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...)

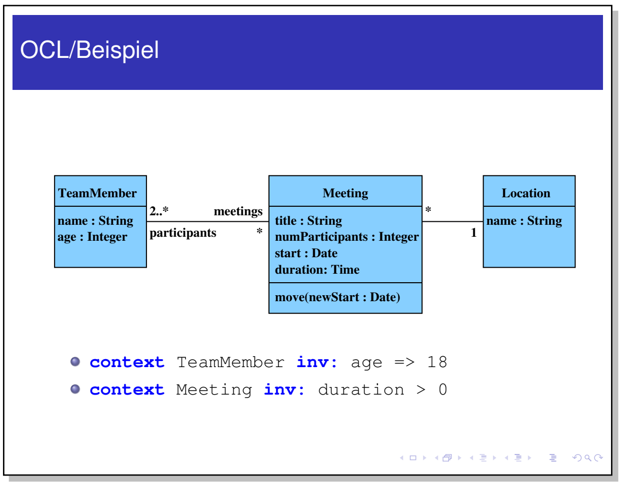
This Lecture:

- **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?

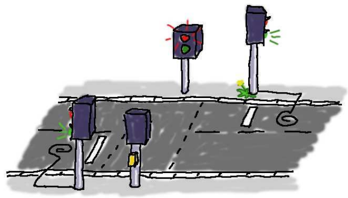
- **OCL**: Object Constraint Logic.

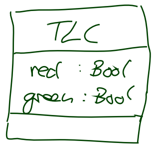


What's It Good For?

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

  Often targeting all alive objects of a certain class.





context TLC inv : not (red and green)

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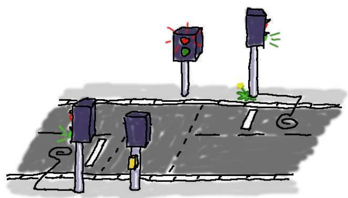
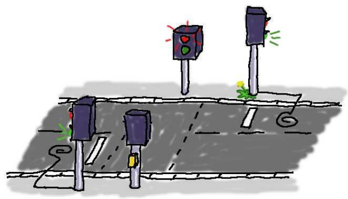


- **Not unknown**:
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.

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

What's It Good For?



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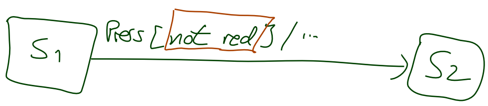
- **Common with State Machines**:
  guards in transitions.



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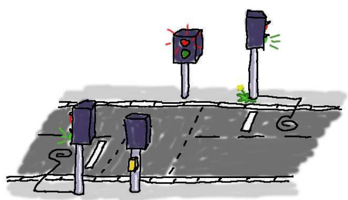

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- **Common with State Machines**:
  guards in transitions.

- **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.

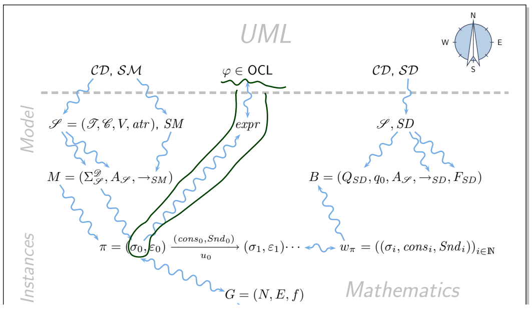
$I : OCLExpr(\mathscr{S}) \times \Sigma_{\mathscr{S}}^{\mathscr{D}} \times B \longrightarrow \{true, false, \bot\}$

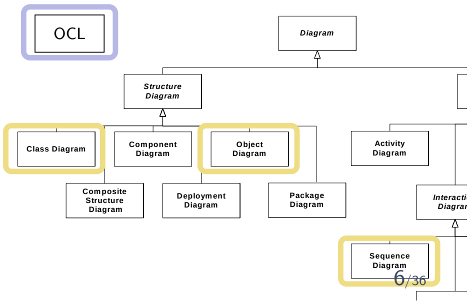
$I(expr, \sigma, \beta)$ valuations of ω

- **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

set comprehension operator

type of $expr_1$ | type of $expr_2$ | type of $expr_1 =_\tau expr_2$

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

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 $\tau(w)$
- $\tau(self_C) = \tau_C$
- 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 $\tau_0 \in T_B \cup T_\mathscr{C}$ (sufficient because of "flattening" (cf. standard))
- $v : \tau(v) \in atr(C)$, $\tau(v) \in \mathscr{T}$,
- $r_1 : D_{0,1} \in atr(C)$,
- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

$\mathscr{S} = (\{Integ\}, \{C, D\}, \{x : Integ, y : Integ, p : C_*, q : D_{0,1}\},$
$\{C \mapsto \{x, y, p, q\}$
$D \mapsto \{y, q\})$

$W = \{self_C : \tau_C, self_D : \tau_D\} \cup \{a, b, c : Int\} \cup \{n, m : \tau_C, e : \tau_D\}$
$\cup \{N, M : set(\tau_C)\}$

- $self_C$
- a
- n
- oclIsUndefined(a)
- $\{n, m\} : Set(\tau_C)$
- size$(N) : Int$
- allInstances$_C$

- $p(n) : Set(\tau_C)$
  $n : \tau_C$,
  $p : C_* \in atr(C)$
- $q(n) : \tau_D$
  $n : \tau_C$
  $q : D_{0,1} \in atr(C)$
- $q(\underbrace{q(n)}_{expr_1}) : \tau_D$
  $q : D_{0,1} \in atr(D)$

- $x(n) : Integ$
  $n : \tau_C$, $x : Integ \in atr(C)$, $Integ \in \mathscr{T}$
- $x(a)$? NO (type mismatch)
- $a(n)$? YES ! NO !! ? !!!!!!! NO, a is not an attribute of C
- $x(p)$? NO, p is an attribute and not a logical variable

OCL Syntax: Notational Conventions for Expressions

- Each expression

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

may alternatively be written ("abbreviated as")

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

- **Examples:** $(self : \tau_C \in W; \quad v, w : Int \in V; \quad r_1 : D_{0,1}, r_2 : D_* \in V)$
  - $self \,.\, v$ [expr$_1$] [ω] $v(self)$
  - $self \,.\, r_1 \,.\, w$ [expr] [ω] $w(self.r_1)$ [expr$_1$] [ω] attributes $\in W$ $w(r_1(self))$
  - $self \,.\, r_2$ -> isEmpty [expr$_1$] [ω] isEmpty$(self.r_2)$ isEmpty$(r_2(self))$
  - self -> v NO, self not of collection type

OCL Syntax 2/4: Constants, Arithmetical Operators

For example:

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

Generalised notation:

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

with $\omega \in \{+, -, \dots\}$ e.g. and$(expr_1, expr_2)$

OCL Syntax 3/4: Iterate

$\mathscr{S} = (\emptyset, \{C, D\}, \{p : C_*, q : D_*\}, \{H \mapsto \{p, q\}\})$

self.p -> iterate(iter; res : Int = 0; res + size(iter.q))

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

self : τ_C

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

$Set(\tau_0)$ $hlp = \langle expr_1 \rangle;$
τ_1 $iter;$
τ_2 $result = \langle expr_2 \rangle;$
$while$ $(!hlp.empty())$ do — pick and remove one element
  $iter = hlp.pop();$
  $result = \langle expr_3 \rangle;$ — e.g. result + size(iter.q)
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

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

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

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

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

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

is an **abbreviation** for

allInstances$_{C_1}$ -> forAll($w_1 : C_1$ |
 ...
  allInstances$_{C_n}$ -> forAll($w_n : C_n$ |
   $expr$
)
 ...
)

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Context: More Notational Conventions

- For

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

we may alternatively write ("abbreviate as")

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

e.g. context C_1 inv: expr

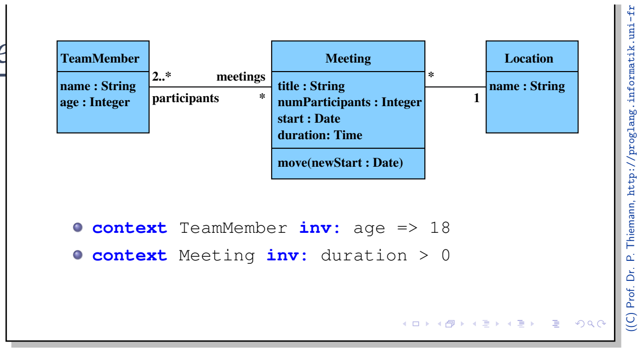
- **Within** the latter abbreviation, we may omit the "self" in expr, i.e. for

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

we may alternatively write ("abbreviate as")

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

Examples (from lecture



context self : TM inv: age ≥ 18

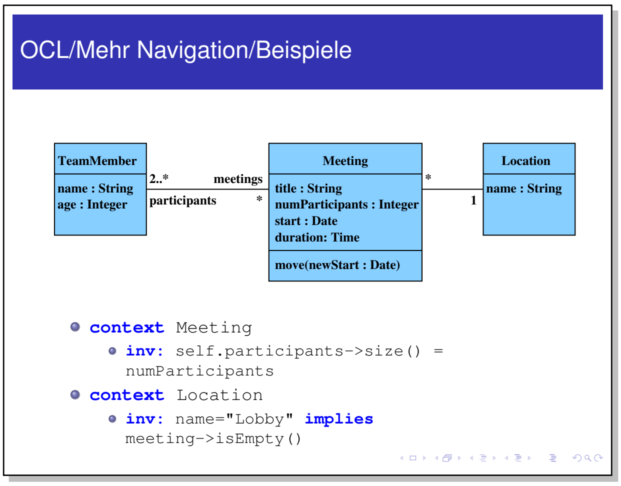
———— " ———— self . age ≥ 18

———— " ———— age(self) ≥ 18

———— " ———— ≥(age(self), 18)

↳ allInstances_{TM} -> forAll(self : TM | ≥(age(self), 18))

Examples (from lecture “Softwaretechnik 2008”)



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

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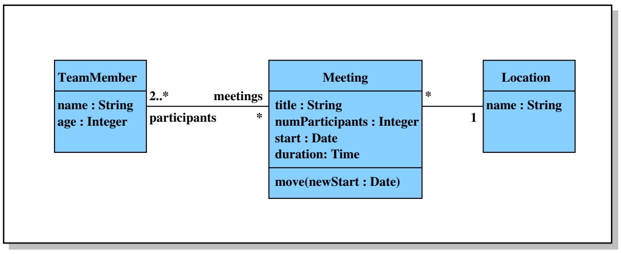

- context $\mathit{Meeting}$ inv :

$$\mathit{participants} \text{ -> iterate}(i : \mathit{TeamMember}; n : \mathit{Int} = 0 \mid n + i\,.\,\mathit{age})$$

$$/\mathit{participants} \text{ -> size}() > 25$$

"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)
- ...

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.