Statecharts and OCL

Ákos Horváth and Dániel Varró

With contributions from
István Majzik and Gergely Pintér

Model Driven Software Development
Lecture 5

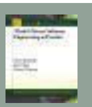
Budapest University of Technology and Economics
Department of Measurement and Information Systems

OCL – The Object Constraint Language

How to capture restrictions / constraints of domain classes?

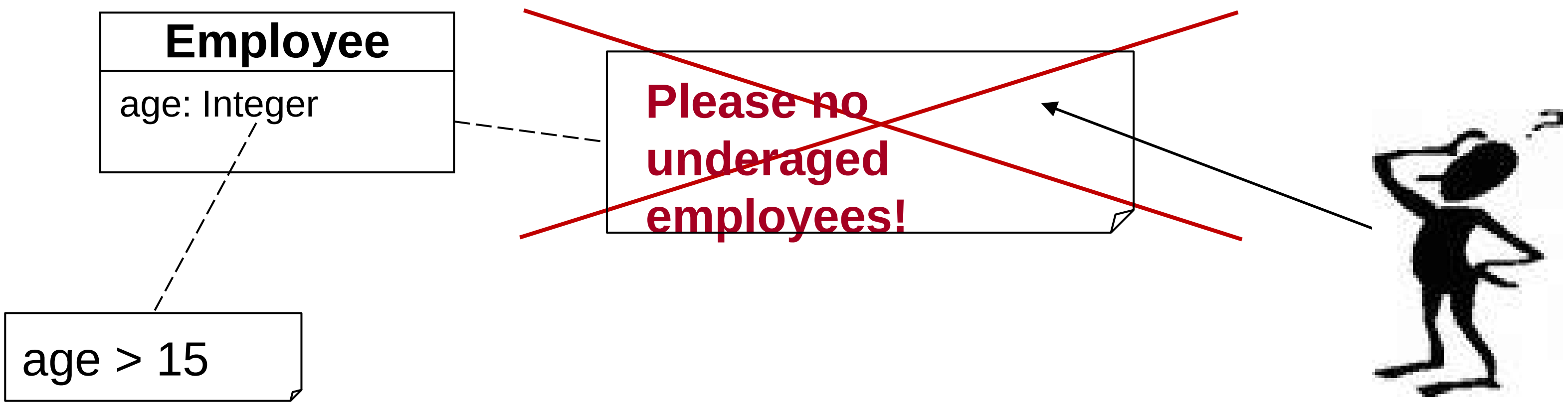
Motivation

- Graphical modeling languages are generally not able to describe all facets of a problem description
  - *MOF, UML, ER, …*
- Special **constraints** are often (if at all) added to the diagrams in **natural language**
  - Often **ambiguous**
  - Cannot be validated **automatically**
  - No **automatic** code generation
- Constraint definition also crucial in the definition of new modeling languages (DSLs).



Motivation

- Example 1



Additional question: How do I get all Employees younger than 30 years old?

Motivation

- **Formal specification languages** are the solution
  - Mostly based on **set theory** or **predicate logic**
  - Requires good mathematical understanding
  - Mostly used in the academic area, but hardly used in the industry
  - Hard to learn and hard to apply
  - Problems when to be used in big systems

- ***Object Constraint Language (OCL)*:** Combination of modeling language and formal specification language
  - Formal, precise, unique
  - Intuitive syntax is key to **large group of users**
  - No programming language (no algorithms, no technological APIs, …)
  - Tool support: *parser, constraint checker, codegeneration,…*

OCL usage

- Constraints in UML-models
  - Invariants for classes, interfaces, stereotypes, …
  - Pre- and postconditions for operations
  - Guards for messages and state transition
  - Specification of messages and signals
  - Calculation of derived attributes and association ends

- Constraints in meta models
  - Invariants for Meta model classes
  - Rules for the definition of well-formedness of meta model

- Query language for models
  - In analogy to SQL for DBMS, XPath and XQuery for XML
  - Used in transformation languages

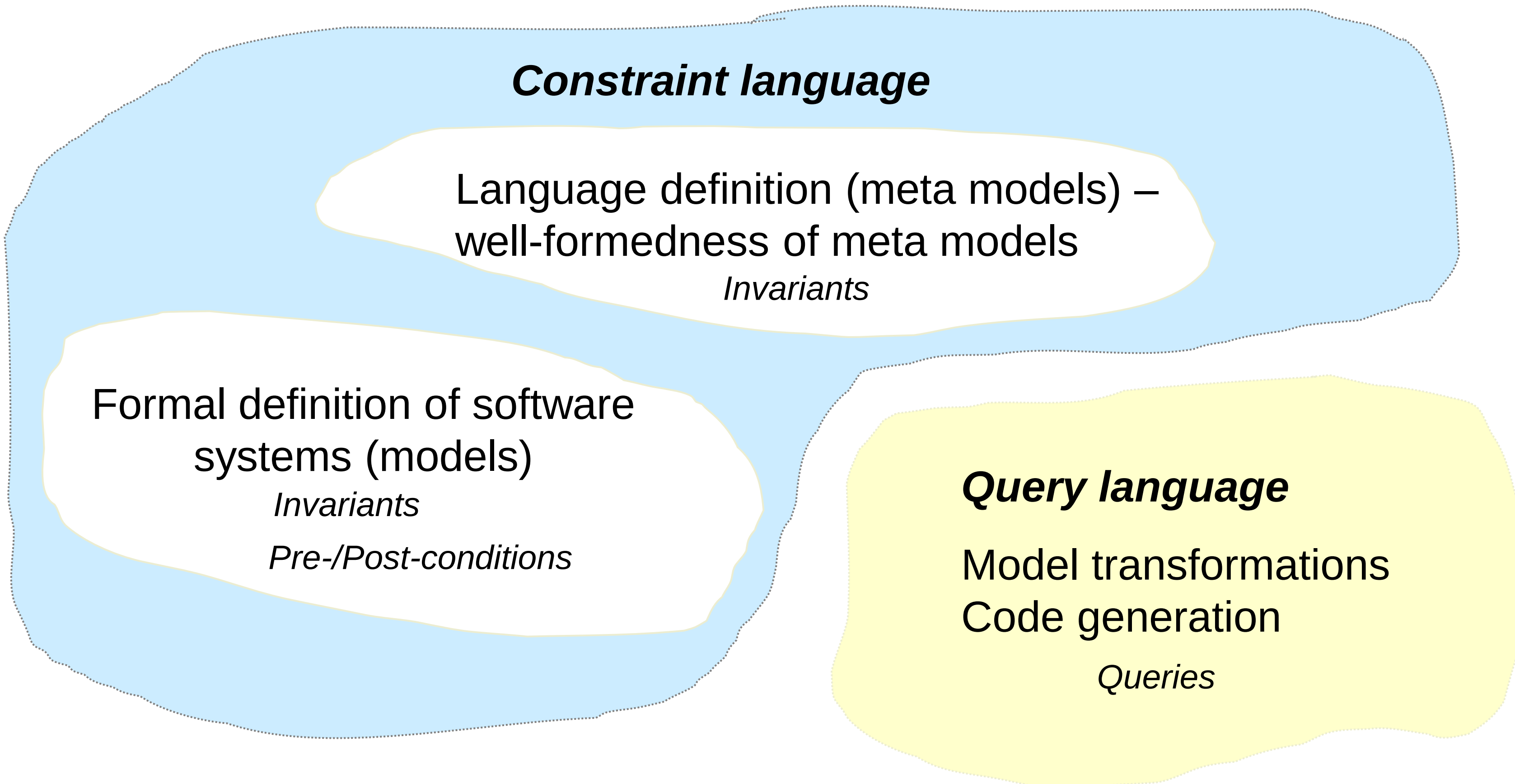
OCL usage

- OCL field of application
  - Invariants **context** *C* **inv:** *I*
  - Pre-/Postconditions **context** *C::op() : T* **pre:** *P* **post:** *Q*
  - Query operations **context** *C::op() : T* **body:** *e*
  - Initial values **context** *C::p : T* **init:** *e*
  - Derived attributes **context** *C::p : T* **derive:** *e*
  - Attribute/operation definition **context** *C* **def:** *p : T = e*

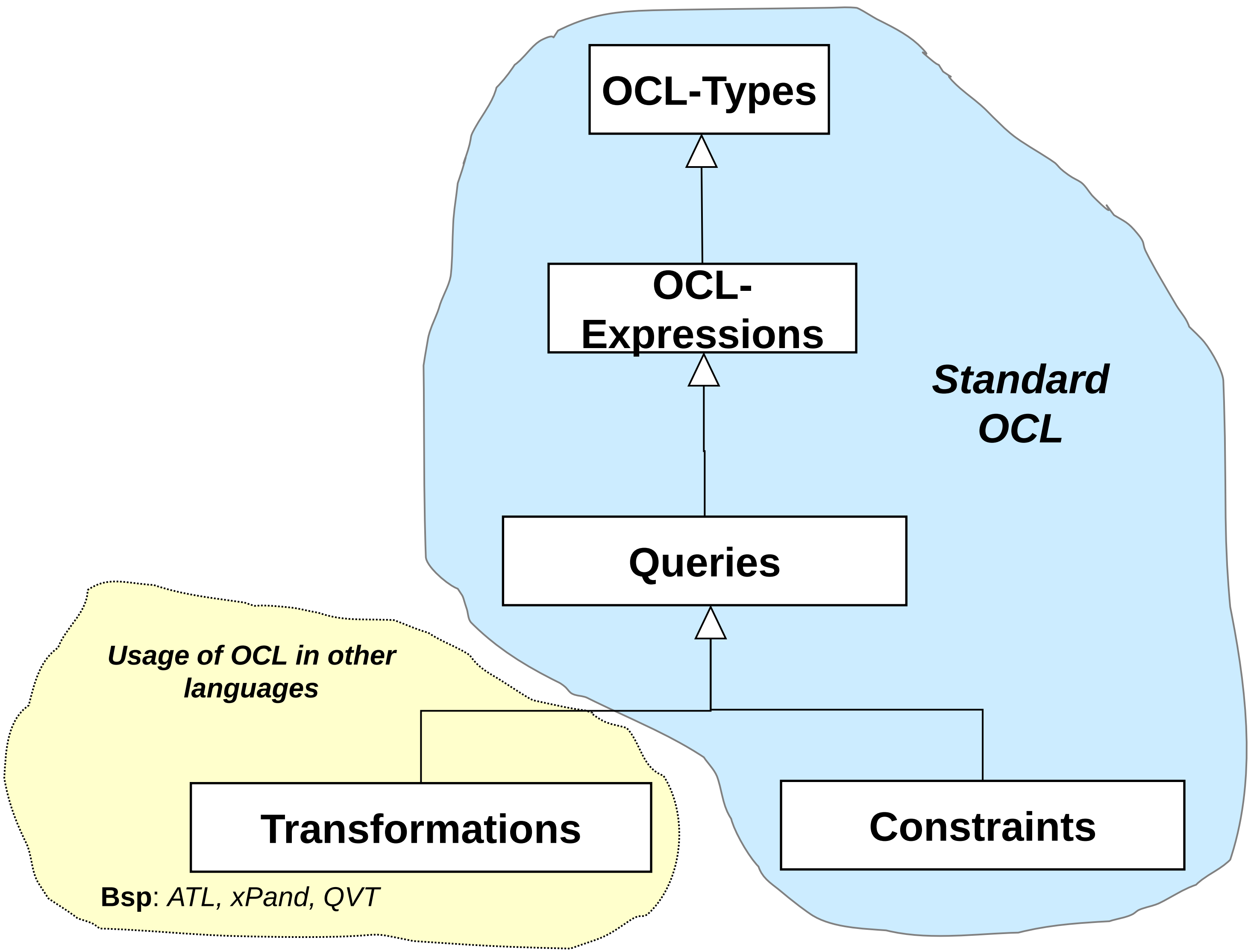
- Caution: Side effects are not allowed!
  - Operation `C::getAtt : String body: att` allowed in OCL
  - Operation `C::setAtt(arg) : T body: att = arg` **not** allowed in OCL

OCL usage

- **Field of application** of OCL in model driven engineering



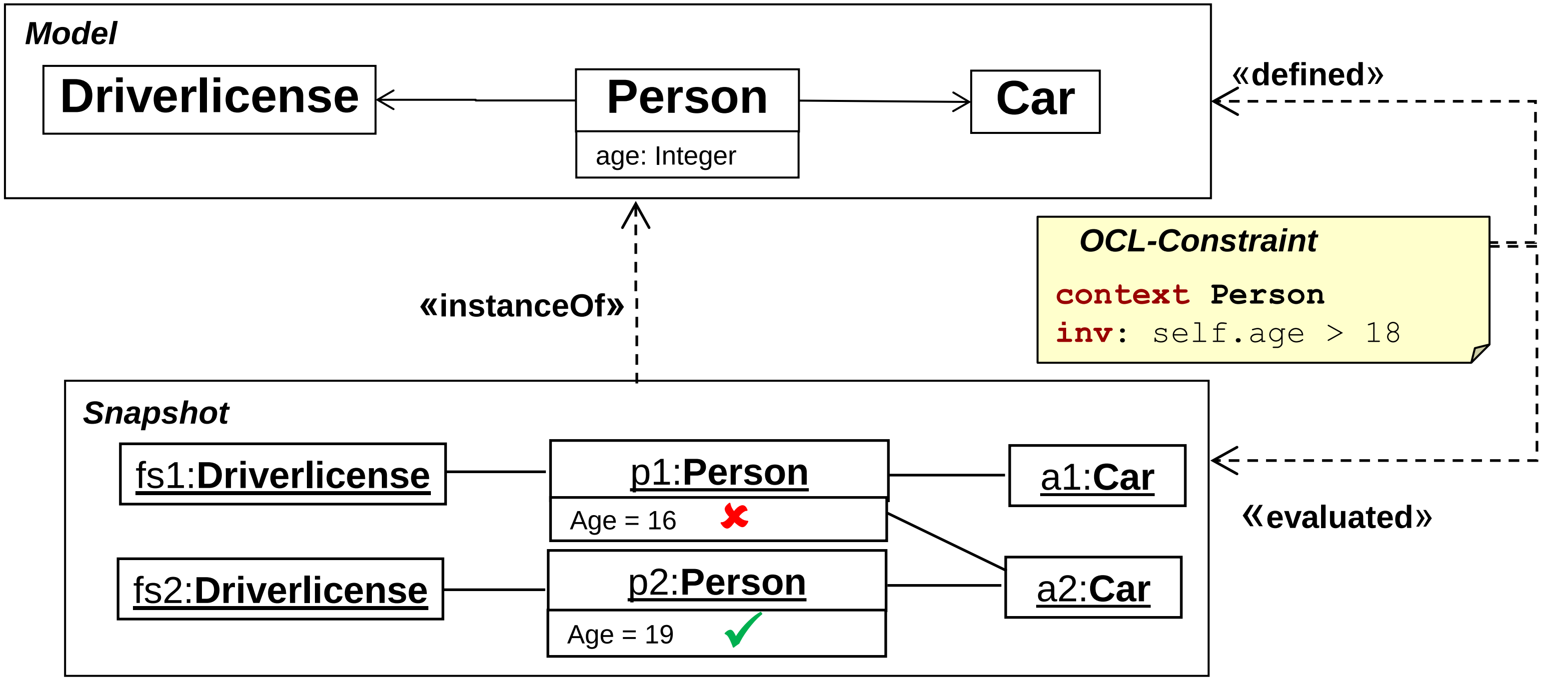
OCL usage


OCL-Types
OCL-
Expressions
Standard
OCL
Queries
Usage of OCL in other
languages
Transformations
Constraints
Bsp: ATL, xPand, QVT

OCL usage

How does OCL work?

- **Constraints** are defined on the modeling level
  - Basis: Classes and their properties
- Information of the **object graph** are **queried**
  - Represents system status, also called ***snapshot***
- **Anaology** to XML query languages
  - XPath/XQuery query XML-documents
  - Scripts are based on XML-schema information
- Examples

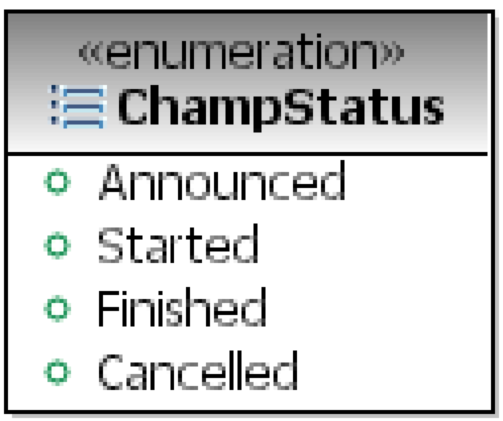


First OCL Examples

Informal Constraints on Championship

- What are the restrictions?
  - `name` is not empty
  - `minParticipants ≤ maxParticipants`
  - `minParticipants ≥ 0`
  - `maxParticipants > 0`

First OCL constraints



- Name is not empty

Context | Invariant

```
context Championship inv:
  self.name <> ''
```

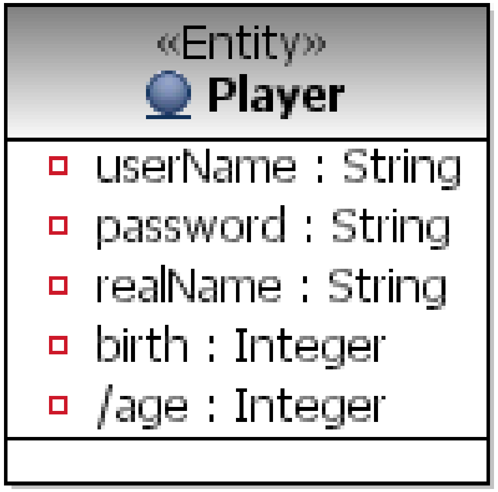
- Constraints on participants

```
context Championship inv:
  self.minParticipants >=
  0
context Championship inv:
  self.maxParticipants >=
  1
context Championship inv:
  self.maxParticipants >=
  self.minParticipants
```

Instance of the class

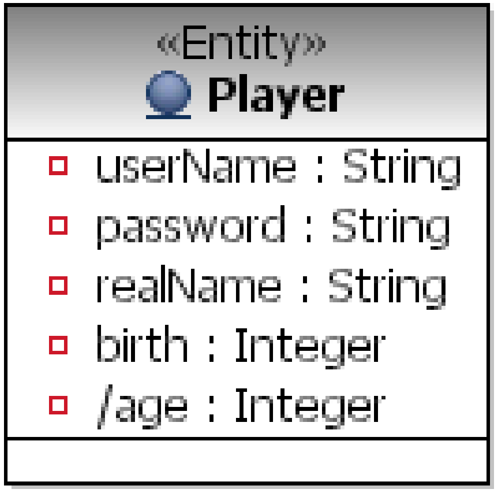
Navigation along attributes

Informal Constraints on Player



- What are the restrictions?
  - `userName` is not empty
  - `userName` is unique
  - `1800 ≤ birth ≤ 3000`
  - `password` is not empty
  - `age = current_year - birth`

Informal Constraints on Player



- 1800 ≤ birth ≤ 3000

```
context Player inv:
  self.birth >= 1800 and
  self.birth <= 3000
```

Get all instances into a collection

Logical AND

- Name is unique

```
context Player inv:
  Player.allInstances()->
  forAll(p1, p2 | p1<>p2 implies
  p1.userName <> p2.userName)
```

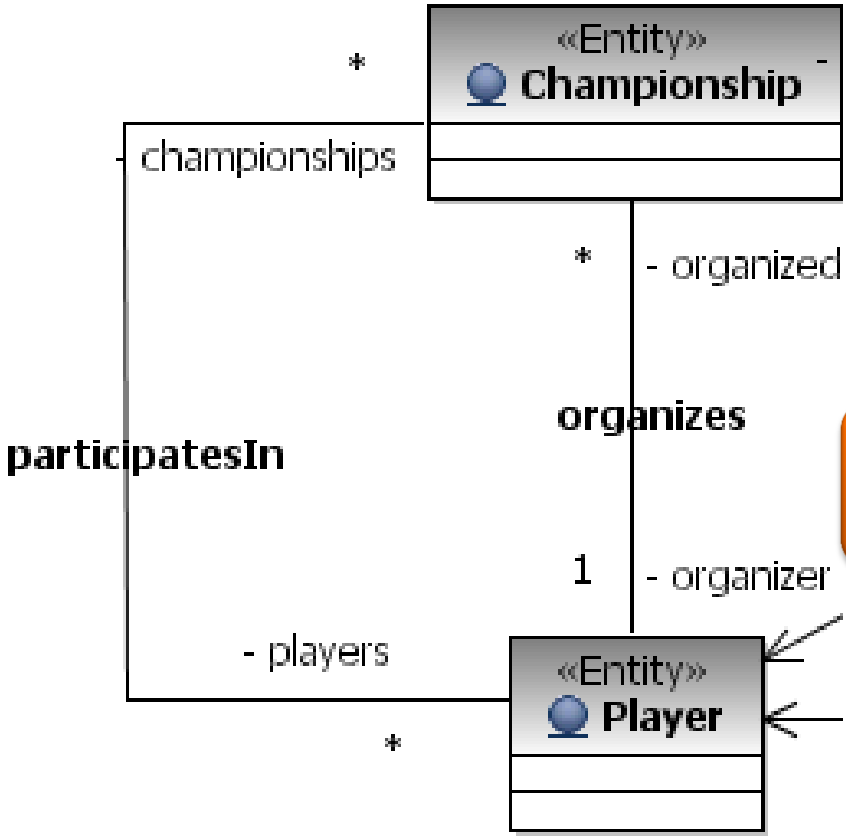
Logical implication

If p1 ≠ p2

Then p1.userName ≠ p2.userName

Universal quantification: For all objects in the collection

Navigation along roles



- Multiplicity 0..1

```
context Championship inv:
  self.organizer.birth > 1976
```

Only attributes of an **object** can be compared with a value

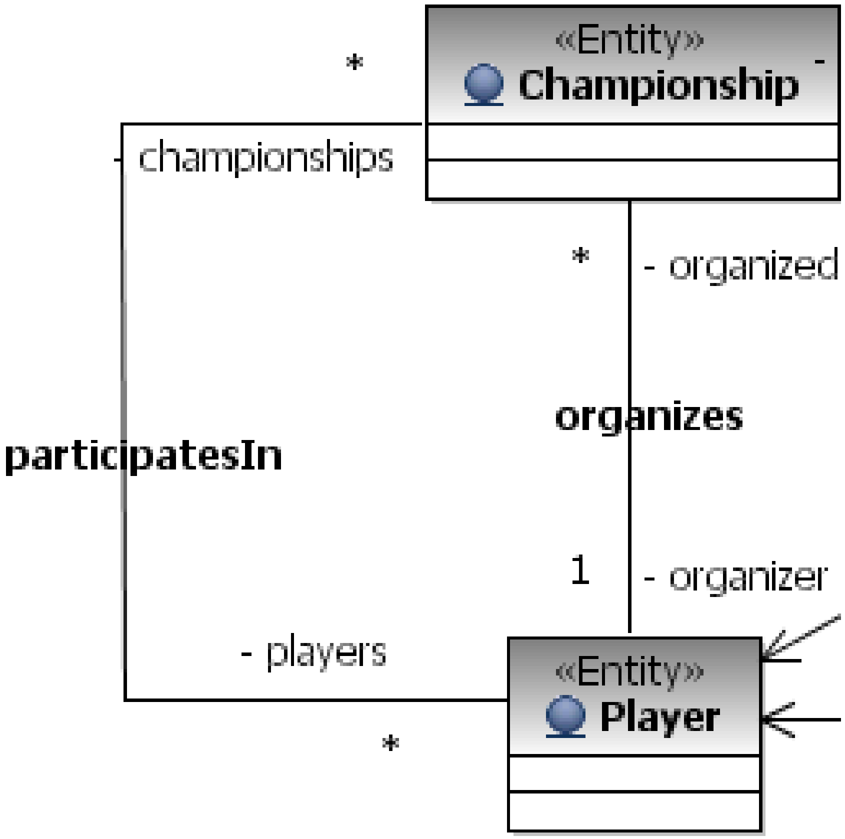
- Multiplicity * (many)

~~`context Championship inv: self.players.birth > 1976`~~

`self.players` results in a **collection**
`self.players.birth`: the coll. of birth years

```
context Championship inv:
  self.players-> …
  (operations on
  collections)
```

Consistency of bidirectional associations



- If a bidirectional association exists between two objects then it is navigable from both directions

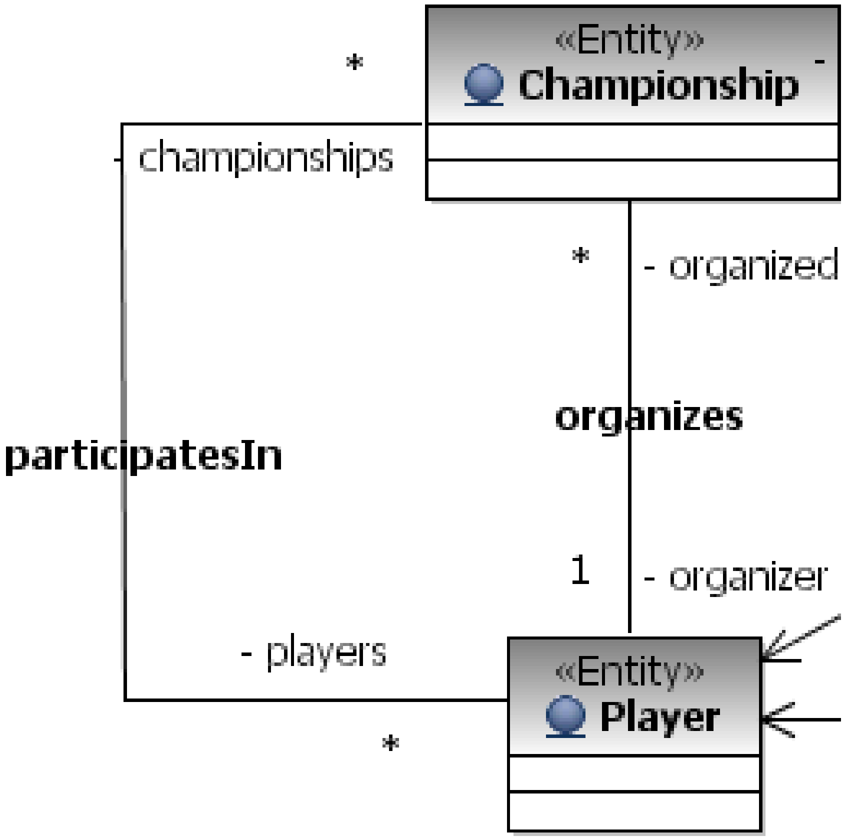
~~context Championship inv:~~
~~self.organizer.organized=self~~

Collection = Single object
Such an equality is invalid

```
context Championship inv:
  self.organizer.organized
  -> includes(self)
```

`Coll->includes(e):` Tests collection membership: **e ∈Coll**

Consistency of bidirectional associations



- If a bidirectional association exists between two objects then it is navigable from both directions

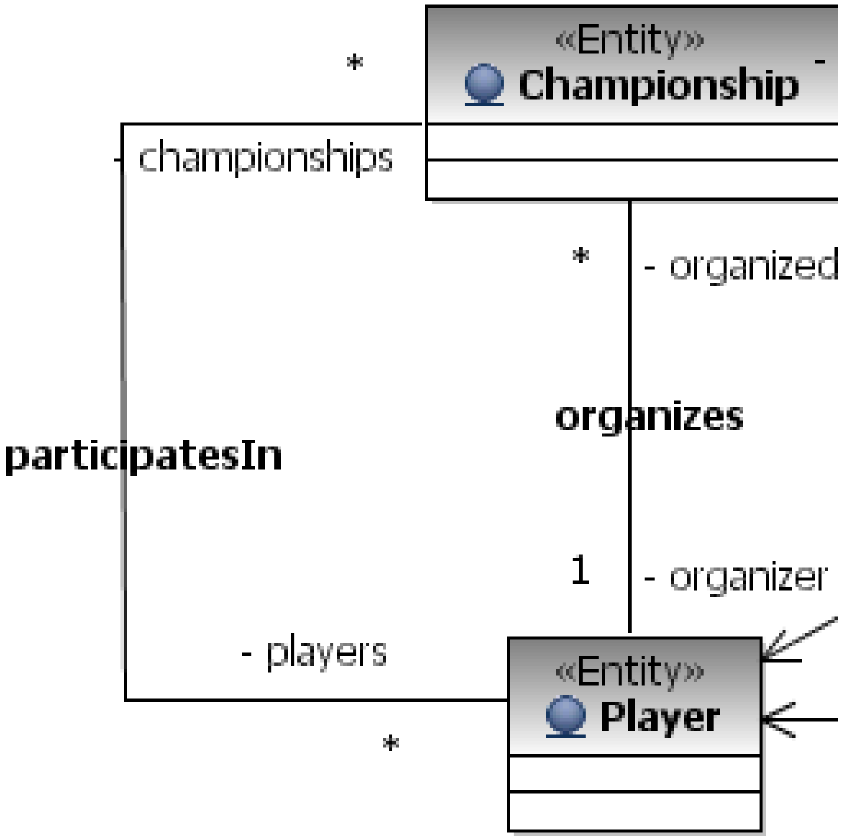
```
context Player inv:
  self.organized->exists(
  c | c.organizer = self)
```

Incorrect: constraint is prescribed **for all** champs

```
context Player inv:
  self.organized->forAll(
  c | c.organizer = self)
```

`Coll->forAll(e|cond(e))`
Quantifiers can only be applied to collections

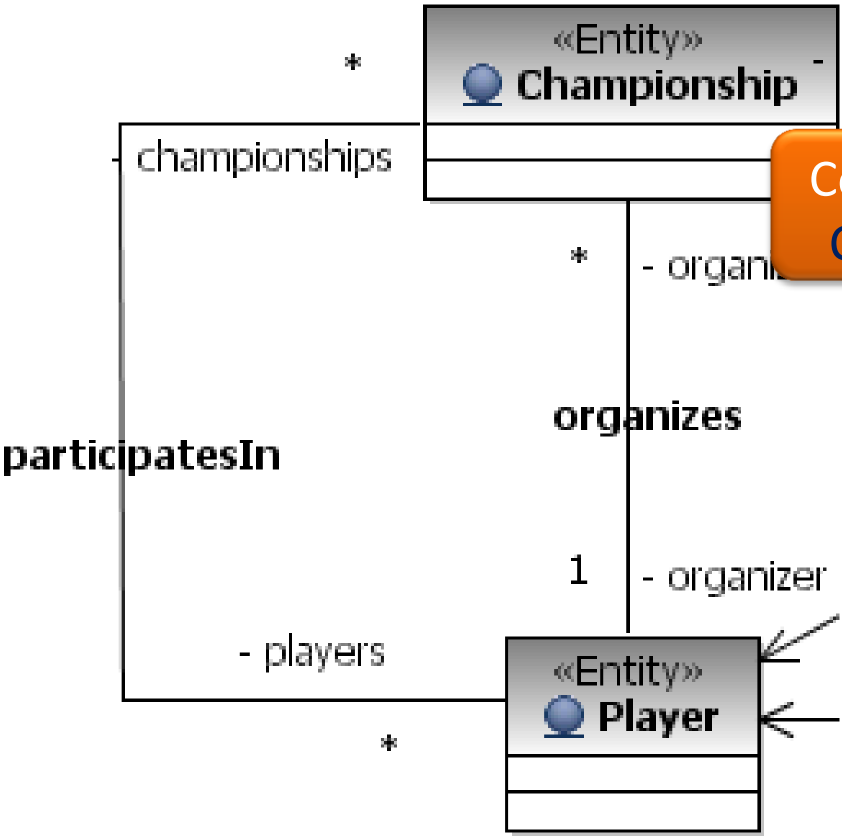
Consistency of bidirectional associations



- If a bidirectional association exists between two objects then it is navigable from both directions

```
context Championship inv:
  self.players->forall(
  p | p.championships->
  includes(self))
context Player inv:
  self.championships->forall(
  c | c.players ->
  includes(self))
```

Consistency of bidirectional associations



- The organizer of the championship organizes at least one championship

~~context Player inv: self.organized->size() > 0~~

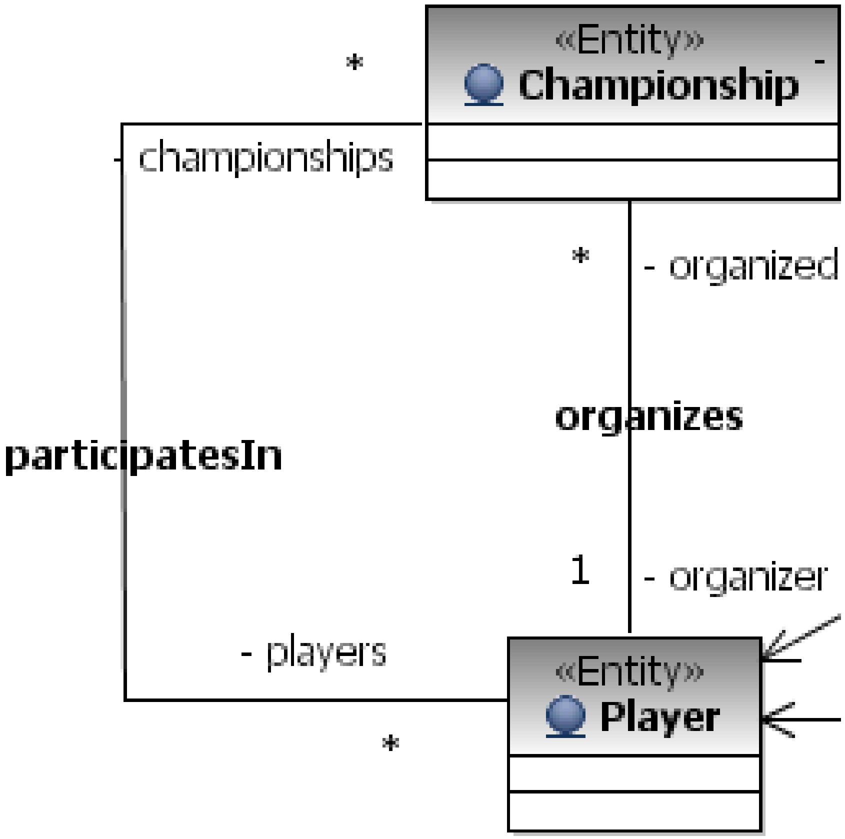
Context should be Championship

No player is forced to organize a champs

```
context Championship inv:
  self.organizer.organized->
  size() > 0
```

```
context Championship inv:
  self.organizer.organized->
  notEmpty()
```

Application specific constraints

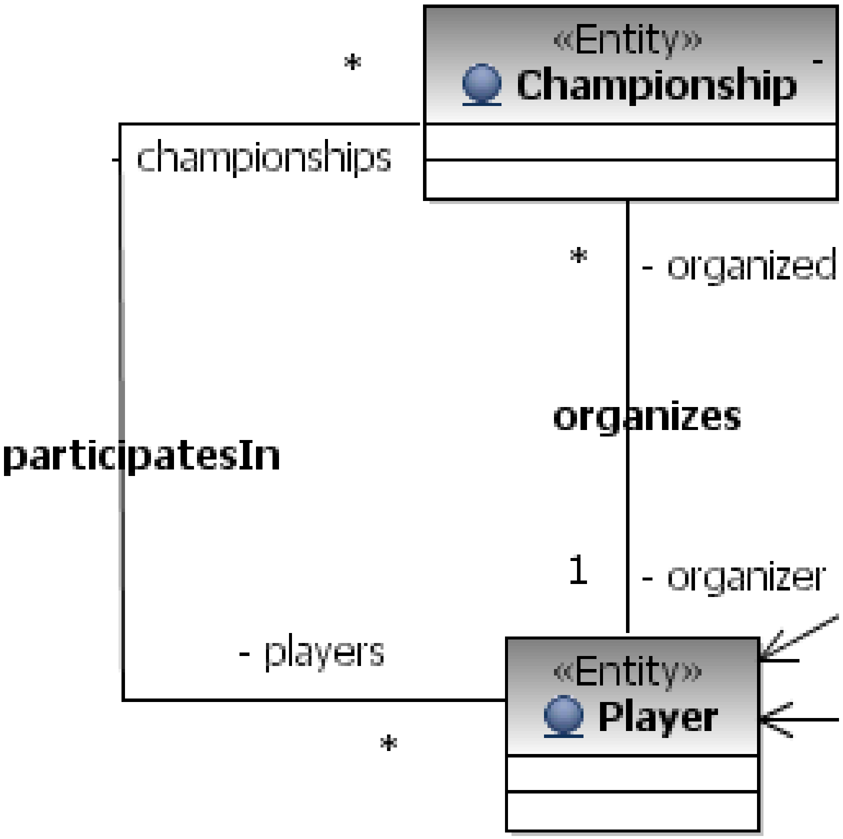


- A player is allowed to organize a single active championship at a time

```
context Player inv:
  self.organized->
  forall(c1, c2 | c1<>c2 implies
  (c1.status = ChS::closed or
   c1.status = ChS::cancelled)
  or
  (c2.status = ChS::closed or
   c2.status = ChS::cancelled))
context Player inv:
  self.organized->select(c |
  c.status = ChS::announced or
  c.status = ChS::started)->
  size() <=1
```

Values of an enumeration

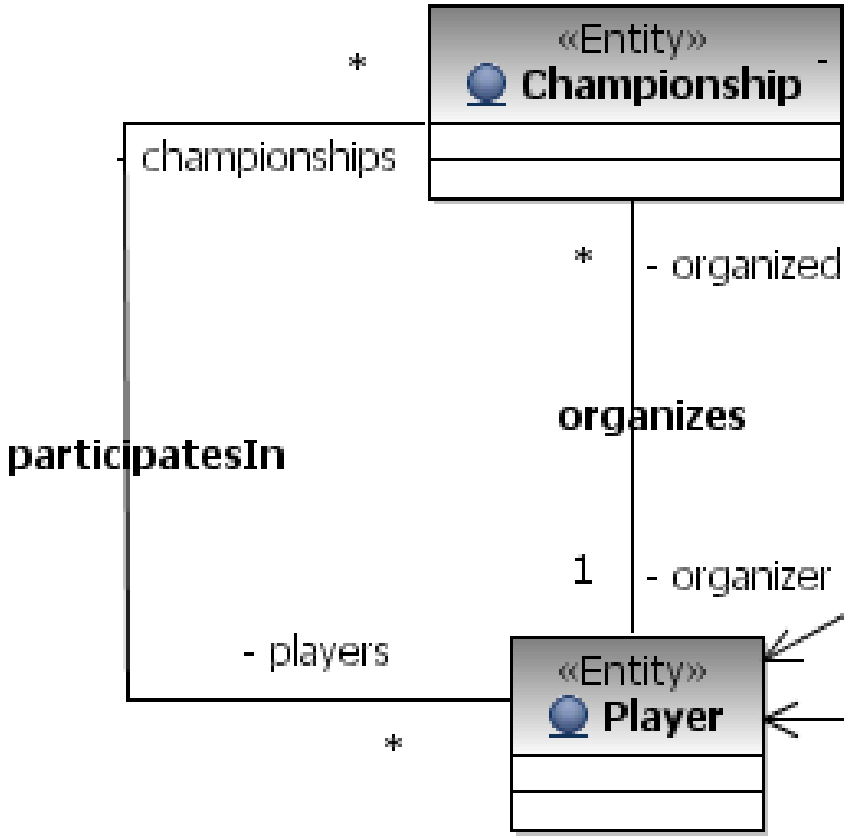
Application specific constraints



- A championship can only be started when the sufficient number of participants are present.

```
context Championship inv:
  (self.status =
  ChampStatus::started or
  self.status =
  ChampStatus::finished)
  implies
  (self.players->size() >=
   self.minParticipants and
   self.players->size() <=
   self.maxParticipants)
```

Application specific constraints



- Youth championship: the average age of participants is below 21.

players.age is the collection of the age attributes of players

```
context Championship inv:
  self.players.age->sum() /
  self.players->size() < 21
```

sum() can only be applied to a collection that contains numbers

An Overview of OCL Constructs

Types and Boole algebra in OCL

- All OCL expressions are typed
  - `OclAny`:
    The type that includes all others. E.g. `x, y : OclAny`
  - `x = y`
    x and y are the same object.
  - `x <> y`
    `not (x = y).`
  - `x.oclType()`
    The type of x.
  - `x.isKindOf ( T )`
    True if T is a supertype (transitive) of the type of x.
  - `T.allInstances() : Collection`
    All the instances of type T.
- Boolean operators:
  - `b and b2, b or b2, b xor b2, not b`
    If any part of a Boolean expression fully determines the result, then it does not matter
    if some other parts of that expression have unknown or undefined results.
  - `b implies b2`
    True if b is false or if b is true and b2 is true.
  - `if b then e1 else e2 endif`
    If b is true the result is the value of e1; otherwise, the result is the value of e2.

Overview of Collection Valued Terms

- Size / aggregation:
  - `c->size()`: Integer
    Number of elements in the collection; for a bag or sequence, duplicates are counted as separate items.
  - `c->sum()`: Integer
    Sum of elements in the collection. Elements must be numbers
  - `c->count(e)`: Integer
    The number of times that e is in c.
  - `c->isEmpty()`: Boolean
    Same as `c->size() = 0`.
  - `c->notEmpty()`: Boolean
    Same as `not c->isEmpty()`.
- Equality
  - `c = c2` : Boolean
- Collection membership
  - `c->includes(e)`: Boolean;
    `c->exists ( x | x = e )`.
  - `c->excludes(e)`: Boolean;
    `not c->includes( e )`.
  - `c->includesAll(c2)`: Boolean;
    c includes all the elements in c2.
  - `c->including(e)`: Collection
    The collection that includes all of c as well as e.
  - `c->excluding(e)`: Collection
    The collection that includes all of c except e.

Overview of Collection Valued Terms

- Existential quantifier:
  - `c->exists(x | P )`:
    Boolean;
    there is at least one element in c, named x, for which predicate P is true.
  - Equivalent notation is:
    `c->exists(P)`,
    `c->exists(x:Type | P(x))`
- Universal quantifier:
  - `c->forAll(x | P)`: Boolean;
    for every element in c, named x, predicate P is true.
  - Equivalent notation is:
    `c->forAll(P)`
    `c->forAll(x:Type | P)`
- Selection:
  - `c->select(x | P)`:
    Collection
    The collection of elements in c for which P is true.
  - Equivalent is: `c->select(P)`
- Filtering:
  - `c->reject(x | P)`:
    Collection
    `c->select(x | not P)`.
  - Equivalent is: `c->reject(P)`
- Collection:
  - `c->collect(x | E)` : Bag
    The bag obtained by applying E to each element of c, named x.
  - `c.attribute` : Collection
    The collection(of type of c) consisting of the attribute of each element of c.

Sets, Bags, Sequences

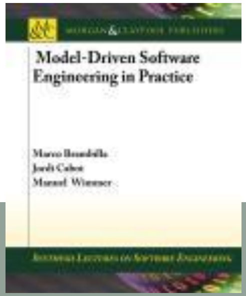
Literals:

```
Set{ 1, 2, 5, 88 }
Set{ 'apple', 'orange',
   'strawberry'}
Sequence{ 1, 3, 45, 2, 3 }
Sequence{ 'ape', 'nut' }
Bag{1, 3, 4, 3, 5 }
Sequence{ 1..(5+4) } =
Sequence{ 1.. 9 } =
Sequence{ 1, 2, 3, 4, 5, 6,
   7, 8, 9 }
```

Traditional operations are defined (union, intersection, etc.)

- Conversion from Collection:
  - `c->asSet()`: Set
    A set corresponding to the collection (duplicates are dropped, sequencing is lost).
  - `c->asSequence()`: Sequence
    A sequence corresponding to the collection.
  - `c->asBag()`: Bag
    A bag corresponding to the collection.
- Comments:
  - `--`

OCL – OBJECT CONSTRAINT LANGUAGE



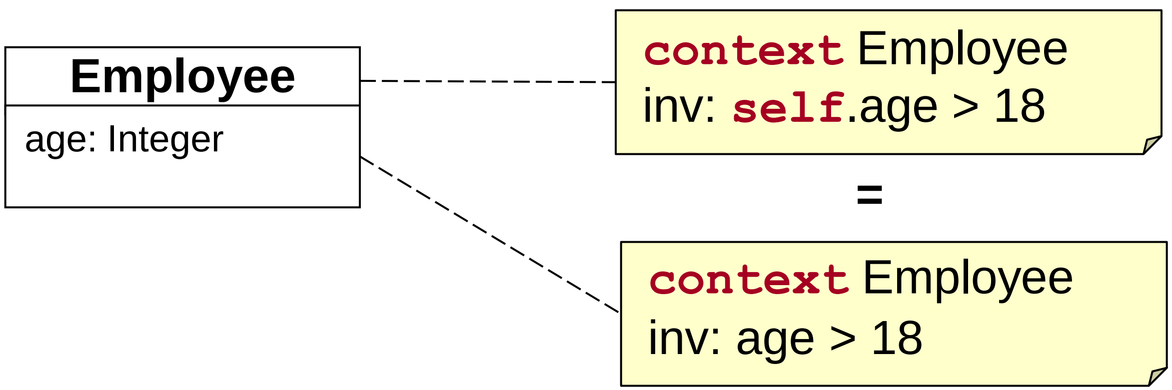
OCL Topics

- Introduction
- OCL Core Language
- OCL Standard Library
- Tool Support
- Examples

Design of OCL

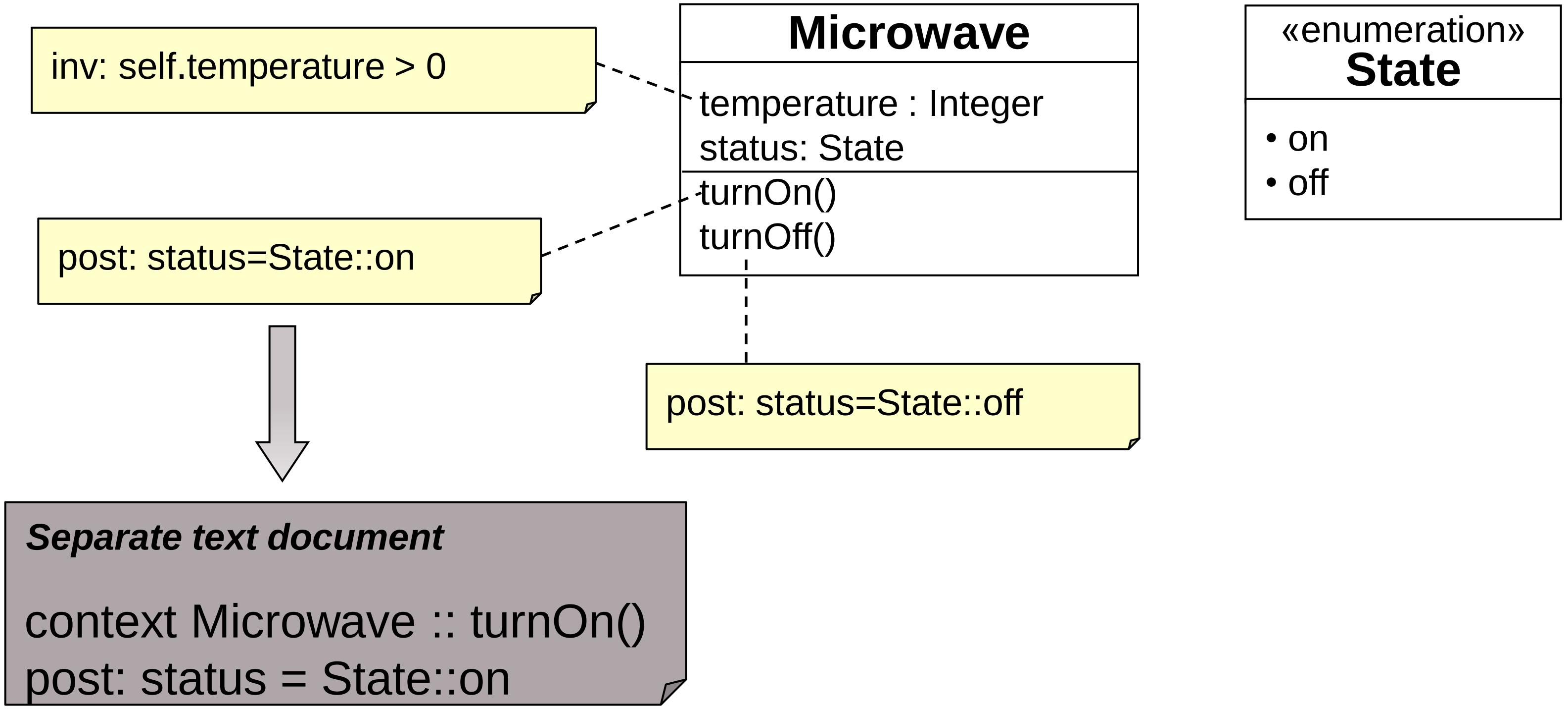
- A context has to be assigned to each OCL-statement
  - **Starting address –** which model element is the OCL-statement defined for
  - Specifies which model elements can be reached using path expressions
- The context is specified by the keyword `context` followed by the name of the model element (mostly class names)
- The keyword `self` specifies the current instance, which will be evaluated by the invariant (context instance).
  - `self` can be omitted if the context instance is unique

- Example:



Design of OCL

- OCL can be specified in **two** different ways
  - As a comment **directly** in the class diagram (context described by connection)
  - Separate document file



Types

- **OCL** is a typed language
  - Each **object, attribute,** and **result** of an operation or navigation is assigned to a **range of values** (type)

- **Predefined types**
  - **Basic types**
    - Simple types: *Integer, Real, Boolean, String*
    - OCL-specific types: *AnyType, TupleType, InvalidType, …*
  - **Set-valued, parameterized Types**
    - Abstract supertyp: Collection(T)
    - Set(T) – no duplicates
    - Bag(T) – duplicates allowed
    - Sequence(T) – Bag with ordered elements, association ends {*ordered*}
    - OrderedSet(T) – Set with ordered elements, association ends {*ordered, unique*}

- **Userdefined Types**
  - Instances of *Class* in MOF and indirect instances of *Classifier* in UML are types
  - *EnumerationType* – user defined set of values for defining constants

Types

Examples

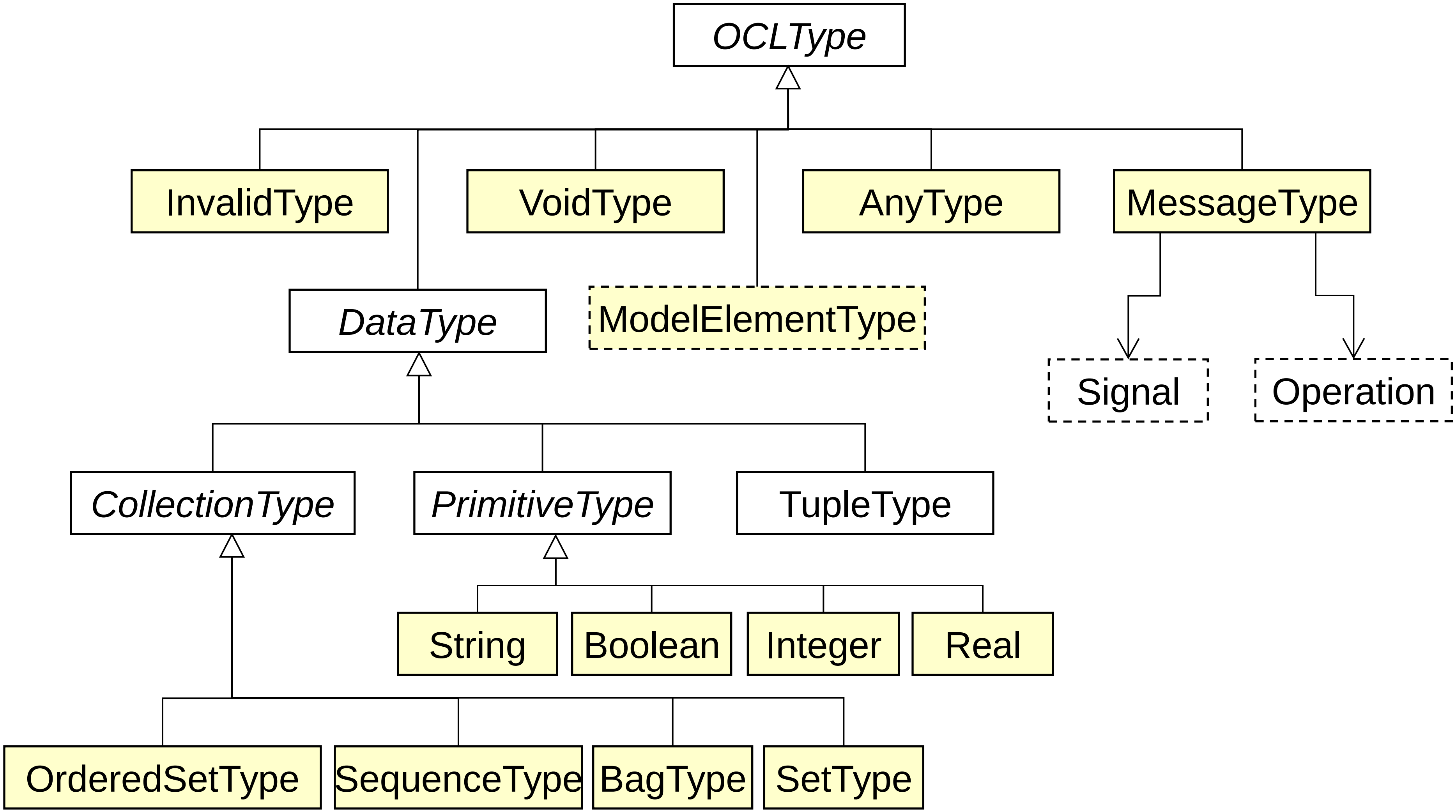
- **Basic types**
  - true, false : *Boolean*
  - -17, 0, 1, 2 : *Integer*
  - -17.89, 0.01, 3.14 : *Real*
  - “Hello World” : *String*

- **Set-valued, parameterized types**
  - Set{ Set{1}, Set{2, 3} } : *Set(Set(Integer))*
  - Bag{ 1, 2.0, 2, 3.0, 3.0, 3 } : *Bag(Real)*
  - Tuple{ x = 5, y = false } : *Tuple{x: Integer, y : Boolean}*

- **Userdefined types**
  - Passenger : *Class*, Flight : *Class*, Provider : *Interface*
  - Status::started - enum Status {started, landed}

Types

OCL meta model (extract)



Expressions

- Each OCL expression is an indirect instance of *OCLExpression*
  - Calculated in certain environment – cf. context
  - Each OCL expression has a **typed return value**
  - **OCL Constraint is an OCL expression with return value Boolean**

- **Simple OCL expressions**
  - *LiteralExp, IfExp, LetExp, VariableExp, LoopExp*

- **OCL expressions for querying model information**
  - *FeatureCallExp* – abstract superclass
  - *AttributeCallExp* – querying attributes
  - *AssociationEndCallExp* – querying association ends
    - Using role names; if no role names are specified, lowercase class names have to be used (if unique)
  - *AssociationClassCallExp* – querying association class (only in UML)
  - *OperationCallExp* – Call of query operations
    - Calculate a value, but do **not** change the system state!

Expressions

- Examples for *LiteralExp, IfExp, VariableExp, AttributeCallExp*

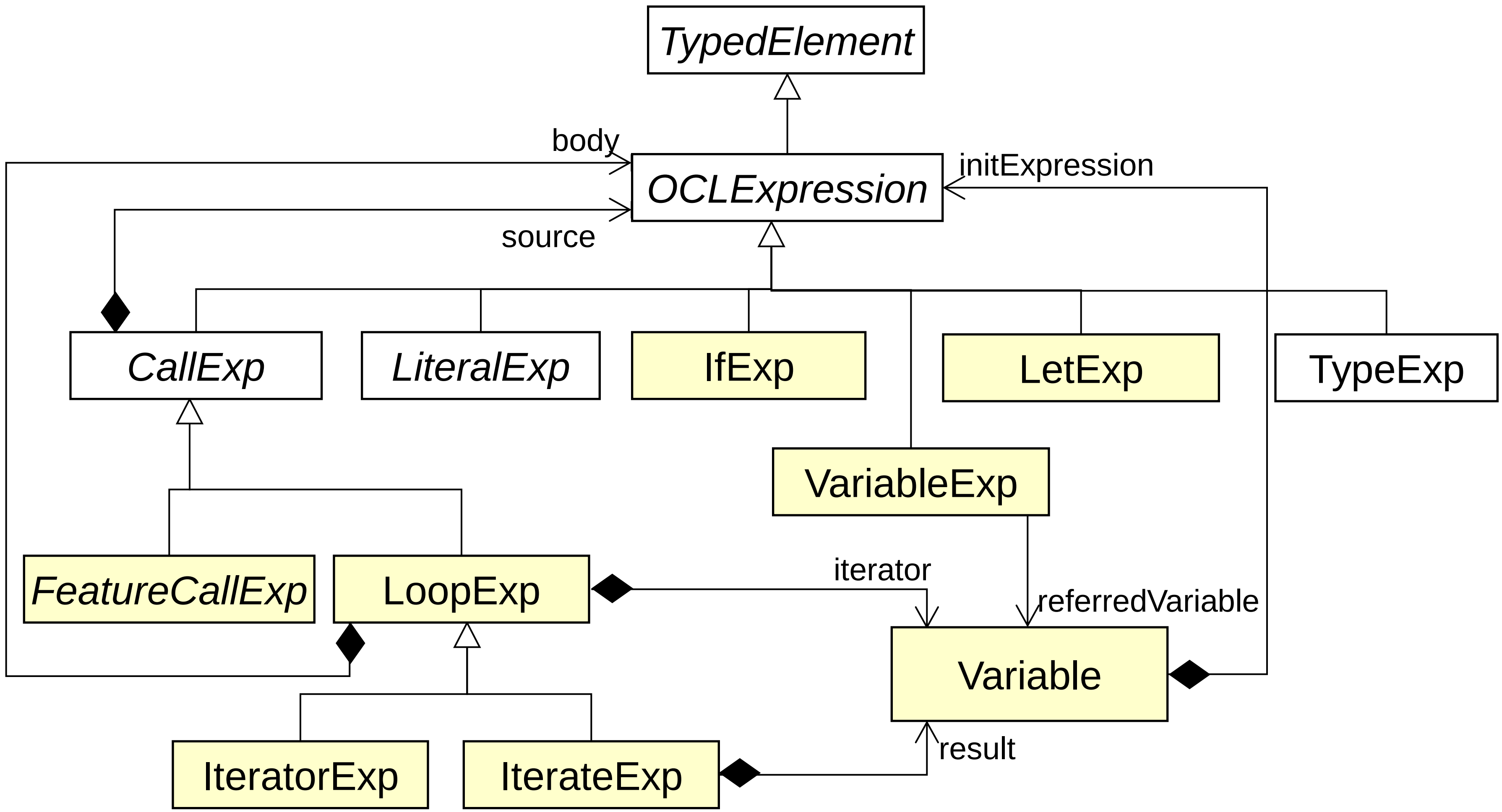
LetExp | VariableExp | AttributeCallExp | IntegerLiteralExp | IfExp

```
let annualIncome : Real = self.monthlyIncome * 14 in
   if self.isUnemployed then
        annualIncome < 8000
   else
        annualIncome >= 8000
   endif
```

- **Abstract syntax** of OCL is described as **meta model**
- **Mapping from abstract syntax to concrete syntax**
  - *IfExp -> **if** Expression **then** Expression **else** Expression **endif***

Expressions

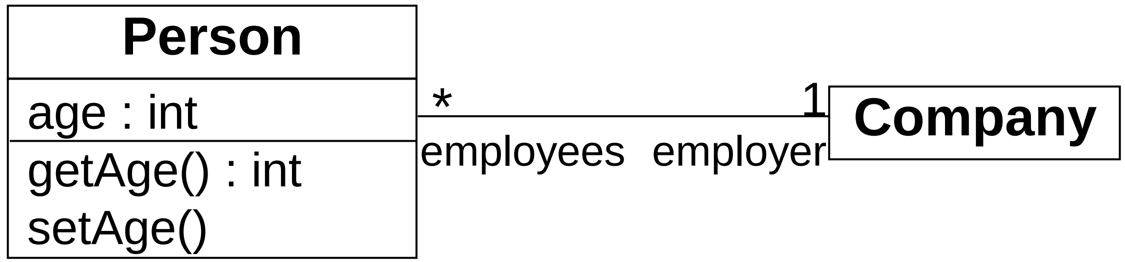
OCL meta model (extract)



LiteralExp: *CollectionLiteralExp*, *PrimitiveLiteralExp*, *TupleLiteralExp*, *EnumLiteralExp*

Query of model information

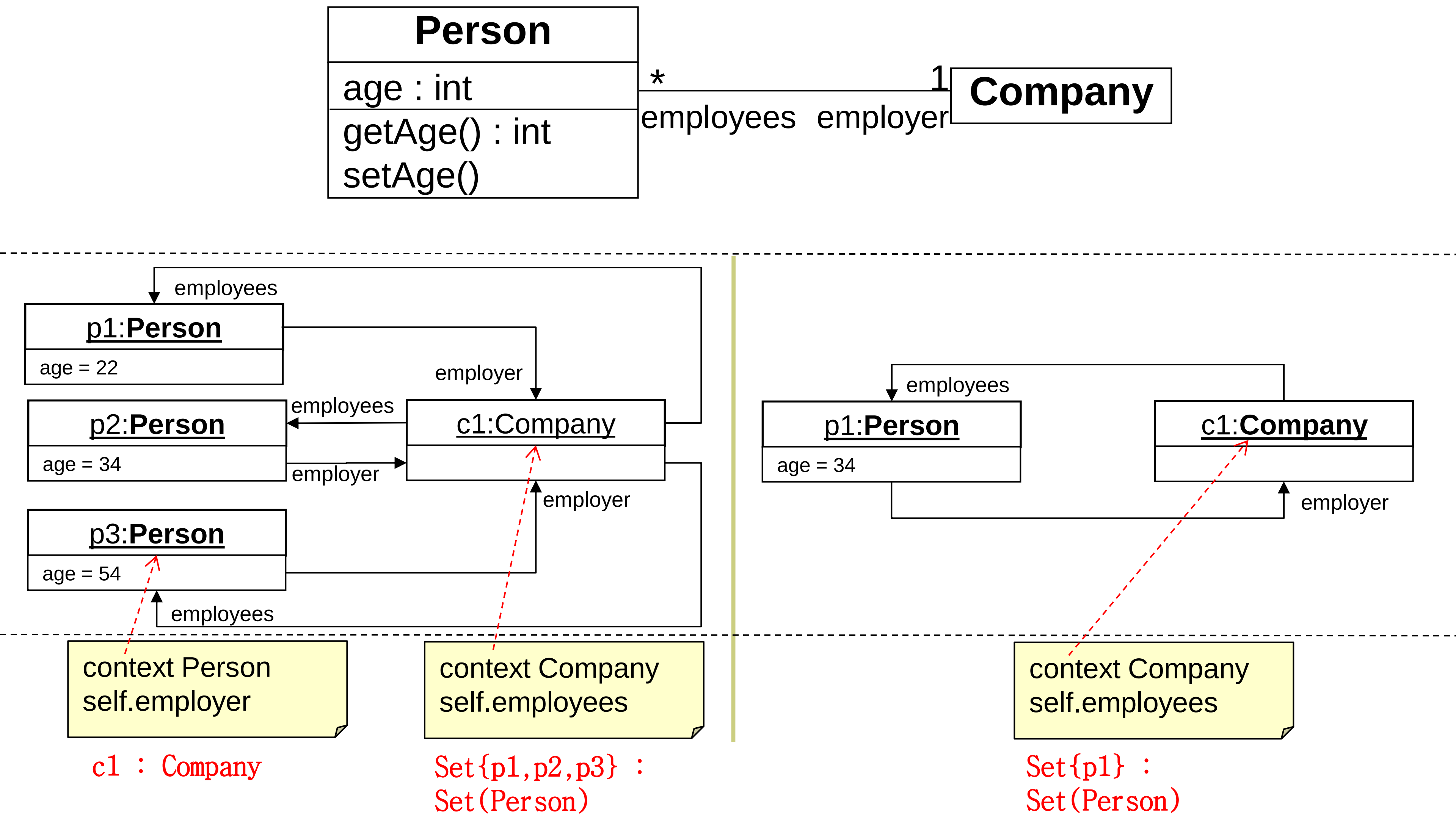
- Context instance
  - `context` **`Person`**
- AttributeCallExp
  - `self.age : int`



- OperationCallExp
  - Operations must not have **side effects**
  - Allowed: `self.getAge() : int`
  - **Not allowed**: `self.setAge()`
- AssociationEndCallExp
  - Navigate to the opposite association end using role names
    `self.employer` – Return value is of type ***Company***
  - Navigation often results into a set of objects – Example
    `context` **`Company`**
    `self.employees` – Return value is of type **Set (Person)**

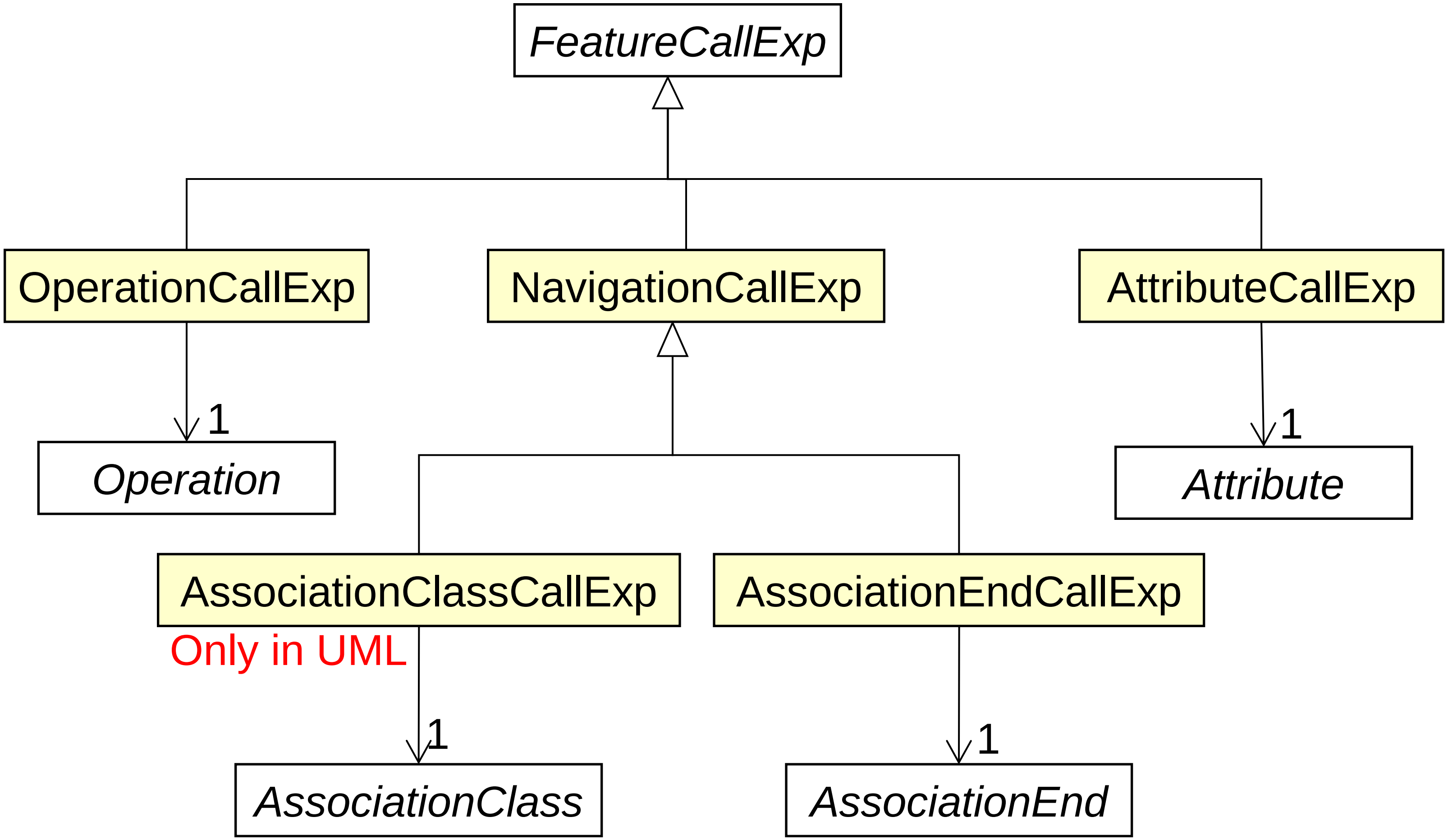
Query of model information

Example



Query of model information

OCL meta model (extract)



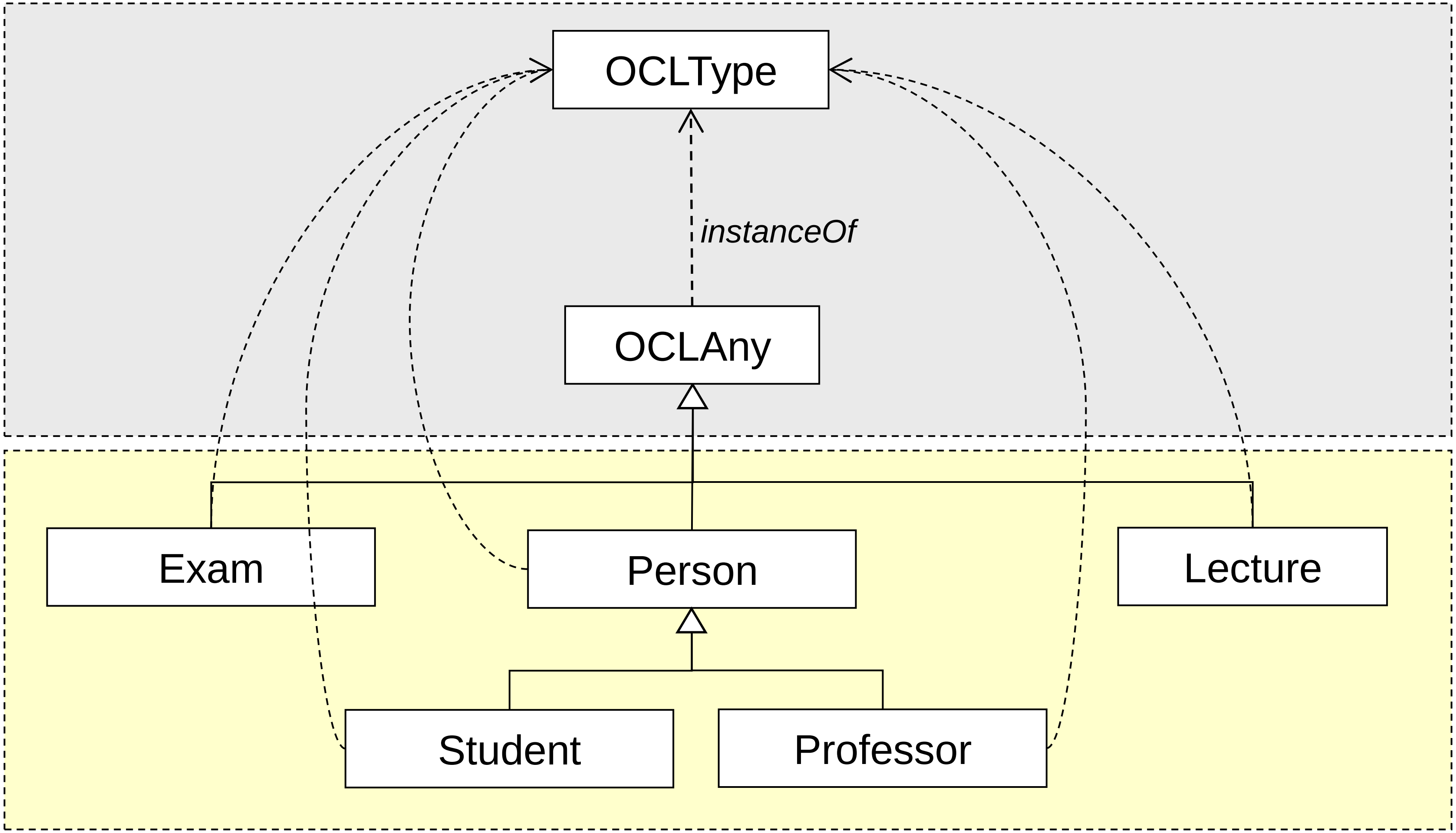
OCL Library: Operations for OclAny

- *OclAny* - **Supertype** of all other types in OCL
  - **Operations** are **inherited** by all other types.
- **Operations** of *OclAny* (extract)
  - Receiving object is denoted by *obj*

Operation	**Explanation of result**
=(obj2:OclAny):Boolean	True, if *obj2* and *obj* reference the same object
oclIsTypeOf(type:OclType):Boolean	True, if *type* is the type of *obj*
oclIsKindOf(type:OclType): Boolean	True, if *type* is a direct or indirect supertype or the type of *obj*
oclAsType(type:Ocltype): Type	The result is *obj* of type *type*, or *undefined*, if the current type of *obj* is not *type* or a direct or indirect subtype of it (casting)

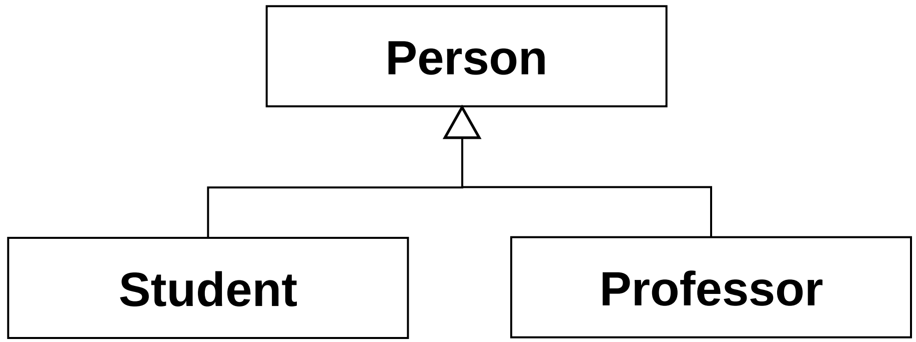
Operations for OclAny

Predefined environment for model types



Operations for OclAny

- ***oclIsKindOf vs. oclIsTypeOf***



context **Person**
self.oclIsKindOf(Person) : *true*
self.oclIsTypeOf(Person) : *true*
self.oclIsKindOf(Student) : *false*
self.oclIsTypeOf(Student) : *false*

context **Student**
self.oclIsKindOf(Person) : *true*
self.oclIsTypeOf(Person) : *false*
self.oclIsKindOf(Student) : *true*
self.oclIsTypeOf(Student) : *true*
self.oclIsKindOf(Professor) : *false*
self.oclIsTypeOf(Professor) : *false*

Operations for simple types

- **Predefined** simple types
  - Integer {Z}
  - Real {R}
  - Boolean {true, false}
  - String {ASCII, Unicode}

- Each simple type has predefined operations

Simple type	**Predefined operations**
Integer	*, +, -, /, abs(), …
Real	*, +, -, /, floor(), …
Boolean	and, or, xor, not, implies
String	concat(), size(), substring(), …

Operations for simple types

- Syntax
  - v.operation(para1, para2, …)
    - Example: “bla”.**concat**(“bla”)
  - Operations without brackets (Infix notation)
    - Example: 1 **+** 2, true **and** false

Signature	**Operation**
Integer **X** *Integer* → *Integer*	{+, -, *}
t1 **X** *t2* → *Boolean*	{<,>,≤,≥}, *t1, t2* typeOf {Integer or Real}
Boolean **X** *Boolean* → *Boolean*	{and, or, xor, implies}

Operations for simple types

Boolean operations - semantic

- OCL is based on a **three-valued (trivalent) logic**
  - Expressions are mapped to the three values {true, false, undefined}
- Semantic of the operations
  - $\mathcal{M}$(I, *exp*)= *I(exp)*, if exp not further resolvable
  - $\mathcal{M}$(I, **not** *exp*)= ¬$\mathcal{M}$ (I, *exp*)
  - $\mathcal{M}$(I,(*exp1* **and** *exp2*)) = $\mathcal{M}$(I, *exp1*) $\wedge$ $\mathcal{M}$(I, *exp2*)
  - $\mathcal{M}$(I,(*exp1* **or** *exp2*)) = $\mathcal{M}$(I, *exp1*) $\vee$ $\mathcal{M}$(I, *exp2*)
  - $\mathcal{M}$(I,(*exp1* **implies** *exp2*)) = $\mathcal{M}$(I, *exp1*) $\rightarrow$ $\mathcal{M}$(I, *exp2)*

Undefined: Return value if an expression fails

1. Access on the first element of an empty set
2. Error during *Type Casting*
3. …

- Truth table: true(1), false (0),undefined (?)

¬	
0	1
1	0
?	?

∧	0	1	?
0	0	0	0
1	0	1	?
?	0	?	?

∨	0	1	?
0	0	1	?
1	1	1	1
?	?	1	?

→	0	1	?
0	1	1	1
1	0	1	?
?	?	1	?

Operations for simple types

Boolean operations - semantic

- Simple example for an **undefined** OCL expression
  - *1/0*

- **Query** if undefined– OCLAny.oclIsUndefined()
  - *(1 / 0).oclIsUndefined() : true*

- Examples for the evaluation of Boolean operations
  - *(1/0 = 0.0)* ***and*** *false : false*
  - *(1/0 = 0.0)* ***or*** *true : true*
  - *false* ***implies*** *(1.0 = 0.0) : true*
  - *(1/0 = 0.0) implies true : true*

Operations for collections

- Collection is an **abstract supertype** for all set types
  - Specification of the **mutual** operations
  - *Set, Bag, Sequence, OrderedSet* inherit these operations
- **Caution:** Operations with a return value of a set-valued type create a new collection (no side effects)
- Syntax: v -> op(…) – Example: {1, 2, 3} -> size()

- Operations of collections (extract)
  - Receiving object is denoted by *coll*

Operation	**Explanation of result**
size():Integer	Number of elements in *coll*
includes(obj:OclAny):Boolean	True, if *obj* exists in *coll*
isEmpty:Boolean	True, if *coll* contains no elements
sum:T	Sum of all elements in *coll* Elements have to be of type Integer or Real

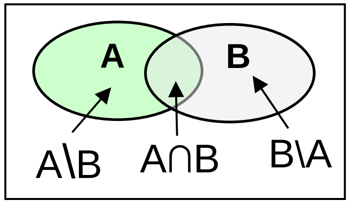
Operations for collections

- **Model operations vs. OCL operations**

OCL-Constraint	*Semantic*
context Container inv: self.content -> first().isEmpty()	Operation *isEmpty()* always has to return true
context Container inv: self.content -> isEmpty()	Container instances must not contain bottles

Operationen for Set/Bag

- *Set* and *Bag* define additional operations
  - Generally based on **theory of set concepts**



- **Operations** of **Set** (extract)
  - Receiving object is denoted by set

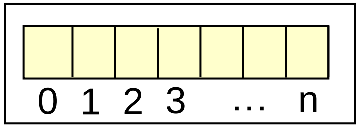
Operation	Explanation of result
union(set2:Set(T)):Set(T)	Union of *set* and *set2*
intersection(set2:Set(T)):Set(T)	Intersection of *set* and *set2*
difference(set2:Set(T)):Set()	Difference set; elements of *set*, which do not consist in *set2*
symmetricDifference(set2:Set(T)): Set(T)	Set of all elements, which are either in *set* or in *set2*, but do not exist in both sets at the same time

- **Operations** of **Bag** (extract)
  - Receiving object is denoted by bag

Operation	Explanation of result
union(bag2:Bag(T)):Bag(T)	Union of *bag* and *bag2*
intersection(bag2:Bag(T)): Bag(T)	Intersection of *bag* and *bag2*

Operations for OrderedSet/Sequence

- *OrderedSet* and *Sequences* define additional operations
  - Allow access or modification through an **Index**



- **Operations** of **OrderedSet** (extract)
  - Receiving object is denoted by *orderedSet*

Operation	Explanation of result
first:T	First element of *orderedSet*
last:T	Last element of *orderedSet*
at(i:Integer):T	Element on index i of *orderedSet*
subOrderedSet(lower:Integer, upper:Integer):OrderedSet(T)	Subset of *orderedSet,* all elements of *orderedSet* including the element on position *lower* and the element on position *upper*
insertAt(index:Integer,object:T) :OrderedSet(T)	Result is a copy of the *orderedSet*, including the element *object* at the position *index*

- **Operations** of **Sequence**
  - Analogous to the operations of OrderedSet

Iterator-based operations

- OCL defines operations for *Collections* using *Iterators*
  - Expression Package: LoopExp
  - **Projection** of new *Collections* out of existing ones
  - Compact **declarative specification** instead of imperative algorithms

- Predefined Operations
  - select(exp) : *Collection*
  - reject(exp) : *Collection*
  - collect(exp) : *Collection*
  - forAll(exp) : *Boolean*
  - exists(exp) : *Boolean*
  - isUnique(exp) : *Boolean*

- iterate(…) – Iterate over all elements of a *Collection*
  - Generic operation
  - Predefined operations are defined with iterate(…)

Iterator-based operations

Select-/Reject-Operation

- **Select** and **Reject** return subsets of collections
  - Iterate over the complete collection and collect elements
- Select
  - **Result**: Subset of collection, including elements where *booleanExpr* is **true**

```
collection -> select( v : Type | booleanExp(v) )
collection -> select( v | booleanExp(v) )
collection -> select( booleanExp )
```

- Reject
  - **Result**: Subset of collection, including elements where *booleanExpr* is **false**
  - Just *Syntactic* Sugar, because each *reject-Operation* can be defined as a *select-Operation* with a negated expression

```
collection-> reject(v : Type | booleanExp(v))
```

=

```
collection-> select(v : Type | not (booleanExp(v)))
```


Iterator-based operations

Select-/Reject-Operation

- Semantic of the *Select-Operation*

OCL

```
context Company inv:
   self.employee -> select(e : Employee | e.age>50)  ->
notEmpty()
```

Java

```
List persons<Person> = new List();
for ( Iterator<Person> iter = comp.getEmployee();
iter.hasNext() ){
    Person p = iter.next();
    if ( p.age > 50 ){
        persons.add(p);
    }
}
```

Iterator-based operations

Collect-Operation

- *Collect-Operation* returns a new collection from an existing one. It collects the **Properties** of the objects and not the objects itself.
  - Result of *collect* always **Bag<T>**.**T** defines the type of the property to be collected

collection -> collect(v : Type | exp(v))
collection -> collect(v | exp(v))
collection -> collect(exp)

- Example
  - *self.employees -> collect(age)* – Return type: Bag(Integer)
- Short notation for collect
  - *self.employees.age*

Iterator-based operations

Collect-Operation

- Semantic of the *Collect-Operator*

OCL

```
context Company inv:
  self.employee -> collect(birthdate) -> size() > 3
```

Java

```
List birthdate<Integer> = new List();
for ( Iterator<Person> iter = comp.getEmployee();
iter.hasNext() ){
    birthdate.add(iter.next().getBirthdate()); }
```

- Use of *asSet()* to eliminate duplicates

OCL

```
context Company inv:
  self.employee -> collect(birthdate) -> asSet()
```

Set (without duplicates)

Bag (with duplicates)

Iterator-based operations

ForAll-/Exists-Operation

- **ForAll** checks, if all elements of a collection evaluate to true

```
collection -> forAll( v : Type | booleanExp(v) )
collection -> forAll( v | booleanExp(v) )
collection -> forAll( booleanExp )
```

- **Example:** self.employees -> forAll(age > 18)

- **Nesting** of forAll-Calls (*Cartesian Product*)

```
context Company inv:
self.employee->forAll (e1 | self.employee -> forAll (e2 |
        e1 <> e2 implies e1.svnr <> e2.svnr))
```

- ***Alternative***: Use of multiple iterators

```
context Company inv:
self.employee -> forAll (e1, e2 | e1 <> e2 implies e1.svnr <> e2.svnr))
```

- **Exists** checks, if at least one element evaluates to true
  - Beispiel: employees -> exists(e: Employee | e.isManager = true)

Iterator-based operations

Iterate-Operation

- **Iterate** is the generic form of all iterator-based operations

- **Syntax**
  collection -> iterate(**elem** : Typ; **acc** : Typ =
  <initExp> | **exp(elem**, **acc**))
  - Variable **elem** is a typed ***Iterator***
  - Variable **acc** is a typed ***Accumulator***
  - Gets assigned initial value initExp
  - **exp(elem, acc)** is a function to calculate **acc**

- **Example**
  collection -> collect(x : T | x.property)

  -- semantically equivalent to:

  collection -> iterate(x : T; acc : T2 = Bag{} | acc -> including(x.property))

Iterator-based operations

Iterate-Operator

- Semantic of the *Iterate-Operator*

OCL

```
collection -> iterate(x : T; acc : T2 = value | acc -> u(acc, x)
```

Java

```
iterate (coll : T, acc : T2 = value){
        acc=value;
        for( Iterator<T> iter =
coll.getElements(); iter.hasNext(); ){
                T elem = iter.next();
                acc = u(elem, acc);
        }
}
```

- Example
  - Set{1, 2, 3} -> iterate(i:Integer, a:Integer=0 | a+i)
  - Result: 6

Tool Support

- **Wishlist**
  - Syntactic analysis: Editor support
  - Validation of logical consistency (Unambiguous)
  - Dynamic validation of invariants
  - Dynamic validation of Pre-/Post-conditions
  - Code generation and test automation

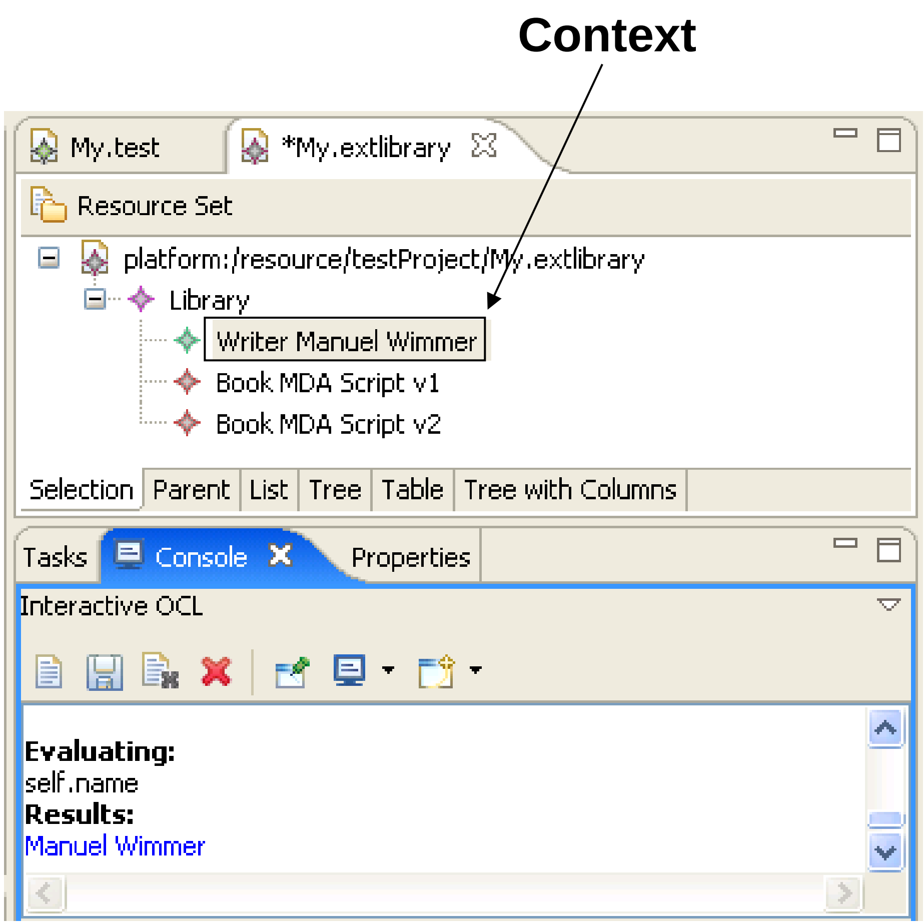
- **Today**
  - UML-tools provide OCL-editors
  - MDA-tools provide code generation of OCL-expressions
  - Meta modeling platforms provide the opportunity to define OCL Constraints for meta models.
    - The editor should dynamically check constraints or restrict modeling, respectively.

OCL Tools

- Some OCL-parsers, which check the syntax of OCL-constraints and apply them to the models, are for free.
  - IBM Parser
- Dresden OCL Toolkit 2.0
  - Generation of Java code out of OCL-constraints
  - Possible integration with ArgoUML
- OCL-frameworks are originated in the areas of EMF and the UML2 project of Eclipse
  - Octopus
  - Frauenhofer Toolkit
  - OSLO
  - EMFT OCL-Framework/Query-Framework

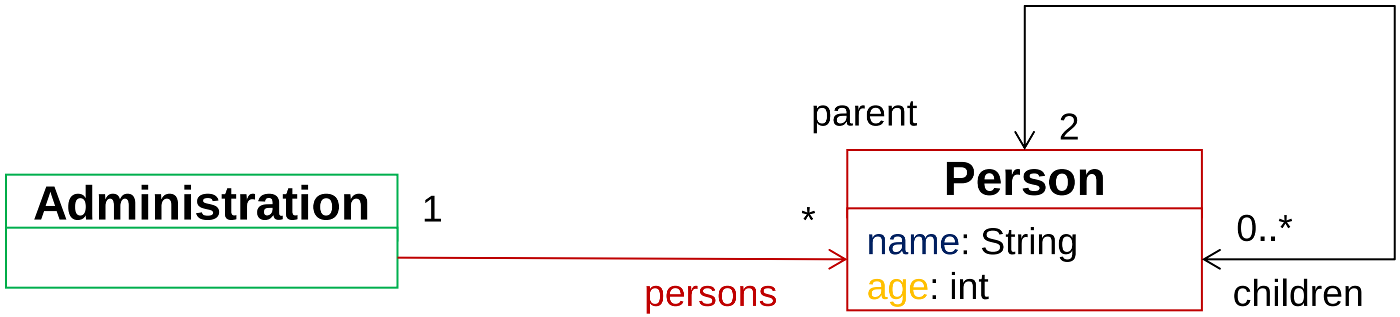
OCL-Tools

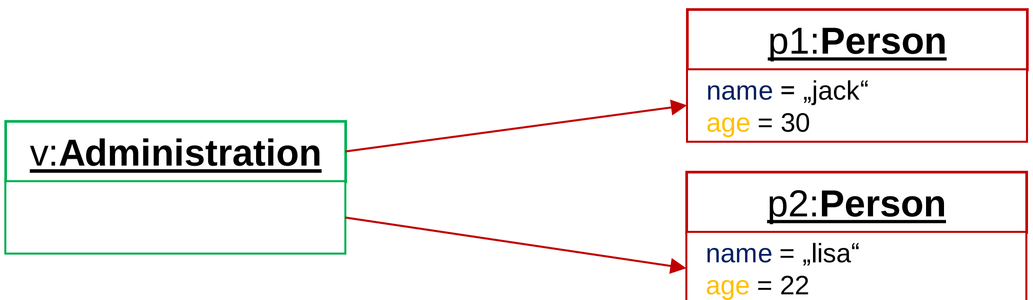
- **EMFT OCL-Framework**
  - Based on EMF
  - *OCL-API* – Enables the use of OCL in Java programs
  - *Interactive OCL Console* – Enables the definition and evaluation of OCL-constraints
- **EMFT Query-Framework**
  - **Goal**: SQL-like query of model information
  - **select** exp **from** exp **where** *oclExp*



TUWEL: Interactive OCL Console Screencast

Example 1: Navigation (1)

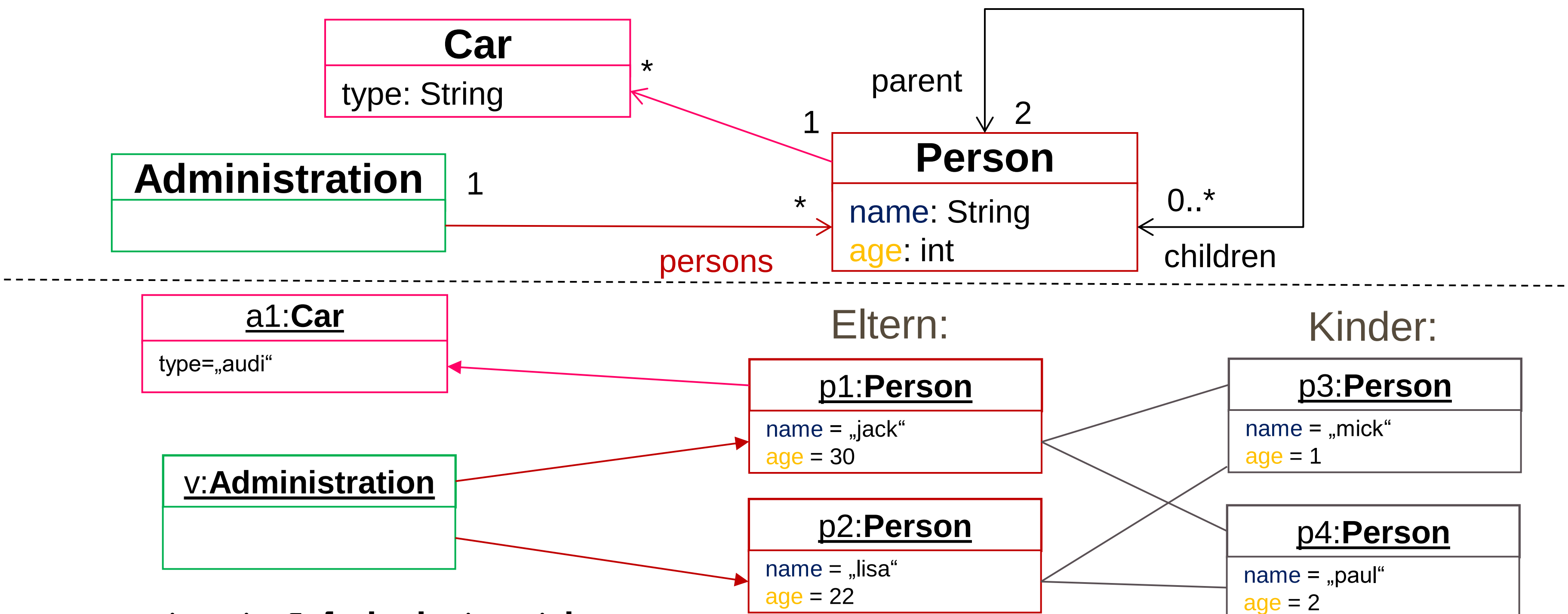




context Administration:

- self.persons → {Person p1, Person p2}
- self.persons.name → {jack, lisa}
- self.persons.alter → {30, 22}

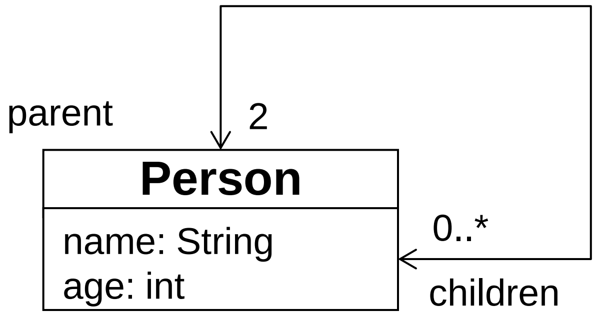
Example 1: Navigation (2)



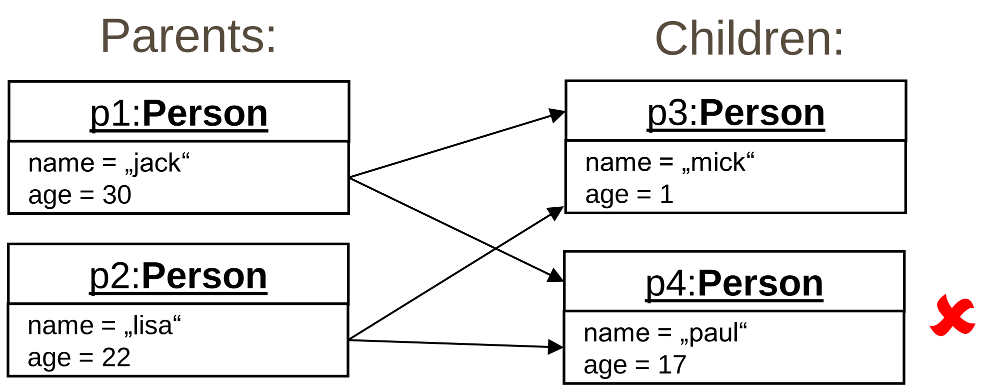
context Administration:

- `self.persons.children` → {{p3, p4}, {p3, p4}}
- `self.persons.children.parent` → {{{p1, p2}, {p1, p2}}, ...}
- `self.persons.car.type` → {{"audi"}}

Example 2: Invariant (1)

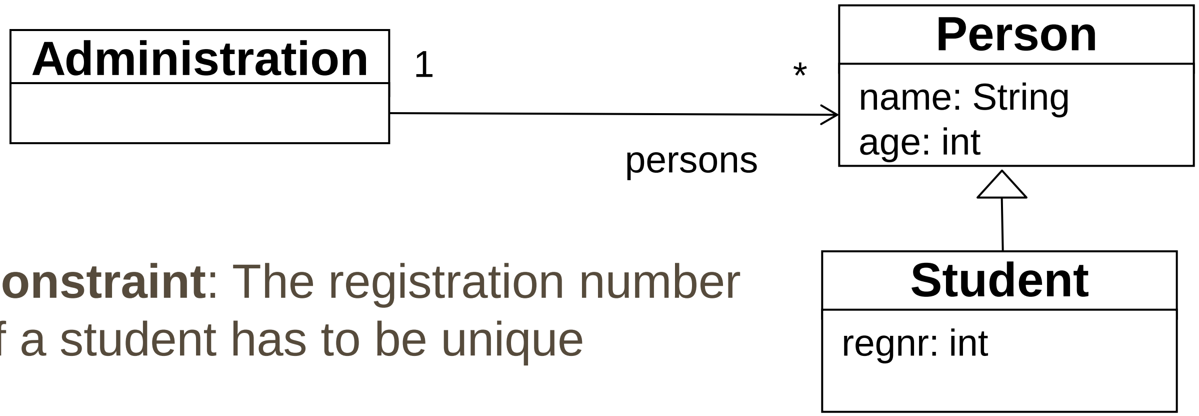


Constraint: A child is at least 15 years younger than his parents.




```
context Person
inv: self.children->forAll(k : Person | k.age
 < self.age-15)
```

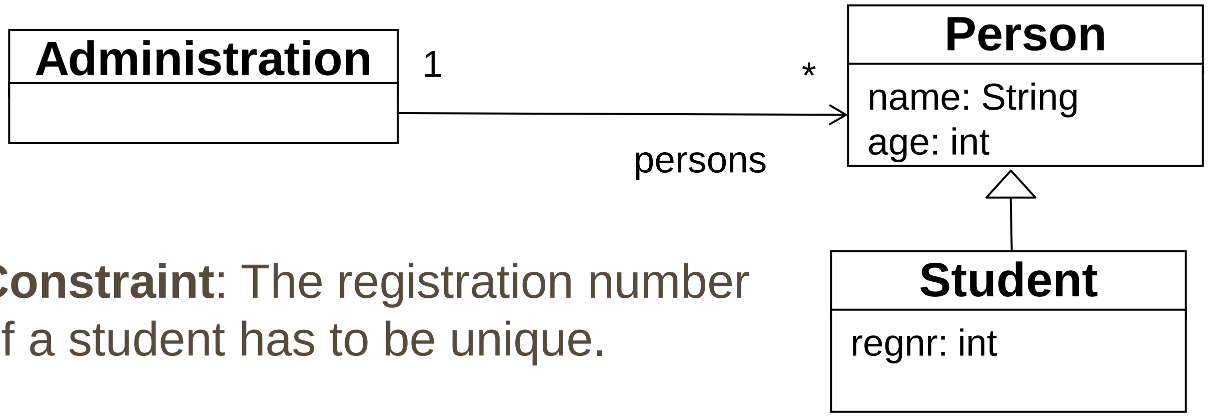
Example 2: Invariant (2)



Constraint: The registration number of a student has to be unique

```
context Administration
inv uniqueRegnr :
  self.persons -> select(e : Person| e.oclIsTypeOf(Student))
                              -> forAll(e1 |
   self.persons -> select(e : Person | e.oclIsTypeOf(Student))
                              -> forAll(e2 |
  e1 <> e2 implies   e1.oclAsType(Student).regnr        <>
                                        e2.oclAsType(Student).regnr))
```

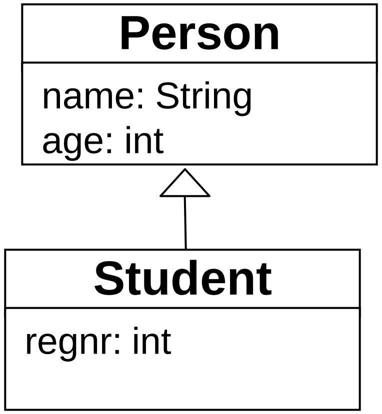
Example 2: Invariant (2) cont.



Constraint: The registration number of a student has to be unique.

```
context Administration
inv uniqueRegnr :
  self.persons -> select(e : Person| e.oclIsTypeOf(Student))
       -> forAll(e1, e1 | e1 <> e2 implies
       e1.oclAsType(Student).regnr <>
       e2.oclAsType(Student).regnr)
       )
```

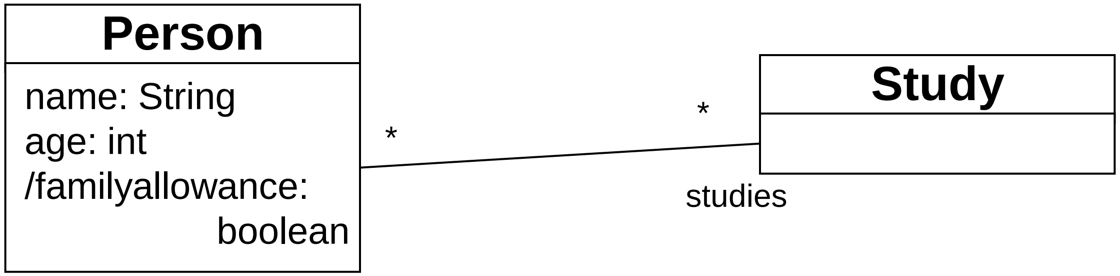
Example 2: Invariant (2) cont.



Constraint: The registration number of a student has to be unique.

```
context Student
inv uniqueRegnr :
  Student.allInstances() -> forAll(e1, e1 | e1 <> e2 implies
        e1.oclAsType(Student).regnr <>
        e2.oclAsType(Student).regnr))
```

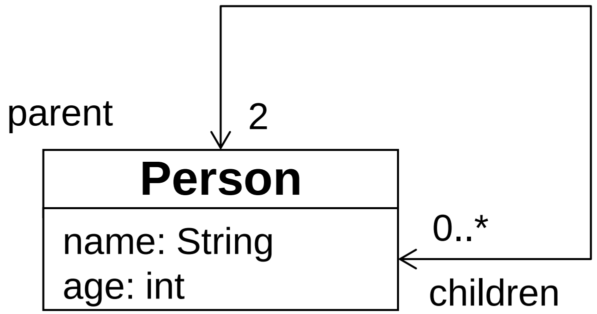

Example 3: Inherited attribute



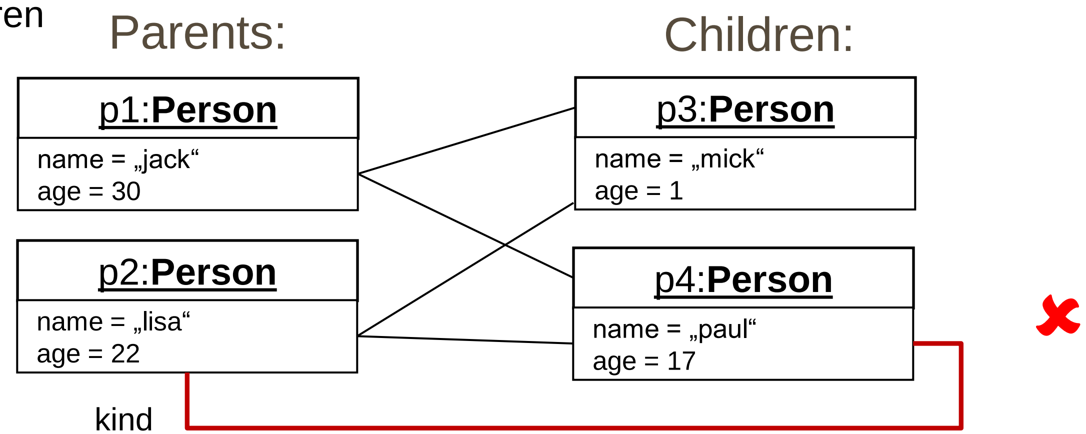
A Person obtains family allowance, if he/she is younger than 18 years, or if he/she is studying and younger than 27 years old.

```
context Person::familyallowance
derive: self.age < 18 or
       (self.age < 27 and self.studies -> size() > 0)
```

Example 4: Definitions



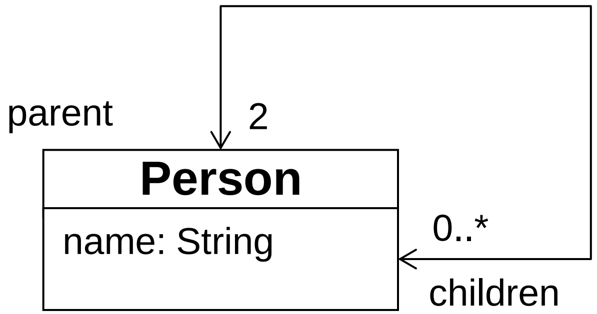
Constraint: A Person is not a relative of itself




```
context Person
def: relative: Set(Person) = children-> union(relative)
inv: self.relative -> excludes(self)
```

Assumption: Fixed-point semantic, otherwise if then else required

Example 5: equivalent OCL-formulations (1)



Constrain: A person is not its own child

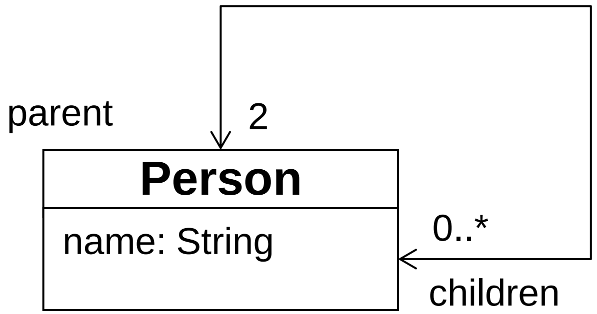
- `(self.children->select(k | k = self))->size() = 0`

  The Number of children for each person „self“, where the children are the person „self“, have to be 0.

- `(self.children->select(k | k = self))->isEmpty()`

  The set of children for each person „self, where the children are the person „self“, has to be empty.

Example 5: equivalent OCL-formulations (2)



Constrain: A person is not its own child

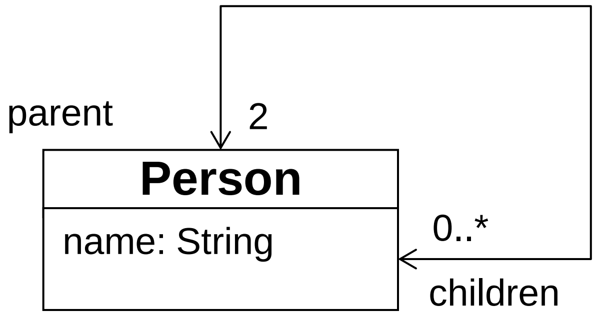
- `not self.children->includes(self)`

  It is not possible, that the set of children of each person „self“ contains the person „self“.

- `self.children->excludes(self)`

  The set of children of each person „self“ cannot contain „self“.

Example 5: equivalent OCL-formulations (3)



Constrain: A person is not its own child

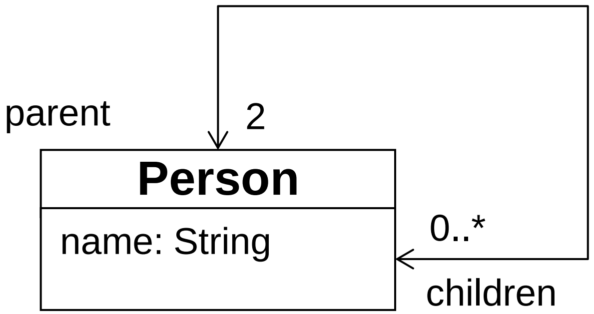
- `Set{self}->intersection(self.children)->isEmpty()`

  The intersection between the one element set, which only includes one person „self" and the set of the children of „self" has to be empty.

- `(self.children->reject(k | k <> self))->isEmpty()`

  The set of children for each person „self", for whome does not apply, that they are not equal to the person „self", has to be empty.

Example 5: equivalent OCL-formulations (4)



Constrain: A person is not its own child

- ```
  self.children->forAll(k | k <> self)
  ```

  Each child of the person „self“ is not the person „self“.

- ```
  not self.children->exists(k | k = self)
  ```

  There is no child for each person „self“, which is the person „self“

References on OCL

- **Literature**
  - Object Constraint Language Specification, Version 2.0
    - http://www.omg.org/technology/documents/formal/ocl.htm
  - Jos Warmer, Anneke Kleppe: The Object Constraint Language - Second Edition, Addison Wesley (2003)
  - Martin Hitz et al: UML@Work, d.punkt, 2. Auflage (2003)
- **Tools**
  - OSLO - http://oslo-project.berlios.de
  - Octopus - http://octopus.sourceforge.net
  - Dresden OCL Toolkit - http://dresden-ocl.sourceforge.net
  - EMF OCL - http://www.eclipse.org/modeling/mdt/?project=ocl