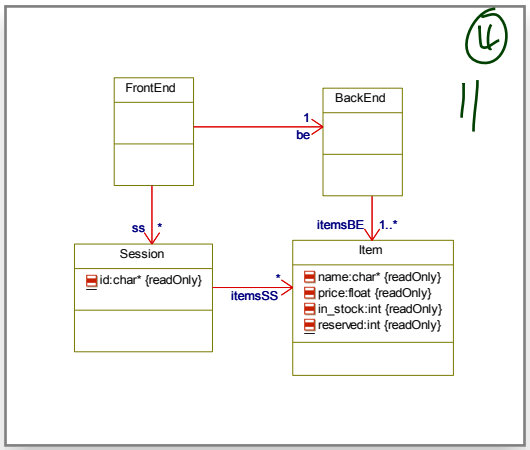


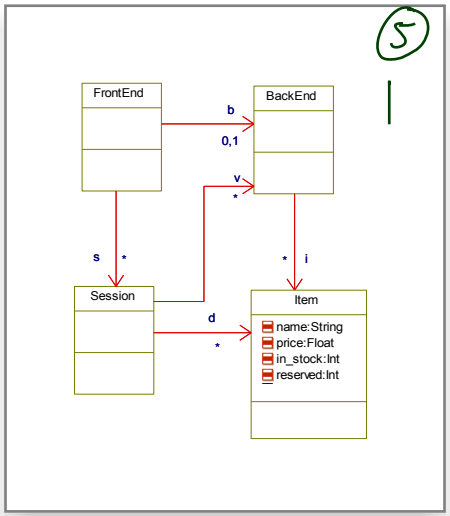
Some Web-Shop Class Diagrams

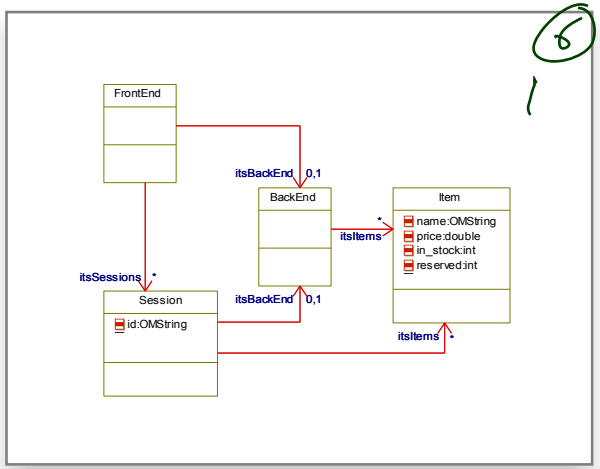












So: what makes a class diagram a **good class diagram**?

Main and General Modelling Guideline

Be good to your audience.

"Imagine you're given **your** diagram $\mathcal{D}$ and asked to conduct task $\mathcal{T}$.

- Can you do $\mathcal{T}$ with $\mathcal{D}$?

  (semantics sufficiently clear? all necessary information available? ...)

- Does doing $\mathcal{T}$ with $\mathcal{D}$ cost you more nerves/time/money/...than it should?"

  (syntactical well-formedness? readability? intention of deviations from standard syntax clear? reasonable selection of information? layout? ...)

In other words:

- the things **most relevant** for task $\mathcal{T}$, do they **stand out** in $\mathcal{D}$?
- the things **less relevant** for task $\mathcal{T}$, do they **disturb** in $\mathcal{D}$?

Main and General Quality Criterion

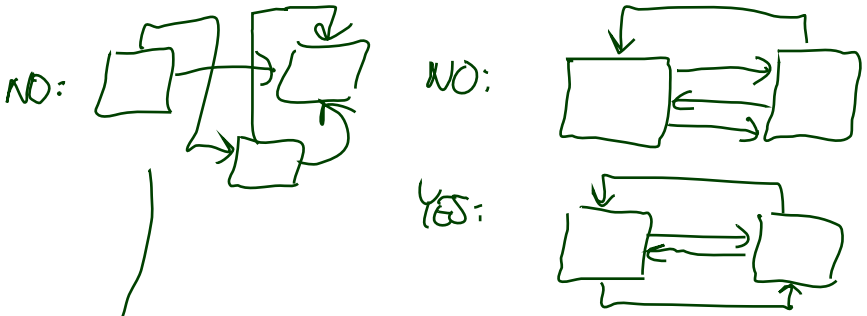
- **Q:** When is a (class) diagram a good diagram?
- **A:** If it serves its purpose/makes its point.

Examples for purposes and points and rules-of-thumb:

- **Analysis/Design**
  - realizable, no contradictions
  - abstract, focused, admitting degrees of freedom for (more detailed) design
  - platform independent – as far as possible but not (artificially) farer
- **Implementation/A**
  - close to target platform
    ($C_{0,1}$ is easy for Java, C_* comes at a cost – other way round for RDB)
- **Implementation/B**
  - complete, executable
- **Documentation**
  - Right level of abstraction: "if you've only one diagram to spend, illustrate the concepts, the architecture, the difficult part"
  - The more detailed the documentation, the higher the probability for regression
    "outdated/wrong documentation is worse than none"

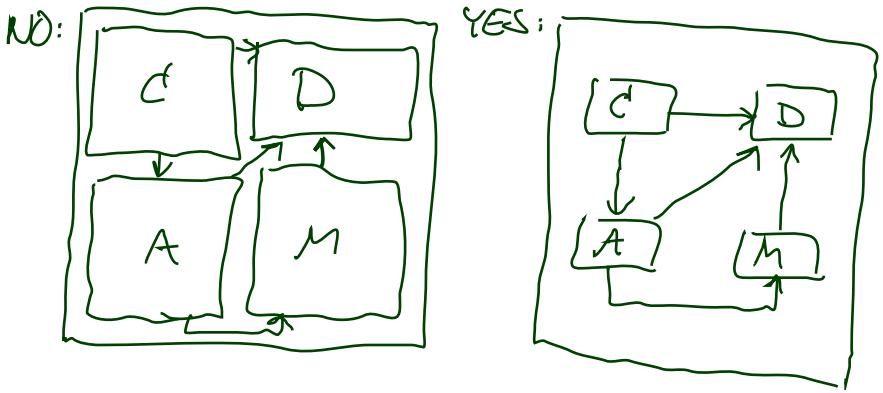
General Diagramming Guidelines Ambler (2005)

(Note: "Exceptions prove the rule.")

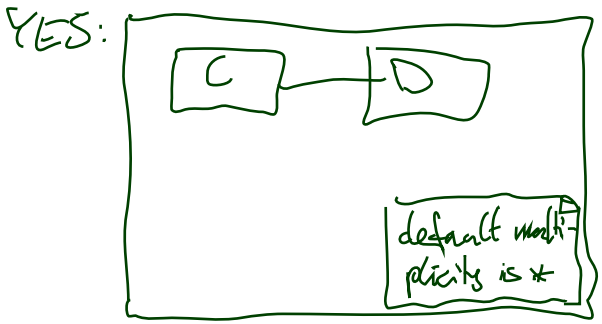


- **2.1 Readability**
  - 1.–3. Support Readability of Lines
  - 4. Apply Consistently Sized Symbols

  - 9. Minimize the Number of "Bubbles" / Things
  - 10. Include White-Space in Diagrams

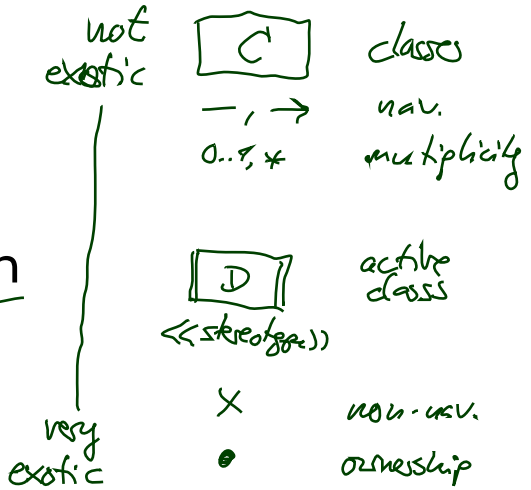


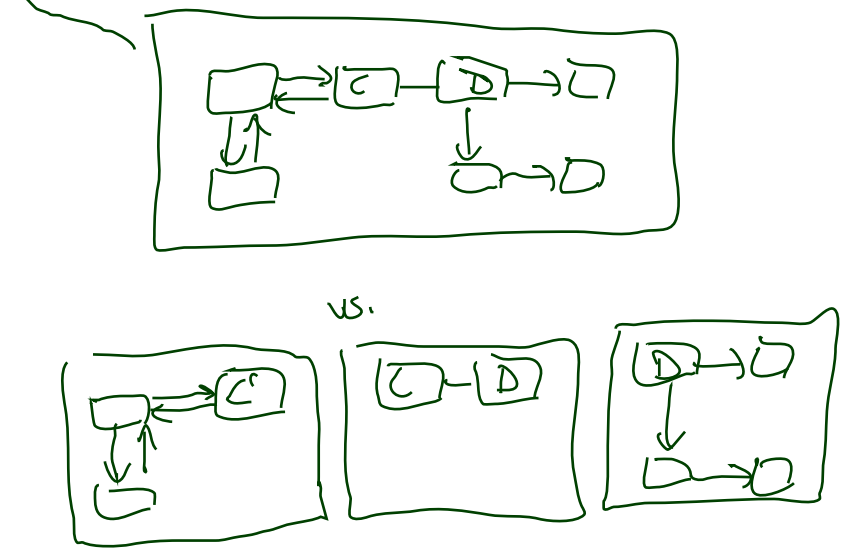
  - 13. Provide a Notational Legend



General Diagramming Guidelines Ambler (2005)

- **2.2 Simplicity**
  - 14. Show Only What You Have to Show
  - 15. Prefer Well-Known Notation over Exotic Notation
  - 16. Large vs. Small Diagrams
  - 18. Content First, Appearance Second





General Diagramming Guidelines Ambler (2005)

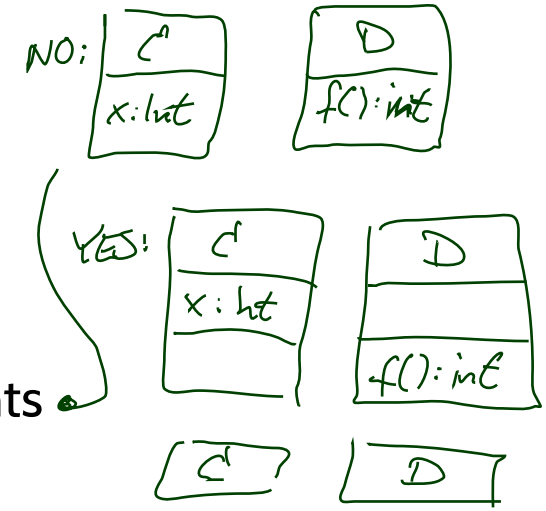
- **2.2 Simplicity**
  - 14. Show Only What You Have to Show
  - 15. Prefer Well-Known Notation over Exotic Notation
  - 16. Large vs. Small Diagrams
  - 18. Content First, Appearance Second
- **2.3 Naming**
  - 20. Set and (23. Consistently) Follow Effective Naming Conventions
- **2.4 General**
  - 24. Indicate Unknowns with Question-Marks
  - 25. Consider Applying Color to Your Diagram
  - 26. Apply Color Sparingly

Class Diagram Guidelines Ambler (2005)

- **5.1 General Guidelines**
  - 88. Indicate Visibility Only on Design Models **(in contrast to analysis models)**
- **5.2 Class Style Guidelines**
  - 96. Prefer Complete Singular Nouns for Class Names
  - 97. Name Operations with Strong Verbs
  - 99. Do Not Model Scaffolding Code **[Except for Exceptions]**

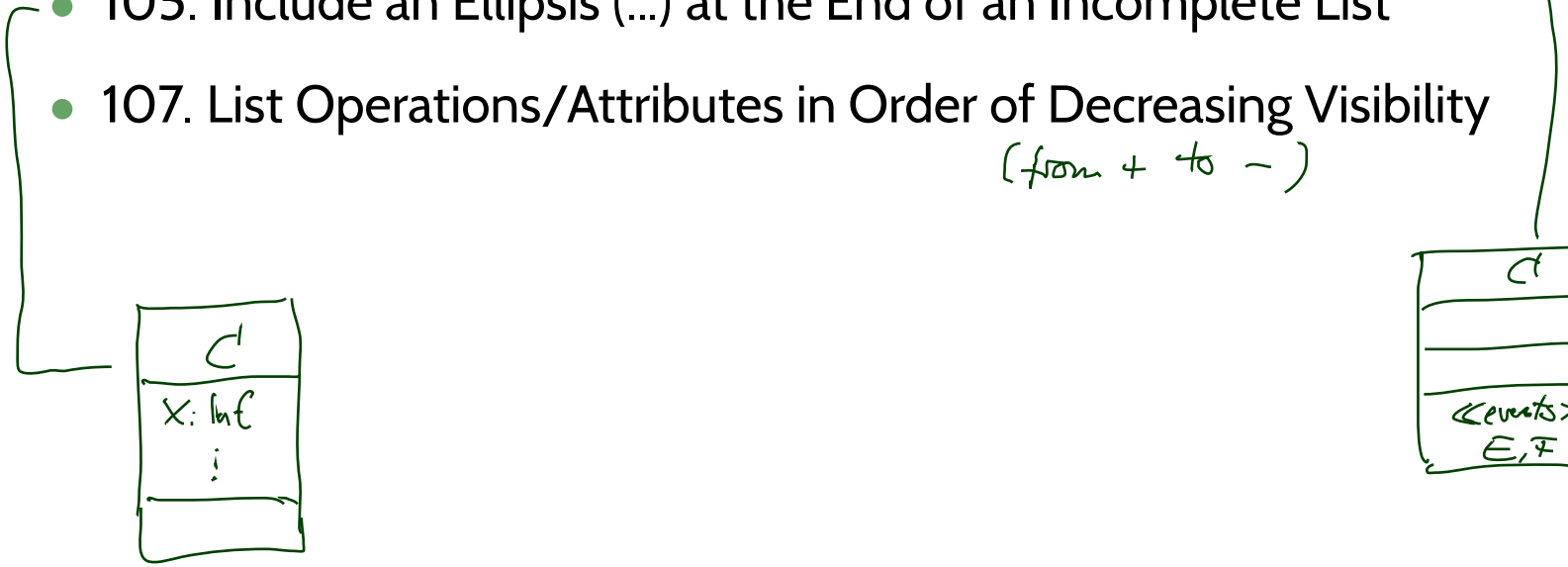
e.g. get/set methods

Class Diagram Guidelines Ambler (2005)



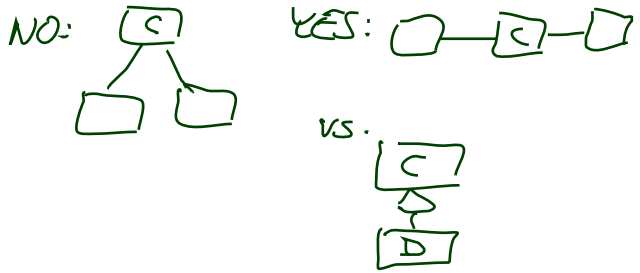
- **5.2 Class Style Guidelines**
  - 103. Never Show Classes with Just Two Compartments
  - 104. Label Uncommon Class Compartments
  - 105. Include an Ellipsis (...) at the End of an Incomplete List
  - 107. List Operations/Attributes in Order of Decreasing Visibility

(from + to −)

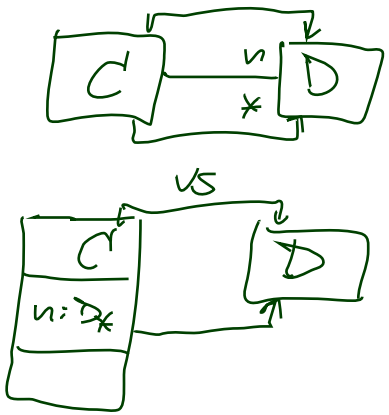


Class Diagram Guidelines Ambler (2005)

- **5.3 Relationships**
  - 112. Model Relationships Horizontally



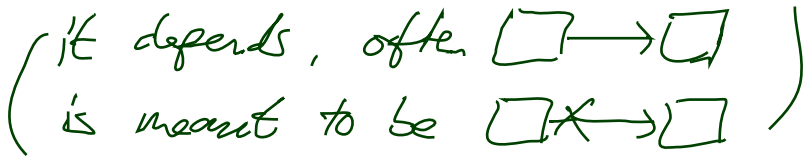
  - 115. Model a Dependency When the Relationship is Transitory
  - 117. Always Indicate the Multiplicity (or have good defaults)
  - 118. Avoid Multiplicity "∗"
  - 119. Replace Relationship Lines with Attribute Types (to have fewer lines)



Class Diagram Guidelines Ambler (2005)

- **5.4 Associations**

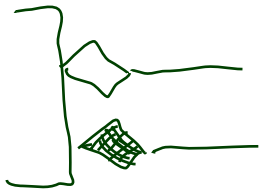
  - 127. Indicate Role Names When Multiple Associations Between Two Classes Exist
  - 129. Make Associations Bidirectional Only When Collaboration Occurs in Both Directions
  - **131. Avoid Indicating Non-Navigability**



  - 133. Question Multiplicities Involving Minimums and Maximums

e.g. 3..10

- **5.6 Aggregation and Composition**
  - → exercises



Tell Them What You've Told Them...

- **Associations**:
  - view **multiplicities** as shorthand for **constraints**,
- **OCL constraints** can be added to a class diagram in **notes** or at **dedicated places**.
- The semantics of a **class diagram** is its (extended) signature, and a set of (explicit and implicit) OCL constraints.
- **Class Diagrams** can be "drawn" **well** or **not so well**.
- A **diagram** is **a good diagram** if it serves its purpose.
- Purposes (for class diagrams):
  - **Documentation of the top-level architecture**.
  - **Documentation of the structural design decisions**.
  - Details can go into comments in the code.
- Ambler (2005): **The Elements of UML 2.0 Style**.

References

References

Ambler, S. W. (2005). *The Elements of UML 2.0 Style*. Cambridge University Press.

OMG (2011a). Unified modeling language: Infrastructure, version 2.4.1. Technical Report formal/2011-08-05.

OMG (2011b). Unified modeling language: Superstructure, version 2.4.1. Technical Report formal/2011-08-06.