Software Design, Modelling and Analysis in UML

Lecture 03: Object Constraint Language (OCL)

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Contents & Goals

Last Lecture:

- Basic Object System Signature $\mathscr{S}$ and Structure $\mathscr{D}$
- System State $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$

(Smells like they're related to class/object diagrams, officially we don't know yet...)

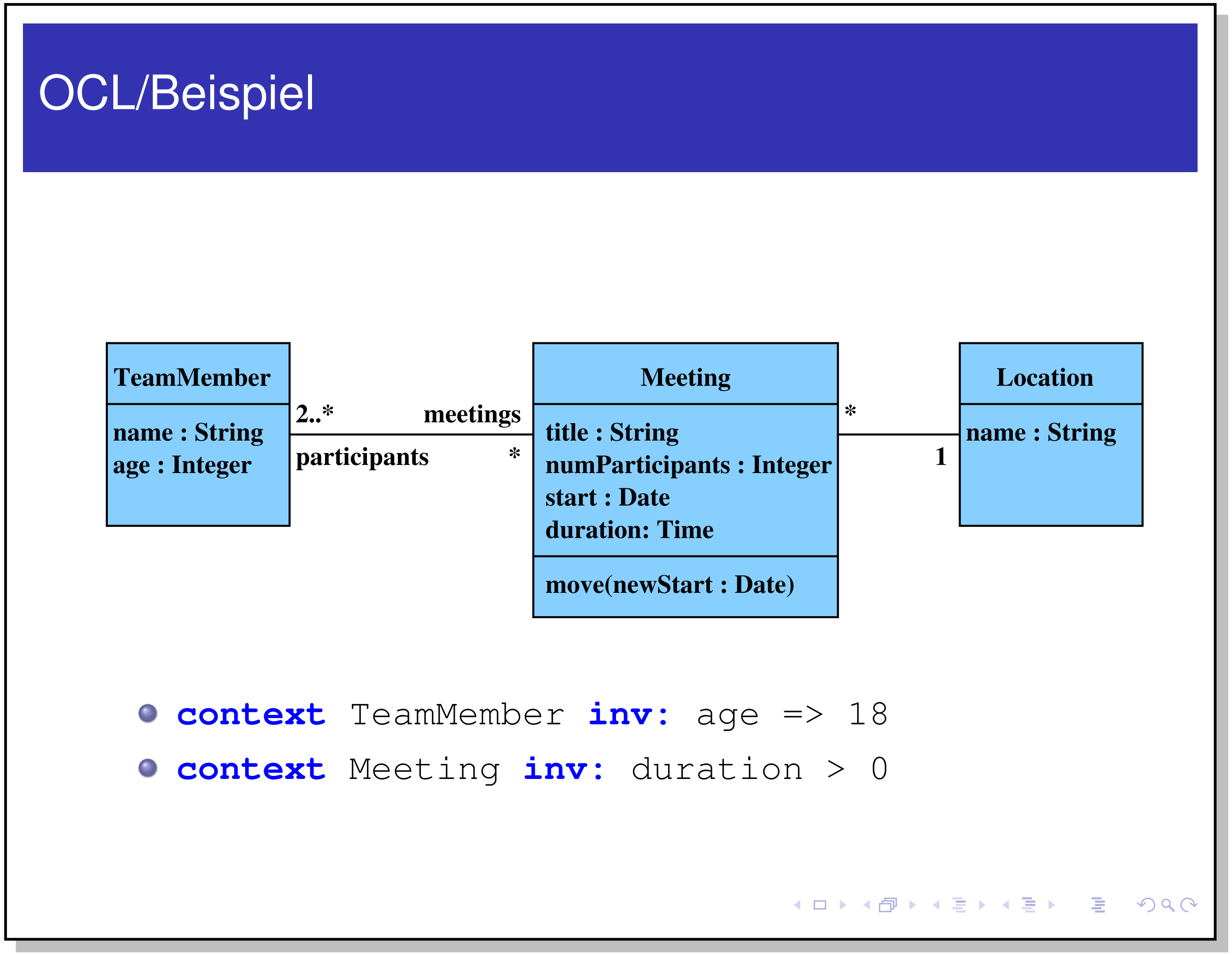
This Lecture:

- **Educational Objectives:** Capabilities for these tasks/questions:
  - Please explain this OCL constraint.
  - Please formalise this constraint in OCL.
  - Does this OCL constraint hold in this system state?
  - Can you think of a system state satisfying this constraint?
  - Please un-abbreviate all abbreviations in this OCL expression.
  - In what sense is OCL a three-valued logic? For what purpose?
  - How are $\mathscr{D}(C)$ and τ_C related?
- **Content:**
  - OCL Syntax, OCL Semantics over system states

What is OCL? And What is It Good For?

What is OCL? How Does it Look Like?

- **OCL**: Object Constraint Logic.

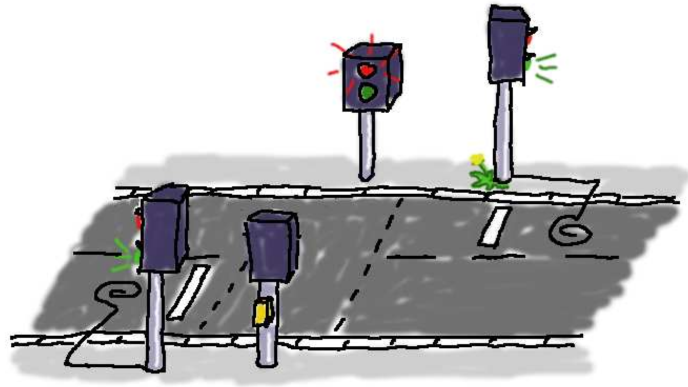


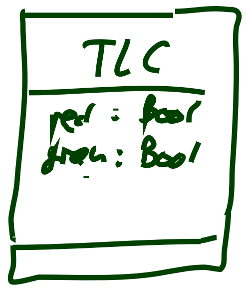
((C) Prof. Dr. P. Thiemann, http://proglang.informatik.uni-freiburg.de/teaching/swt/2008/)

What's It Good For?

- **Most prominent**:
  write down **requirements** supposed to be satisfied by all system states.

  Often targeting all alive objects of a certain class.





context TLC inv : not (red and green)

What's It Good For?

- **Most prominent**:
  write down **requirements** supposed to be satisfied by all system states.

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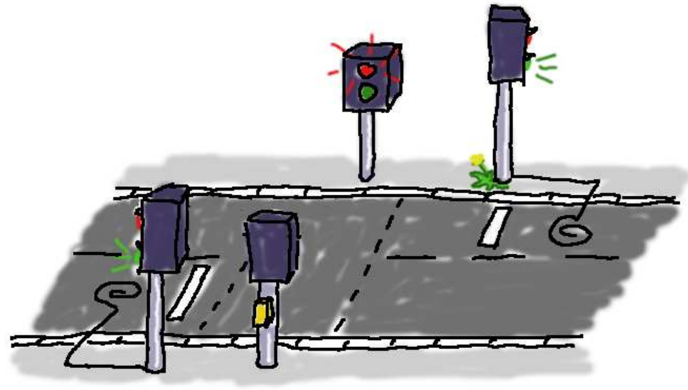
- **Not unknown**:
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.

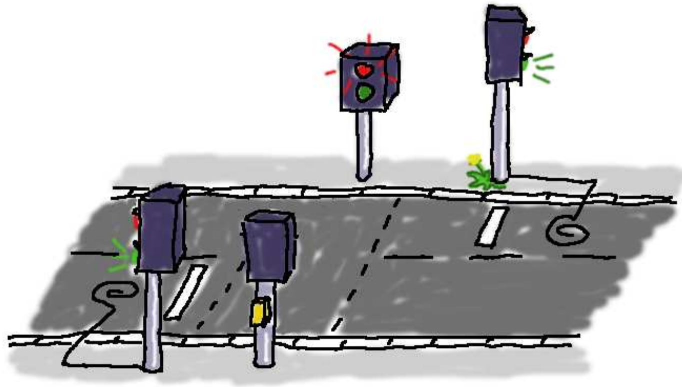


TLC

off()

context off
pre: (true)
post: (not green and not red)

What's It Good For?



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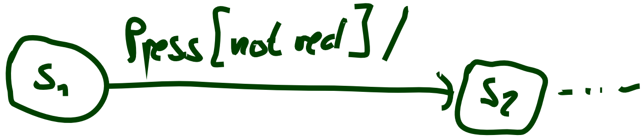
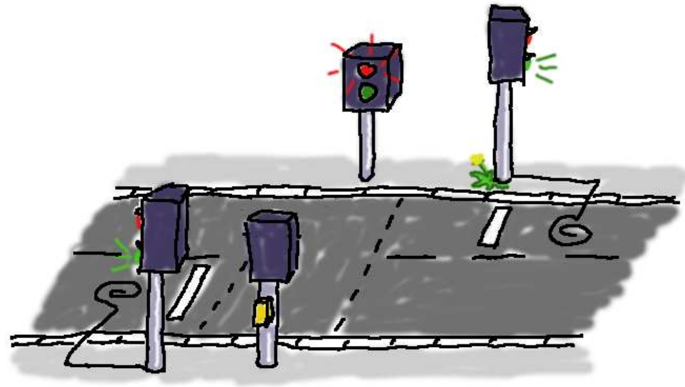
- **Common with State Machines**:
  guards in transitions.



What's It Good For?



- **Most prominent**:
  write down **requirements** supposed to be satisfied by all system states.

  Often targeting all alive objects of a certain class.

- **Not unknown**:
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.
- **Common with State Machines**:
  guards in transitions.
- **Lesser known**:
  provide **operation bodies**.

- **Metamodeling**: the UML standard is a MOF-Model of UML.
  OCL expressions define well-formedness of UML models (cf. Lecture $\sim$ 21).

Plan.

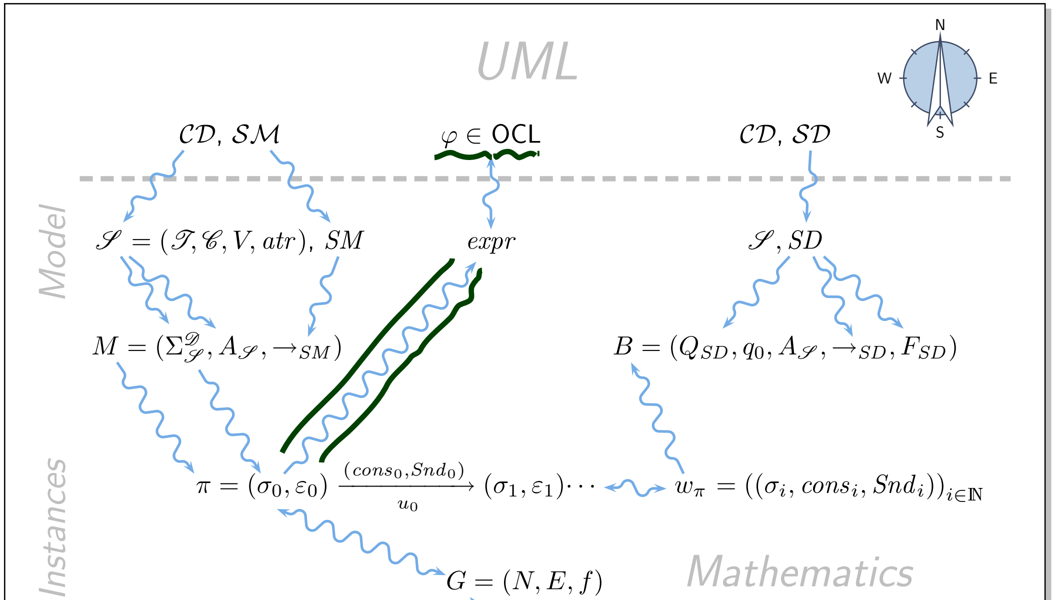
$I(expr, \sigma, \beta) \in \{true, false, \bot\}$

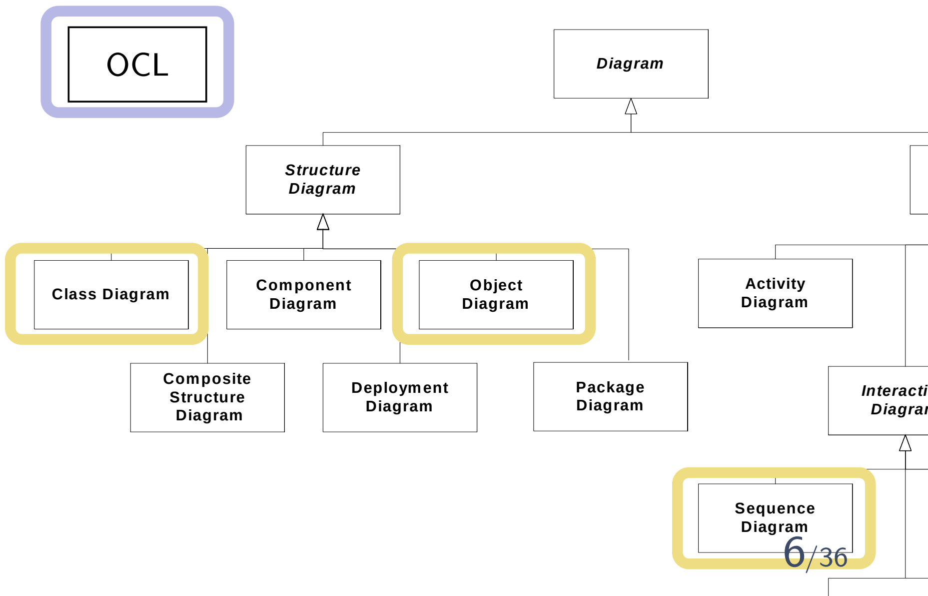
$I : OCLExpressions(\mathscr{S}) \times \Sigma_{\mathscr{S}}^{\mathscr{D}} \times \omega \to \{true, false, \bot\}$

- **Today**:
  - The set $OCLExpressions(\mathscr{S})$ of OCL expressions over $\mathscr{S}$.
  - Given an OCL expression $expr$, a system state $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$, and a valuation of logical variables β, define

$$I[\![expr]\!](\sigma, \beta) \in \{\mathit{true}, \mathit{false}, \bot\}.$$

- **Later**: use I to define $\models \; \subseteq \Sigma_{\mathscr{S}}^{\mathscr{D}} \times OCLExpressions(\mathscr{S})$.





(Core) OCL Syntax [OMG, 2006]

OCL Syntax 1/4: Expressions

$expr ::=$

w	$: \tau(w)$
$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
$\mid$ oclIsUndefined$_\tau(expr_1)$	$: \tau \to Bool$
$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
$\mid$ isEmpty$(expr_1)$	$: Set(\tau) \to Bool$
$\mid$ size$(expr_1)$	$: Set(\tau) \to Int$
$\mid$ allInstances$_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$

type of $expr_2$

type of $expr_1$

Where, given $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr)$,

- $W \supseteq \{self_C \mid C \in \mathscr{C}\}$ is a set of typed logical variables, w has type $\tau(w)$

assumption: disjoint

- τ is any type from $\mathscr{T} \cup T_B \cup T_\mathscr{C} \cup \{Set(\tau_0) \mid \tau_0 \in T_B \cup T_\mathscr{C}\}$
  - T_B is a set of basic types, in the following we use $T_B = \{Bool, Int, String\}$
  - $T_\mathscr{C} = \{\tau_C \mid C \in \mathscr{C}\}$ is the set of object types,
  - $Set(\tau_0)$ denotes the set-of-τ_0 type for $\tau_0 \in T_B \cup T_\mathscr{C} \cup \mathscr{T}$ (sufficient because of "flattening" (cf. standard))
- $v : \tau(v) \in atr(C)$, $\tau(v) \in \mathscr{T}$,
- $r_1 : D_{0,1} \in atr(C)$,
- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

OCL Syntax: Notational Conventions for Expressions

- Each expression

$$\omega(expr_1, expr_2, \dots, expr_n) : \tau_1 \times \dots \times \tau_n \to \tau$$

may alternatively be written ("abbreviated as")

  - $expr_1$. $\omega(expr_2, \dots, expr_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_{\mathscr{C}}$.
  - $expr_1$ -> $\omega(expr_2, \dots, expr_n)$ if τ_1 is a **collection type** (here: only sets), i.e. if $\tau_1 = Set(\tau_0)$ for some $\tau_0 \in T_B \cup T_{\mathscr{C}}$.

OCL Syntax: Notational Conventions for Expressions

- Each expression

$$\omega(expr_1, expr_2, \dots, expr_n) : \tau_1 \times \dots \times \tau_n \to \tau$$

may alternatively be written ("abbreviated as")　omit parentheses if $n=1$

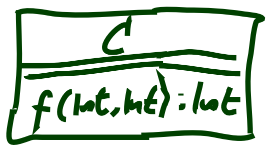
- $expr_1 \;.\; \omega(expr_2, \dots, expr_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_{\mathscr{C}}$.
- $expr_1$ -> $\omega(expr_2, \dots, expr_n)$ if τ_1 is a **collection type** (here: only sets), i.e. if $\tau_1 = Set(\tau_0)$ for some $\tau_0 \in T_B \cup T_{\mathscr{C}}$.

expr₁　ω　logical variables　attributes

- **Examples:** $(self : \tau_C \in W;\quad v, w : Int \in V;\quad r_1 : D_{0,1}, r_2 : D_* \in V)$

assume: $v \in atr(C)$

- $self \;.\; v$ ()
  - ~~$\omega(self, v)$~~
  - $v(self)$
  - $self \to v$ not OCL
  - if we have methods, e.g.



then we will also allow in OCL $self.f(1,2)$ which normalises to $f(self, 1, 2)$

NOT: $1.f(2)$

$r_1 \in atr(C)$, $w \in atr(D)$

- $self \;.\; r_1 \;.\; w$
  - $w(r_1(self))$　$: \tau_C$　$: \tau_D$

$r_2 \in atr(C)$

- $self \;.\; r_2$ -> isEmpty
  - $isEmpty(r_2(self))$　$: \tau_C$　$: Set(\tau_D)$

– 03 – 2012-10-30 – Soclsyn –

OCL Syntax 2/4: Constants, Arithmetical Operators

For example:

$$
\begin{aligned}
expr ::=\ & \dots \\
& \mid \mathsf{true} \mid \mathsf{false} && : Bool \\
& \mid expr_1\ \{\mathsf{and}, \mathsf{or}, \mathsf{implies}\}\ expr_2 && : Bool \times Bool \to Bool \\
& \mid \mathsf{not}\ expr_1 && : Bool \to Bool \\
& \mid 0 \mid -1 \mid 1 \mid -2 \mid 2 \mid \dots && : Int \\
& \mid \mathsf{OclUndefined} && : \tau \\
& \mid expr_1\ \{+, -, \dots\}\ expr_2 && : Int \times Int \to Int \\
& \mid expr_1\ \{<, \leq, \dots\}\ expr_2 && : Int \times Int \to Bool
\end{aligned}
$$

$\in \mathcal{T}_B$

Generalised notation:

$$expr ::= \omega(expr_1, \dots, expr_n) \qquad : \tau_1 \times \dots \times \tau_n \to \tau$$

$expr_1 + (expr_2 + expr_3)$

with $\omega \in \{+, -, \dots\}$ i.e. $+(expr_1, expr_2)$ instead of $expr_1 + expr_2$

OCL Syntax 3/4: Iterate

$$expr ::= \cdots \mid expr_1\texttt{->iterate}(\overbrace{w_1 : \tau_1}\ ;\ \underbrace{w_2 : \tau_2 = expr_2} \mid \overbrace{expr_3})$$

or, with a little renaming,

$$expr ::= \cdots \mid expr_1\texttt{->iterate}(iter : \tau_1;\ result : \tau_2 = expr_2 \mid expr_3)$$

where

- $expr_1$ is of a **collection type** (here: a set $Set(\tau_0)$ for some τ_0),
- $iter \in W$ is called **iterator**, gets type τ_1
  (if τ_1 is omitted, τ_0 is assumed as type of $iter$)
- $result \in W$ is called **result variable**, gets type τ_2,
- $expr_2$ in an expression of type τ_2 giving the **initial value** for $result$,
  ('OclUndefined' if omitted)
- $expr_3$ is an expression of type τ_2
  in which in particular $iter$ and $result$ may appear.

Iterate: Intuitive Semantics (Formally: later)

$$expr ::= expr_1 \texttt{->iterate}(iter : \tau_1;$$
$$result : \tau_2 = expr_2 \mid expr_3)$$

pseudo code

$$
\begin{array}{l}
Set(\tau_0)\ hlp = \langle expr_1 \rangle; \\
\tau_1\ iter; \\
\tau_2\ result = \langle expr_2 \rangle; \\
while\ (!hlp.empty())\ do \\
\qquad iter = hlp.pop(); \\
\qquad result = \langle expr_3 \rangle; \\
od
\end{array}
$$

pick and remove one element

e.g. result + iter

Note: In our (simplified) setting, we always have $expr_1 : Set(\tau_1)$ and $\tau_0 = \tau_1$.

In the type hierarchy of full OCL with inheritance and `oclAny`, they may be different and still type consistent.

Abbreviations on Top of Iterate

$$expr ::= expr_1\texttt{->iterate}(w_1 : \tau_1;\; w_2 : \tau_2 = expr_2 \mid expr_3)$$

- $$expr_1\texttt{->forAll}(w : \tau_1 \mid expr_3)$$
  is an abbreviation for
  $$expr_1\texttt{->iterate}(w{:}\ \tau_1;\ w_1 : Bool = true \mid w_1 \underset{\text{and}}{\cancel{=}} expr_3).$$
  (To ensure confusion, we may again omit all kinds of things, cf. [OMG, 2006]).
- Similar: $$expr_1\texttt{->Exists}(w : \tau_1 \mid expr_3)$$

OCL Syntax 4/4: Context

$$context ::= \textsf{context}\ w_1 : \tau_1, \dots, w_n : \tau_n\ \textsf{inv :}\ expr$$

where $w \in W$ and $\tau_i \in T_{\mathscr{C}}$, $1 \leq i \leq n$, $n \geq 0$.

denotes τ_{C_1}

$$\text{context } w_1 : C_1, \dots, w_n : C_n \text{ inv : } expr$$

requires that $w_1 : \tau_{C_1} \in W$

is an **abbreviation** for

$$\begin{array}{l}
\text{allInstances}_{C_1} \text{ -> forAll}(w_1 : C_1 \mid \\
\quad \dots \\
\qquad \text{allInstances}_{C_n} \text{ -> forAll}(w_n : C_n \mid \\
\qquad\quad expr \\
\qquad) \\
\quad \dots \\
)
\end{array}$$

Context: More Notational Conventions

- For

$$\text{context } \mathit{self} : \tau_C \text{ inv} : \mathit{expr}$$

we may alternatively write ("abbreviate as")

$$\text{context } \tau_C \text{ inv} : \mathit{expr}$$

- **Within** the latter abbreviation, we may omit the "self" in expr, i.e. for

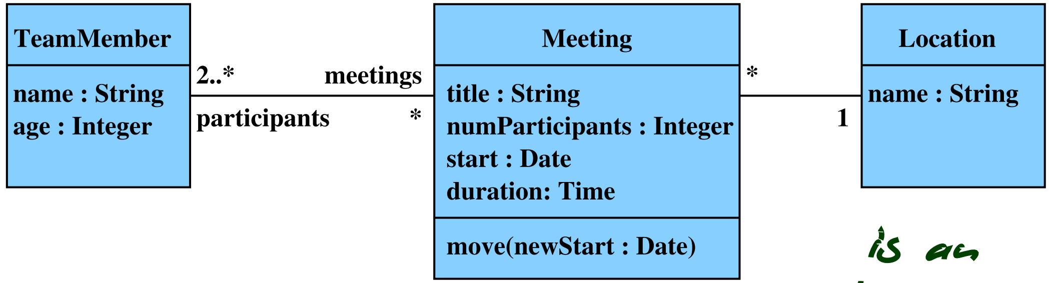
$$\mathit{self}.v \quad \text{and} \quad \mathit{self}.r$$

we may alternatively write ("abbreviate as")

$$v \quad \text{and} \quad r$$

Examples (from lecture)

$\mathcal{S} = (\{String, Integer, Date, Time\},$
$\{TeamMember, Meeting, Location\},$
$\{age : Integer, \ldots\},$
$\{TeamMember \mapsto \{age, name\}\})$



- `context TeamMember inv: age => 18`
- `context Meeting inv: duration > 0`

is an OCL expression w.r.t. $\mathcal{S}$

context TeamMember inv : age ≥ 18

⇝ context self : TeamMember inv: age ≥ 18

⇝ allInstances$_{TeamMember}$ ->forAll(self : TeamMember | age ≥ 18)

⇝ ———— " ———— ->iterate(self : TeamMember ; res : Bool = true | res and age ≥ 18)

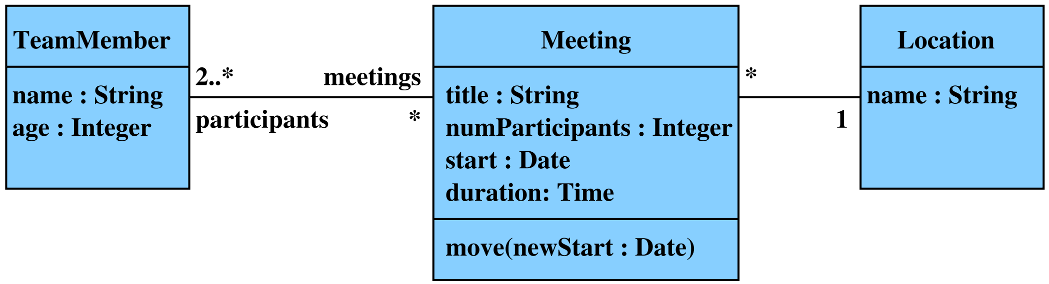
⇝ ———— " ———— res and self.age ≥ 18)

⇝ ———— " ———— age(self) ≥ 18)

⇝ allInstances$_{TeamMember}$ ->iterate(self : TeamMember ; res : Bool = true | res and ≥(age(self), 18))

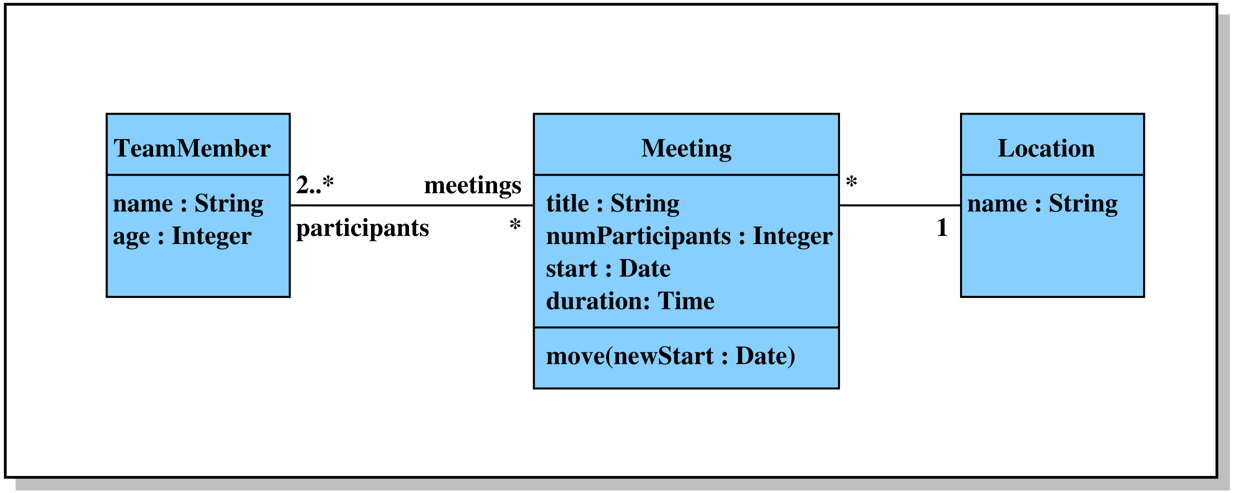
Examples (from lecture "Softwaretechnik 2008")

OCL/Mehr Navigation/Beispiele



- **context** Meeting
  - **inv:** `self.participants->size() = numParticipants`
- **context** Location
  - **inv:** `name="Lobby"` **implies** `meeting->isEmpty()`

Example (from lecture “Softwaretechnik 2008”)



- context self : $Meeting$ inv :

  $$((\mathit{self}\,.\,participants\ \texttt{->}\ \mathsf{iterate}(i : TeamMember; n : Int = 0 \mid n + i\,.\,age))$$
  $$/\,(participants\ \texttt{->}\ \mathsf{size}()))\ > 25$$

“Not Interesting”

Among others:

- Enumeration types
- Type hierarchy
- Complete list of arithmetical operators
- The two other collection types Bag and Sequence
- Casting
- Runtime type information
- Pre/post conditions
  (maybe later, when we officially know what an operation is)
- ...

OCL Semantics [OMG, 2006]

The Task

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$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
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$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
$\mid \mathsf{isEmpty}(expr_1)$	$: Set(\tau) \to Bool$
$\mid \mathsf{size}(expr_1)$	$: Set(\tau) \to Int$
$\mid \mathsf{allInstances}_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
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Where, given $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr)$,

- $W \supseteq \{self\}$ is a set of typed logical variables, w has type $\tau(w)$
- τ is any type from $\mathscr{T} \cup T_B \cup T_\mathscr{C}$ $\cup \{Set(\tau_0) \mid \tau_0 \in T_B \cup T_\mathscr{C}\}$
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- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

- Given an OCL expression $expr$, a system state $\sigma \in \Sigma_\mathscr{S}^\mathscr{D}$, and a valuation of logical variables β, define

$$I[\![\cdot]\!](\cdot\,,\cdot) : OCLExpressions(\mathscr{S}) \times \Sigma_\mathscr{S}^\mathscr{D} \times (W \to I(\mathscr{T} \cup T_B \cup T_\mathscr{C})) \to I(Bool)$$

such that

$$I[\![expr]\!](\sigma, \beta) \in \{\mathit{true}, \mathit{false}, \bot_{Bool}\}.$$

References

References

[OMG, 2006] OMG (2006). Object Constraint Language, version 2.0. Technical Report formal/06-05-01.

[OMG, 2007a] OMG (2007a). Unified modeling language: Infrastructure, version 2.1.2. Technical Report formal/07-11-04.

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[Warmer and Kleppe, 1999] Warmer, J. and Kleppe, A. (1999). *The Object Constraint Language*. Addison-Wesley.