2017-2018

Cycle Ingénieur – 2ème année

Département Informatique

Verification and Validation

Part III : Formal Specification with UML/MOAL

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Plan of the Chapter

- Syntax & Semantics of our own language

  MOAL

  - mathematical
  - object-oriented
  - UML-annotation
  - language

  (conceived as the „essence" of annotation languages like OCL, JML, Spec#, ACSL, ...)

Plan of the Chapter

- Concepts of MOAL
  - Basis: Logic and Set-theory
  - MOAL is a Typed Language
  - Basic Types, Sets, Pairs and Lists
  - Object Types from UML
  - Navigation along UML attributes and associations
    (Idea from OCL and JML)
- Purpose :
  - Class Invariants
  - Method Contracts with Pre- and Post-Conditions
  - Annotated Sequence Diagrams for Scenarios, . . .

Plan of the Chapter

- Ultimate Goal:

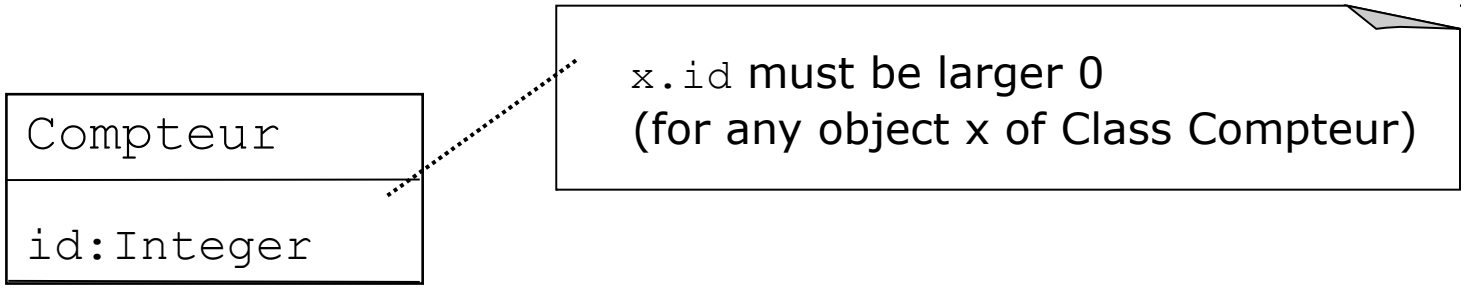
  Specify system components to improve analysis, design, test and verification activities

- . . . understanding how some analysis tools work . . .

- . . . understanding key concepts such as class invariants and contracts for analysis and design

Motivation: Why Logical Annotations

- More precision needed
  (like JML, VCC) that constrains an underlying state σ



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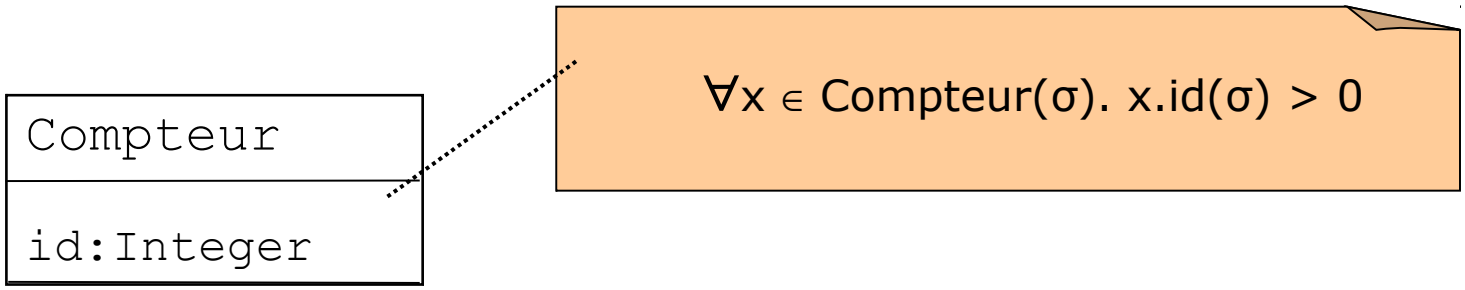

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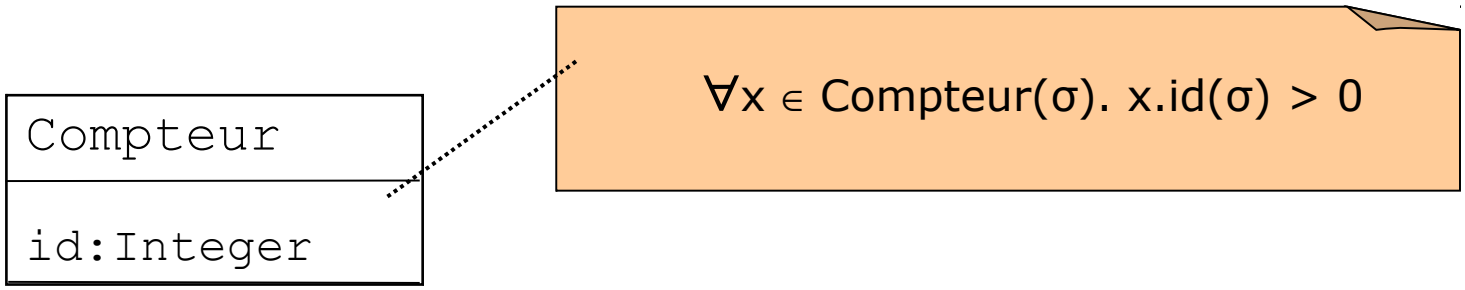

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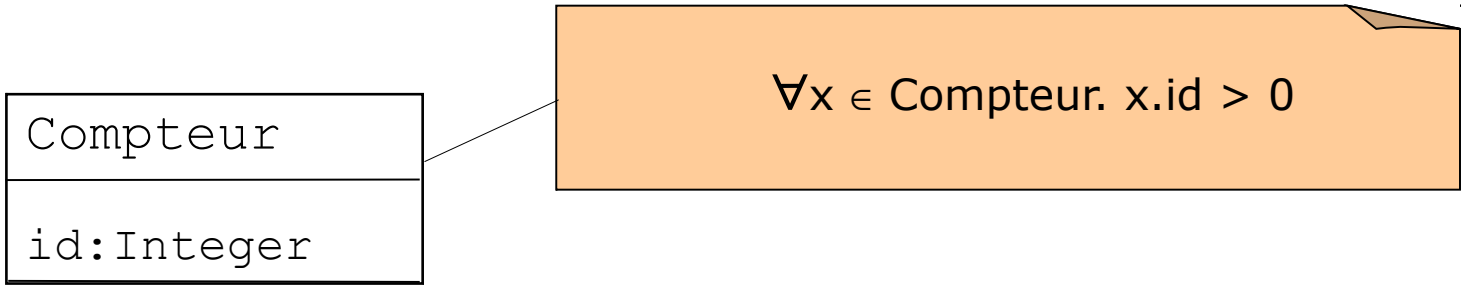

... by abbreviation convention if no confusion arises.

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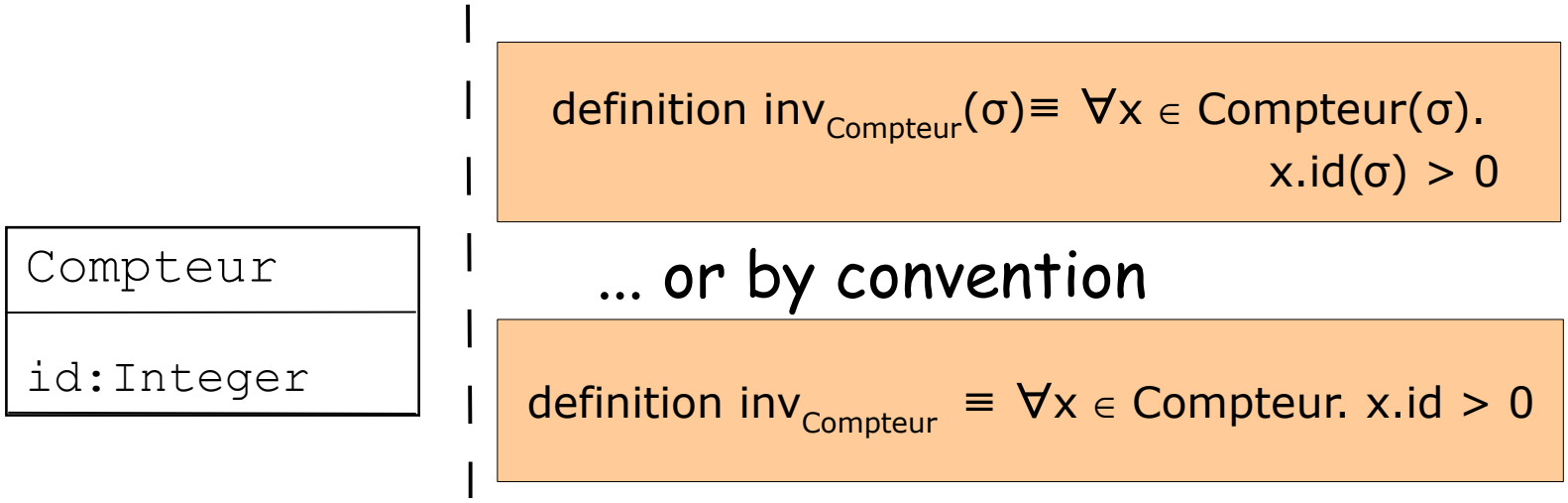
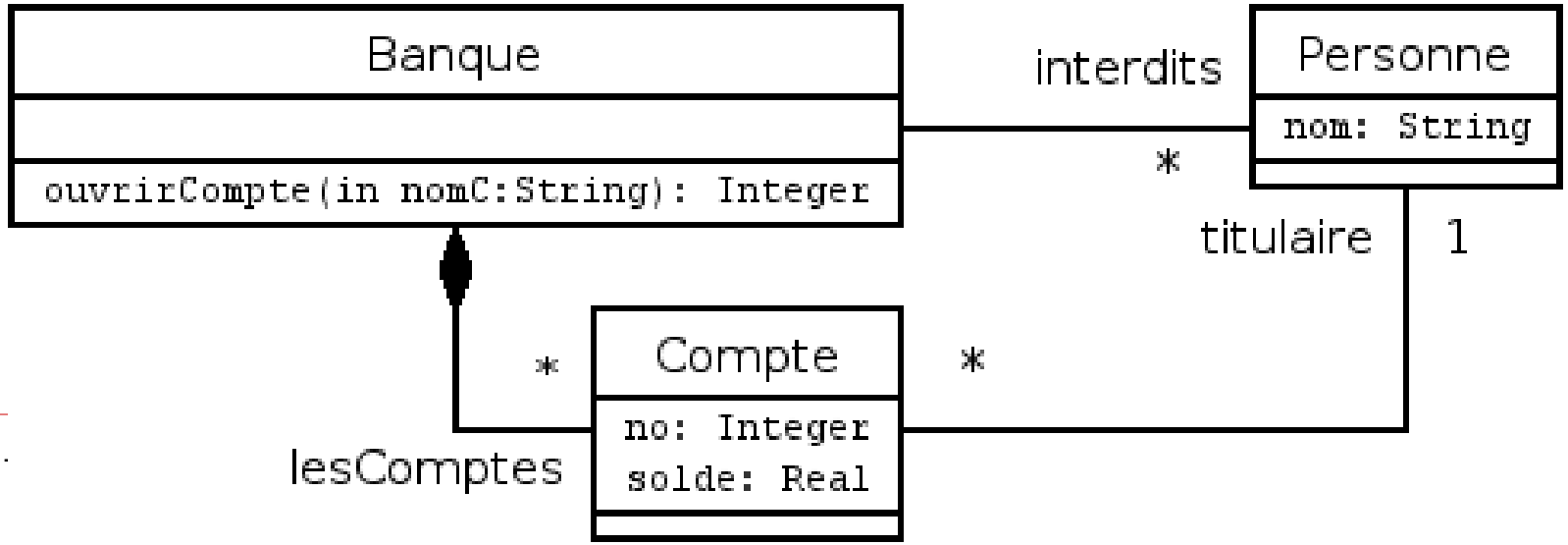


… or as mathematical definition in a separate document or text …

A first Glance to an Example: Bank

Opening a bank account. Constraints:

- there is a blacklist
- no more overdraft than 200 EUR
- there is a present of 15 euros in the initial account
- account numbers must be distinct.



A first Glance to an Example: Bank (2)

- **definition** unique ≡ isUnique(.no)(Compte)

  definition noOverdraft ≡ $\forall$c ∈ Compte. c.id ≥ -200

  definition $pre_{ouvrirCompte}$(b:Banque, nomC:String)≡

  $\forall$p ∈ Personne. p.nom ≠ nomC

  definition $post_{ouvrirCompte}$(b:Banque,nomC:String,r::Integer)≡

  |{p ∈ Personne | p.nom = nomC ∧ isNew(p)}| = 1

  ∧ |{c∈Compte | c.titulaire.nom = nomC}| = 1

  ∧ $\forall$c∈Compte. c.titulaire.nom = nomC ⟶ c.solde = 15

  ∧ isNew(c)

MOAL: a specification langage?

- In the following, we will discuss the

  MOAL Language in more detail ...

Syntax and Semantics of MOAL

- The usual logical language:
  - True, False
  - negation : $\neg E$,
  - or: $E \vee E'$, and: $E \wedge E'$, implies: $E \longrightarrow E'$
  - $E = E'$, $E \neq E'$,
  - if C then E else E' endif
  - let x = E in E'
  - Quantifiers on sets and lists:

$\forall x \in Set.\ P(x)$ $\exists x \in Set.\ P(x)$

Syntax and Semantics of MOAL

- MOAL is (like OCL or JML) a typed language.
  - Basic Types:
    `Boolean, Integer, Real, String`
  - Pairs: $X \times Y$
  - Lists: List(X)
  - Sets: Set(X)

Syntax and Semantics of MOAL

- The arithmetic core language.
  expressions of type `Integer` or `Real`:
  - `1,2,3 ...  resp. 1.0, 2.3, pi.`
  - `- E, E + E',`
  - `E * E', E / E',`
  - `abs(E), E div E', E mod E'...`

Syntax and Semantics of MOAL

- The expressions of type `String`:
  - *S* `concat S'`
  - *size(S)*
  - `substring(i,j,S)`
  - `'Hello'`

Syntax and Semantics of MOAL Sets

- | S | size as Integer
- isUnique(*f*)(S) ≡ ∀x,y ∈ S. f(x)=f(y) ⟶ x=y
- {}, {a,b,c} *empty and finite sets*
- e∈S, e∉S is element, not element
- S⊆ S′ is subset
- {x ∈ S | P(S)} filter
- S ∪ S′,S ∩ S′ union , intersect
  between sets of same type
-
- Integer, Real, String ...
  are symbols for the set
  of all Integers,Reals, ...

Syntax and Semantics of MOAL Pairs

- `(X,Y)` pairing
- `fst(X,Y) = X` projection
- `snd(X,Y) = Y` projection

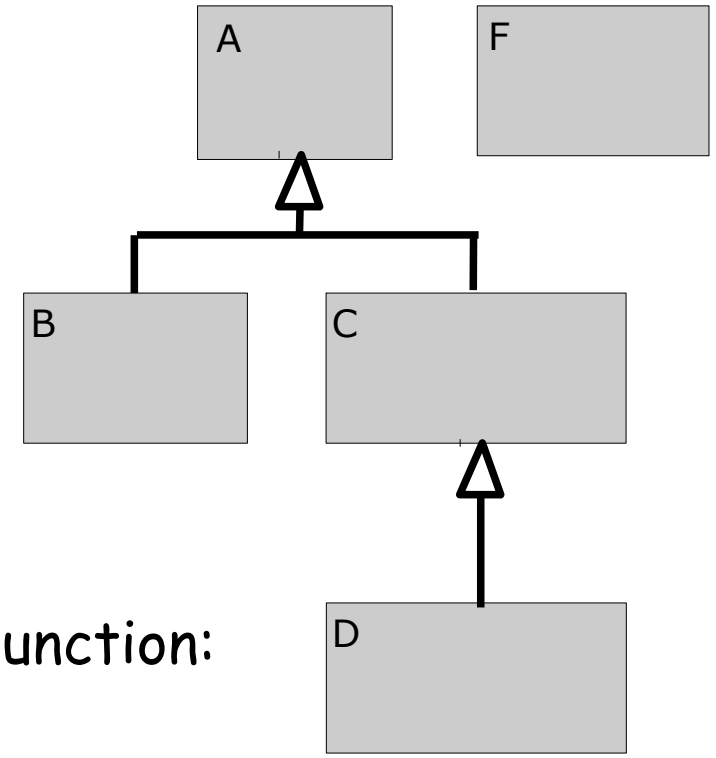
Syntax and Semantics of MOAL Lists

Lists *S* have the following operations:

- `x ∈ L` -- is element (overload!)
- `|S|` -- length as Integer
- `head(L),last(L)`
- *`nth`*`(L,`*`i`*`)` -- for `i` between `0` et `|S|-1`
- *`L@L'`* -- concatenate
- *`e#S`* -- append at the beginning
- $\forall_{x \in List.\ P(x)}$ -- quantifiers :
- `[x∈L | P(x)]` -- filter
- Finally, denotations of lists: [1,2,3], ...

Syntax and Semantics of Objects

- Objects and Classes follow the semantics of UML
  - inheritance / subtyping
  - casting
  - objects have an id
  - NULL is a possible value in each class-type
  - for any class A, we assume a function:



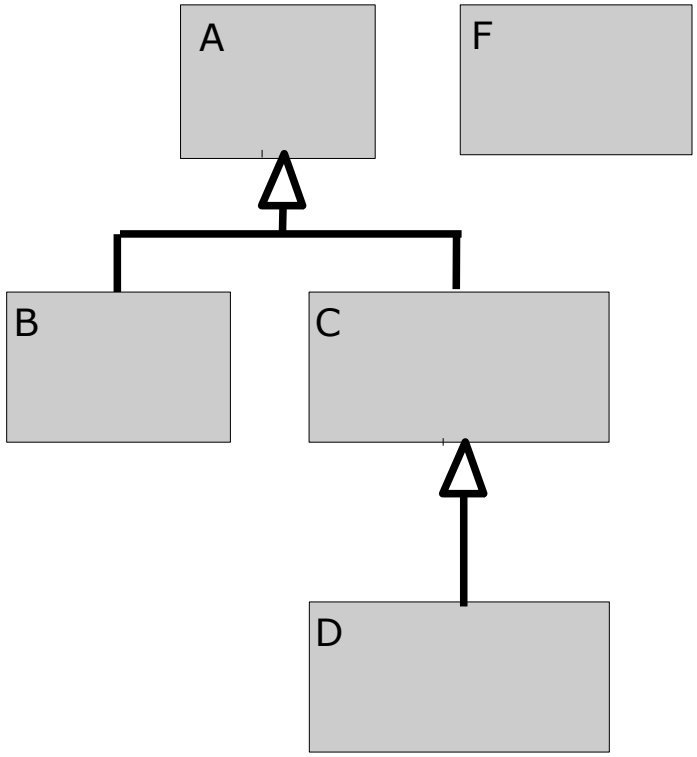
$$A(\sigma)$$

which returns the set of objects of class A in state σ (the « instances » in σ).

Syntax and Semantics of Objects

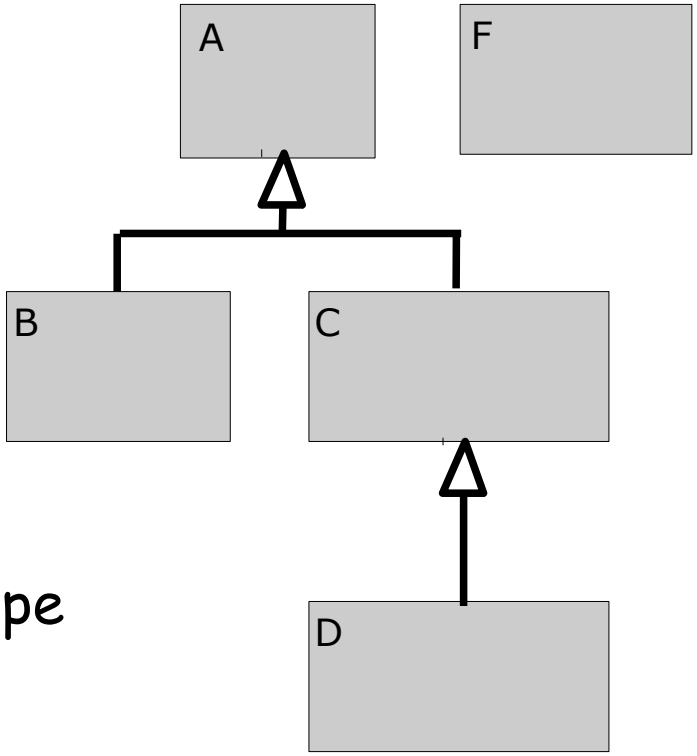
- Objects and Classes follow the semantics of UML

  Recall that we will drop the index (σ) whenever it is clear from the context



Syntax and Semantics of Objects

- As in all typed object-oriented languages casting allows for converting objects.
- Objects have two types:
  - the « apparent type » (also called static type)
  - the « actual type » (the type in which an object was created)
  - casting changes the apparent type along the class hierarchy, but not the actual type



Syntax and Semantics of Objects

- Assume the creation of objects

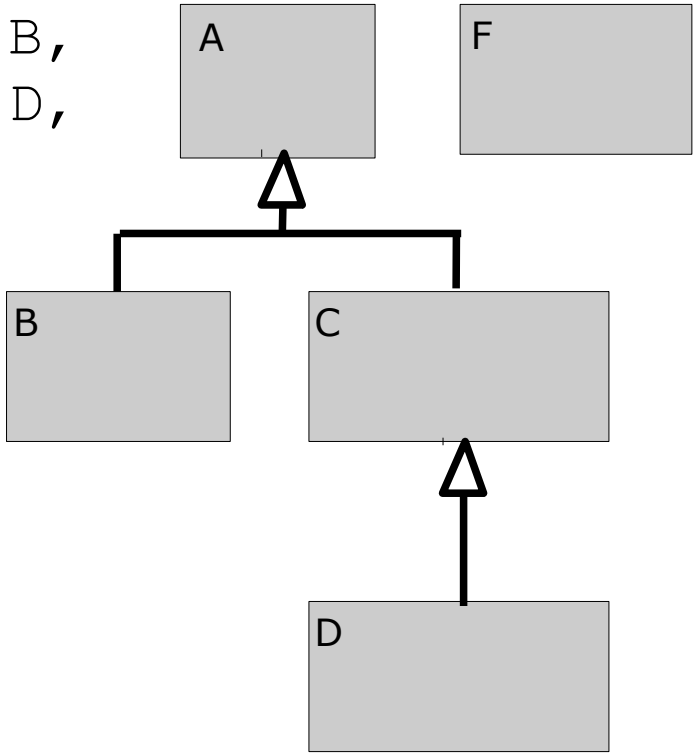
```
a in class A,b in class B,
c in class C,d in class D,
```

- Then casting:

```
⟨F⟩b is illtyped

⟨A⟩b has apparent type A,
     but actual type B

⟨A⟩d has apparent type A,
     but actual type D
```



Syntax and Semantics of OCL / UML

- We will also apply cast-operators to an entire set: So

  ⟨A⟩B(σ) (or just: ⟨A⟩B) is the set of instances of B casted to A.

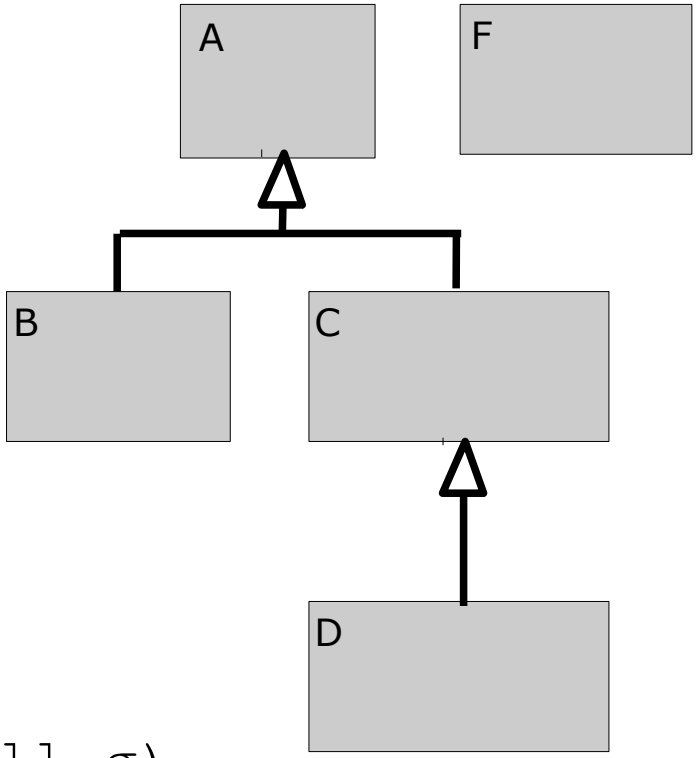
  We have:

  $$\langle A\rangle B \cup \langle A\rangle C \subseteq A$$

  but:

  $$\langle A\rangle B \cap \langle A\rangle C = \{\}$$

  and also: $\langle A\rangle D \subseteq A$ (for all σ)

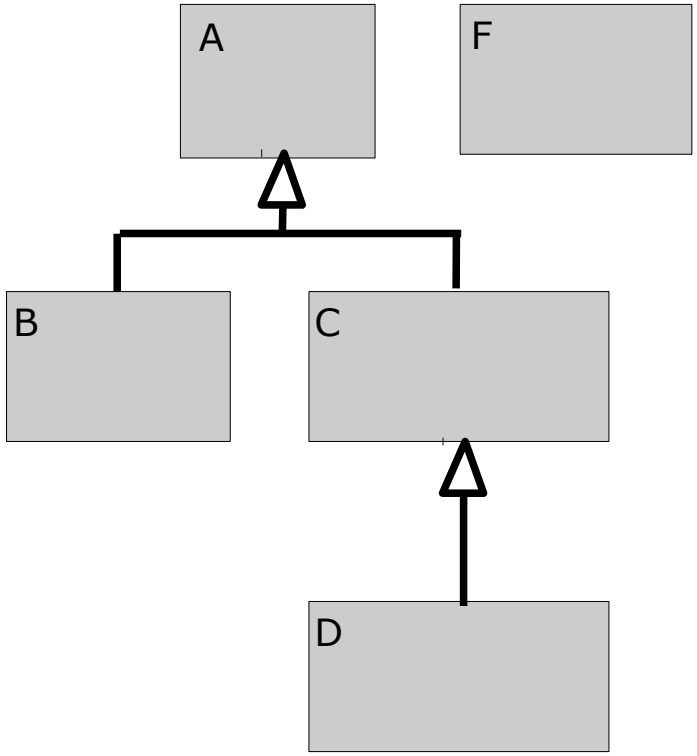


Syntax and Semantics of Objects

- Instance sets can be used to determine the actual type of an object:

  $x \in B$

  corresponds to Java's `instanceof` or OCL's `isKindOf`. Note that casting does NOT change the actual type:



$\langle A \rangle b \in B$, and $\langle B \rangle \langle A \rangle b = b$!!!

Syntax and Semantics of Objects

- Summary:
  - there is the concept of **actual** and **apparent** type (anywhere outside of Java: **dynamic** and **static** type)
  - type tests check the former
  - type casts influence the latter,

    but not the former
  - up-casts possible
  - down-casts invalid
  - consequence:

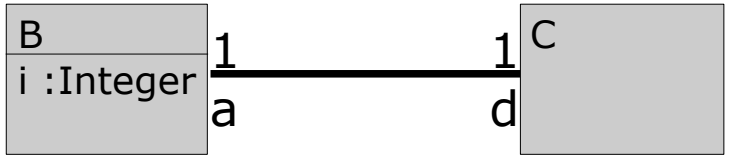
    up-down casts are identities.

Syntax and Semantics of Object Attributes

- Objects represent structured, typed memory in a state σ. They have attributes.

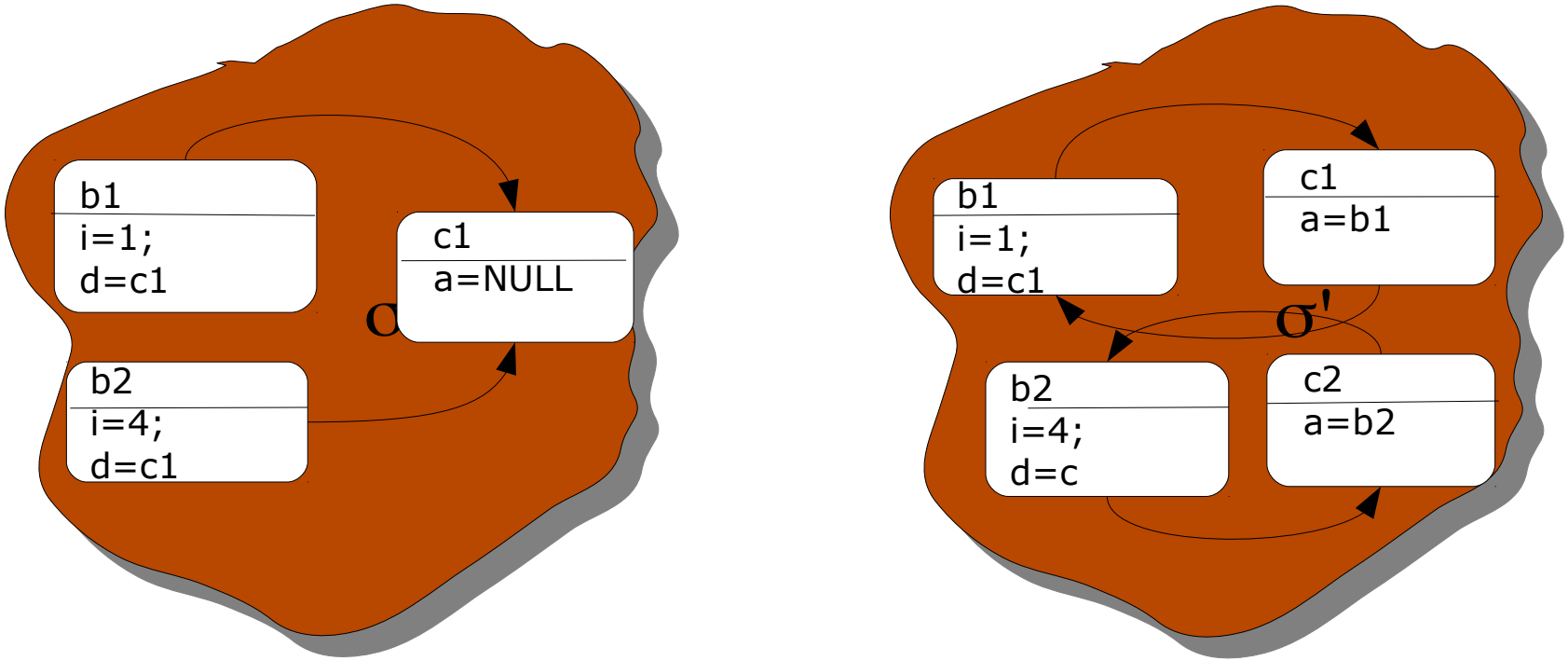
  They can have class types.

- Reminder: In class diagrams, this situation is represented traditionally by Associations (equivalent)



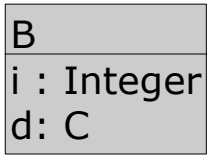
Syntax and Semantics of Object Attributes

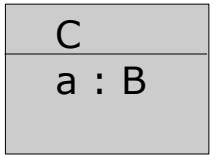
- Example:
  attributes of class type in states σ' and σ.



Syntax and Semantics of Object Attributes

- each attribute is represented by a function in MOAL. The class diagram right corresponds to delaration of accessor functions:





$.i(\sigma)$ :: B -> Integer
$.a(\sigma)$ :: C -> B
$.d(\sigma)$ :: B -> C

- Applying the σ-convention, this makes navigation expressions possible:
  - `b1.d :: C`
    `c1.a :: B` `b1.d.a.d.a ...`

Syntax and Semantics of Object Attributes

- Object assessor functions are „dereferentiations of pointers in a state"
- Accessor functions of class type are strict wrt. NULL.
  - `NULL.d = NULL`
    `NULL.a = NULL`
  - Note that navigation expressions depend on their underlying state:

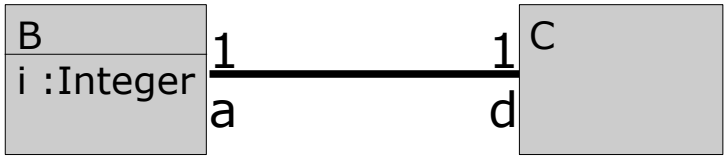
    $b1.d(\sigma).a(\sigma).d(\sigma).a(\sigma) = \text{NULL}$

    $b1.d(\sigma\}).a(\sigma\}).d(\sigma\}).a(\sigma\}) = b1$!!!

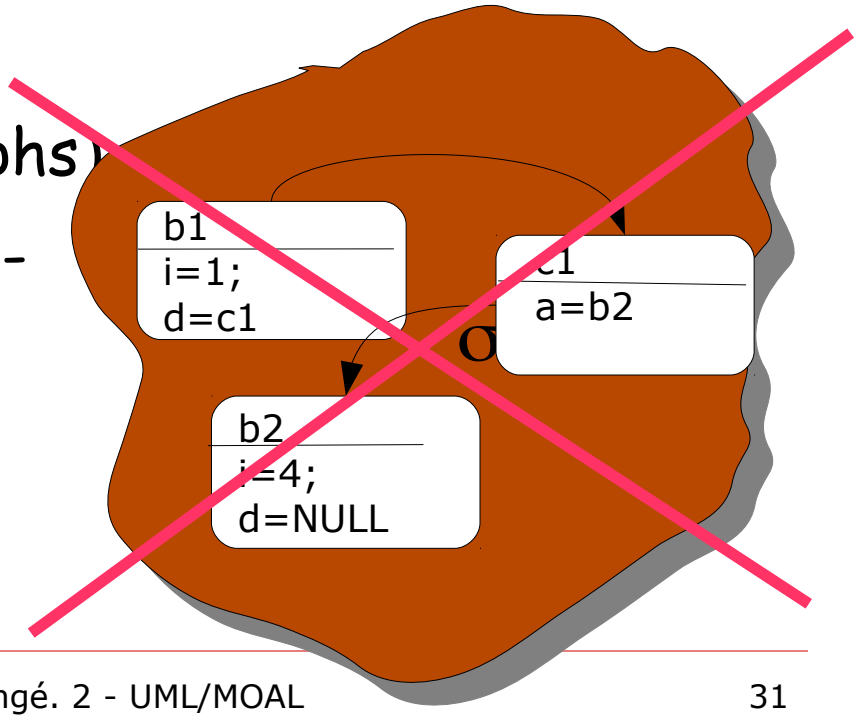
    (cf. Object Diagram pp 28)

Syntax and Semantics of Object Attributes

- Note that associations are meant to be « relations » in the mathematical sense.

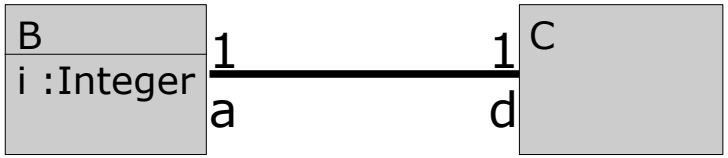


Thus, states (object-graphs) of this form do not represent an association:



Syntax and Semantics of Object Attributes

- This is reflected by 2 « association integrity constraints ».
  For the 1-1-case, they are:



- definition $ass_{B.d.a} \equiv \forall x \in B.\ x.d.a = x$
- definition $ass_{C.a.d} \equiv \forall x \in C.\ x.a.d = x$

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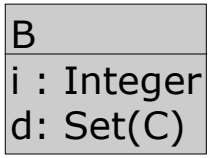
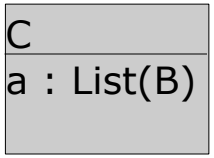
    (cf. Object Diagram pp 28)

Syntax and Semantics of Object Attributes

- Attibutes can be List or Sets of class types:





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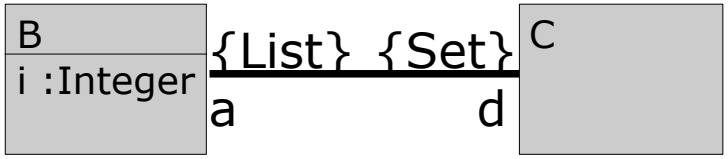
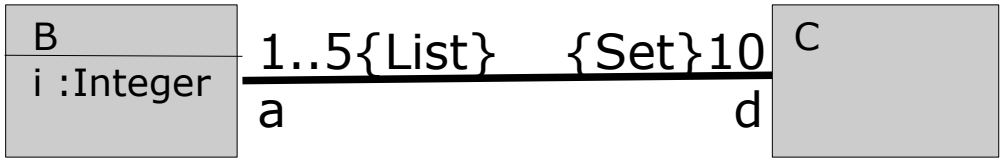


- In analysis-level Class Diagrams, the type information is still ommitted; due to overloading of $\forall x \in X.\ P(x)$ etc. this will not hamper us to specify …

Syntax and Semantics of Object Attributes

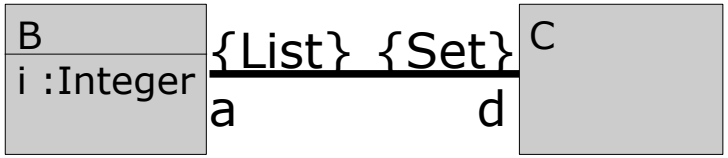
- Cardinalities in Associations can be translated canonically into MOCL invariants:



- $\texttt{definition card}_{B.d} \equiv \forall x \in B.\ |x.d| = 10$
- $\texttt{definition card}_{C.a} \equiv \forall x \in C.\ 1 \leq |x.a| \leq 5$

Syntax and Semantics of Object Attributes

- Accessor functions are defined as follows for the case of NULL:



  - NULL.d = {} -- mapping to the neutral element
  - NULL.a = [] -- mapping to the neural element.

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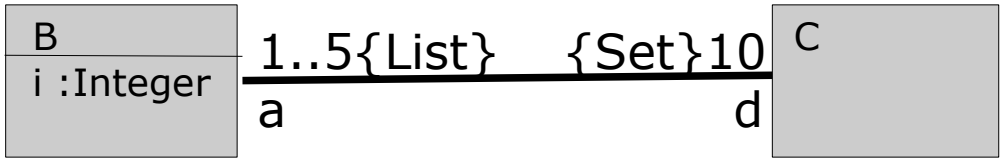

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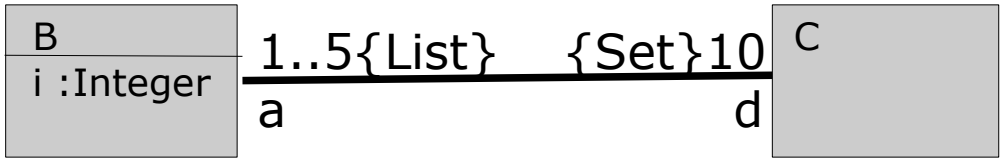
Syntax and Semantics of Object Attributes

- The corresponding association integrity constraints for the *-*-case are:



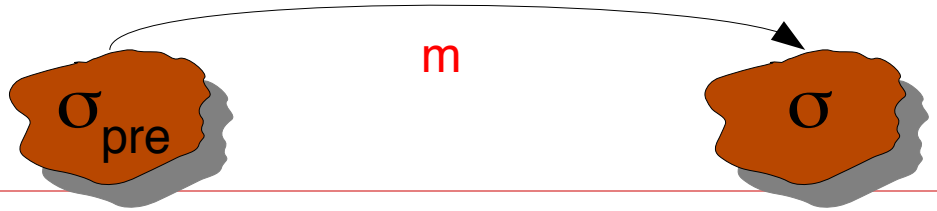
- definition $ass_{B.d.a} \equiv \forall x \in B.\ x \in x.d.a$
- definition $ass_{C.a.d} \equiv \forall x \in C.\ x \in x.a.d$

Operations in UML and MOAL

- Many UML diagrams talk over a sequence of states (not just individual global states)
- This appears for the first time in so-called contracts for (Class-model) methods:

B
i : Integer
m(k:Integer) : Integer

- The « method » m can be seen as a « transaction » of a B object transforming the underlying pre-state σ_{pre} in the state « after » m yielding a post-state σ.



Syntax and Semantics of Object Attributes

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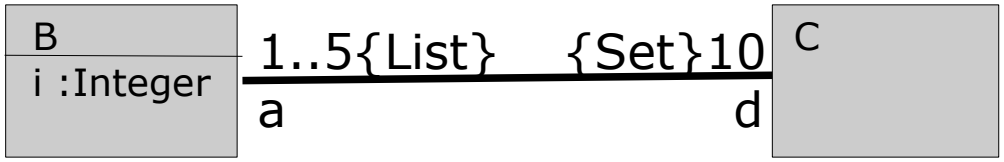

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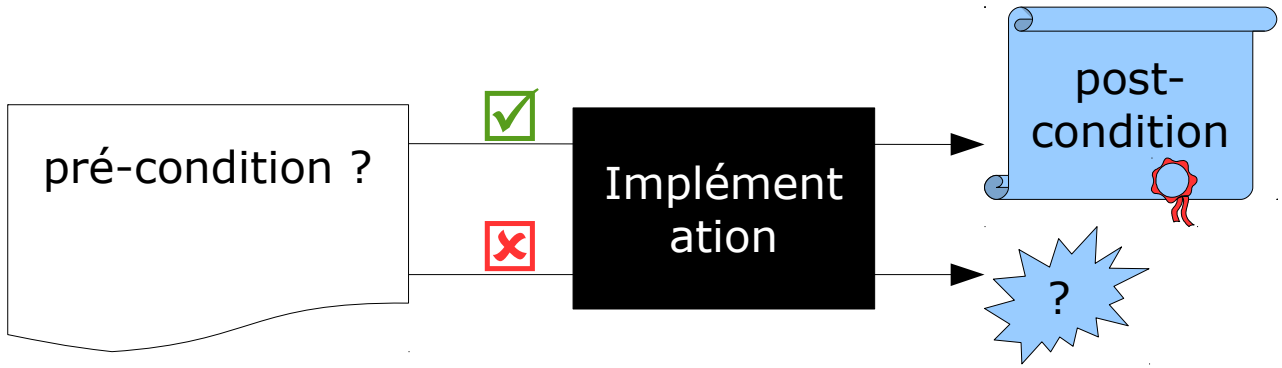
Pré et post-conditions (piqué de Delphine !)

Principe de la conception par contrats : contrat entre l'opération appelée et son appelant

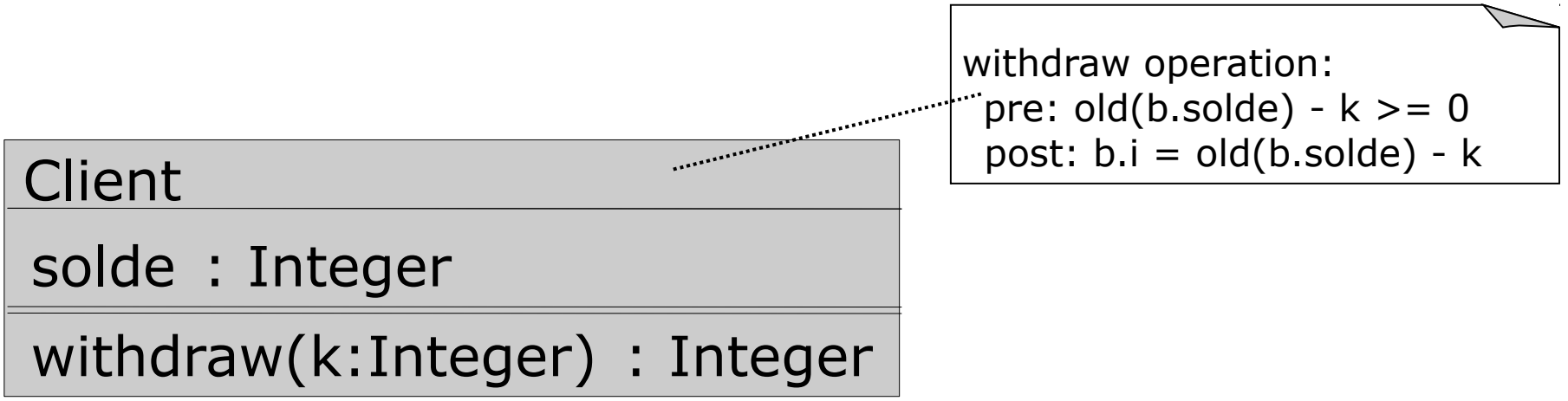
- Appelant responsable d'assurer que la pré-condition est vraie
- Implémentation de l'opération appelée responsable d'assurer la terminaison et la post-condition à la sortie, si la pré-condition est vérifiée à l'entrée

Si la pré-condition n'est pas vérifiée, aucune garantie sur l'exécution de l'opération



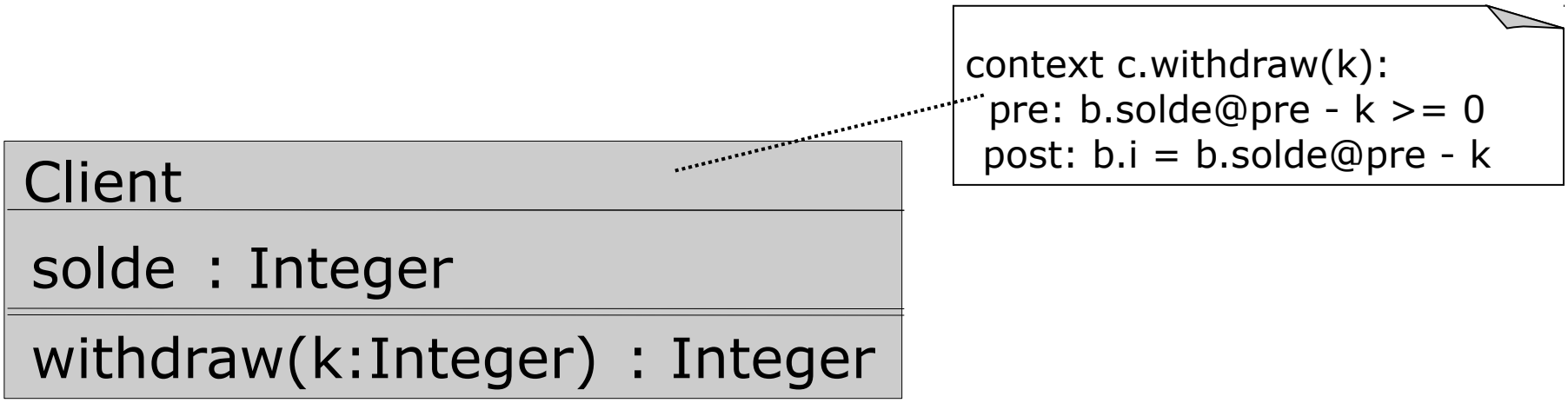
Operations in UML and MOAL

- Syntactically, contracts are annotated like this (JML-ish):



Operations in UML and MOAL

- … or like this (OCL-ish):



Operations in UML and MOAL Contracts

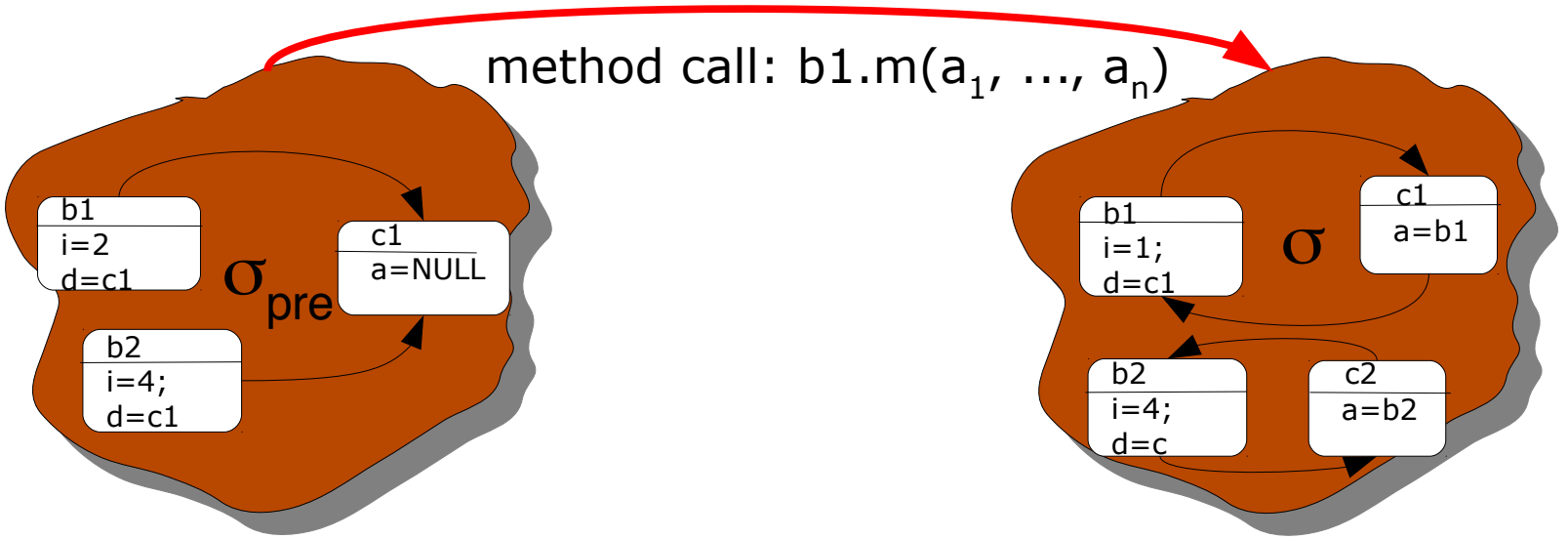
- This appears for the first time in so-called contracts for (Class-model) methods:

B
i : Integer
add(k:Integer) : Integer

- The « method » add can be seen as a « transaction » of a B object transforming the underlying pre-state σ_{pre} in the state « after » add yielding a post-state σ.

Syntax and Semantics of MOAL Contracts

- Again: This is the view of a transaction (like in a data-base), it completely abstracts away intermediate states or time. (This possible in other models/calculi, like the Hoare-calculus, though).



Syntax and Semantics of MOAL Contracts

- Consequence:
  - The pre-condition is a formula referring to the σ_{pre} and the method arguments b1, a_1, ..., a_n only.
  - the post-condition is only assured if the pre-condition is satisfied
  - otherwise the method
    - ...may do anything on the state and the result, may even behave correctly , may non-terminate !
    - raise an exception (recommended in Java Programmer Guides for public methods to increase robustness)

Syntax and Semantics of MOAL Contracts

- Consequence:
  - The post-condition is a formula referring to both σ_{pre} and σ, the method arguments b1, a_1, ..., a_n and the return value captured by the variable result.
  - any transition is permitted that satisfies the post-condition (provided that the pre-condition is true)

Syntax and Semantics of MOAL Contracts

- Consequence:
  - The semantics of a method call:

$$b1.m(a_1, ..., a_n)$$

is thus:

$$pre_m(b1,a_1, ..., a_n)\ (\sigma_{pre})$$
$$\longrightarrow$$
$$post_m(b1,a_1, ..., a_n,result)(\sigma_{pre},\sigma)$$

  - Note that moreover all global class invarants have to be added for both pre-state σ_{pre} and post-state σ !
    For an entire transition, the following must hold:

$$Inv(\sigma_{pre}) \wedge pre_m ... (\sigma_{pre}) \wedge post ... (\sigma_{pre},\sigma) \wedge Inv(\sigma)$$

Syntax and Semantics of MOAL Contracts

- Example:

Client
solde : Integer
withdraw(k:Integer) : {ok,nok}

class invariant:
c.solde >= 0 for all clients c.

operation c.withdraw(k) :
pre: k >= 0 ∧ old(c.solde) - k>=0
post: c.solde = old(c.solde) - k

- definition $inv_{Client}(\sigma) \equiv$
  $\forall c \in Client(\sigma).\ 0 \leq c.solde(\sigma)$
- definition $pre_{withdraw}(c, k)(\sigma) \equiv$
  $c \in Client(\sigma) \wedge 0 \leq k \wedge 0 \leq c.solde(\sigma) - k$
- definition $post_{withdraw}(c, k, result)(\sigma_{pre}, \sigma) \equiv$
  $c \in Client(\sigma_{pre}) \wedge c.solde(\sigma) = c.solde(\sigma_{pre}) - k \wedge$
  $result = ok$

Syntax and Semantics of MOAL Contracts

- Notation:
  - In order to relax notation, we will use for applications to σ_{pre} the old-notation:

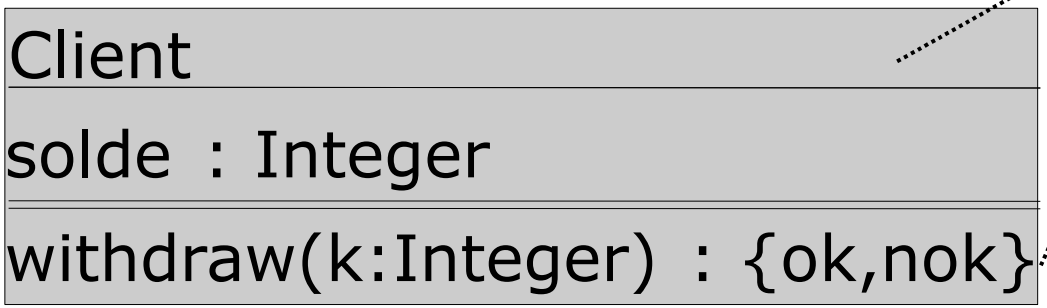
    Client(σ_{pre}) **becomes** old(Client)

    `c.solde`(σ_{pre}) **becomes** old(`c.solde`)

    etc.

Syntax and Semantics of MOAL Contracts

- Example (revised):



class invariant:
c.solde >= 0 for all clients c.

operation c.withdraw(k) :
pre: k >= 0 ∧ old(c.solde) - k>=0
post: c.solde = old(c.solde) - k

- definition $inv_{Client} \equiv \forall c \in Client.\ 0 \leq c.solde$
- definition $pre_{withdraw}(c, k) \equiv$
  $c \in Client \wedge 0 \leq k \wedge 0 \leq c.solde - k$
- definition $post_{withdraw}(c, k, result) \equiv$
  $c \in old(Client) \wedge c.solde = old(c.solde) - k \wedge result = ok$

Semantics of MOAL Contracts

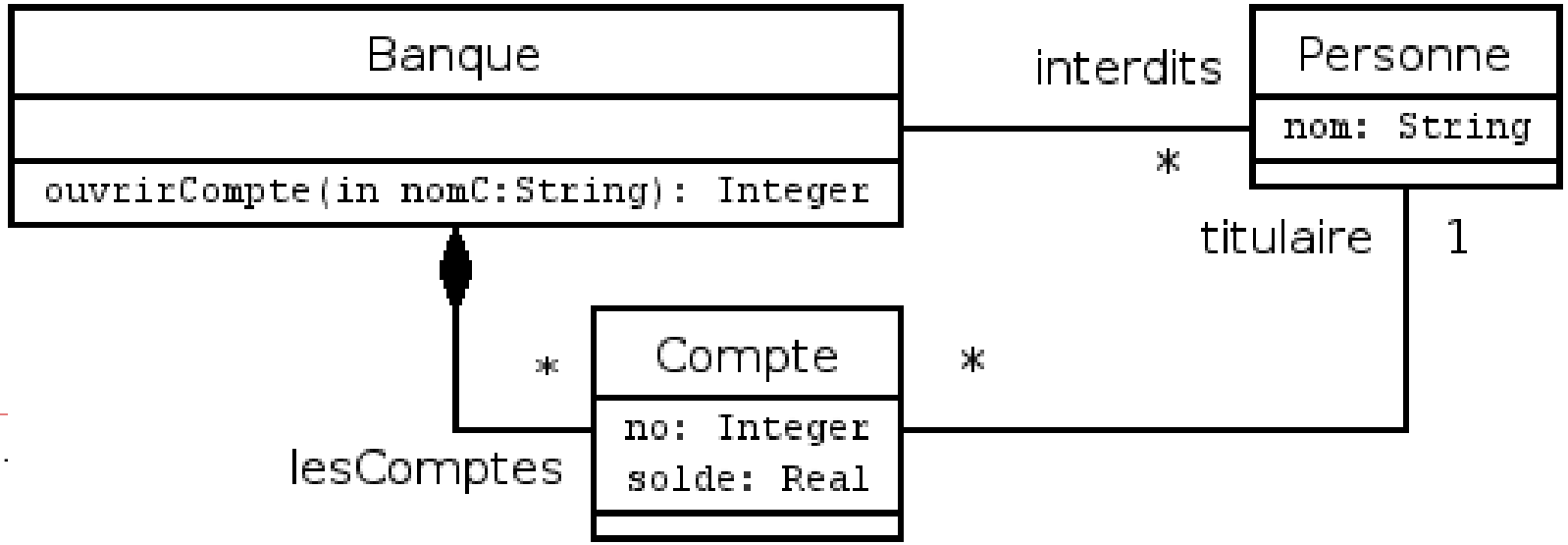
- Two predicates are helpful when defining contracts. They exceptionally refer to both (σ_{pre},σ)
  - `isNew(p)` (σ_{pre},σ) is true only if object p of class C does not exist in σ_{pre} but exists in σ
  - modifiesOnly(S)(σ_{pre},σ) is only true iff
    - all objects in σ_{pre} are except those in S identical in σ
    - all objects in σ exist either in are or are contained in S

With this predicate, one can express : „and nothing else changes". It is also called «framing condition».

A Revision of the Example: Bank

Opening a bank account. Constraints:

- there is a blacklist
- no more overdraft than 200 EUR
- there is a present of 15 euros in the initial account
- account numbers must be distinct.



A Revision of the Example: Bank (2)

- **definition** $pre_{ouvrirCompte}$(b:Banque, nomC:String) ≡

  $\forall p \in Personne.\ p.nom \neq nomC$

  definition $post_{ouvrirCompte}$(b:Banque,nomC:String,r:Integer) ≡

  $|\{p \in Personne \mid p.nom = nomC\}| = 1$

  $\wedge\ \forall p \in Personne.\ p.nom = nomC \longrightarrow isNew(p)$

  $\wedge\ |\{c \in Compte \mid c.titulaire.nom = nomC\}| = 1$

  $\wedge\ \forall c \in Compte.\ c.titulaire.nom = nomC \longrightarrow c.solde = 15 \wedge isNew(c)$

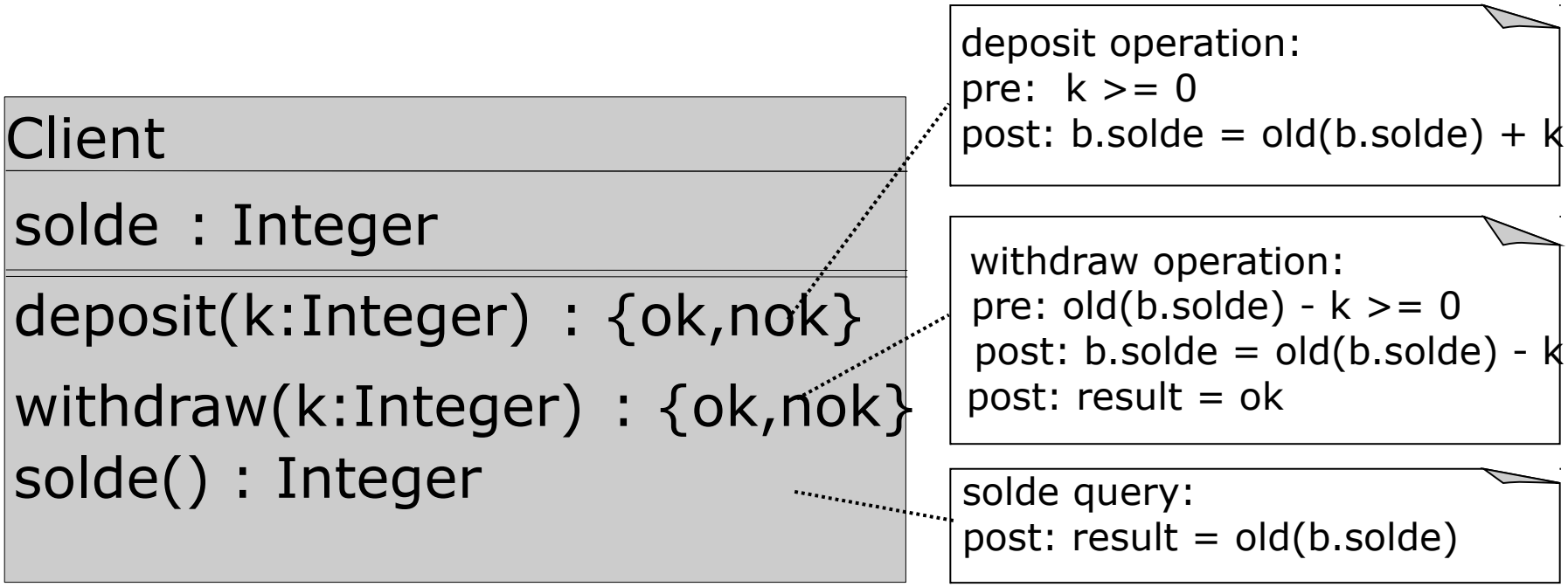
  $\wedge\ b.lesComptes = old(b.lesComptes) \cup \{c \in Compte \mid c.titulaire.nom = nomC\}$

  $\wedge\ b.interdits = old(b.interdits) \cup \{c \in Compte \mid c.titulaire.nom = nomC\}$

  $\wedge\ modifiesOnly(\{b\} \cup \{c \in Compte\ c.titulaire.nom = nomC\} \cup \{p \in Personne \mid p.nom = nomC\})$

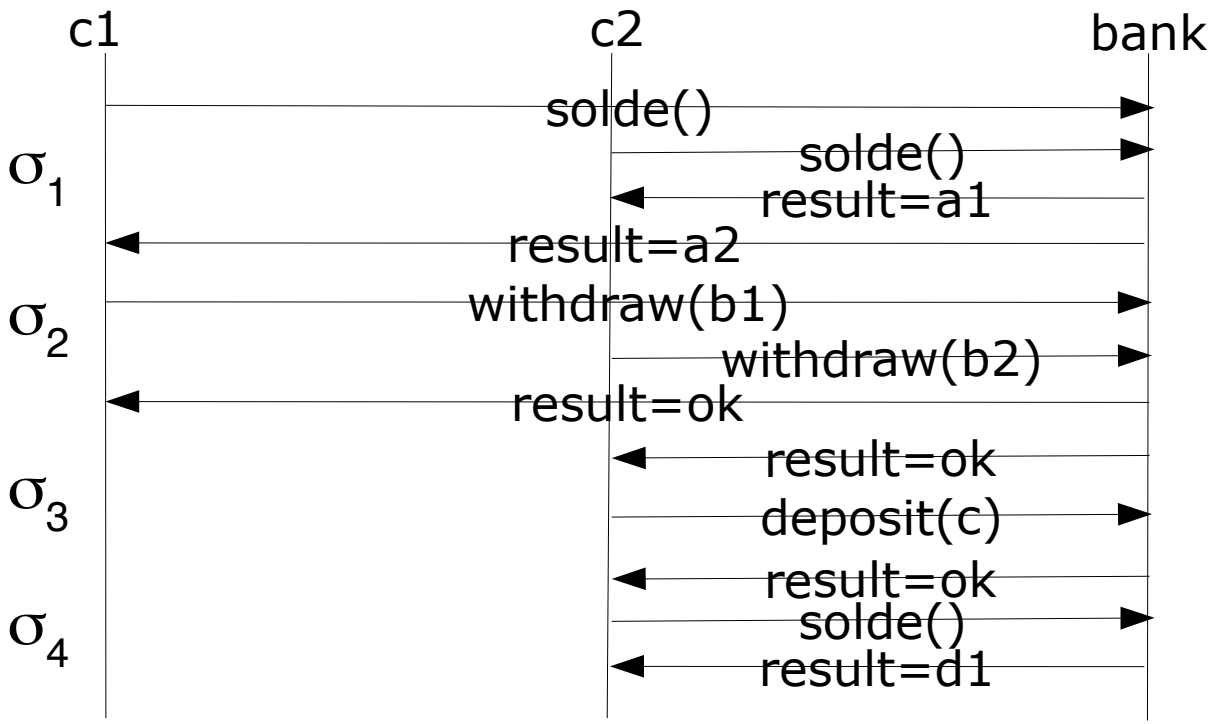
Operations in UML and MOAL

- Example:



Operations in UML and MOAL

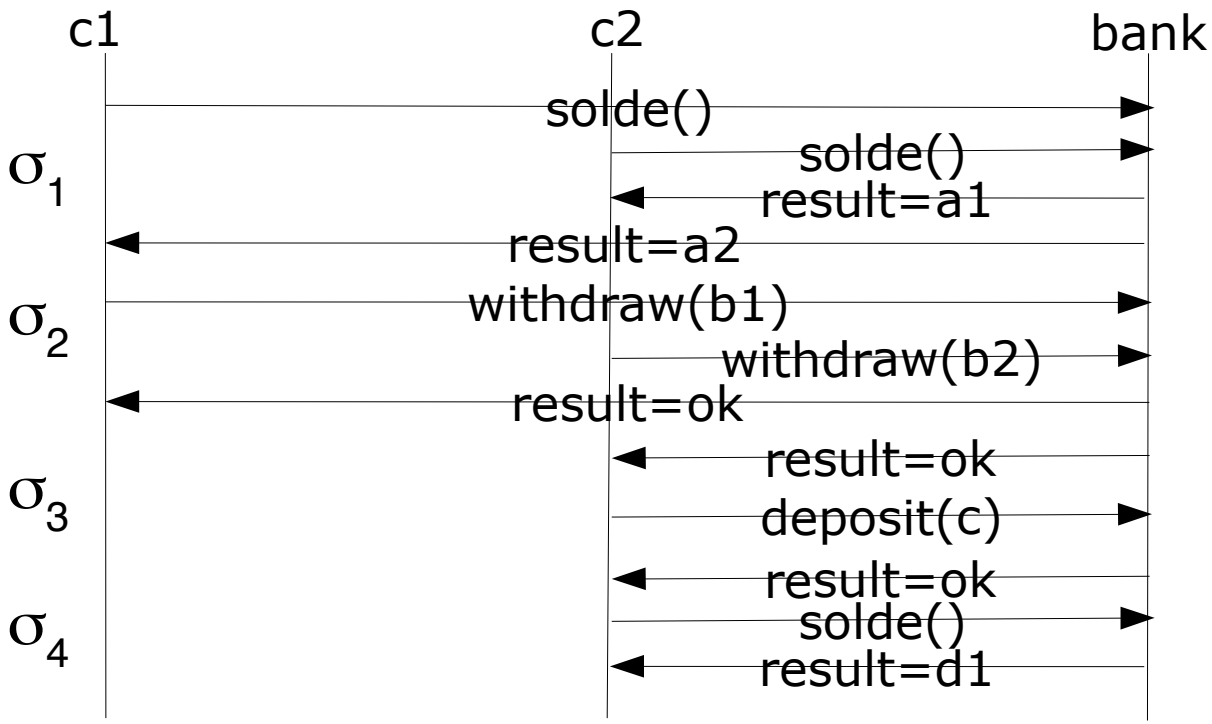
- Abstract Concurrent Test Scenario:



assert c1.solde(σ_4)=a2-b1 $\wedge$ b1 $\geq$ 0 $\wedge$ a2 $\geq$ b1

Operations in UML and MOAL

- Abstract Concurrent Test Scenario:



Any instance of b1 and a1 is a test ! This is a „Test Schema“ !
Note: b1 can be chosen dynamically during the test !

Summary

- MOAL makes the UML to a real, formal specification language
- MOAL can be used to annotate Class Models, Sequence Diagrams and State Machines
- Working out, making explicit the constraints of these Diagrams is an important technique in the transition from Analysis documents to Designs.