L3 Mention Informatique
Parcours Informatique et MIAGE

Génie Logiciel Avancé - Advanced Software Engineering

UML with MOAL-Contracts

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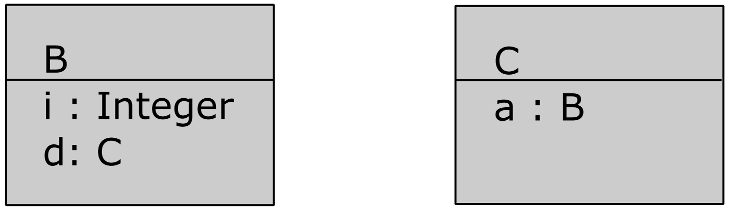
Recall:

- MOAL is a logic used to make UML diagrams more precise
- it comprises
  - typed sets, lists, and some base types
  - classes and objects from UML class diagrams
  - subtyping and casts
  - a semantics for path navigation and associations.

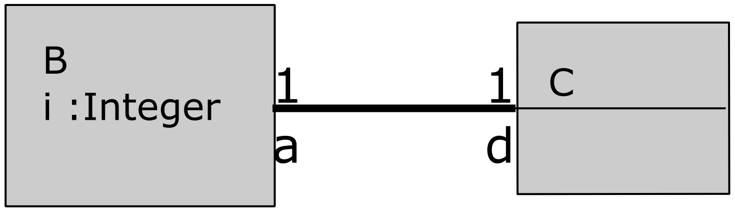
Recall: Object Attributes

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

  They can have class types.



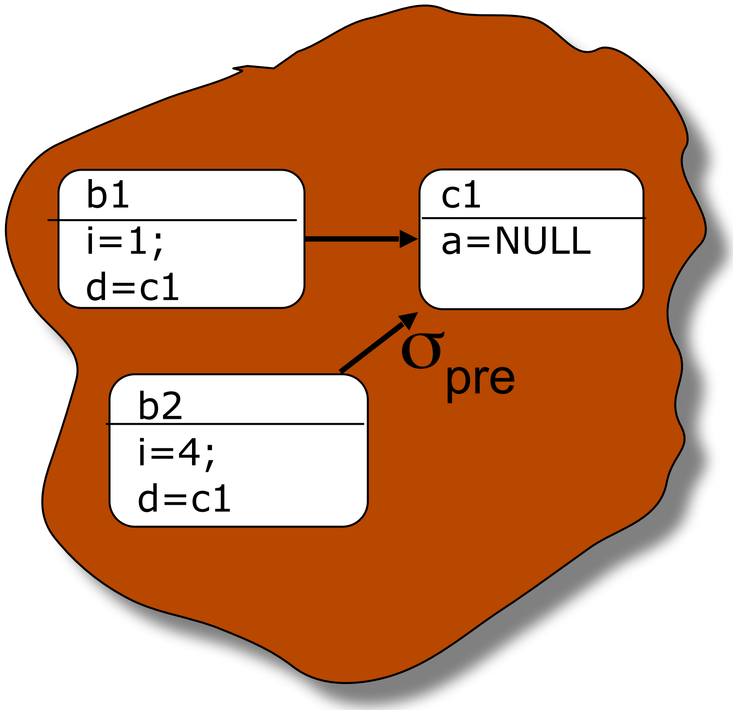
- Reminder: In class diagrams, this situation is represented traditionally by Associations (equivalent)

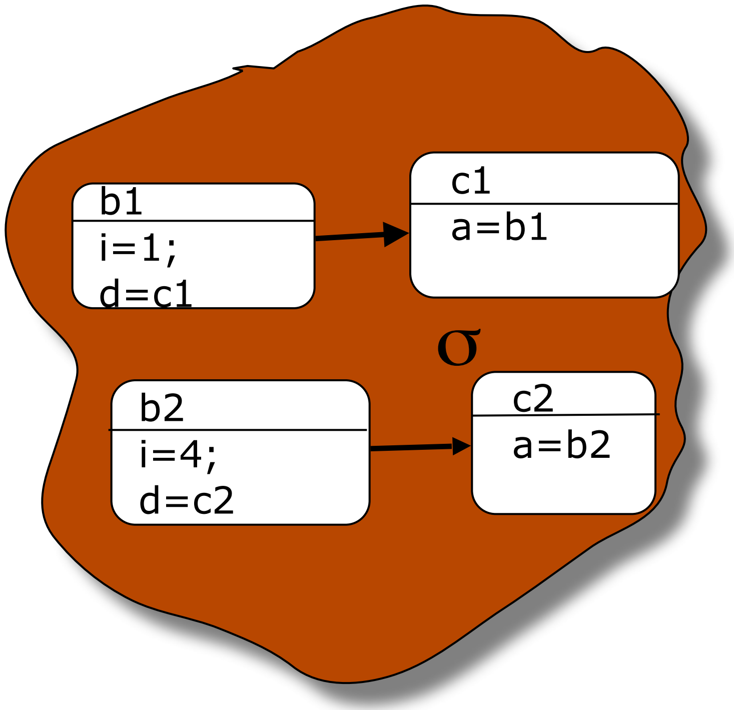


Syntax and Semantics of Object Attributes

- Example:

  attributes of class type in states σ_{pre} and σ.





Recall Navigation

- 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
    ```
  - Recall that navigation expressions depend on their underlying state:

    $b1.d(\sigma_{pre}).a(\sigma_{pre}).d(\sigma_{pre}).a(\sigma_{pre}) = NULL$

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

    (cf. Object Diagram pp 28)

Recall Object Attributes

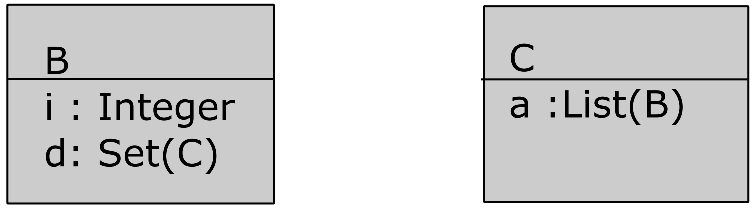
- Object assessor functions are „dereferentiations of pointers in a state“
- Accessor functions of class type are strict wrt. NULL.

  -
    ```
    NULL.d = NULL
    NULL.a = NULL
    ```
  - The σ convention allows to write :

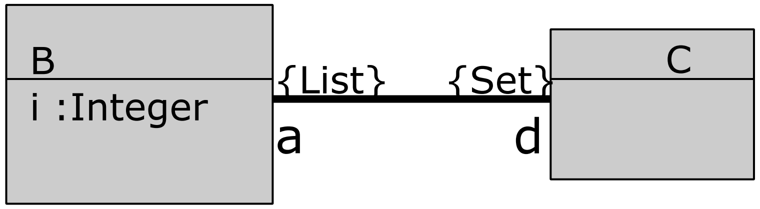
    old(b1.d.a.d.a) = NULL
    b1.d.a.d.a = b1 !!!
    (cf. Object Diagram pp 28)

Recall Object Attributes

- Attibutes can be List or Sets of class types:



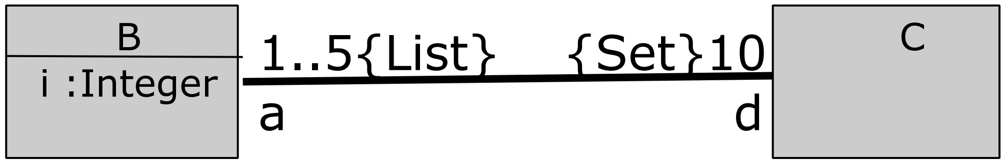
- Reminder: In class diagrams, this situation is represented traditionally by Associations (equivalent)



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

Recall Cardinalities vs Invariants

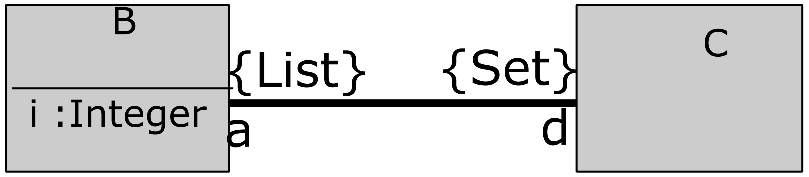
- Cardinalities in Associations can be translated canonically into MOCL invariants:



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

Strictness of Collection Attributes

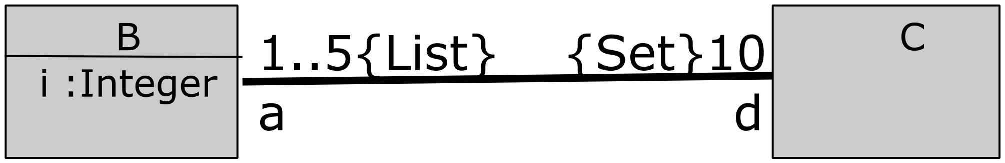
- Accessor functions are defined as follows for the case of NULL:



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

Syntax and Semantics of Object Attributes

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

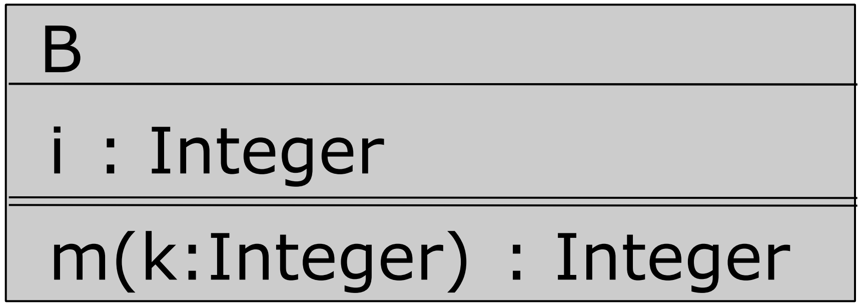


- definition $card_{B.d} \equiv \forall x \in B.\ |x.d| = 10$
- definition $card_{C.a} \equiv \forall x \in C.\ 1 \leq |x.a| \leq 5$

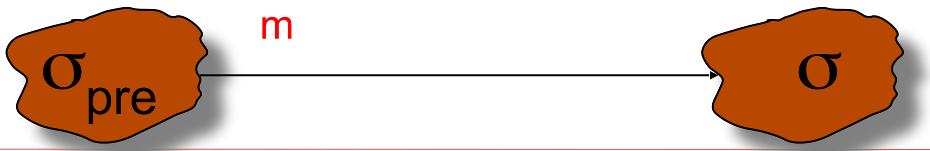
Operation Contracts

Operation Contracts

- 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:



- 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.

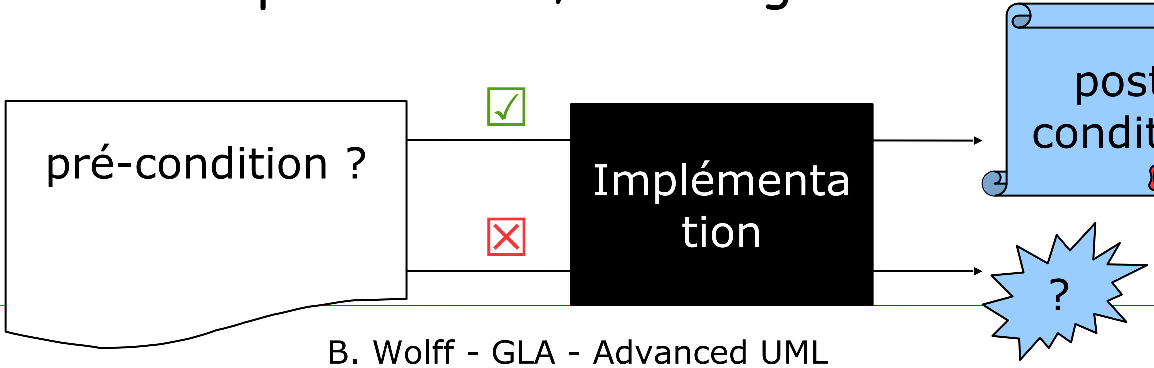

$$\begin{tikzcd} \sigma_{pre} \arrow[r, "m"] & \sigma \end{tikzcd}$$

Pré et post-conditions
(piqué de Delphine !)

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

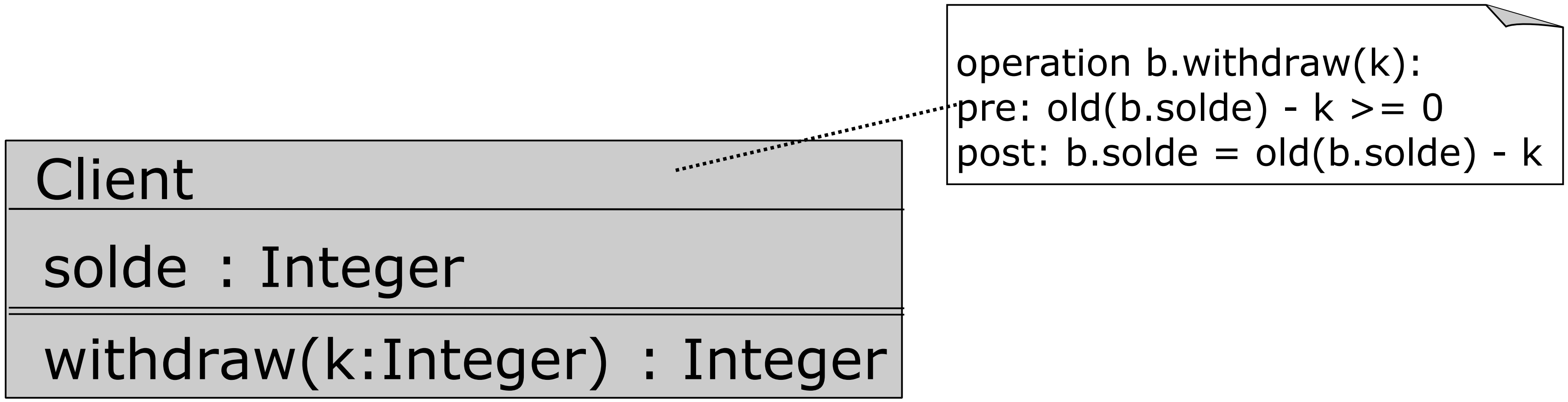
- Appelant responsable d'assurer que la pré-condition est vraie
- Implémentation de l'opération appelée responsable d'assurer la terminaison et la post-condition à la sortie, si la pré-condition est vérifiée à l'entrée

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



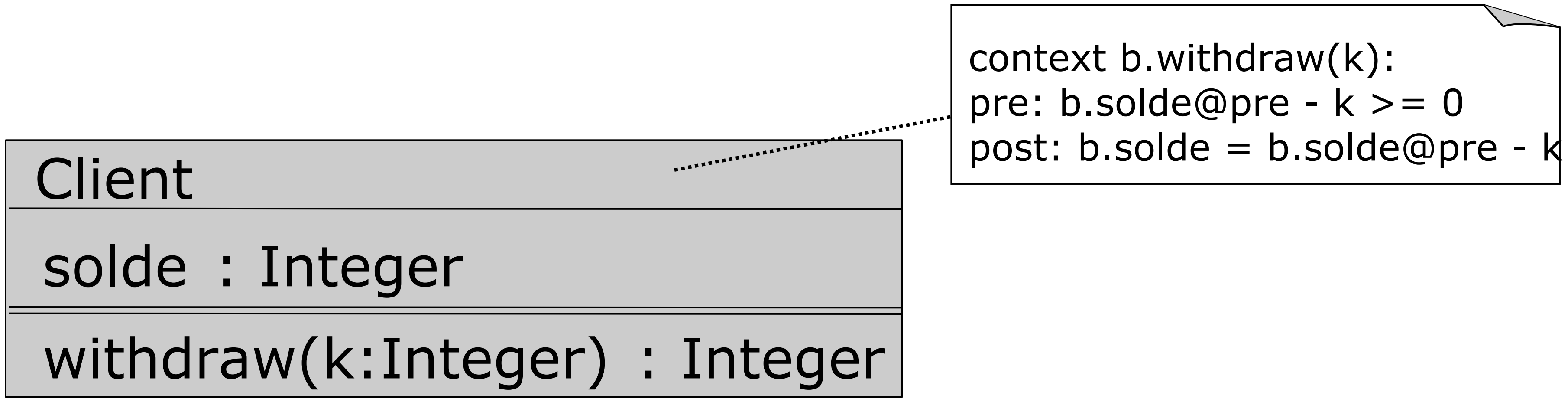
Operations in UML and MOAL

- Syntactically, contracts are annotated like this (in MOAL convention):


Client
solde : Integer
withdraw(k:Integer) : Integer
operation b.withdraw(k):
pre: old(b.solde) - k >= 0
post: b.solde = old(b.solde) - k

Operations in UML and MOAL

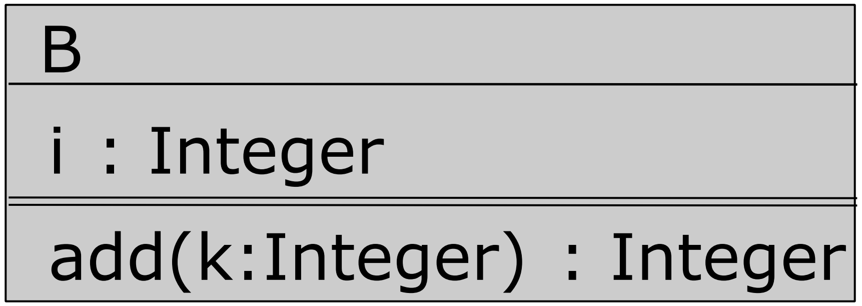
- ... or like this   (OCL-ish):



```
context b.withdraw(k):
pre: b.solde@pre - k >= 0
post: b.solde = b.solde@pre - k
```

Operations in UML and MOAL Contracts

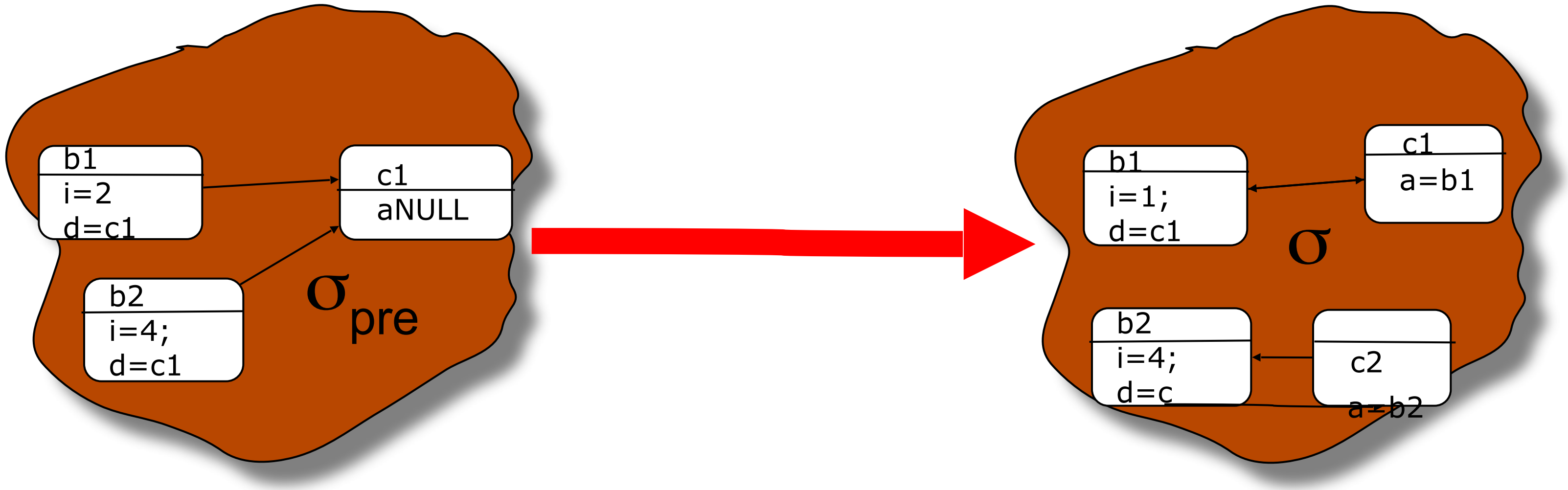
- This appears for the first time in so-called contracts for (Class-model) methods:



- 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:

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

is thus:

$$pre_m(b1,a_1, \ldots, a_n)\ (\sigma_{pre})$$

$$\longrightarrow$$

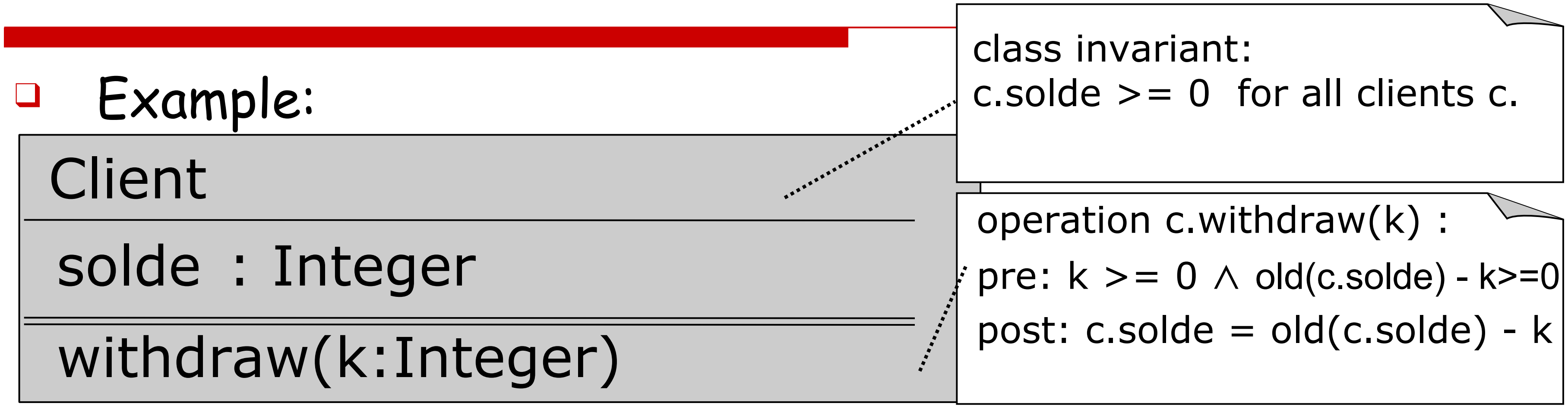
$$post_m(b1,a_1, \ldots, a_n,result)(\sigma_{pre},\sigma)$$

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

$$Inv(\sigma_{pre}) \wedge pre_m(b1,a_1,\ldots,a_n)(\sigma_{pre}) \wedge post(b1,a_1,\ldots,a_n,r)(\sigma_{pre},\sigma) \wedge\ Inv(\sigma)$$

Syntax and Semantics of MOAL Contracts

- Example:



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

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

- definition $\mathrm{inv}_{\mathrm{Client}}(\sigma) \equiv$
  $\forall c \in \mathrm{Client}(\sigma).\ 0 \leq c.\mathrm{solde}(\sigma)$
- definition $\mathrm{pre}_{\mathrm{withdraw}}(c, k)(\sigma) \equiv$
  $c \in \mathrm{Client}(\sigma) \wedge 0 \leq k \wedge 0 \leq c.\mathrm{solde}(\sigma) - k$
- definition $\mathrm{post}_{\mathrm{withdraw}}(c, k, \mathrm{result})(\sigma_{pre}, \sigma) \equiv$
  $c.\mathrm{solde}(\sigma) = c.\mathrm{solde}(\sigma_{pre}) - k$

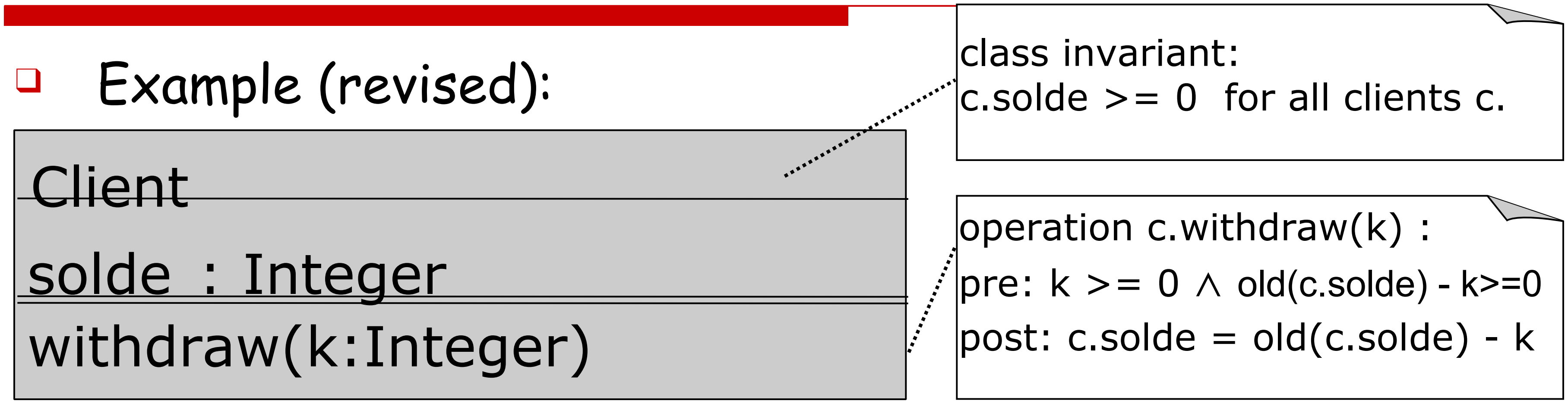
Syntax and Semantics of MOAL Contracts

- Notation:
  - In order to relax notation, we will refine the σ convention by the old-notation:

Client(σ)	just becomes	`Client`
`c.solde`(σ)	just becomes	`c.solde`
Client(σ_{pre})	becomes	`old(Client)`
`c.solde`(σ_{pre})	becomes	`old(c.solde)`

Syntax and Semantics of MOAL Contracts

- Example (revised):

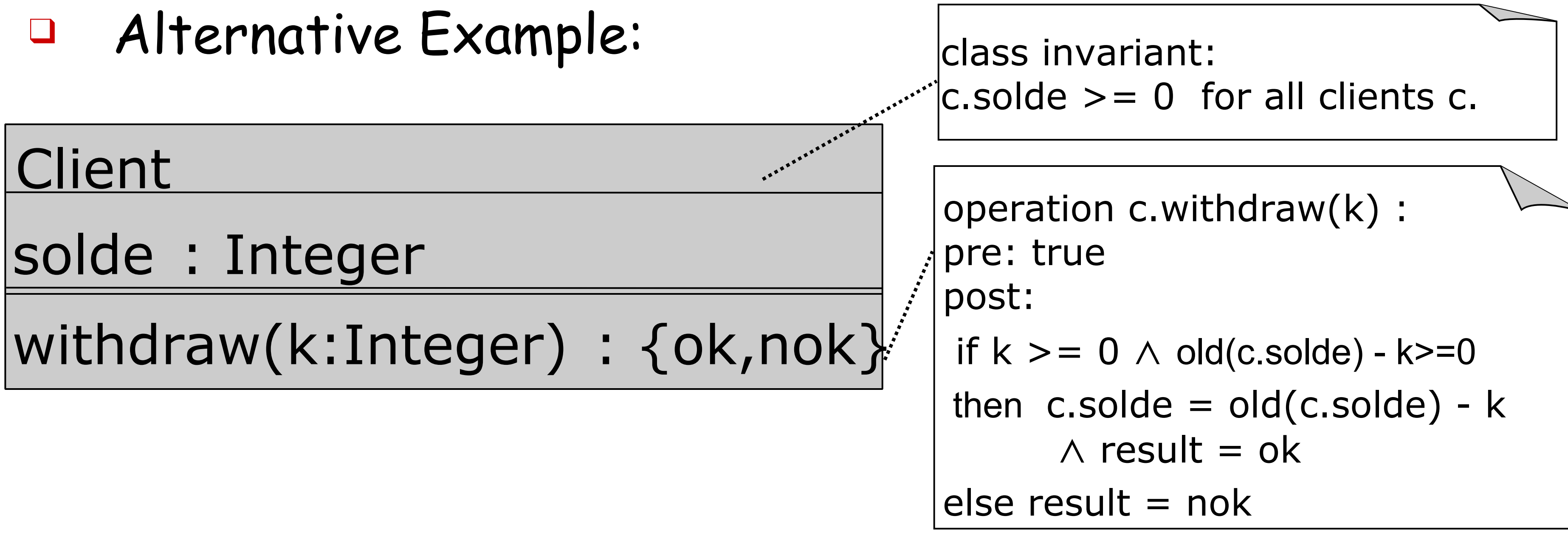

Client
solde : Integer
withdraw(k:Integer)
class invariant:
c.solde >= 0 for all clients c.
operation c.withdraw(k) :
pre: k >= 0 ∧ old(c.solde) - k>=0
post: c.solde = old(c.solde) - k

- definition $\text{inv}_{\text{Client}} \equiv \forall c \in \text{Client}.\ 0 \leq c.\text{solde}$
- definition $\text{pre}_{\text{withdraw}}(c, k) \equiv$
  $c \in \text{Client} \wedge 0 \leq k \wedge 0 \leq c.\text{solde} - k$
- definition $\text{post}_{\text{withdraw}}(c, k, \text{result}) \equiv$
  $c.\text{solde} = \text{old}(c.\text{solde}) - k$

MOAL σ convention !

Syntax and Semantics of MOAL Contracts

- Alternative Example:



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

```
operation c.withdraw(k) :
pre: true
post:
 if k >= 0 ∧ old(c.solde) - k>=0
 then  c.solde = old(c.solde) - k
         ∧ result = ok
else result = nok
```

What are the differences between these contracts?

Syntax and Semantics of MOAL Contracts

- Answer:

```
operation c.withdraw(k) :
pre: true
post:
 if k >= 0 ∧ old(c.solde) - k>=0
 then  c.solde = old(c.solde) - k
          ∧ result = ok
else result = nok
```

"withdraw" is now always defined; in case of illegal arguments it yields an error

Semantics of MOAL Contracts

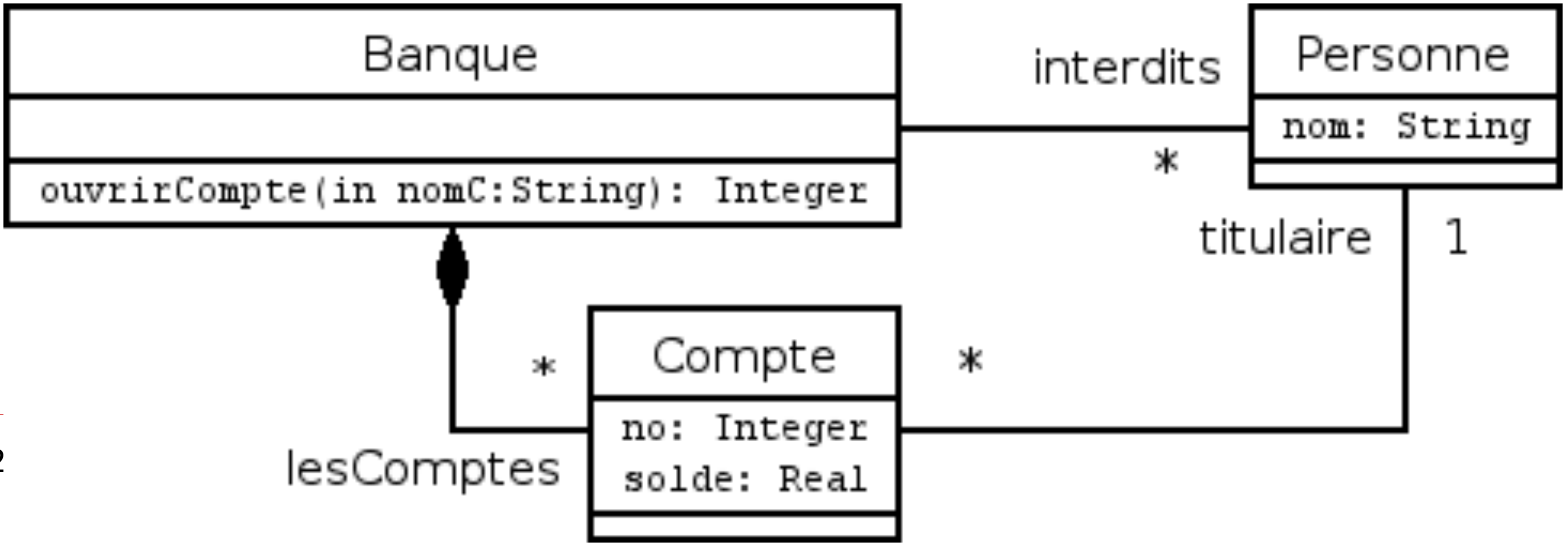
- Two predicates are helpful when defining contracts. They exceptionally refer to both (σ_{pre},σ)
  - isNew(p) (σ_{pre},σ) is true only if object p of class C does not exist in σ_{pre} but exists in σ
  - modifiesOnly(S)(σ_{pre},σ) is only true iff
    - all objects in σ_{pre} are except those in S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

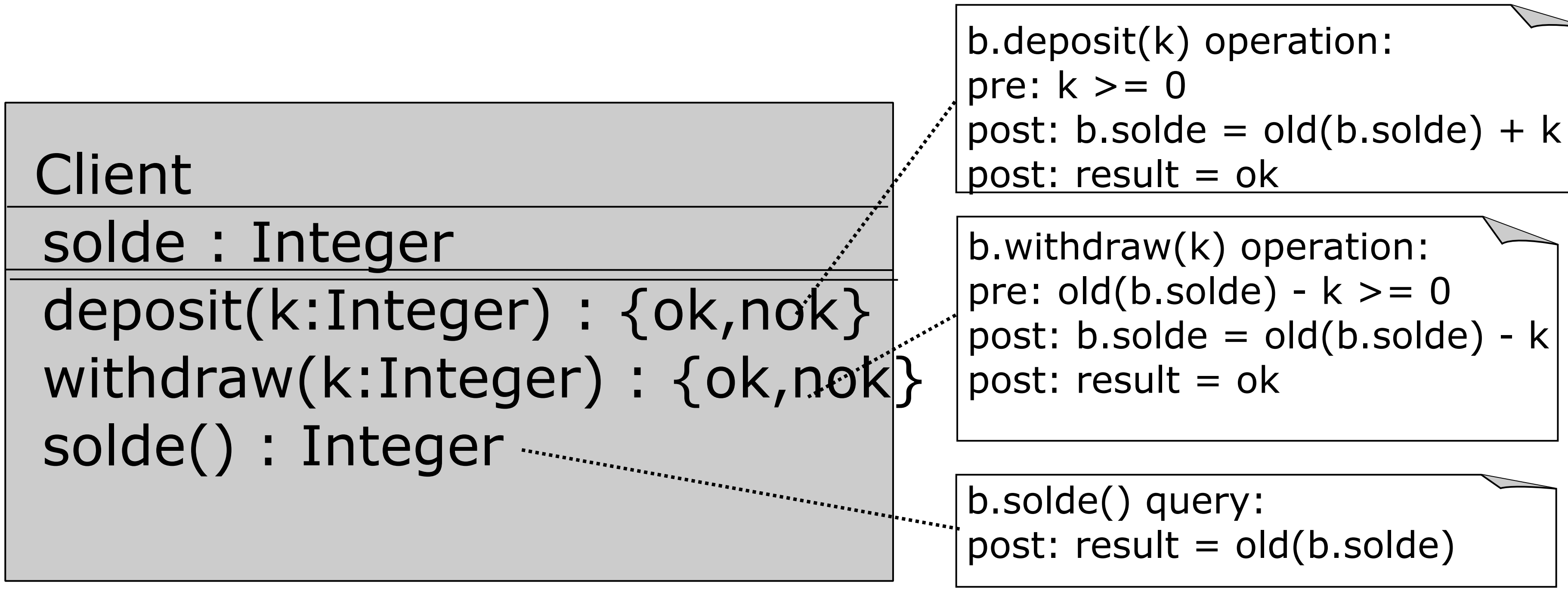
```
definition pre_ouvrirCompte (b:Banque, nomC:String)≡
                              ∀p ∈ Personne. p.nom ≠ nomC

definition post_ouvrirCompte (b:Banque,nomC:String,r:Integer)≡
      | {p ∈ Personne | p.nom = nomC} | = 1
      ∧ ∀p ∈ Personne. p.nom = nomC ⟶ isNew(p)
      ∧ |{c∈Compte | c.titulaire.nom = nomC}|  = 1
      ∧ ∀c∈Compte. c.titulaire.nom = nomC ⟶ c.solde = 15
                                            ∧ c.isNew()
      ∧ b.lesComptes=old(b.lesComptes)∪
                    {c∈Compte | c.titulaire.nom = nomC}
      ∧ b.interdits=old(b.interdits)∪
                    {p ∈ Personne | p.nom = nomC}
      ∧ modifiesOnly({b}∪{c∈Compte c.titulaire.nom = nomC}
                    ∪ {p ∈ Personne | p.nom = nomC})
```

Now we can understand the complex looking contract of part III intro for the Bank:

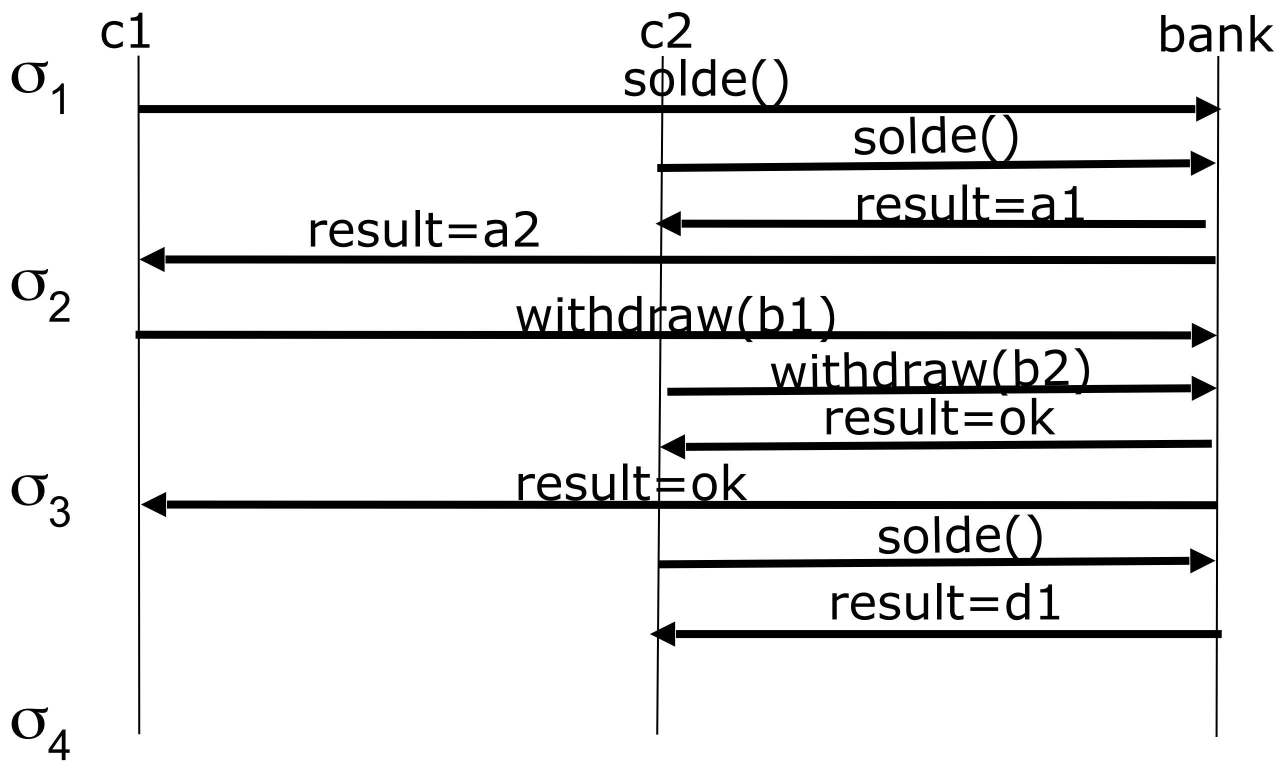
Operations in UML and MOAL

- A more complete example at a glance:
  (still ignoring framing conditions)


Client
solde : Integer
deposit(k:Integer) : {ok,nok}
withdraw(k:Integer) : {ok,nok}
solde() : Integer
b.deposit(k) operation:
pre: k >= 0
post: b.solde = old(b.solde) + k
post: result = ok
b.withdraw(k) operation:
pre: old(b.solde) - k >= 0
post: b.solde = old(b.solde) - k
post: result = ok
b.solde() query:
post: result = old(b.solde)

Operations in UML and MOAL

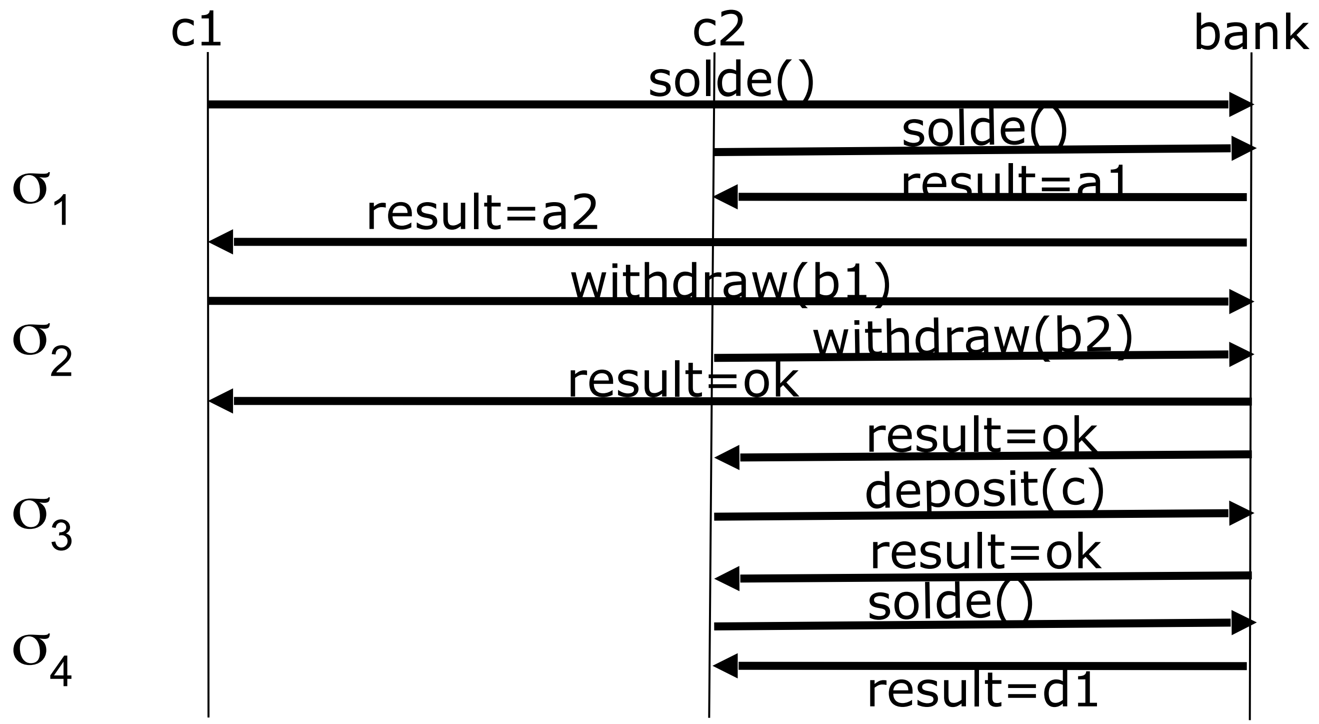
- Abstract Concurrent Test Scenario:



Assume that this scenario was valid, i.e. all conditions were satisfied: what do we know in σ_4 ?

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 "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
  - Cahier de charge to Analysis
  - From Analysis to Designs and Tests.