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...)

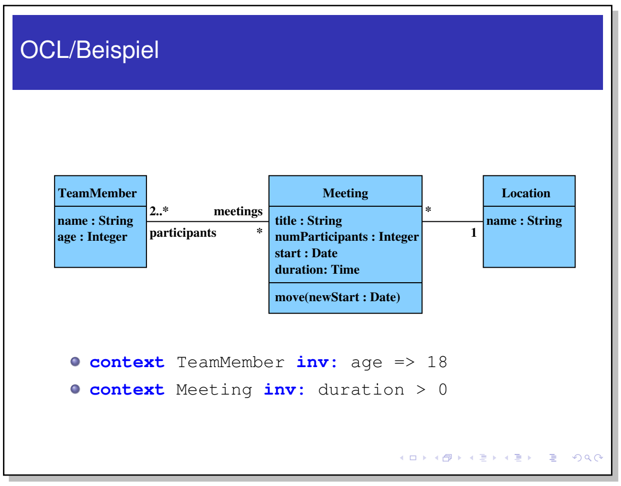
This Lecture:

- **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?

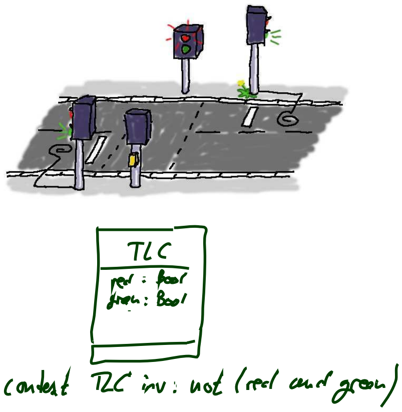
- **OCL**: Object Constraint Logic.



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.



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

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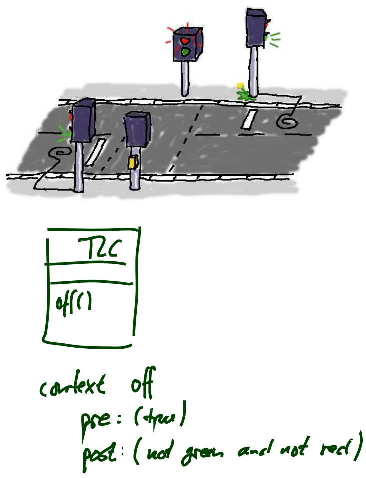
- **Not unknown**:
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.



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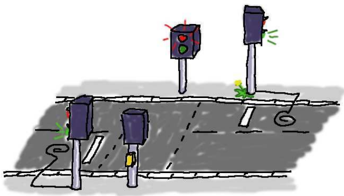

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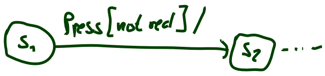
- **Common with State Machines**:
  guards in transitions.



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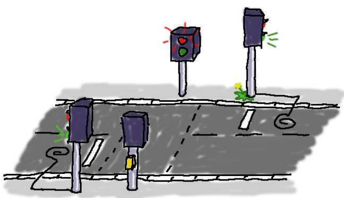

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- **Common with State Machines**:
  guards in transitions.

- **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.

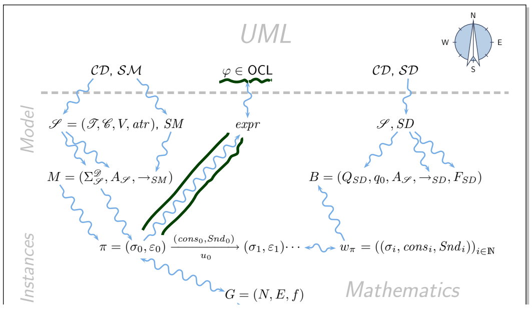
$I(expr, \sigma, \beta) \in \{true, false, \bot\}$

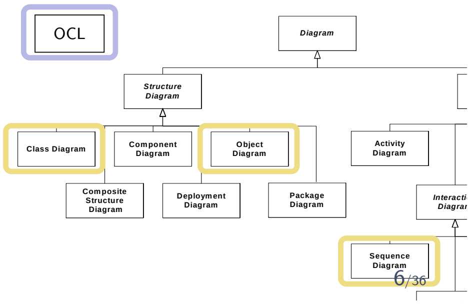
$I : OCLExpressions(\mathscr{S}) \times \Sigma_{\mathscr{S}}^{\mathscr{D}} \times \omega \longrightarrow \{true, false, \bot\}$

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

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

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

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

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

$expr_1$ $\quad\omega\quad$ logical variables $\quad$ 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: $v \in atr(C)$

  - $self \;.\; v()$ $\quad$ • ~~$\omega(self, v)$~~ • $v(self)$ $\quad$ • $self \to v$ not OCL
  - $r_1 \in atr(C)$, $w \in atr(D)$: $self \;.\; r_1 \;.\; w$ $\quad$ • $w(\underbrace{r_1(\underbrace{self}_{:\tau_C})}_{:\tau_D})$
  - $r_2 \in atr(C)$: $self \;.\; r_2$ -> isEmpty $\quad$ • $isEmpty(\underbrace{r_2(\underbrace{self}_{:\tau_C})}_{:Set(\tau_D)})$

• if we have methods, e.g.

$$\boxed{\begin{array}{c} C \\ \hline f(Int, Int) : Int \end{array}}$$

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

NOT: $1.f(2)$

OCL Syntax 2/4: Constants, Arithmetical Operators

For example:

$expr ::= \ \ldots$

$\mid$ true $\mid$ false	$: Bool$
$\mid expr_1 \ \{$and, or, implies$\}\ expr_2$	$: Bool \times Bool \to Bool$
$\mid$ not $expr_1$	$: Bool \to Bool$
$\mid 0 \mid -1 \mid 1 \mid -2 \mid 2 \mid \ldots$	$: Int$ $\quad \in T_B$
$\mid$ OclUndefined	$: \tau$
$\mid expr_1 \ \{+, -, \ldots\}\ expr_2$	$: Int \times Int \to Int$
$\mid expr_1 \ \{<, \leq, \ldots\}\ expr_2$	$: Int \times Int \to Bool$

Generalised notation:

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

$expr_1 + (expr_2 + expr_3)$

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

OCL Syntax 3/4: Iterate

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

or, with a little renaming,

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

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)

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

pseudo code

$Set(\tau_0)\ hlp = \langle expr_1 \rangle;$

$\tau_1\ iter;$

$\tau_2\ result = \langle expr_2 \rangle;$

$while\ (!hlp.empty())\ do$ — pick and remove one element

$\quad iter = hlp.pop();$

$\quad result = \langle expr_3 \rangle;$ — e.g. result + iter

od

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

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

- $expr_1\text{->forAll}(w : \tau_1 \mid expr_3)$

  is an abbreviation for

  $expr_1\text{->iterate}(w : \tau_1;\ w_1 : Bool = true \mid w_1 \underset{\text{and}}{\cancel{\wedge}}\ expr_3).$

  (To ensure confusion, we may again omit all kinds of things, cf. [OMG, 2006]).

- Similar: $expr_1\text{->Exists}(w : \tau_1 \mid expr_3)$

OCL Syntax 4/4: Context

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

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

denotes τ_{C_1}

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

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

is an **abbreviation** for

allInstances$_{C_1}$ -> forAll$(w_1 : C_1 \mid$

$\dots$

allInstances$_{C_n}$ -> forAll$(w_n : C_n \mid$

$expr$

$)$

$\dots$

$)$

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

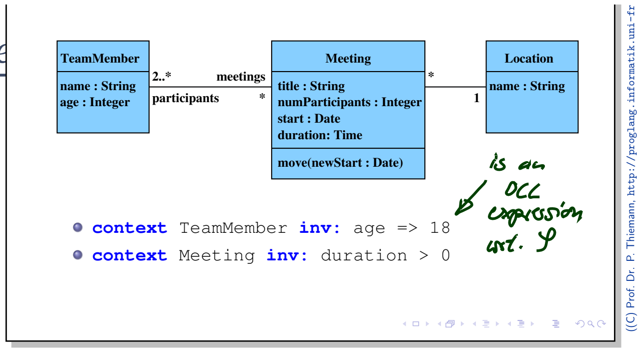
$$\mathit{self}.v \quad \text{and} \quad \mathit{self}.r$$

we may alternatively write ("abbreviate as")

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

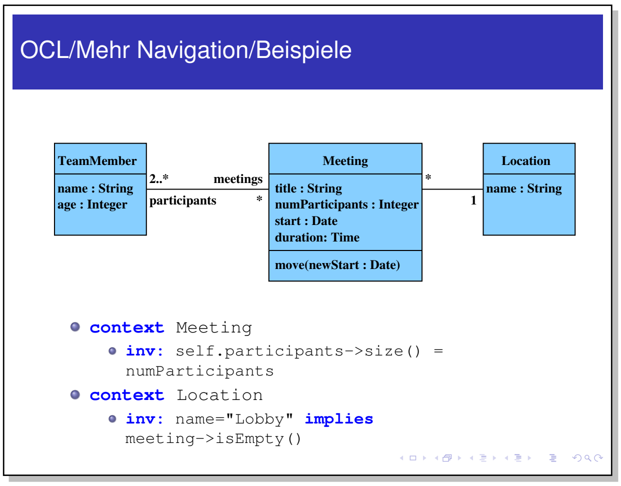
Examples (from lecture

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



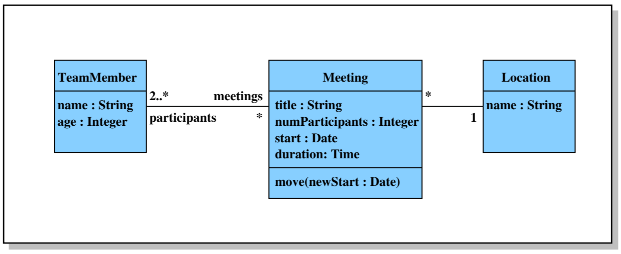
context TeamMember inv : age ≥ 18
context self : TeamMember inv: age ≥ 18
allInstances$_{TeamMember}$ ->forAll (self : TeamMember | age ≥ 18)
——— " ——— ->iterate (self : TeamMember ; res : Bool = true | res and age ≥ 18)
——— " ——— res and self.age ≥ 18)
——— " ——— age (self) ≥ 18)
allInstances$_{TeamMember}$ ->iterate (self : TeamMember ; res : Bool = true | res and ≥ (age(self), 18))

Examples (from lecture "Softwaretechnik 2008")



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

Example (from lecture "Softwaretechnik 2008")



- context $\overbrace{Meeting}^{self:}$ inv :
  $((self . participants$ -> iterate$(i : TeamMember; n : Int = 0 \mid n + i . age))$
  $/ (participants$ -> 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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- 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.

[OMG, 2007b] OMG (2007b). Unified modeling language: Superstructure, version 2.1.2. Technical Report formal/07-11-02.

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