Software Design, Modelling and Analysis in UML

Lecture 09: Class Diagrams IV

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Prof. Dr. Andreas Podelski, **Dr. Bernd Westphal**

Albert-Ludwigs-Universität Freiburg, Germany

Contents & Goals

Last Lectures:

- Started to discuss "associations", the general case.

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - Cont'd: Please explain this class diagram with associations.
  - When is a class diagram a good class diagram?
  - What are purposes of modelling guidelines? (Example?)
  - Discuss the style of this class diagram.
- **Content:**
  - Treat "the rest".
  - Where do we put OCL constraints?
  - Modelling guidelines, in particular for class diagrams (following [Ambler, 2005])

Associations: The Rest

The Rest

Recapitulation: Consider the following association:

$$\langle r : \langle role_1 : C_1, \mu_1, P_1, \xi_1, \nu_1, o_1 \rangle, \dots, \langle role_n : C_n, \mu_n, P_n, \xi_n, \nu_n, o_n \rangle \rangle$$

- **Association name** r and **role names/types** $role_i / C_i$ induce extended system states λ.
- **Multiplicity** μ is considered in OCL syntax.
- **Visibility** ξ/**Navigability** ν: well-typedness.

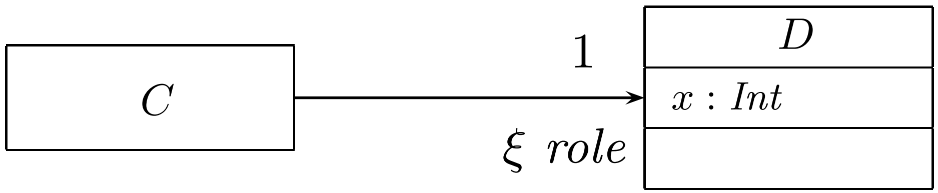
Now the rest:

- **Multiplicity** μ: we propose to view them as constraints.
- **Properties** P_i: even more typing.
- **Ownership** o: getting closer to pointers/references.
- **Diamonds**: exercise.

Visibility

Not so surprising: Visibility of role-names is treated completely similar to visibility of attributes, namely by **typing rules**.

Question: given



is the following OCL expression well-typed or not (wrt. visibility):

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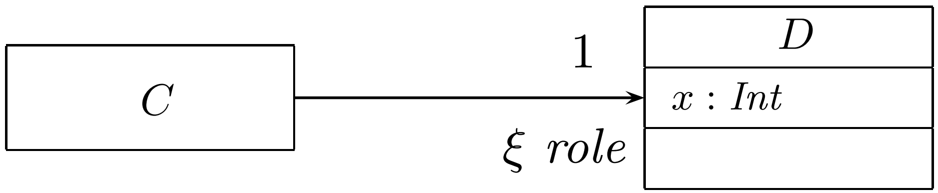

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$$\text{context } C \text{ inv} : \mathit{self}.\mathit{role}.x > 0$$

Basically same rule as before: (analogously for other multiplicities)

$$(\mathit{Assoc}_1) \quad \frac{A, B \vdash \mathit{expr}_1 : \tau_C}{A, B \vdash \mathit{role}(\mathit{expr}_1) : \tau_D}, \quad \begin{array}{l}\mu = 0..1 \text{ or } \mu = 1, \\ \xi = +, \text{ or } \xi = - \text{ and } C = B\end{array}$$

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

Navigability

Navigability is similar to visibility: expressions over non-navigable association ends ($\nu = \times$) are **basically** type-correct, but **forbidden**.

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is the following OCL expression well-typed or not (wrt. navigability):

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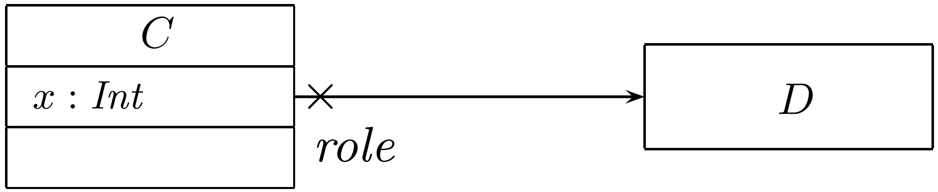

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The standard says:

- '$-$': navigation is possible
- '$>$': navigation is efficient
- '$\times$': navigation is not possible

by context decide what "efficient" means to you and communicate this to the developers

So: In general, UML associations are different from pointers/references!

But: Pointers/references can faithfully be modelled by UML associations.

The Rest of the Rest

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Multiplicities as Constraints

Recall: The multiplicity of an association end is a term of the form:

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

Proposal: View multiplicities (except $0..1$, 1) as additional invariants/constraints.

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e.g. 3, 10..12, 14   *

normalize

3..3, 10..12, 14..14   0..*

Recall: we can normalize each multiplicity μ to the form

$$N_1..N_2, \ \ldots, \ N_{2k-1}..N_{2k}$$

where $N_i \leq N_{i+1}$ for $1 \leq i \leq 2k$, $\quad N_1, \ldots, N_{2k-1} \in \mathbb{N}$, $\quad N_{2k} \in \mathbb{N} \cup \{*\}$.

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

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

for each $\mu \neq 0..1$, $\mu \neq 1$,

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

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

And **define**

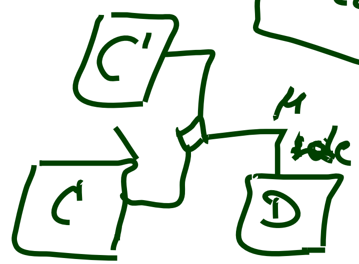
$$\mu^C_{\mathsf{OCL}}(role) := \text{context } C \text{ inv : not(oclIsUndefined}(role))$$

for each $\mu = 1$.

$\mu^C_{OCL}(role)$

$\approx \mu^{C'}_{OCL}(role)$

only difference is the context

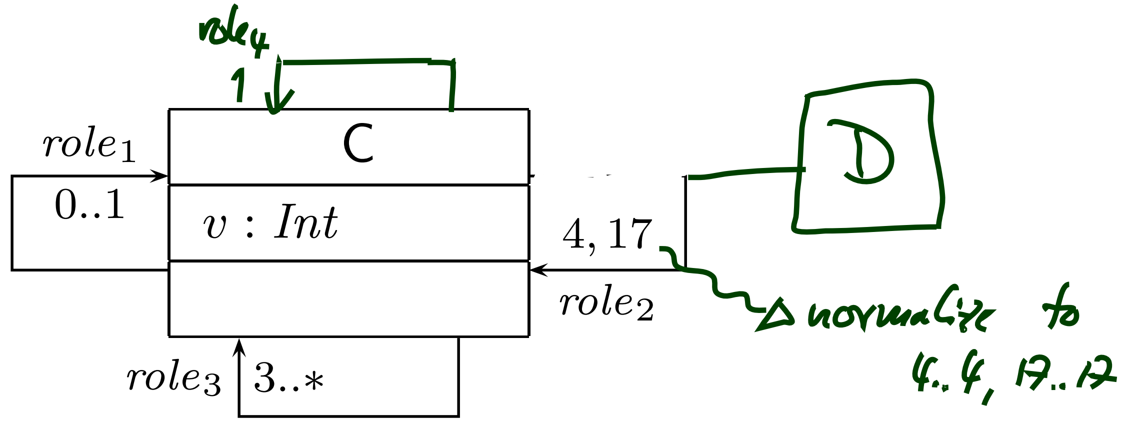


Note: in n-ary associations with $n > 2$, there is redundancy.

Multiplicities as Constraints Example

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

$\mathcal{CD}$:



$Inv(\mathcal{CD}) =$

- $\{$ context D inv : $\underbrace{4 \le role_2 \text{->} size() \le 4 \text{ or } 17 \le role_2 \text{->} size() \le 17}_{\text{equivalent to } role_2 \text{->} size() = 4 \text{ or } role_2 \text{->} size() = 17}$ $\}$
- $\cup \{$ context C inv : $3 \le role_3 \text{->} size() \}$
- $\cup \{$ context C inv : not oclIsUndefined$(role_4) \}$

~~$\cup \{$ context C inv~~

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More precise, can't we just use **types**? (cf. Slide 26)

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  use array of size 4 — if model behaviour (or the implementation) adds 5th identity, we'll get a runtime error, and thereby see that the constraint is violated. **Principally acceptable**, but: checks for array bounds everywhere...?
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- $\mu = 5..7$:
  could be represented by an array of size 7 — but: few programming languages/data structure libraries allow lower bounds for arrays (other than 0).
  If we have 5 identities and the model behaviour removes one, this should be a violation of the constraints imposed by the **model**.
  The implementation which does this removal is **wrong**. How do we see this...?

Multiplicities Never as Types...?

Well, if the **target platform** is known and fixed,
and the target platform has, for instance,

- reference types,
- range-checked arrays with positions $0, \dots, N$,
- set types,

then we could simply **restrict** the syntax of multiplicities to

$$\mu ::= 1 \mid 0..N \mid *$$

and don't think about constraints
(but use the obvious 1-to-1 mapping to types)...

In general, **unfortunately**, we don't know.

Multiplicities as Constraints of Class Diagram

Recall/Later:

$$\mathscr{CD} = \{CD_1, \dots, CD_n\}$$

$[\![\cdot]\!]$

signature $\mathscr{S}(\mathscr{CD})$ — invariants $Inv(\mathscr{CD})$

distinguish

basic (classes and attributes) — extended (visibility)

information in class diagram contributes to/affects...

From now on: $Inv(\mathscr{CD}) = \{\text{constraints occurring in notes}\} \cup \{\mu^C_{\mathsf{OCL}}(role) \mid$

$$\langle r : \dots, \langle role : D, \mu, \_, \_, \_, \_\rangle, \dots, \langle role' : C, \_, \_, \_, \_, \_\rangle, \dots\rangle \in V \text{ or}$$

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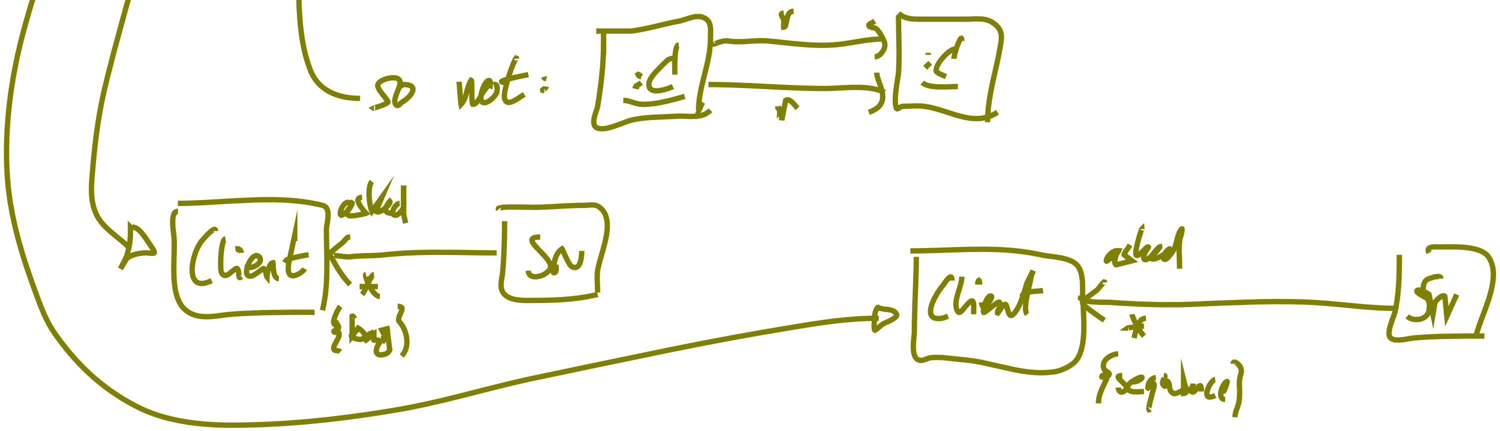
$$role \neq role', \mu \notin \{0..1\}\}.$$

Properties

We don't want to cover association **properties** in detail,
only some observations (assume binary associations):

Property	Intuition	Semantical Effect
unique	one object has **at most one** r-link to a single other object	**current setting**
bag	one object may have **multiple** r-links to a single other object	have $\lambda(r)$ yield multi-sets
ordered, **sequence**	an r-link is a **sequence** of object identities (possibly including duplicates)	have $\lambda(r)$ yield sequences



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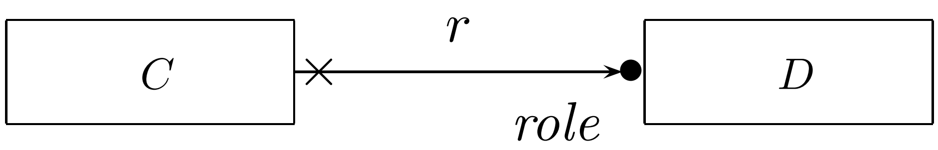
Property	OCL Typing of expression $role(expr)$
unique	$\tau_D \to Set(\tau_C)$
bag	$\tau_D \to Bag(\tau_C)$
ordered, **sequence**	$\tau_D \to Seq(\tau_C)$

For **subsets**, **redefines**, **union**, etc. see [OMG, 2007a, 127].

Ownership



Intuitively it says:

Association r is **not a "thing on its own"** (i.e. provided by λ),
but association end '$role$' is **owned** by C (!).
(That is, it's stored inside C object and provided by σ).

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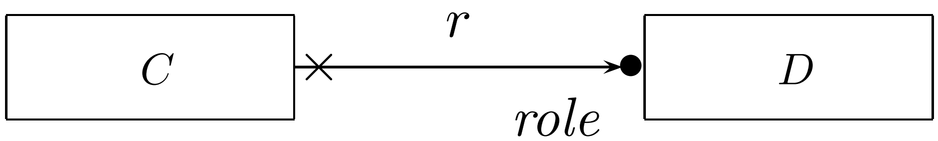

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So: if multiplicity of $role$ is $0..1$ or 1, then the picture above is very close to concepts of pointers/references.

Actually, ownership is seldom seen in UML diagrams. Again: if target platform is clear, one may well live without (cf. [OMG, 2007b, 42] for more details).

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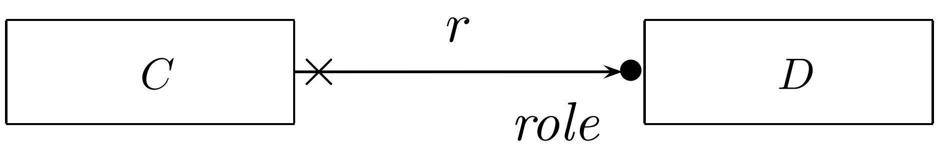

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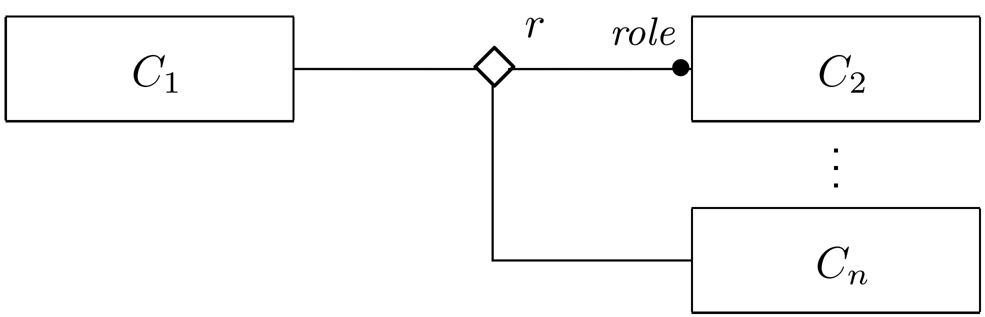
Not clear to me:



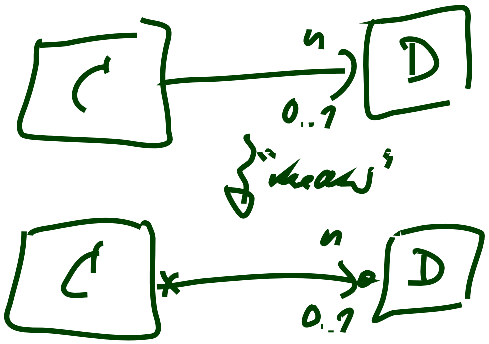
Back to the Main Track

Back to the main track:

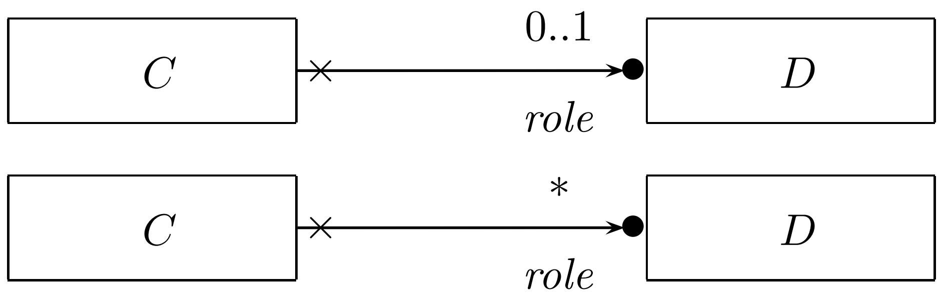
Recall: on some earlier slides we said, the extension of the signature is **only** to study associations in "full beauty".
For the remainder of the course, we should look for something simpler...

Proposal:

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



(i)
(ii)



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

- Form (i) introduces $role : C_{0,1}$, and form (ii) introduces $role : C_*$ in 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?

Numerous options:

(i) Additional documents.

(ii) Notes.

(iii) Particular dedicated places.

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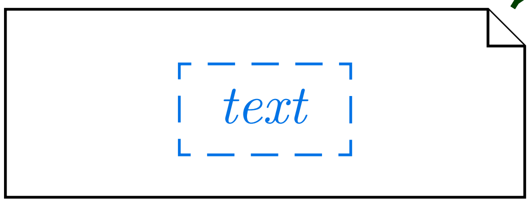
(iii) Particular dedicated places.

(i) **Notes**:

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

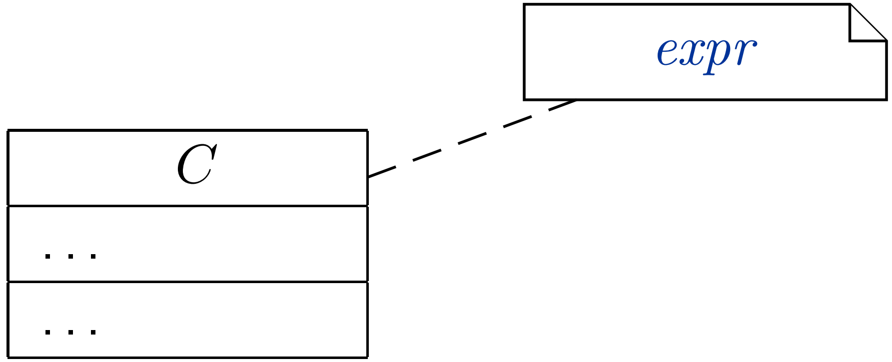
Eselsohr,
(English dog's ears)



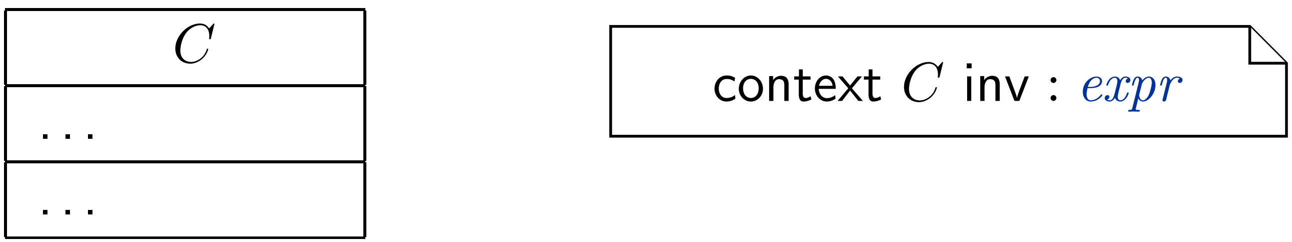
text can principally be **everything**, in particular **comments** and **constraints**.

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: (behav. feature: later)

C
$\xi\ v : \tau\ \{p_1, \dots, p_n\}\ \{expr\}$
$\xi\ f(v_1 : \tau, \dots, v_n : \tau_n) : \tau\ \{p_1, \dots, p_n\}\ \{\mathsf{pre} : expr_1$ $\mathsf{post} : expr_2\}$

Where Shall We Put OCL Constraints?

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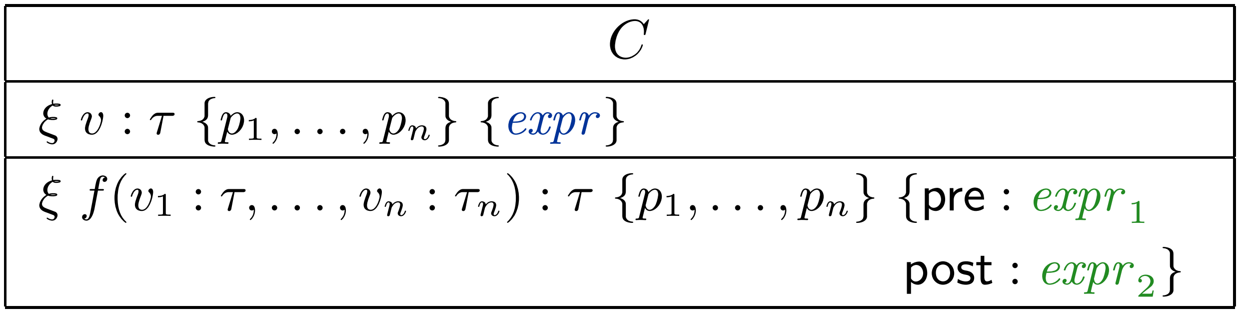
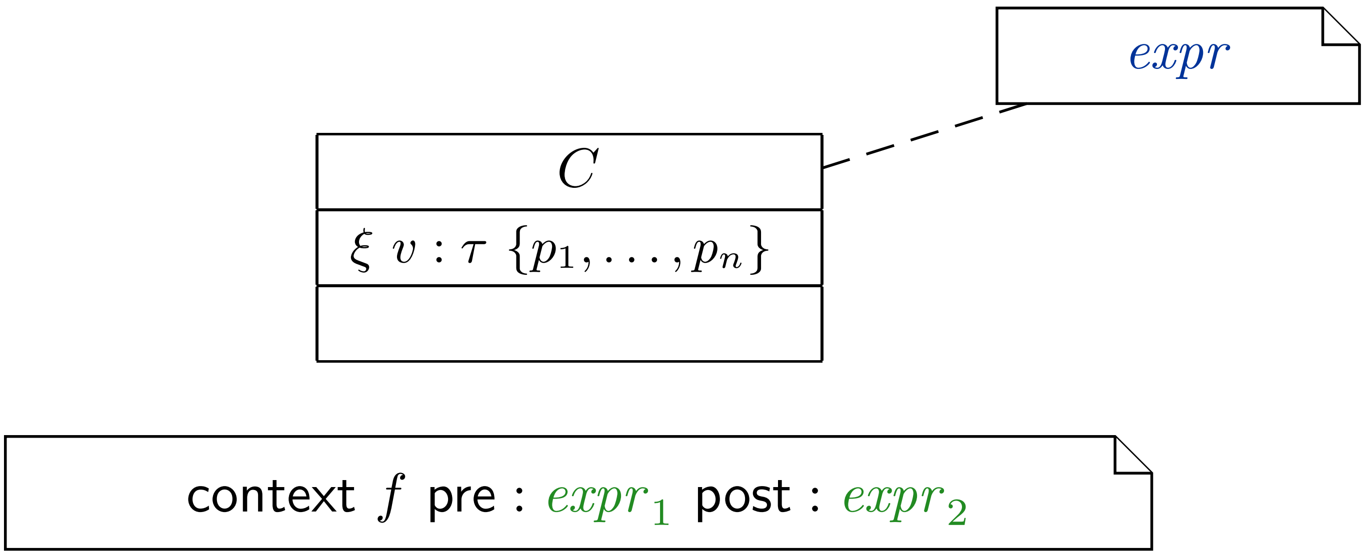


For simplicity, we view the above as an abbreviation for



Invariants of a Class Diagram

- Let $\mathcal{CD}$ be a class diagram.
- As we (now) are able to recognise OCL constraints when we see them, we can define
$$\mathit{Inv}(\mathcal{CD})$$
as the set $\{\varphi_1, \dots, \varphi_n\}$ of OCL constraints **occurring** in notes in $\mathcal{CD}$ — after **unfolding** all abbreviations (cf. next slides).

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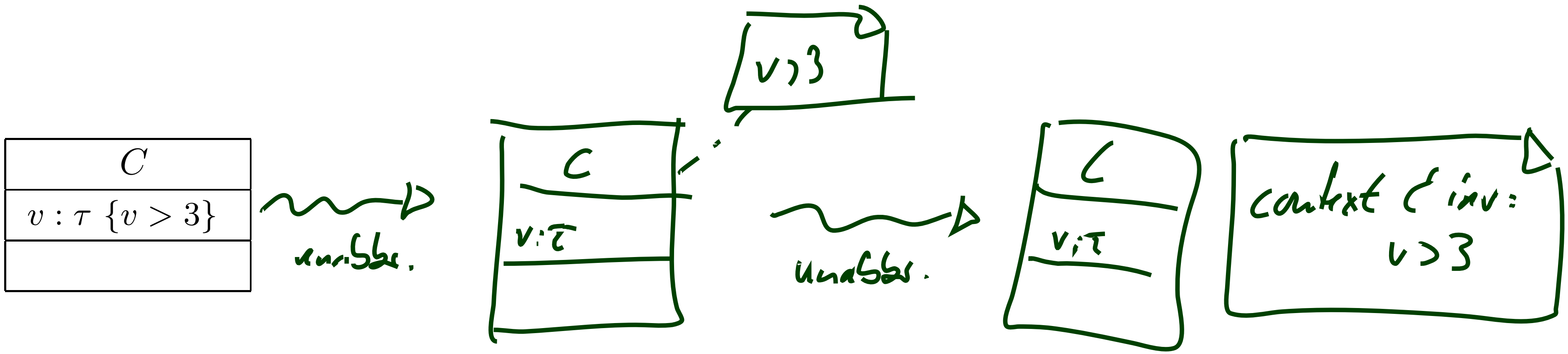
- As usual: $\mathit{Inv}(\mathscr{CD}) := \bigcup_{\mathcal{CD} \in \mathscr{CD}} \mathit{Inv}(\mathcal{CD})$. + implicit constraints from multiplicities (in general)
- **Principally clear**: $\mathit{Inv}(\,\cdot\,)$ for any kind of diagram.

Invariant in Class Diagram Example



If $\mathscr{CD}$ consists of only $\mathcal{CD}$ with the single class C, then

- $\mathit{Inv}(\mathscr{CD}) = \mathit{Inv}(\mathcal{CD}) =$

  $\{$context C inv : $v > 3\}$

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 $\Sigma_{\mathscr{S}}^{\mathscr{D}}$. Of those, **some** satisfy $\mathit{Inv}(\mathscr{CD})$ and some don't.

We call a system state $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$ consistent if and only if $\sigma \models \mathit{Inv}(\mathscr{CD})$.

In pictures:

$\mathscr{CD} = \{CD_1, \dots, CD_n\}$

$[\![\cdot]\!]$

signature $\mathscr{S}(\mathscr{CD})$ invariants $\mathit{Inv}(\mathscr{CD})$

distinguish

basic
(classes and attributes)

extended
(visibility)

induce

$(\sigma \in)\ \Sigma_{\mathscr{S}}^{\mathscr{D}}$

consistent if
all inv. satisfied

Pragmatics

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

A set of class diagrams $\mathscr{CD}$ with invariants $\mathit{Inv}(\mathscr{CD})$ describes the **structure** of system states.

Together with the invariants it can be used to state:

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

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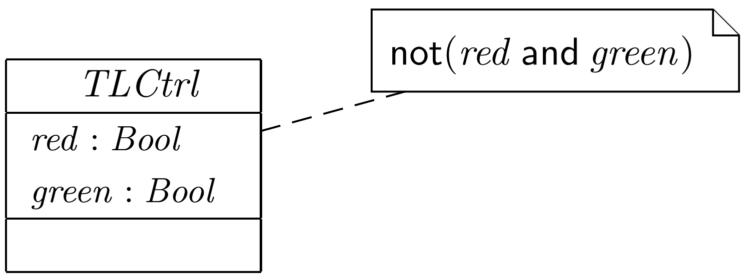
Example: highly abstract model of traffic lights controller.



Constraints vs. Types

Find the 10 differences:

C
$x : Int\ \{x = 3 \vee x > 17\}$

C
$x : T$

$$\mathscr{D}(T) = \{3\} \cup \{n \in \mathbb{N} \mid n > 17\}$$

- $x = 4$ is well-typed in the left context, a system state satisfying $x = 4$ violates the constraints of the diagram.
- $x = 4$ is not even well-typed in the right context, there cannot be a system state with $\sigma(u)(x) = 4$ because $\sigma(u)(x)$ is supposed to be in $\mathscr{D}(T)$ (by definition of system state).

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$$\mathscr{D}(T) = \{3\} \cup \{n \in \mathbb{N} \mid n > 17\}$$

- $x = 4$ is well-typed in the left context, a system state satisfying $x = 4$ violates the constraints of the diagram.
- $x = 4$ is not even well-typed in the right context, there cannot be a system state with $\sigma(u)(x) = 4$ because $\sigma(u)(x)$ is supposed to be in $\mathscr{D}(T)$ (by definition of system state).

Rule-of-thumb:

- If something **"feels like" a type** (one criterion: has a natural correspondence in the application domain), then make it a type.
- If something is a **requirement** or restriction of an otherwise useful type, then make it a constraint.

Design Guidelines for (Class) Diagram

(partly following [Ambler, 2005])

Be careful whose advice you buy, but, be patient with those who supply it.

Baz Luhrmann/Mary Schmich

Main and General Modelling Guideline *(admittedly: trivial and obvious)*

Be good to your audience.

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"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? ...)

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In other words:

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

Main and General Quality Criterion *(again: trivial and obvious)*

- **Q:** When is a (class) diagram a good diagram?

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  - realizable, no contradictions
  - abstract, focused, admitting degrees of freedom for (more detailed) design
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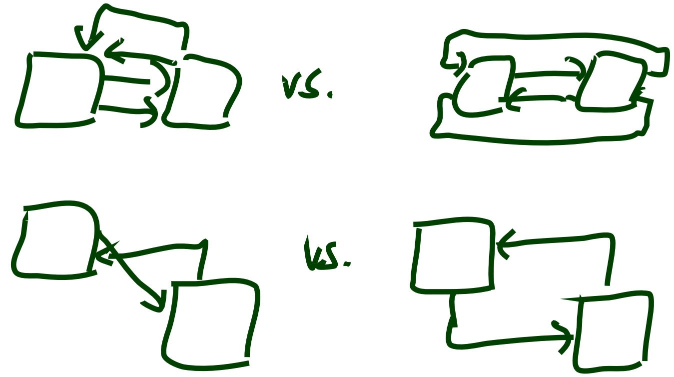
  - complete, executable
- **Documentation**
  - Right level of abstraction: "if you've only one diagram to spend, illustrate the concepts, the architecture, the difficult part"
  - The more detailed the documentation, the higher the probability for regression
    "outdated/wrong documentation is worse than none"

General Diagramming Guidelines [Ambler, 2005]

(Note: "Exceptions prove the rule.")

- **2.1 Readability**
  - 1.–3. Support Readability of Lines



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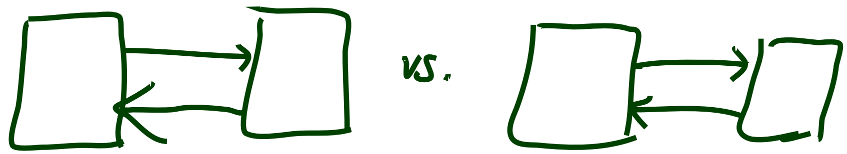

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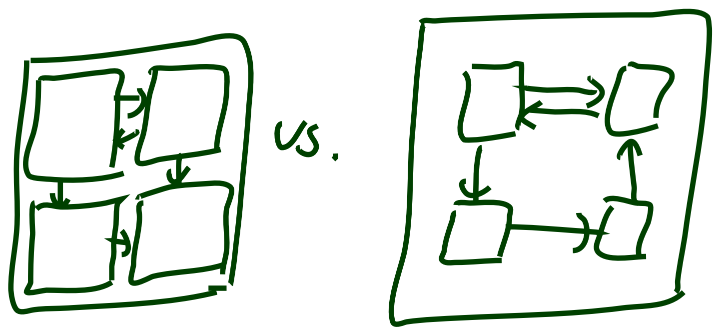

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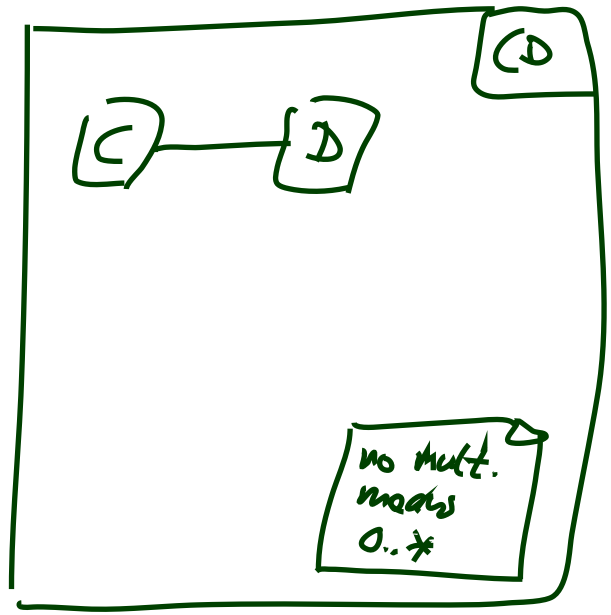
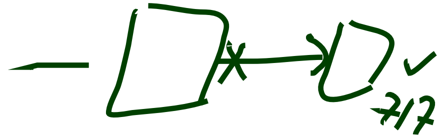


General Diagramming Guidelines [Ambler, 2005]

- **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

depends on
readers,
on group

?

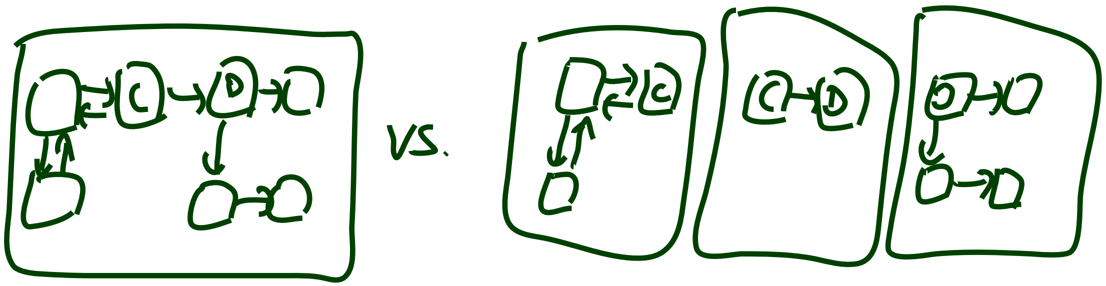


~~understood~~

– reading direction 4/1

– ownership 5/7

– properties 4/7



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- **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)**

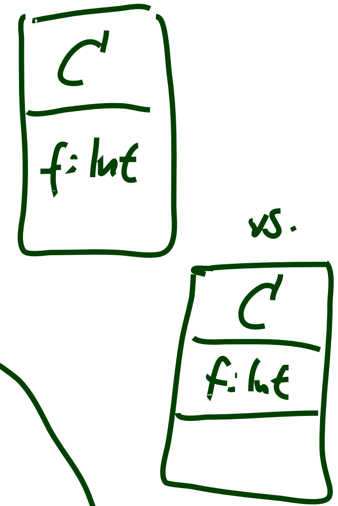
Class Diagram Guidelines [Ambler, 2005]

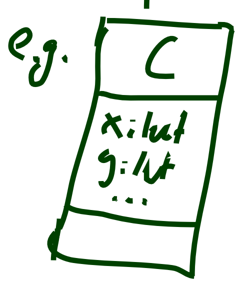
- **5.1 General Guidelines**
  - 88. Indicate Visibility Only on Design Models **(in contrast to analysis models)**
- **5.2 Class Style Guidelines**
  - 96. Prefer Complete Singular Nouns for Class Names
  - 97. Name Operations with Strong Verbs
  - 99. Do Not Model Scaffolding Code **[Except for Exceptions]**

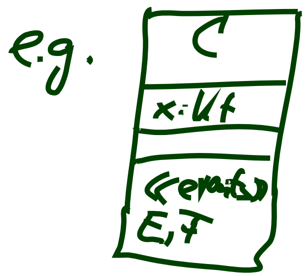
    e.g. get/set

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

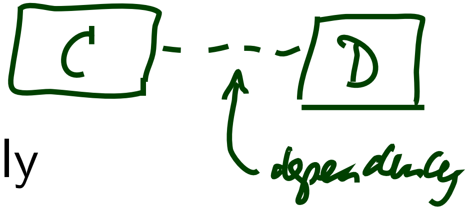




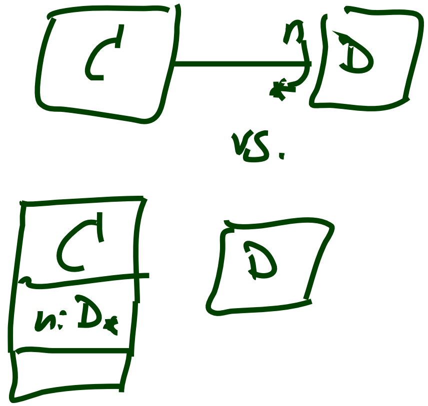


Class Diagram Guidelines [Ambler, 2005]

- **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



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** (it depends, often is meant to be)
  - 133. Question Multiplicities Involving Minimums and Maximums

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  - 133. Question Multiplicities Involving Minimums and Maximums
- **5.6 Aggregation and Composition**
  - $\rightarrow$ exercises

[...] But trust me on the sunscreen.

Baz Luhrmann/Mary Schmich

Example: Modelling Games

Task: Game Development

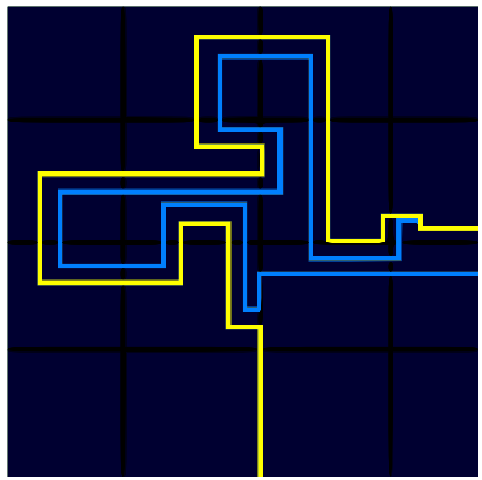
Task: **develop** a **video game**. **Genre**: **Racing**. **Rest**: **open**, i.e.

Degrees of freedom:	
• simulation vs. arcade • platform (SDK or not, open or proprietary, hardware capabilities...) • graphics (3D, 2D, ...) • number of players, AI • controller • game experience	

Task: Game Development

Task: **develop** a **video game**. **Genre**: **Racing**. **Rest**: **open**, i.e.

Degrees of freedom:	Exemplary choice: 2D-Tron
• simulation vs. arcade	arcade
• platform (SDK or not, open or proprietary, hardware capabilities...)	open
• graphics (3D, 2D, ...)	2D
• number of players, AI	min. 2, AI open
• controller	open (later determined by platform)
• game experience	minimal: main menu and game

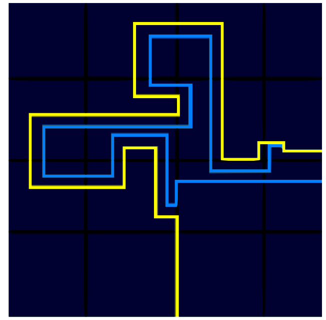


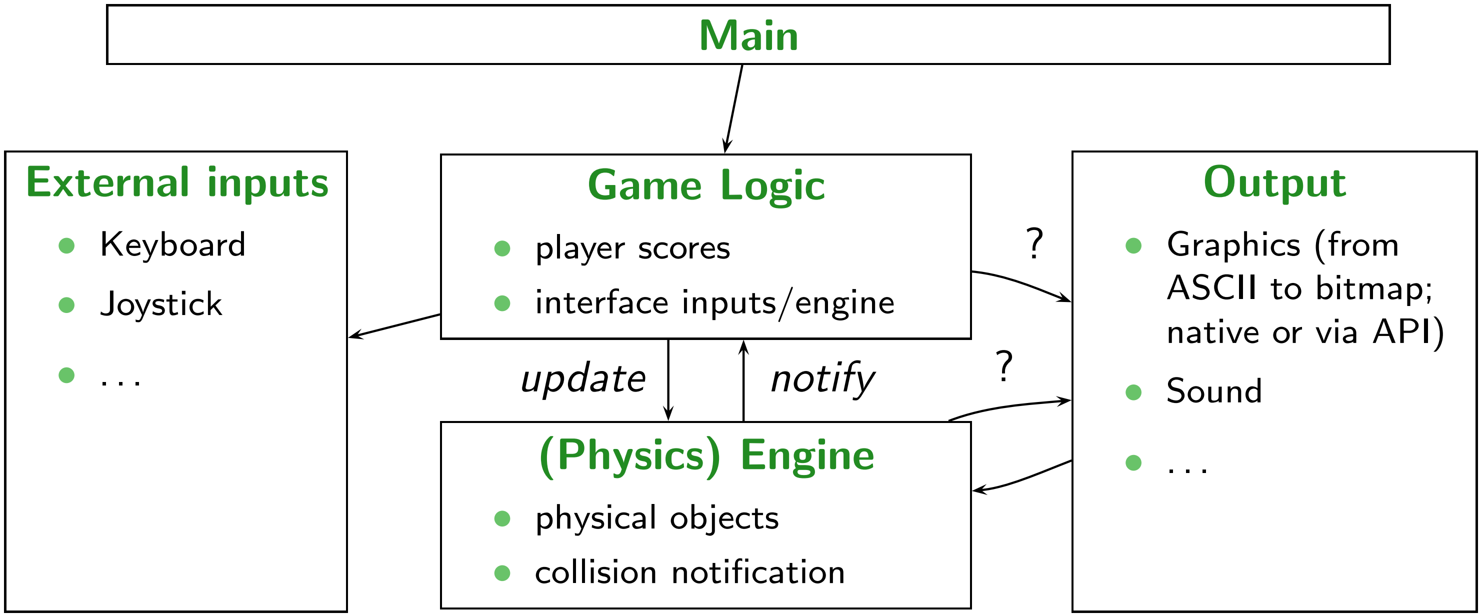
Modelling Structure: 2D-Tron

- In many domains, there are canonical architectures – and adept readers try to see/find/match this!
- For games:

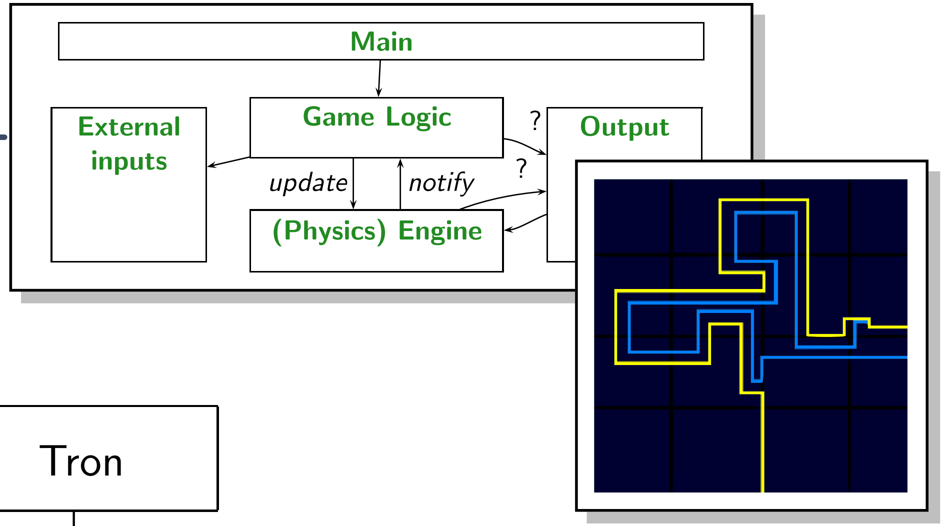
2D-Tron

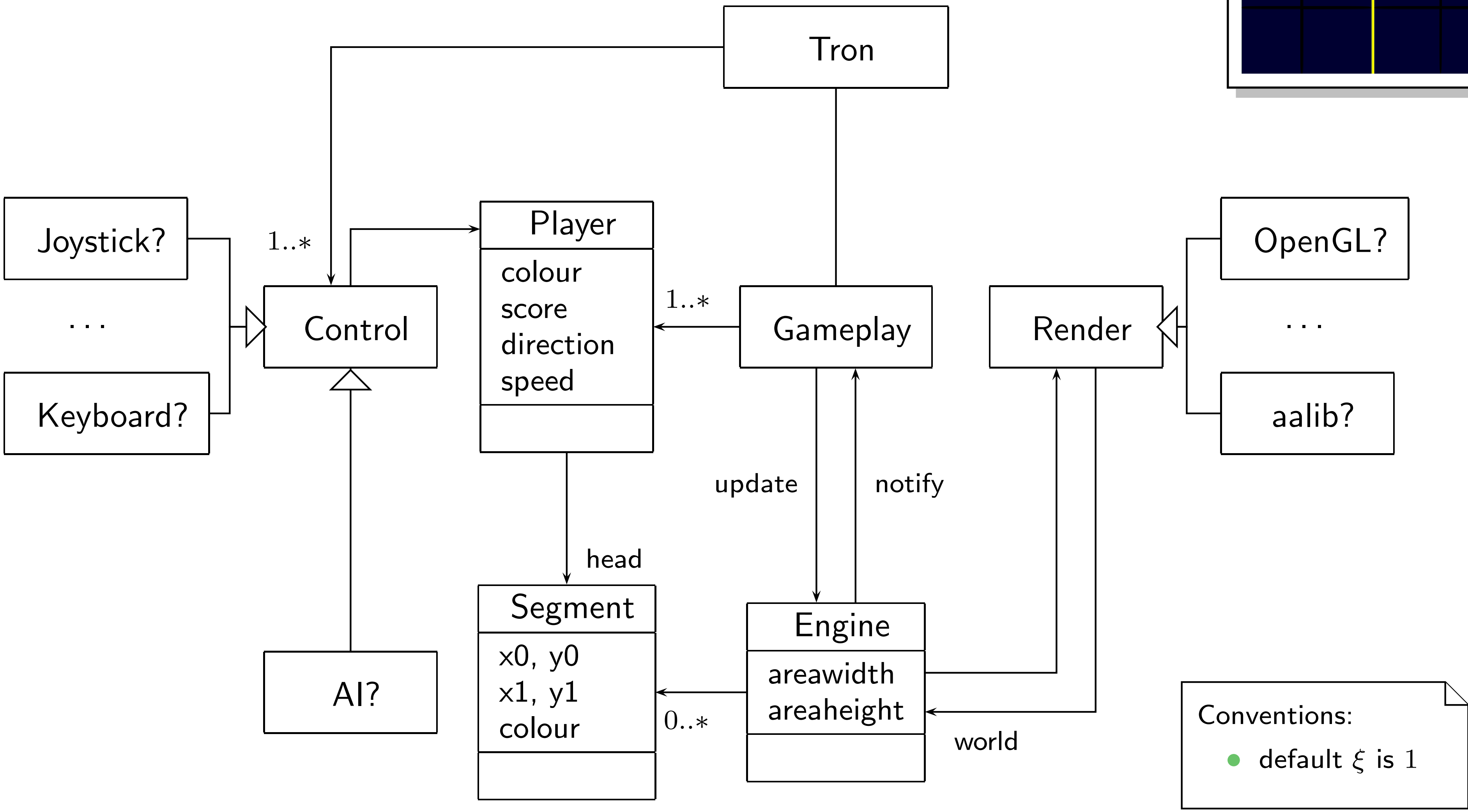
- arcade
- platform open
- 2D
- min. 2, AI open
- controller open
- only game, no menues





Modelling Structure: 2D-Tron





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