Relationships between
Class Diagrams, Object Diagrams and OCL Invariants

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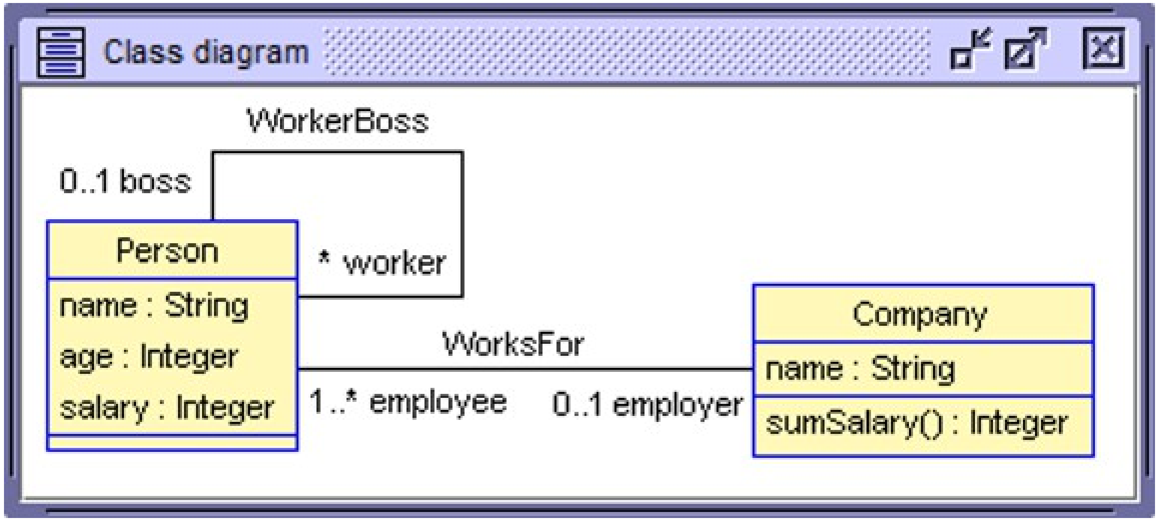
Outline

- Running example

- Basic concepts in class diagrams
  - Class, attribute, association

- Basic concepts in object diagrams
  - Object, value assignment, link

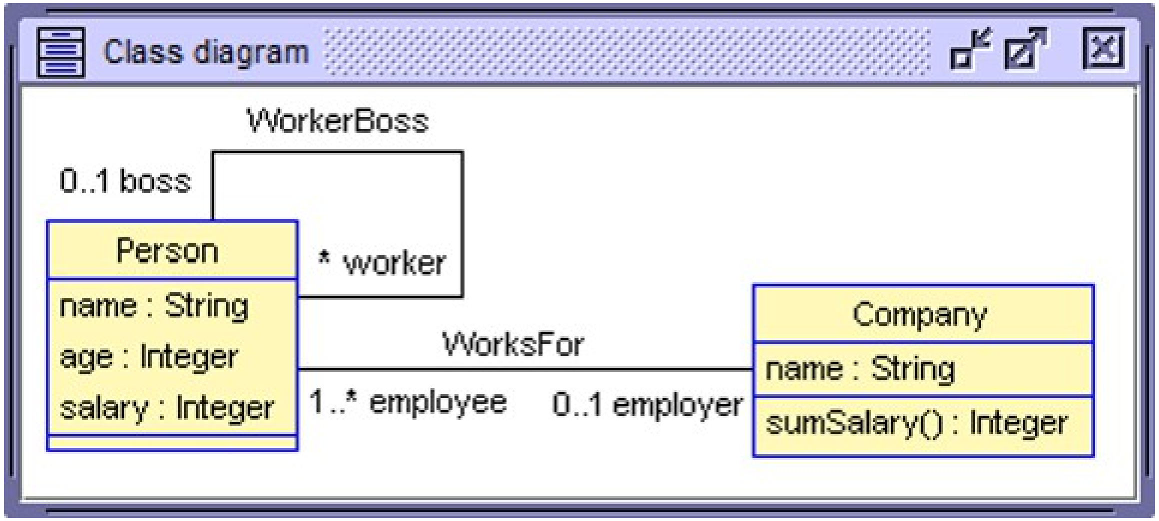
- Invariants for restricting object diagrams
  - Invariant context
  - Invariant fulfilment



Class diagram
WorkerBoss
0..1 boss
* worker
Person
name : String
age : Integer
salary : Integer
WorksFor
1..* employee
0..1 employer
Company
name : String
sumSalary() : Integer

Basic class diagram concepts

- Class with class name
- Attribute with attribute name and datatype
- Datatype with datatype name
  - refers to a set of datatype values and
  - to datatype operations
- Association with association name
  - Role with role name
  - Role multiplicity with lower and upper bound



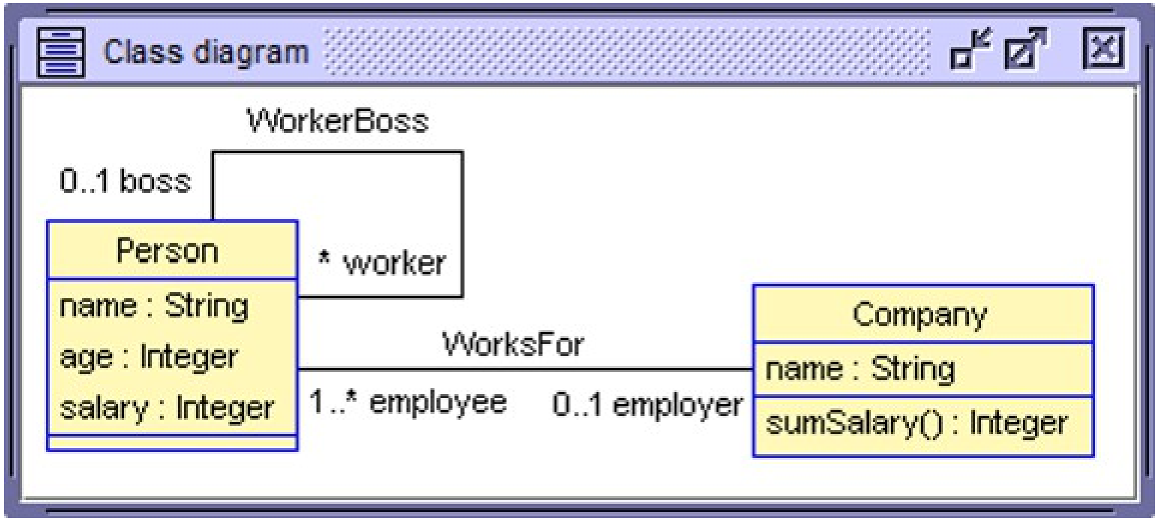
datatypes = { Integer, String }

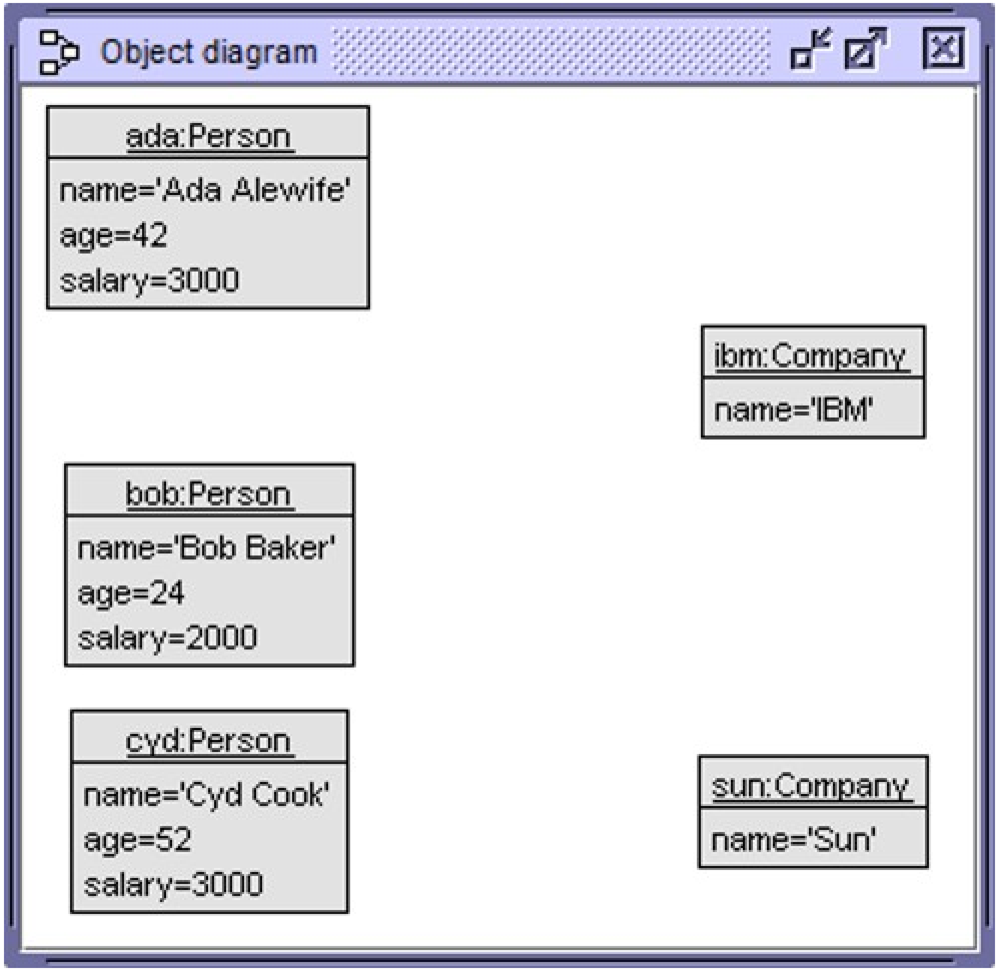
classes = { Person, Company }

associations =
{ WorksFor(1..* : employee : Person, 0..1 : employer : Company),
WorkerBoss(0..1 : boss : Person, 0..* : worker : Person) }

attributes =
{ Person :: name : String,
Person :: age : Integer,
Person :: salary : Integer,
Company :: name : String }

operations =
{ Company :: sumSalary() : Integer }





ada:Person
name='Ada Alewife'
age=42
salary=3000

ibm:Company
name='IBM'

bob:Person
name='Bob Baker'
age=24
salary=2000

cyd:Person
name='Cyd Cook'
age=52
salary=3000

sun:Company
name='Sun'

objects [Person] = { ada, bob, cyd }

objects [Company] = { ibm, sun }

values [Person::name] =
{ ada → 'Ada Alewife',
bob → 'Bob Baker',
cyd → 'Cyd Cook' }

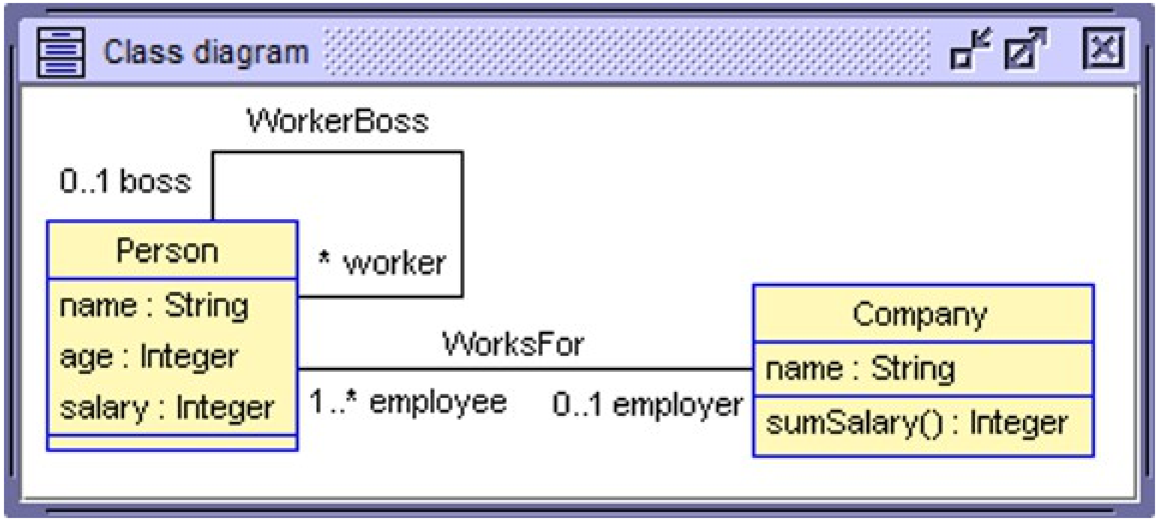
values [Person::age] = …

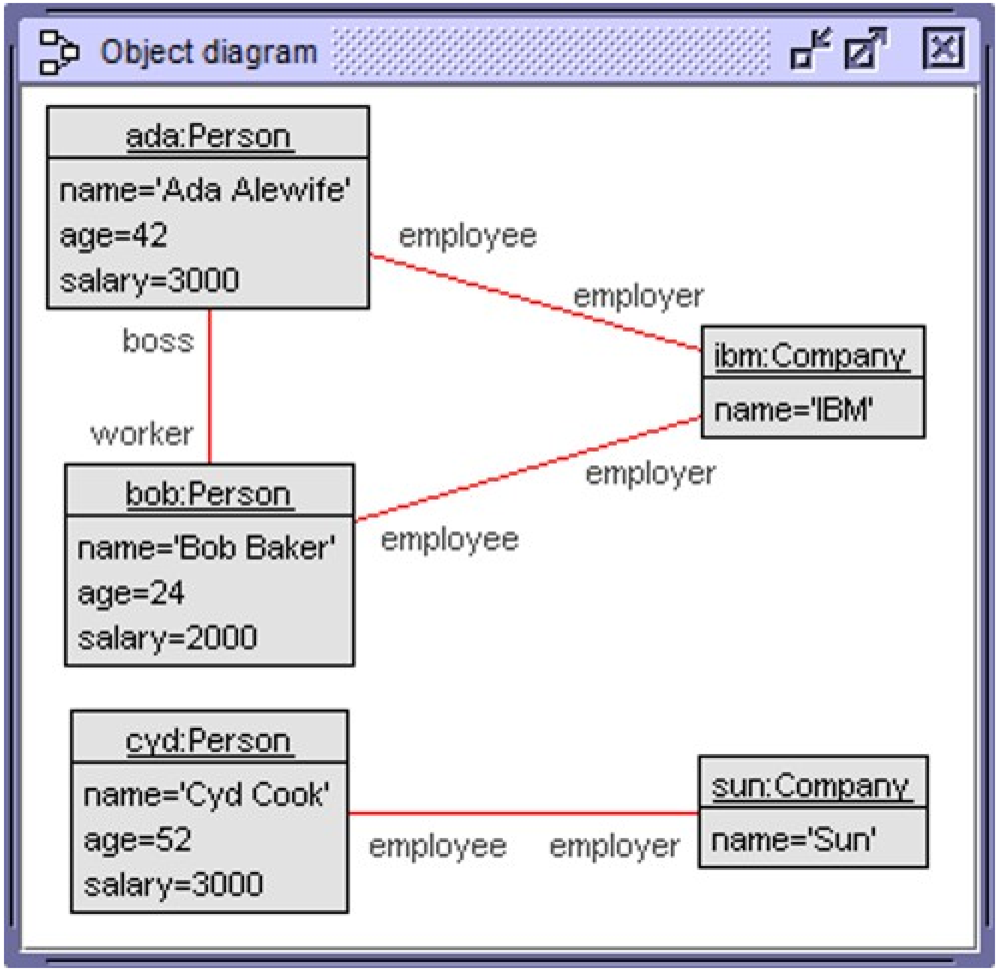
values [Person::salary] = …

values [Company::name] = …

Basic object diagram concepts (for classes, attributes)

- Class diagram interpreted by
  the set of all possible object diagrams
- Each single class interpreted in an object diagram by
  a finite set of objects
- Each object has an object identity that is unique
  in the object diagram
- Each class attribute interpreted by assigning
  a datatype value to the attribute for all relevant objects





objects [Person] = { ada, bob, cyd }

objects [Company] = { ibm, sun }

links [WorksFor] =
{ (employee:ada, employer:ibm),
(employee:bob, employer:ibm),
(employee:cyd, employer:sun) }

links [WorkerBoss] =
{ (worker:bob, boss:ada) }

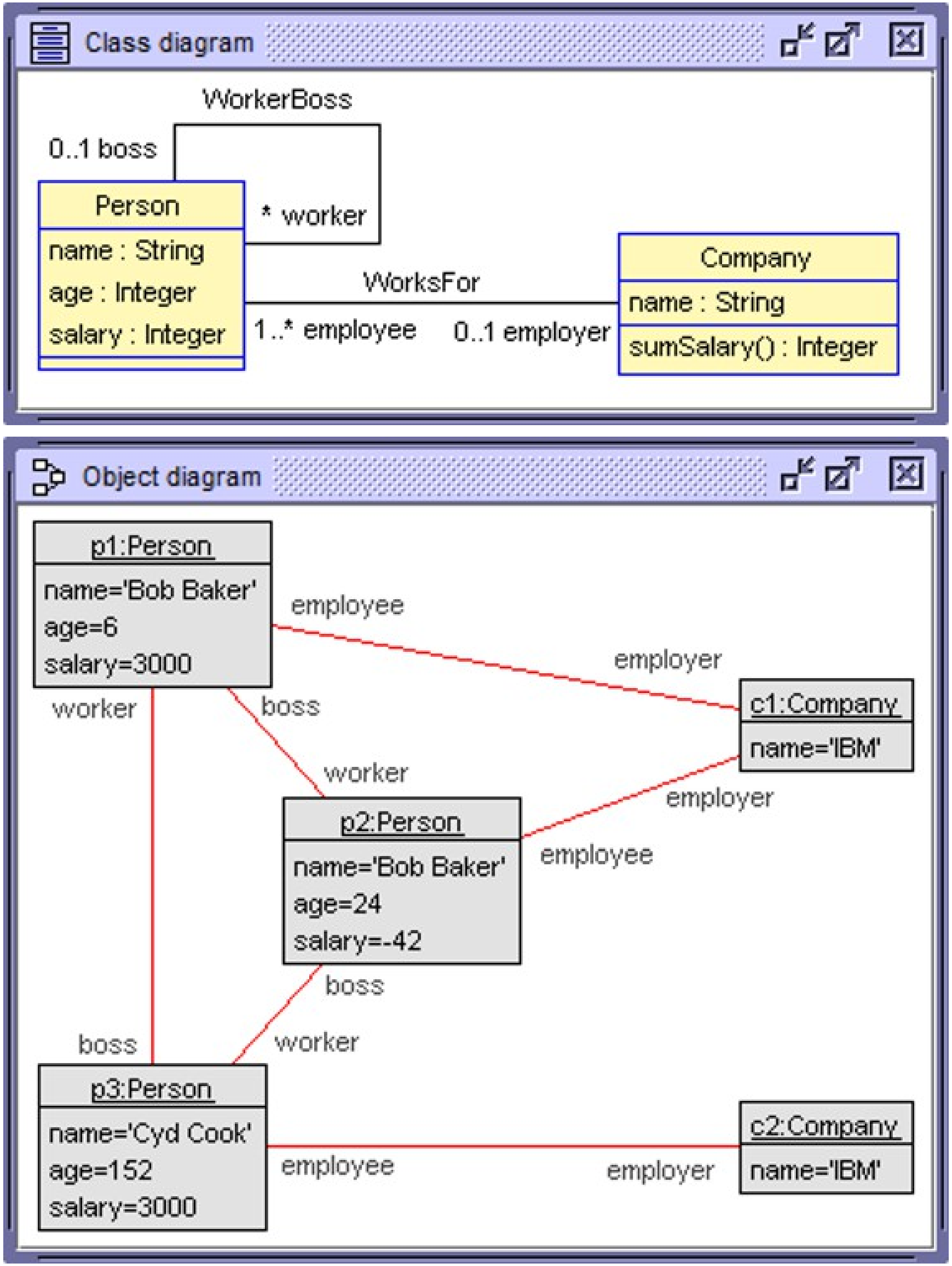
Exchanging the WorkerBoss link roles gives a different object diagram

Basic object diagram concepts (for associations)

- Each single association interpreted in an object diagram by a (finite) set of links (finiteness implied by finite object set)
- A link connects two (or more) objects
- A link can be considered as a tuple of object identities together with roles
- A link uses (association) roles to describe the character that an object plays in the link

Summary

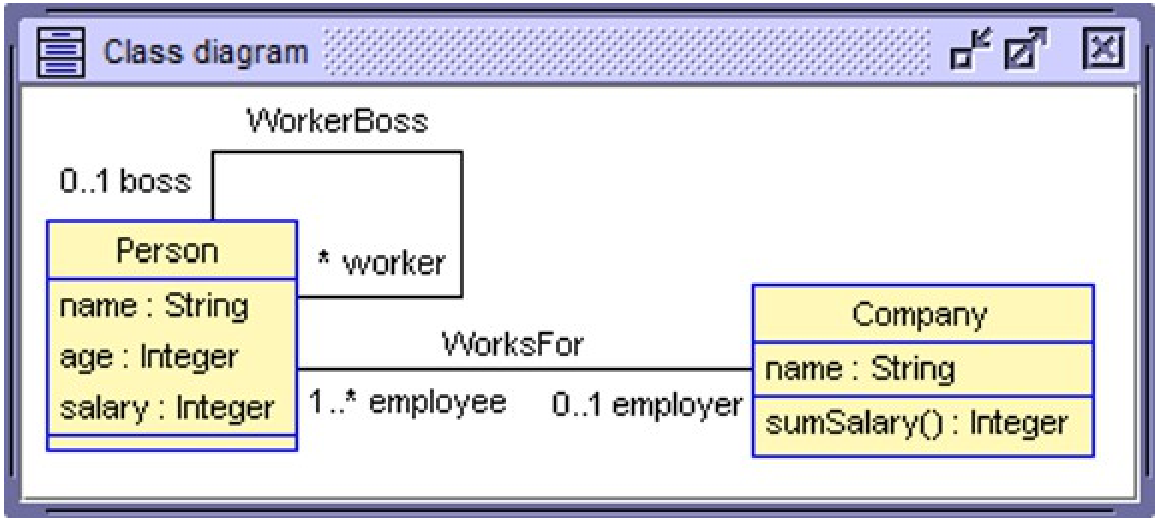
- Class diagram → Set of all object diagrams
- In an object diagram
  - Class cs → Finite set of objects for cs
  - For object ob, attribute at → Value assignment for at in ob
  - Association as → Finite set of links for as

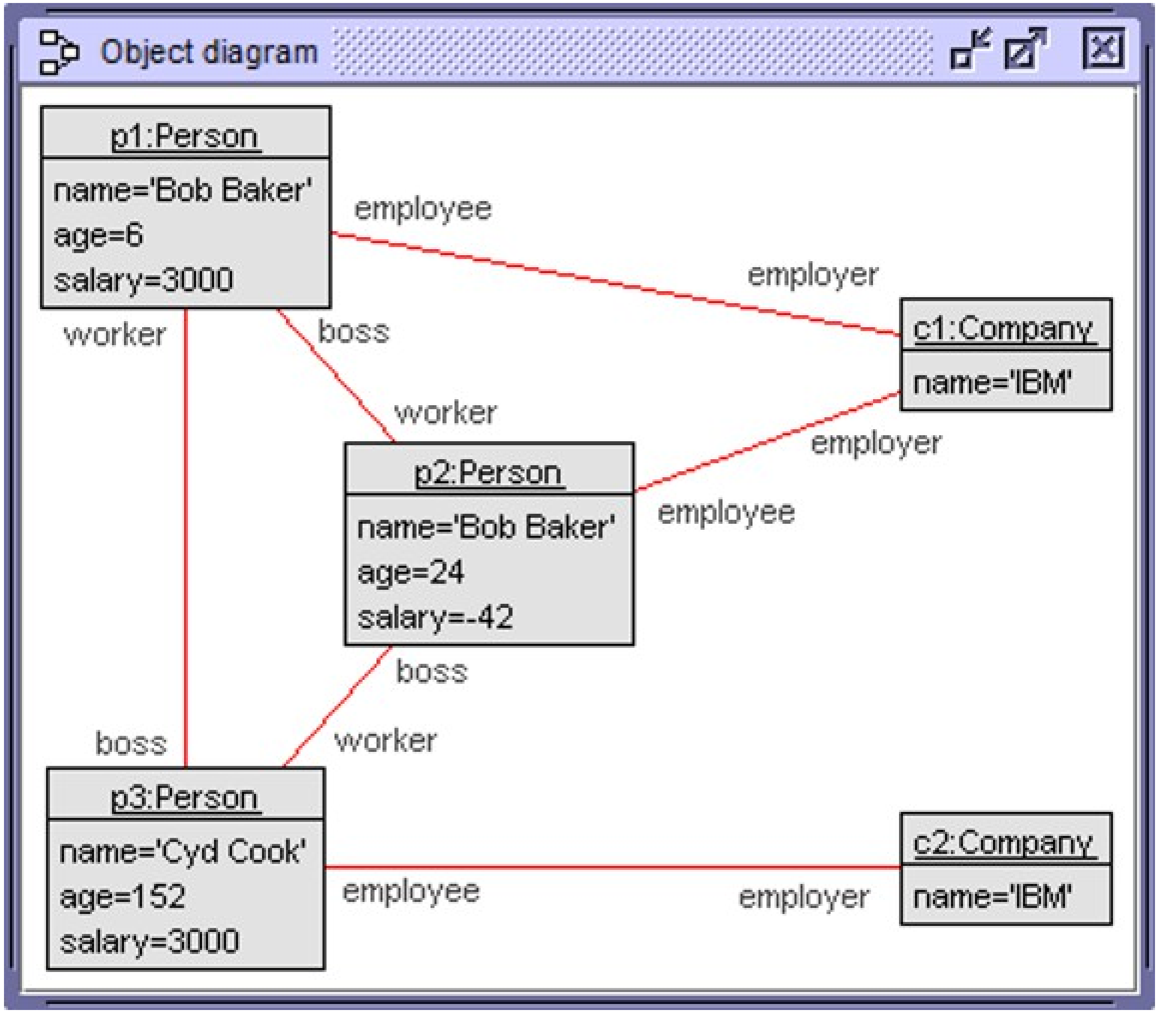


Exchanging any WorkerBoss link role gives a different object diagram

There are object diagrams
that correspond to non-meaningful real-world situations
with regard to attribute values and links

Needed: Mechanism to ban *'bad'* object diagrams





Required conditions in example

context Company inv employeeAtLeast16

context Company inv nameUnique

context Person inv acyclicBossWorker

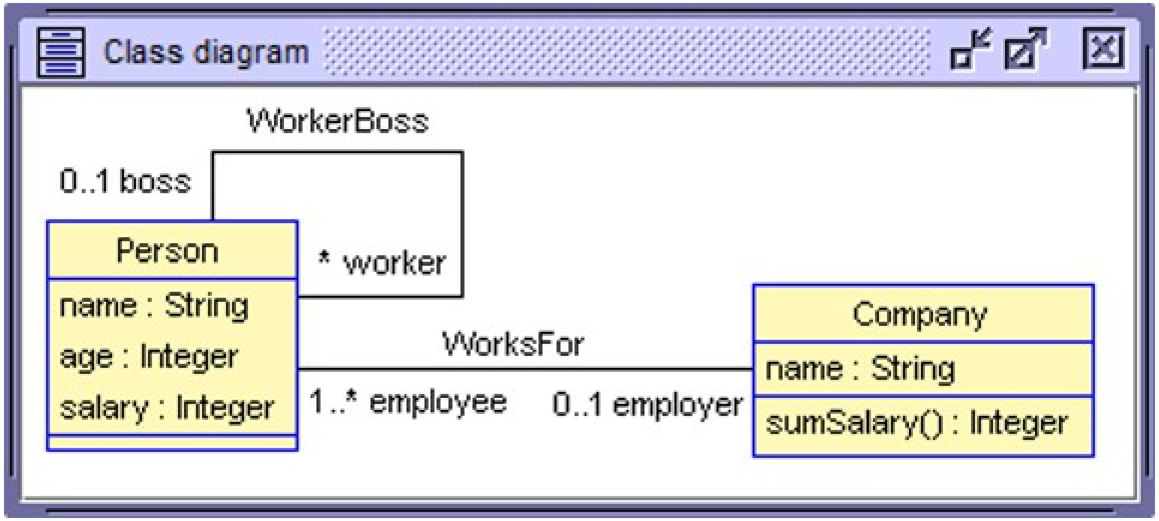
context Person inv ageReasonable

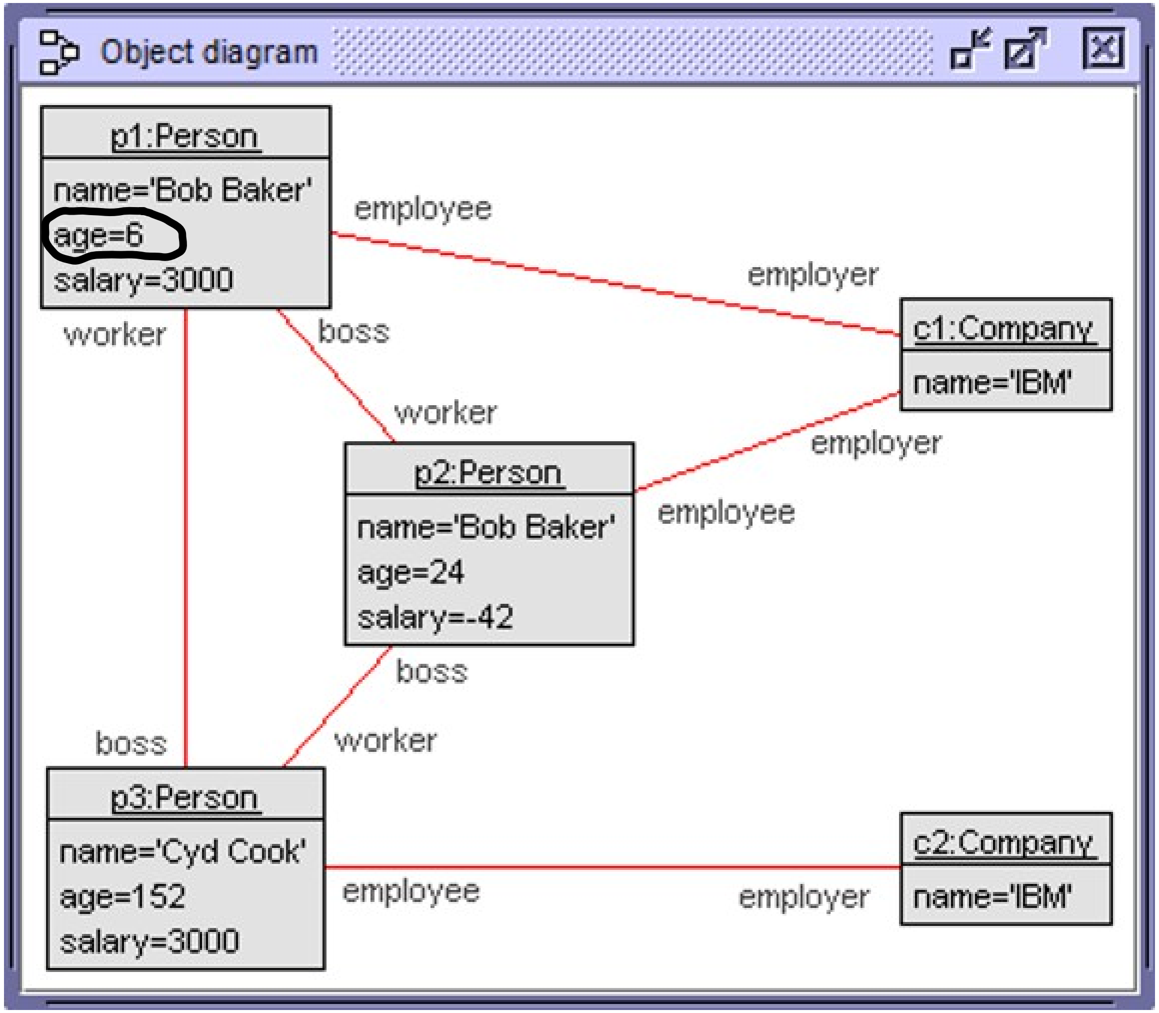
context Person inv bossSameCompany

context Person inv nameUnique

context Person inv salaryPositive

All conditions violated in example





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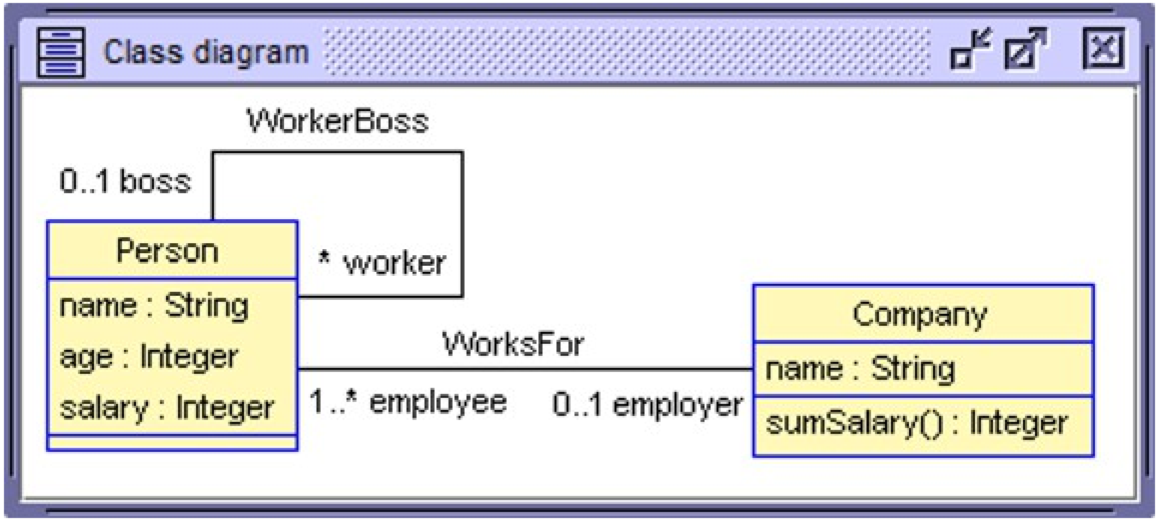

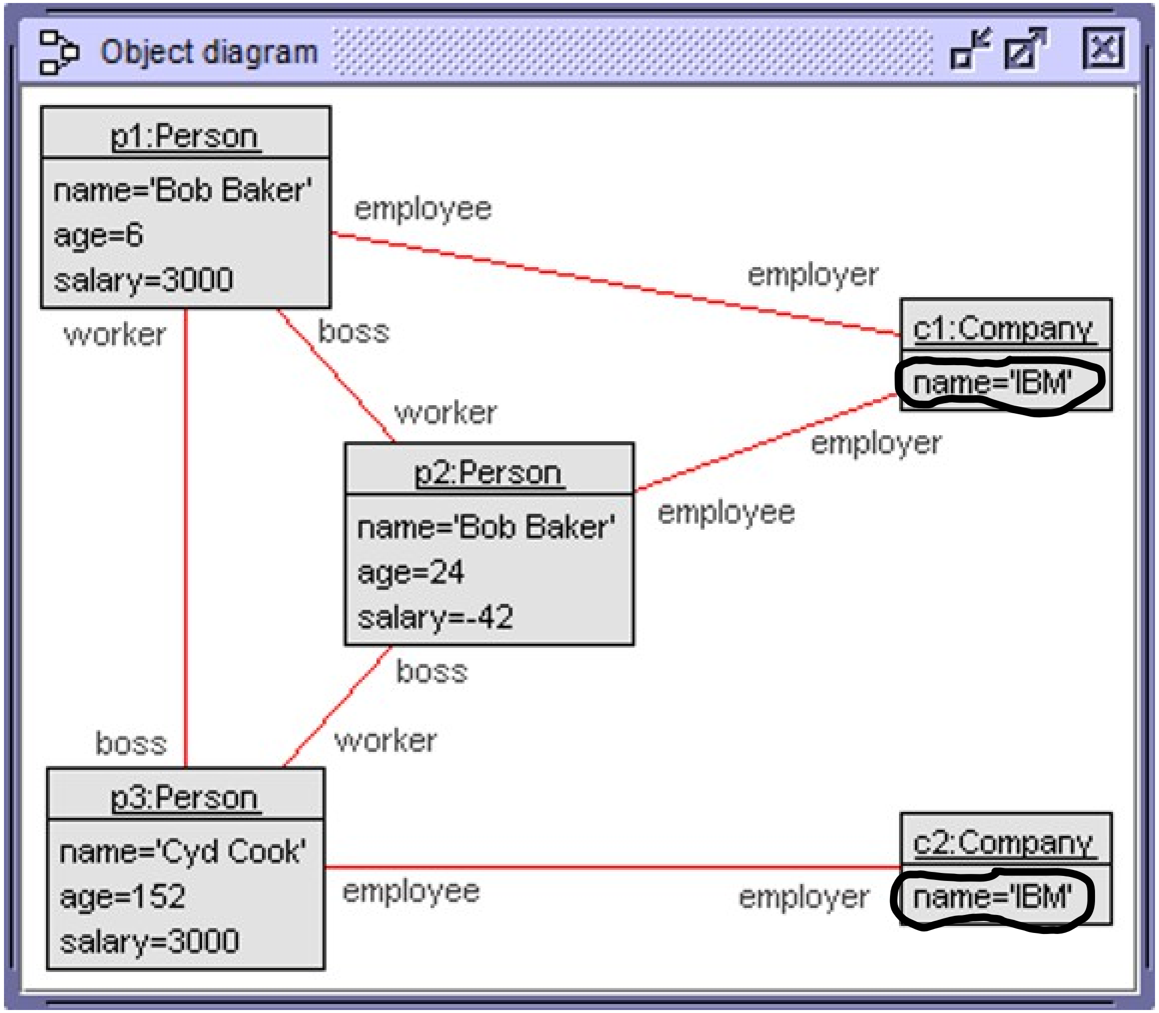

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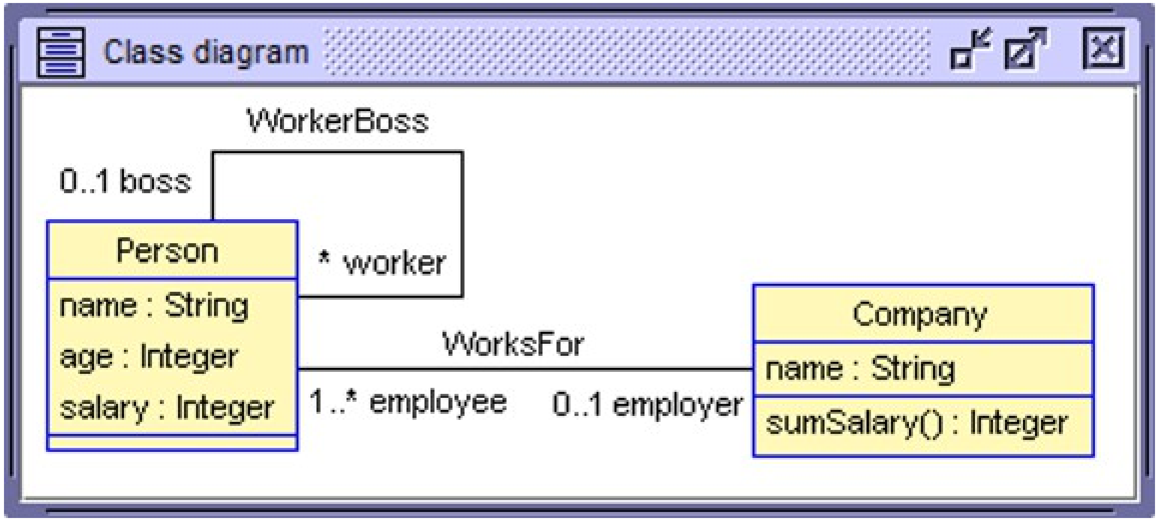

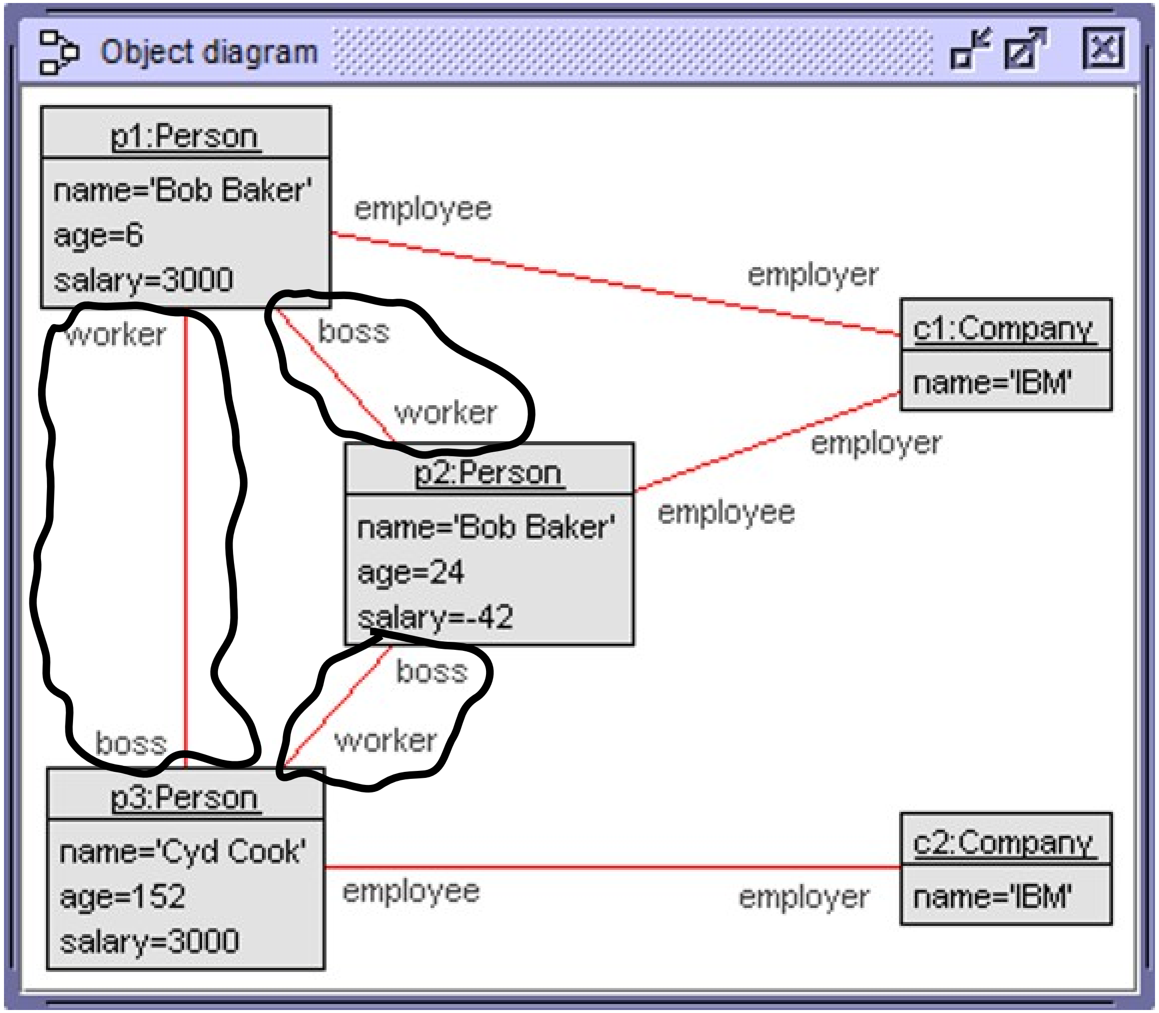

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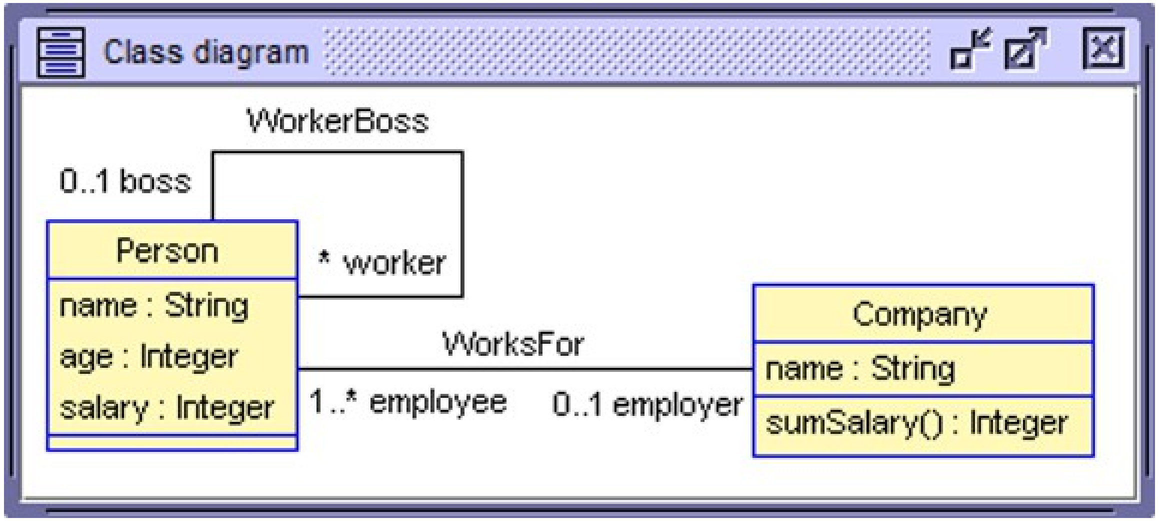

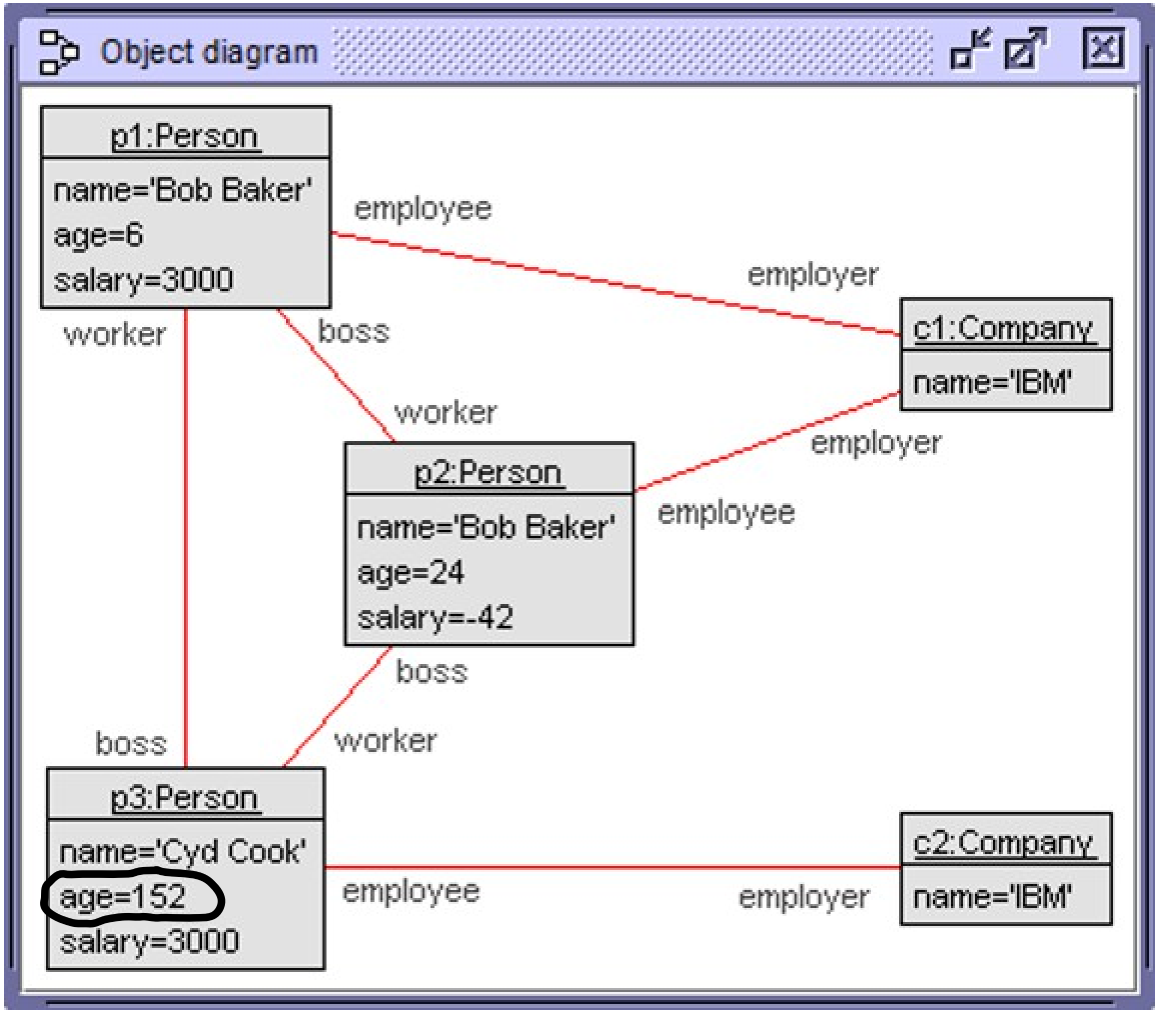

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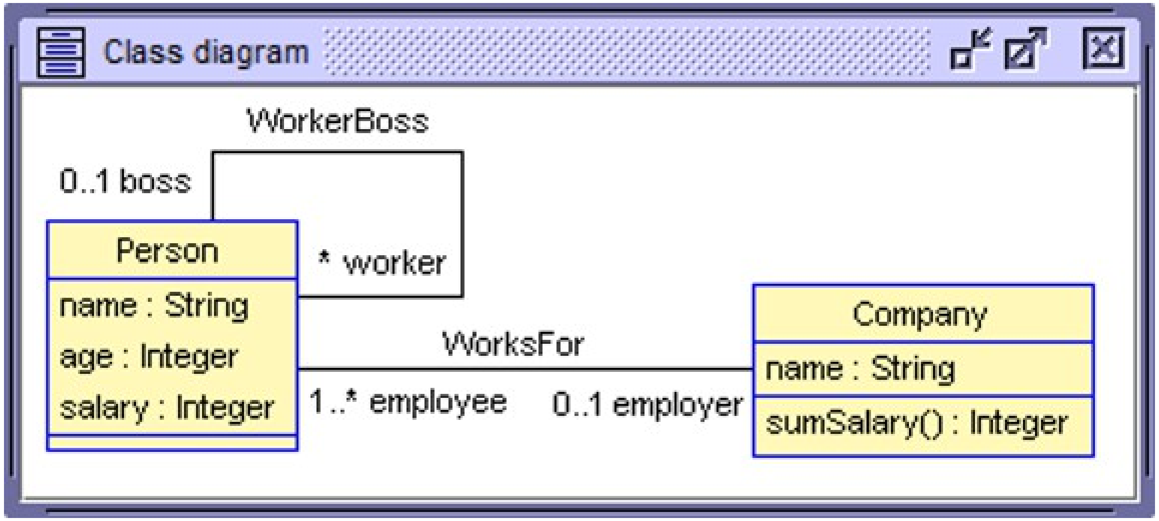

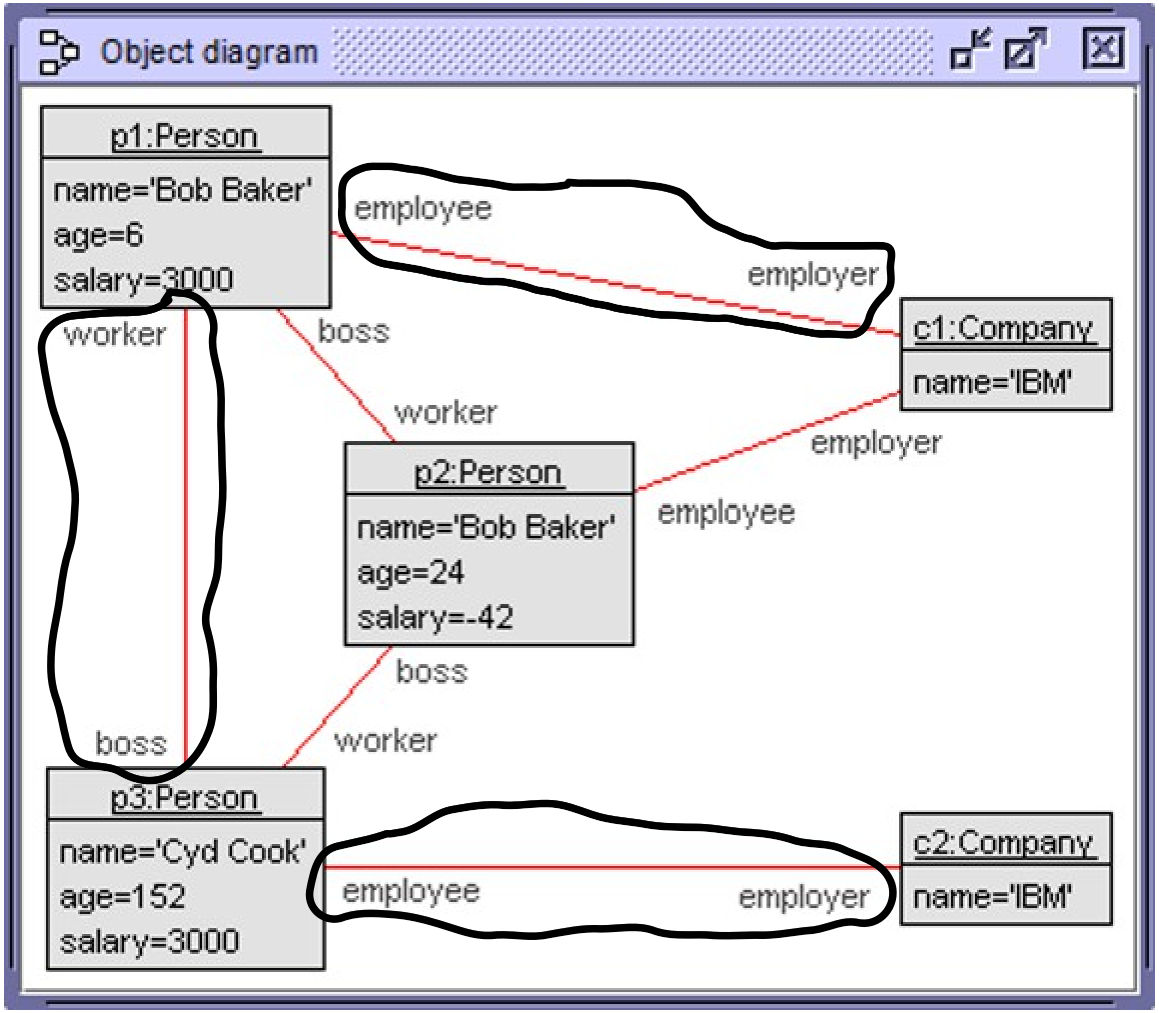

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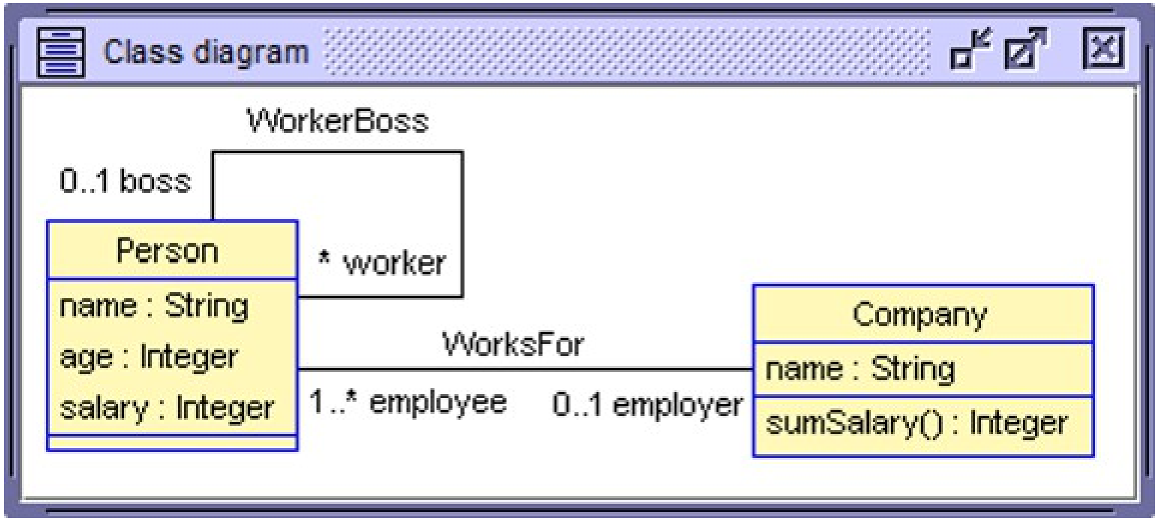

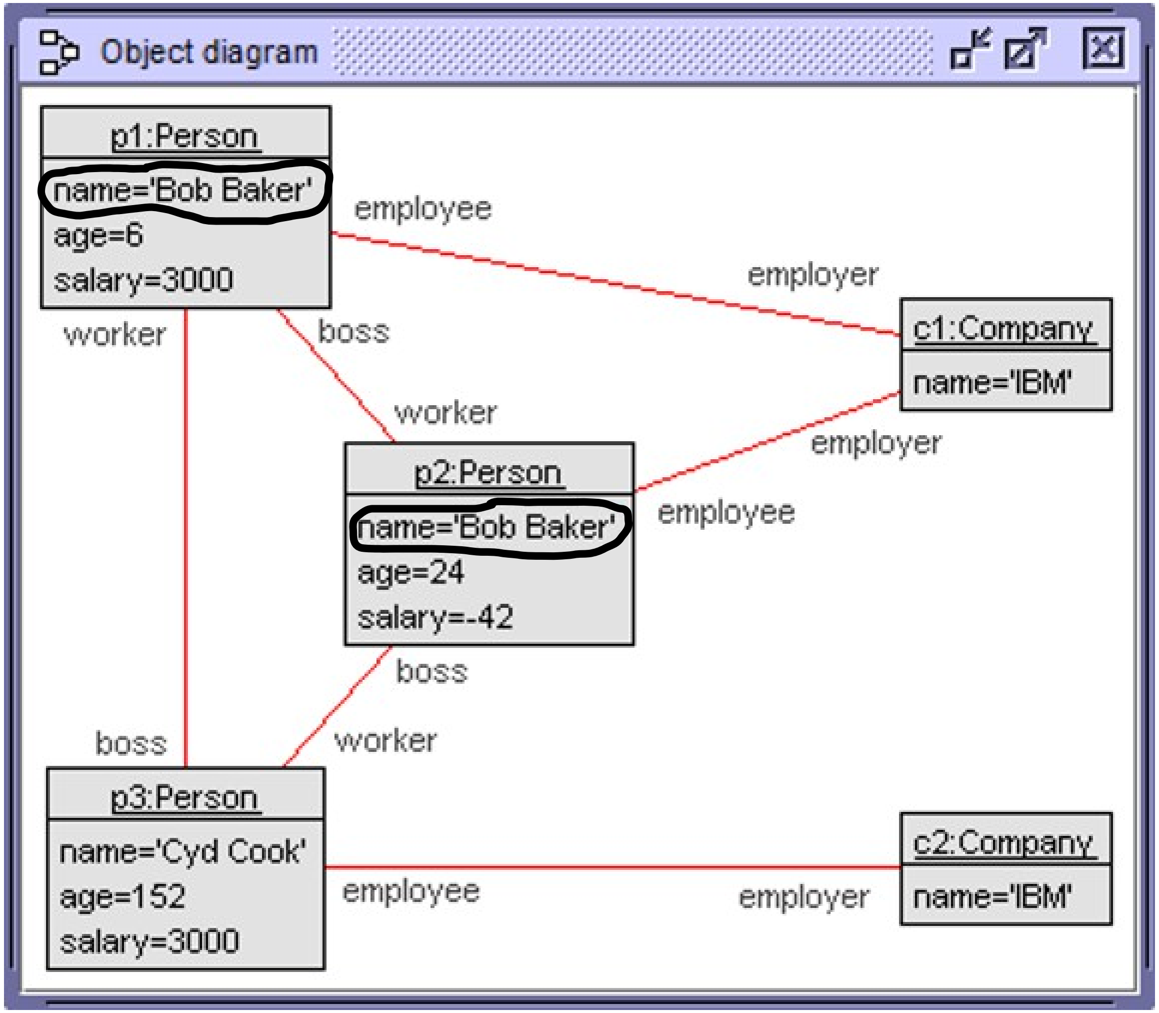

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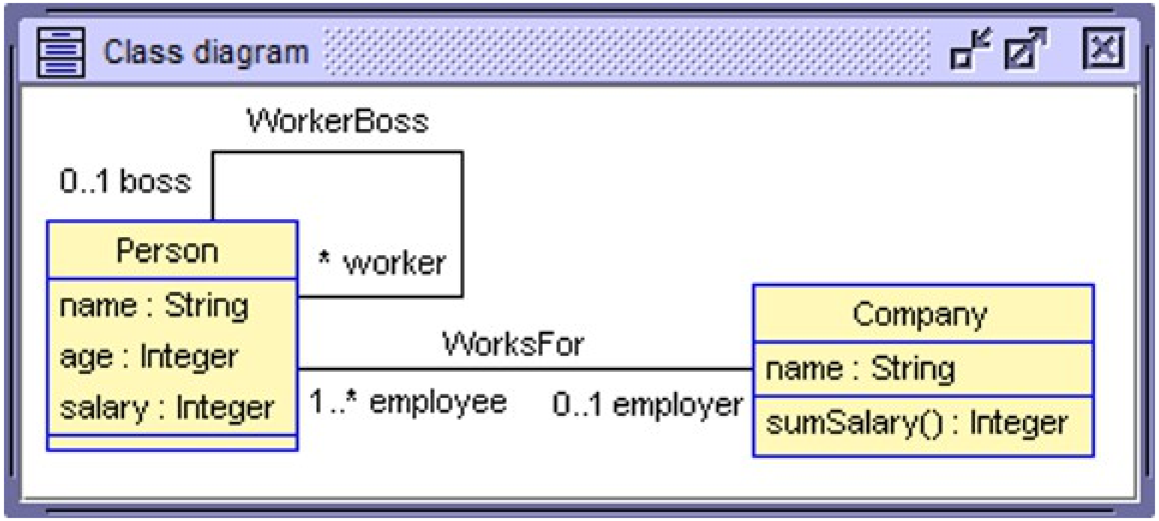

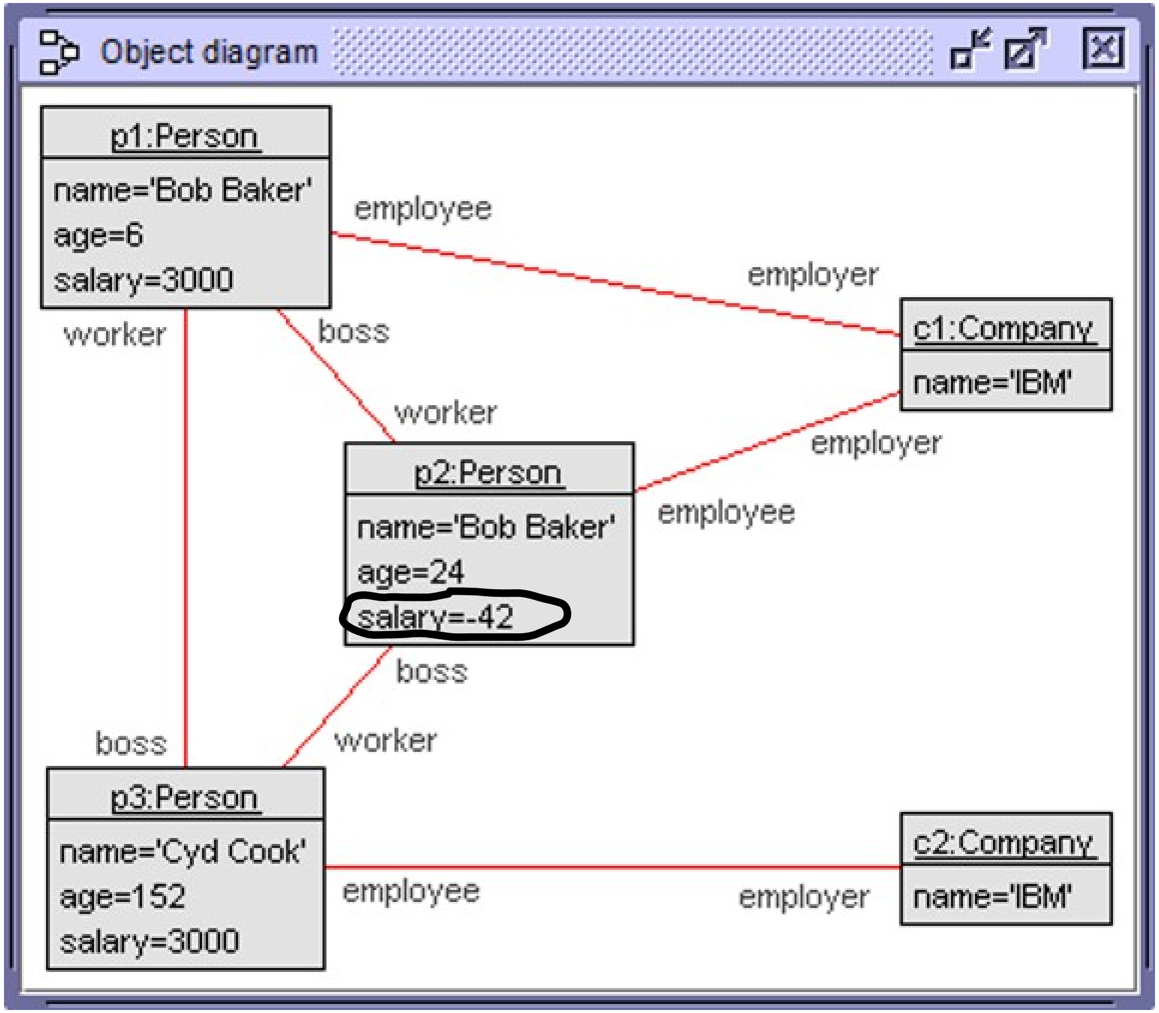

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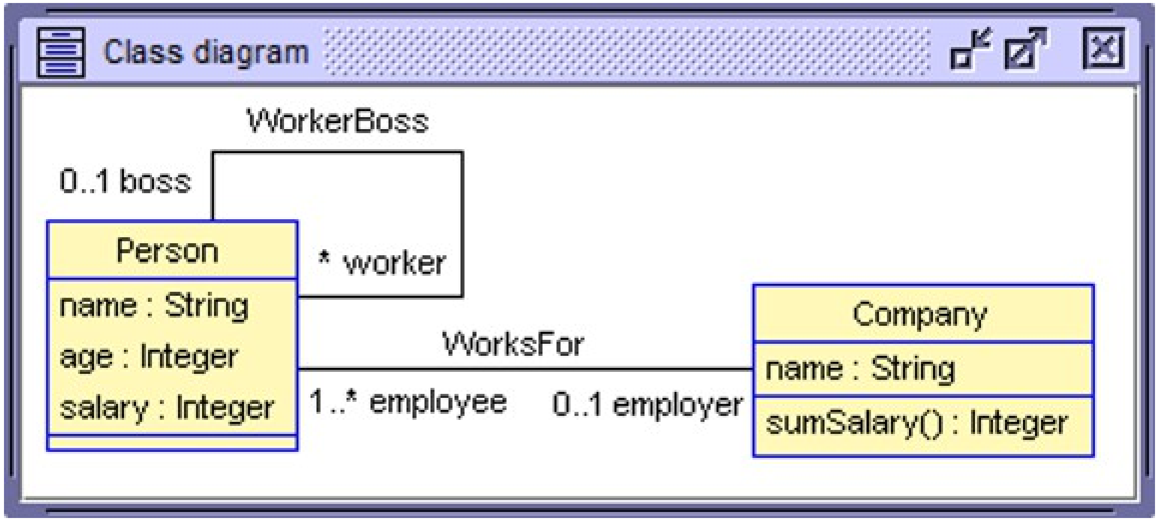
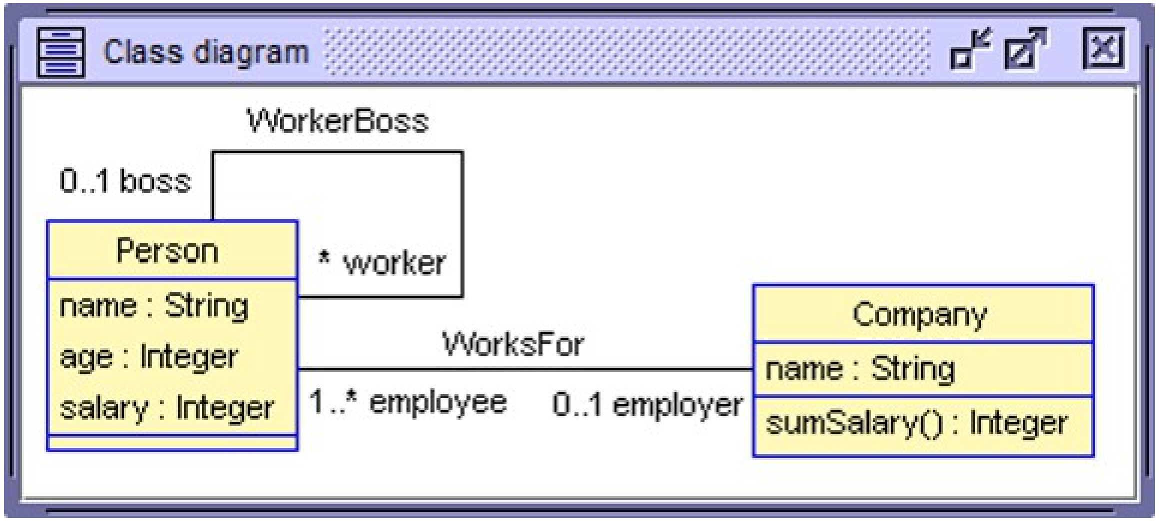
All conditions violated in example

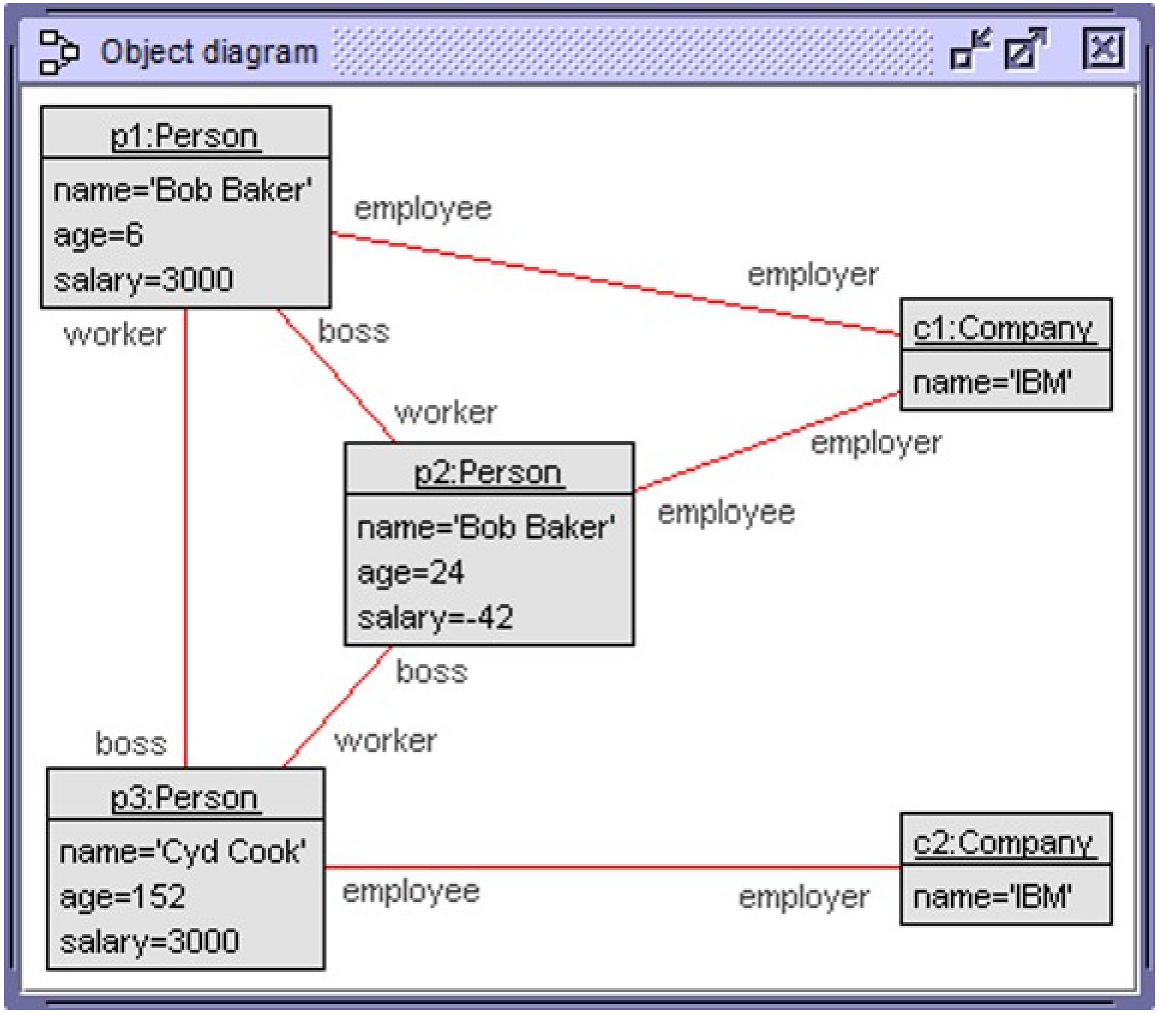
To exclude non-meaningful object diagrams

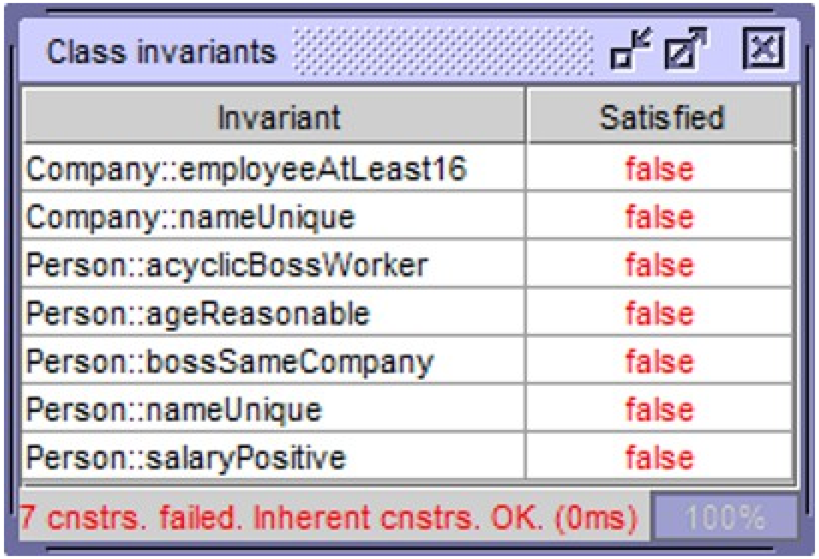
- Additional OCL constraints, called invariants, are introduced
- OCL constraints are formulas that are expressed from the viewpoint of a particular class, the so-called context class
  → *Invariant context*
- Evaluation in an object diagram is done for all objects of the context class and may yield *False* or *True*
- Only when the evaluation of all invariants yields *True*, the object diagram is considered to be meaningful
  → *Invariant fulfillment*



```
context Person inv ageReasonable:
  0<=age and age<=110

context Person inv salaryPositive:
  1<=salary

context p:Person inv bossSameCompany:
  (p.employer->size()=1 and p.boss->size()=1) implies p.employer=p.boss.employer

context p:Person inv acyclicBossWorker:
  p.worker->closure(worker)->excludes(p) -- closure expression ≡  p.worker U p.worker.worker U
                                                                 p.worker.worker.worker U ...
context c:Company inv employeeAtLeast16:
  c.employee->forAll(p | p.age>=16)

context p1,p2:Person inv nameUnique:
  p1<>p2 implies p1.name<>p2.name

context c:Company inv nameUnique:
  not Company.allInstances->exists(d | d<>c and d.name=c.name)
```





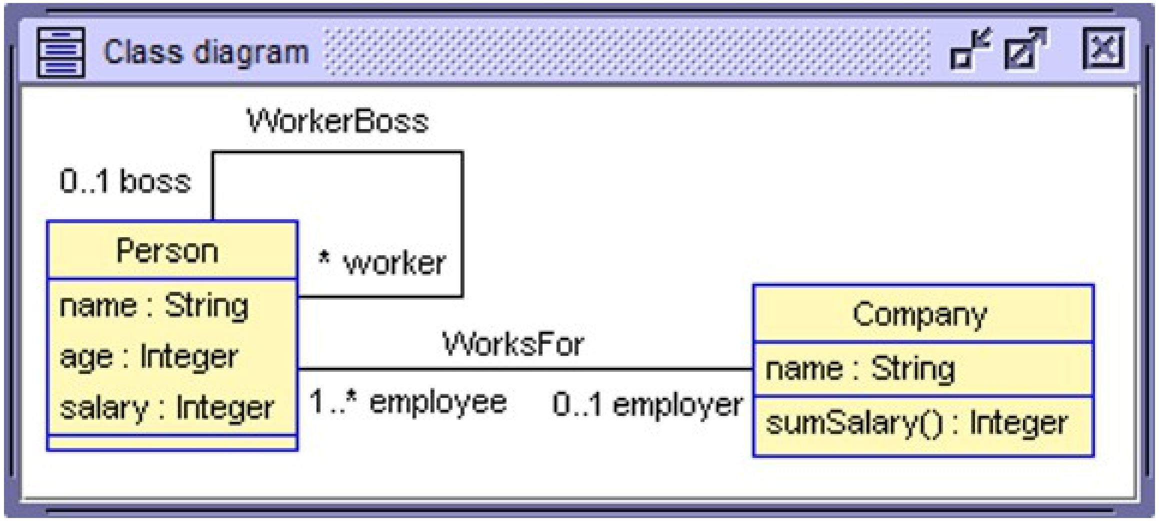

Class invariants

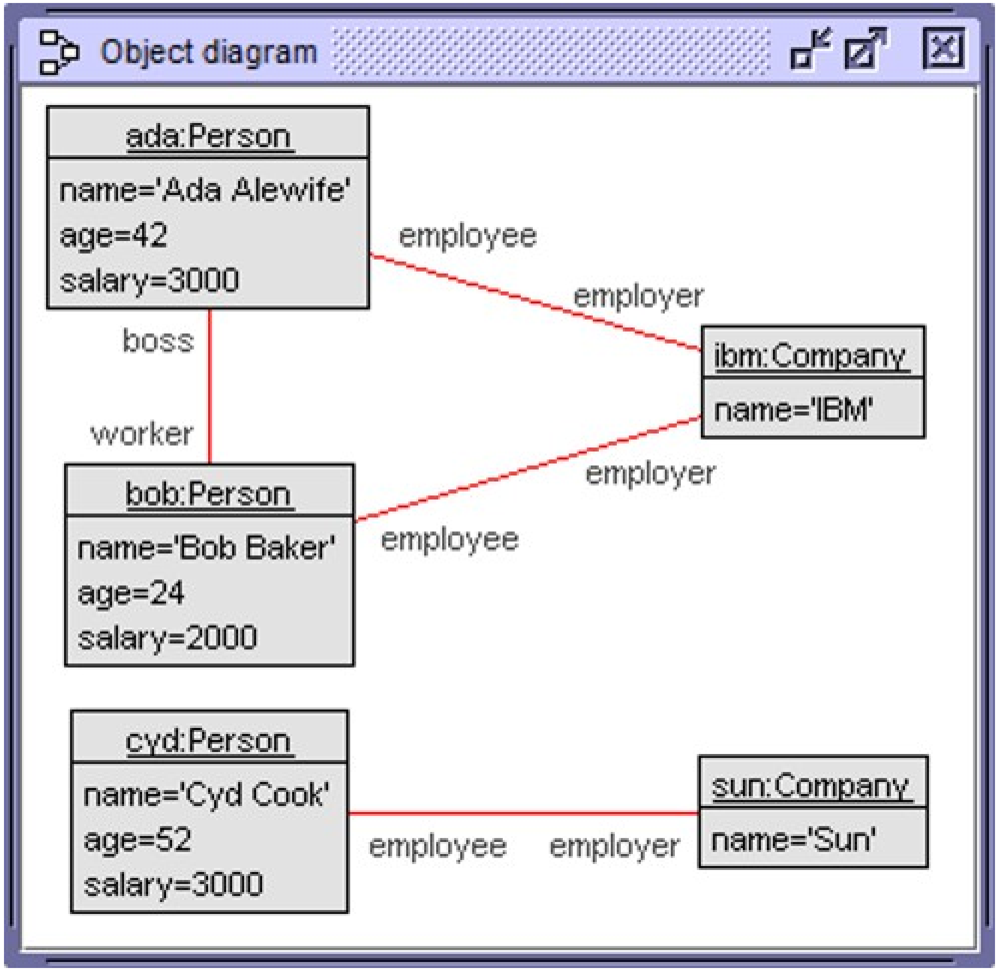
Invariant	Satisfied
Company::employeeAtLeast16	false
Company::nameUnique	false
Person::acyclicBossWorker	false
Person::ageReasonable	false
Person::bossSameCompany	false
Person::nameUnique	false
Person::salaryPositive	false

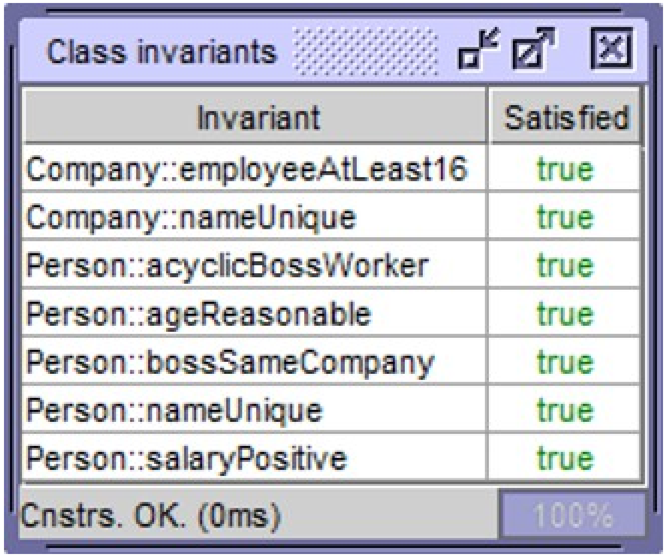
7 cnstrs. failed. Inherent cnstrs. OK. (0ms) 100%

p1.worker->closure(worker) =
Set{ p1, p2, p3 }

p2.worker->closure(worker) =
Set{ p1, p2, p3 }







Invariant	Satisfied
Company::employeeAtLeast16	true
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Person::acyclicBossWorker	true
Person::ageReasonable	true
Person::bossSameCompany	true
Person::nameUnique	true
Person::salaryPositive	true

Cnstrs. OK. (0ms) 100%

ada.worker->closure(worker) =
Set{ bob }

bob.worker->closure(worker) =
Set{}

Summary

- Class diagram → Set of all object diagrams
- In an object diagram
  - Class cs → Finite set of objects for cs
  - For object ob attribute at → Value assignment of at for ob
  - Association as → Finite set of links for as
- Class diagram with invariants → Set of all object diagrams in that all invariants are true for all objects

Thanks for your attention!

How is the operation Company::sumSalary() implemented?

```
Company::sumSalary() =
  self.employee->collect(p | p.salary)->sum()
```

ibm.sumSalary() = 5000 in the 'good' object diagram

How does 'closure' work?

```
p.worker->closure( worker ) : Set(Person) =
'' p.worker ->union( p.worker.worker )
            ->union( p.worker.worker.worker )
            ->union( p.worker.worker.worker.worker )
            ->union ( ... ) … ''
```

until no more new workers appear; only a finite set of workers (persons) possible

What are 'inherent constraints'?

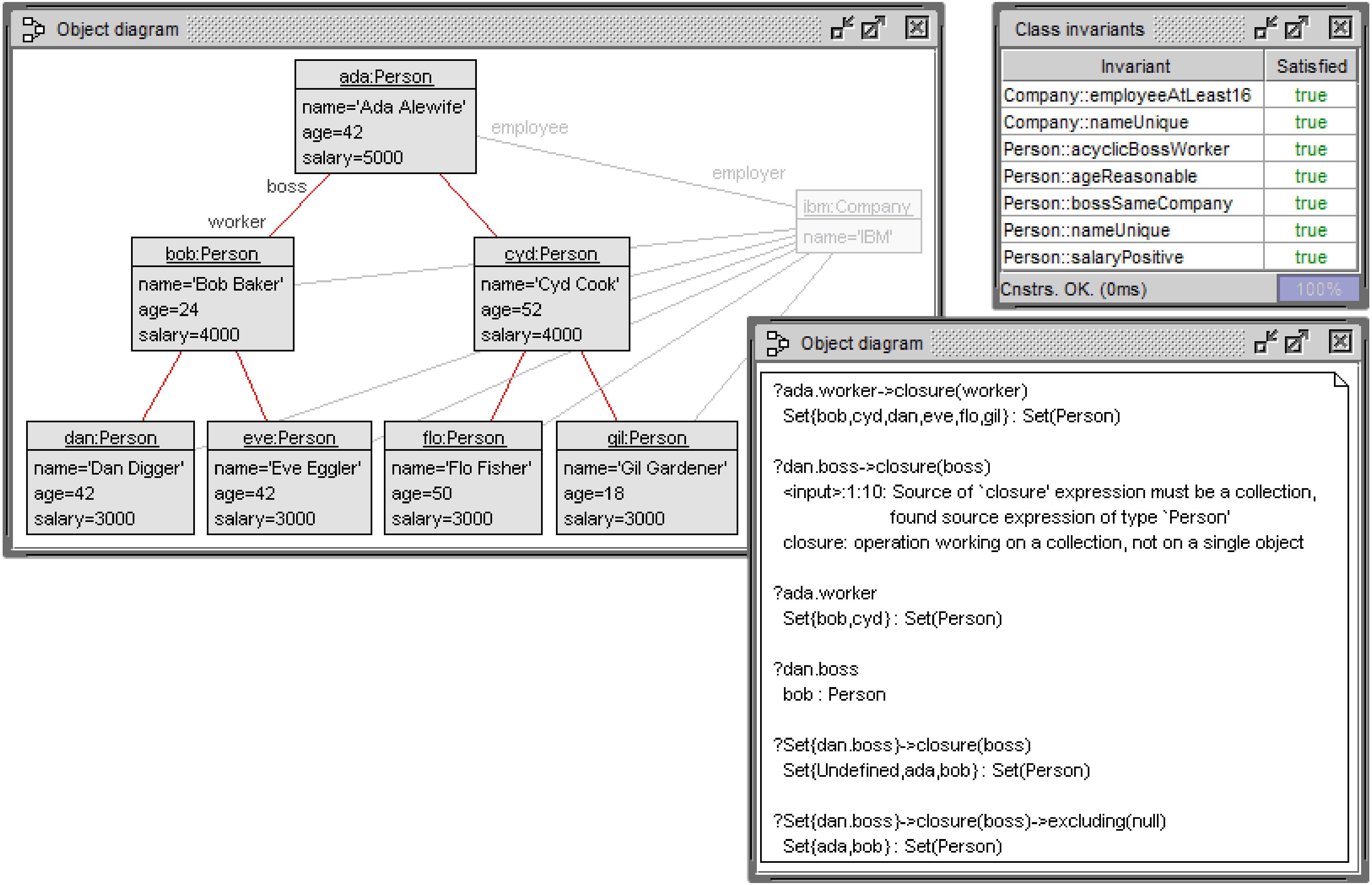
inherent constraints = model inherent constraints

constraints that are already formulated in the UML class diagram

for example, the multiplicity restrictions

```
context p:Person    inv employer_0_1:  p.employer->size()<=1
context c:Company   inv employee_1_*:  c.employee->size()>=1
context p:Person    inv boss_0_1:      p.boss->size()<=1
```

Can you give an example for a WorkerBoss hierarchy with 3 levels?



Invariant	Satisfied
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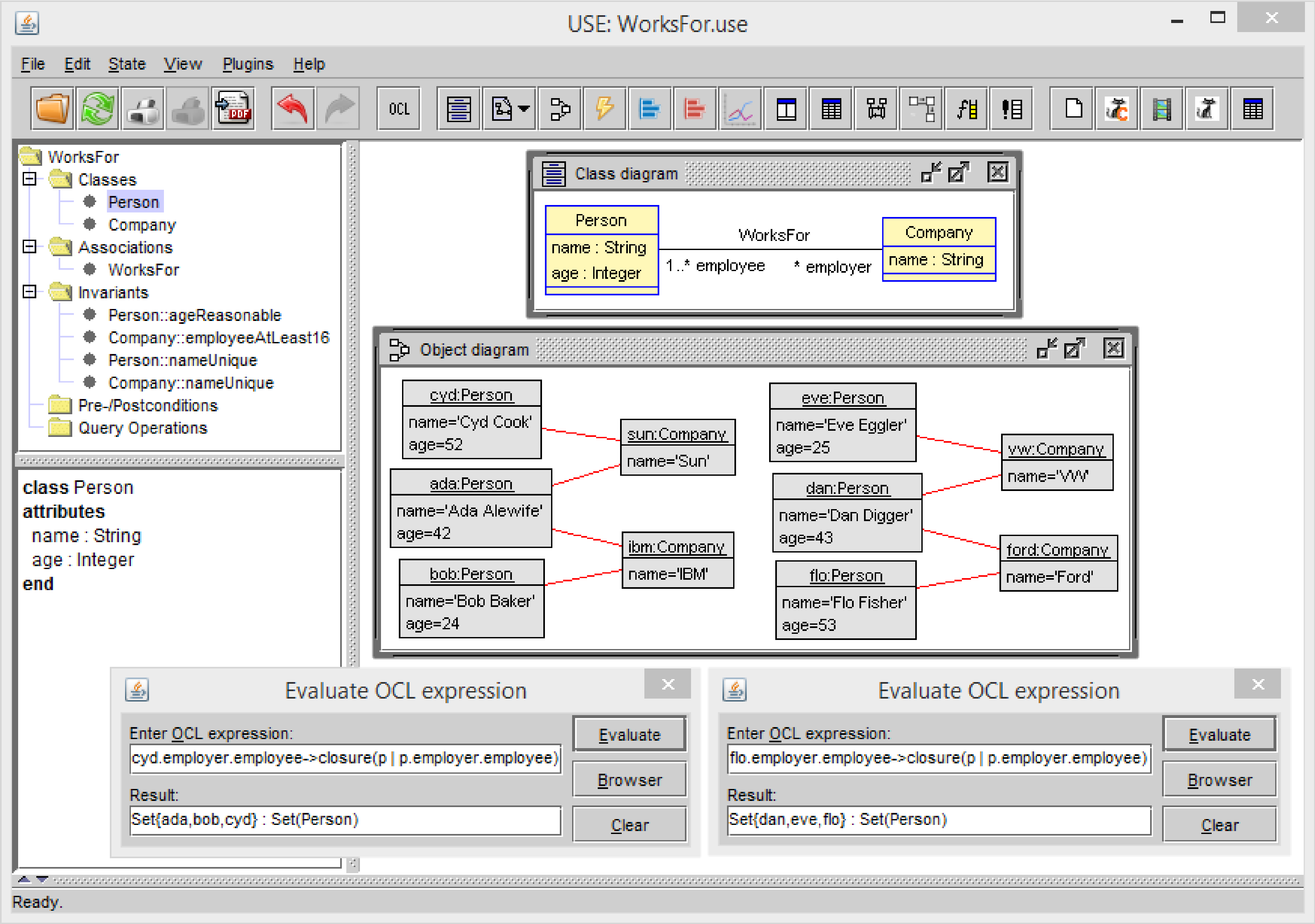
Person::nameUnique	true
Person::salaryPositive	true

Cnstrs. OK. (0ms) 100%

```
?ada.worker->closure(worker)
  Set{bob,cyd,dan,eve,flo,gil} : Set(Person)

?dan.boss->closure(boss)
  <input>:1:10: Source of `closure' expression must be a collection,
                found source expression of type `Person'
  closure: operation working on a collection, not on a single object

?ada.worker
  Set{bob,cyd} : Set(Person)

?dan.boss
  bob : Person

?Set{dan.boss}->closure(boss)
  Set{Undefined,ada,bob} : Set(Person)

?Set{dan.boss}->closure(boss)->excluding(null)
  Set{ada,bob} : Set(Person)
```

Can closure be used only in context of reflexive associations (one class used twice)?



```
class Person
attributes
  name : String
  age : Integer
end
```

Evaluate OCL expression

Enter OCL expression:
cyd.employer.employee->closure(p | p.employer.employee)

Result:
Set{ada,bob,cyd} : Set(Person)

Evaluate OCL expression

Enter OCL expression:
flo.employer.employee->closure(p | p.employer.employee)

Result:
Set{dan,eve,flo} : Set(Person)

Are there other collection operations apart from size(), closure(...), excludes(...), forAll(...), exists(...)?

```
context p:Person inv bossSameCompany:
  (p.employer->size()=1 and p.boss->size=1) implies p.employer=p.boss.employer

context p:Person inv acyclicBossWorker:
  p.worker->closure(worker)->excludes(p)

context c:Company inv employeeAtLeast16:
  c.employee->forAll(p | p.age>=16)

context c:Company inv nameUnique:
  not Company.allInstances->exists(d | d<>c and d.name=c.name)

context c:Company inv nameUnique:
  Company.allInstances->select(d | d<>c and d.name=c.name)->isEmpty() -- allowed: ...->notEmpty()

context c:Company inv nameUnique:
  not Company.allInstances->select(d | d<>c)->collect(c | c.name)->includes(c.name)
```

Important collection operations (even more operations reject(...), one(...), any(...), iterate(...), ...):

- size() : size of collection = number of collection elements
- isEmpty(), notEmpty() : collection has no elements, collection has at least one element
- forAll(cond), exists(cond) : condition holds for all elements, condition holds for at least one element
- select(cond), collect(term) : sub-collection with elements satisfying condition,
  collection with elements mapped by term
- includes(elem), excludes(elem) : collection contains element, collection does not contain element
- closure(term) : collection obtained by continuation of term computation = reflexive, transitive closure