The Object Constraint Language (OCL): Specifying constraints in UML models

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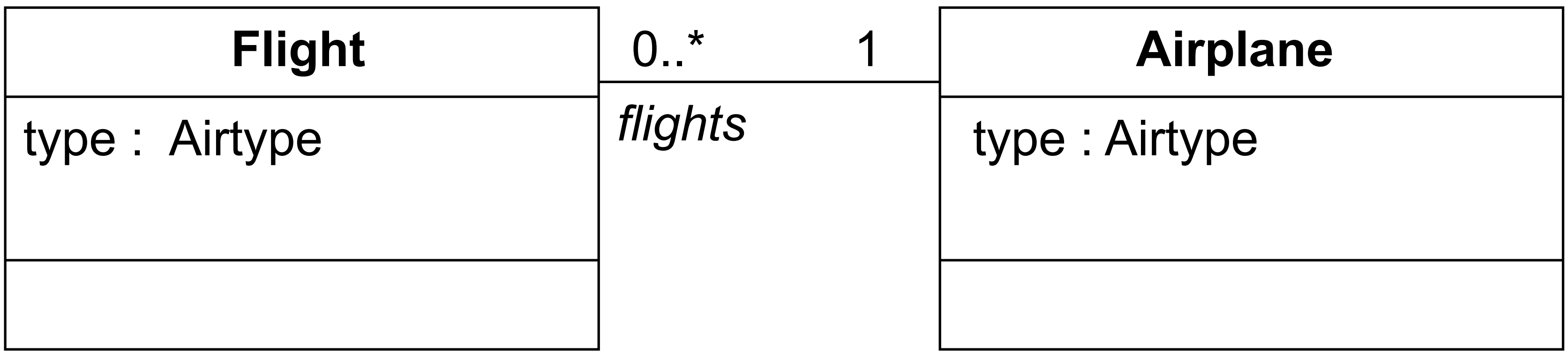
What is OCL?

- OCL is
  - a textual language to describe constraints
  - the constraint language used in UML models
    - As well as the UML meta-model
- OCL expressions are always bound to a UML model
  - OCL expressions can be bound to any model element in UML

Diagram with added invariants

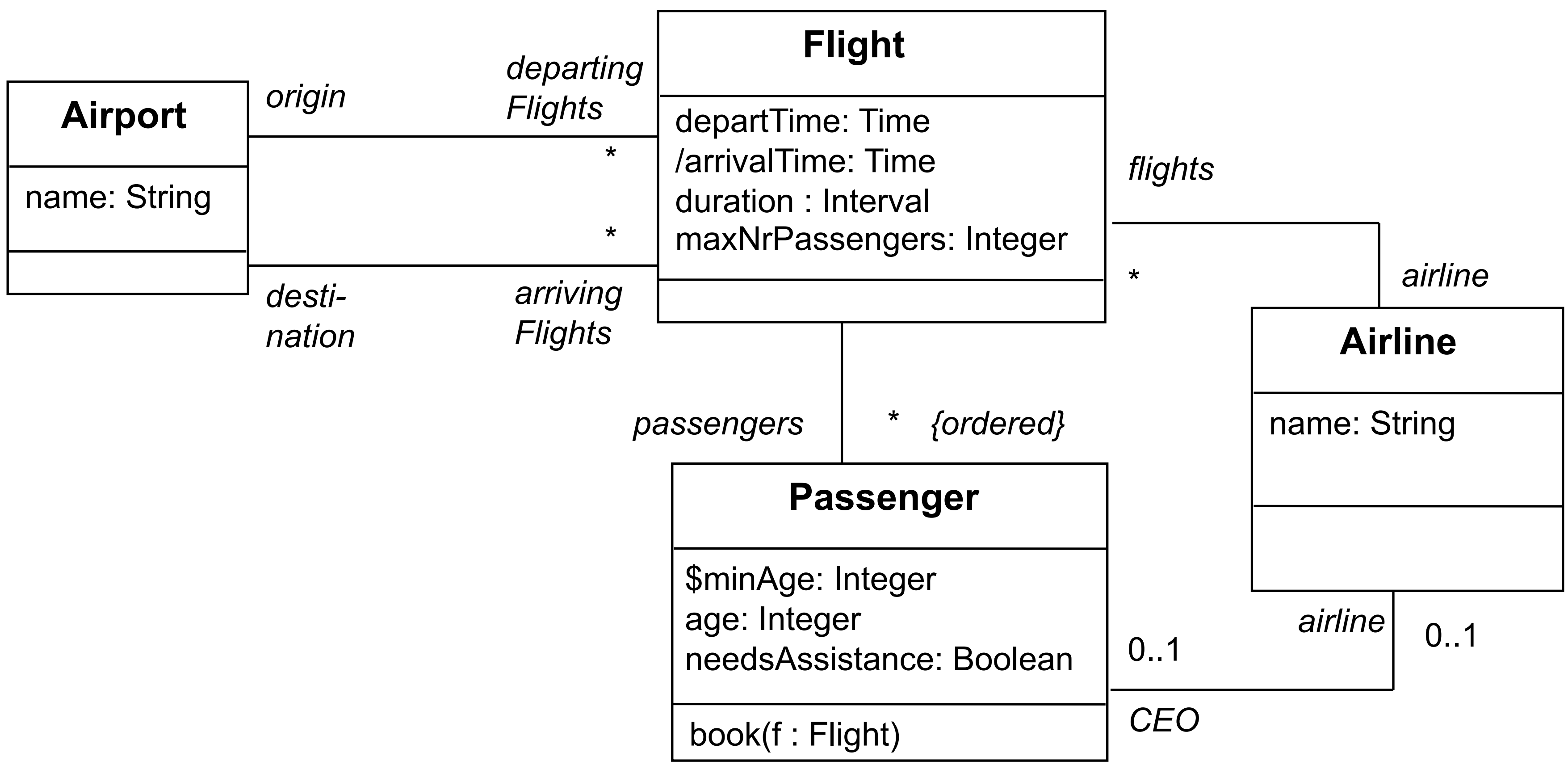


{context Flight
inv: type = Airtype::cargo implies airplane.type = Airtype::cargo
inv: type = Airtype::passenger implies
airplane.type = Airtype::passenger}

Different kinds of constraints

- Class invariant
  - a constraint that must always be met by all instances of the class
- Precondition of an operation
  - a constraint that must always be true BEFORE the execution of the operation
- Postcondition of an operation
  - a constraint that must always be true AFTER the execution of the operation

Example model



Constraint context and self

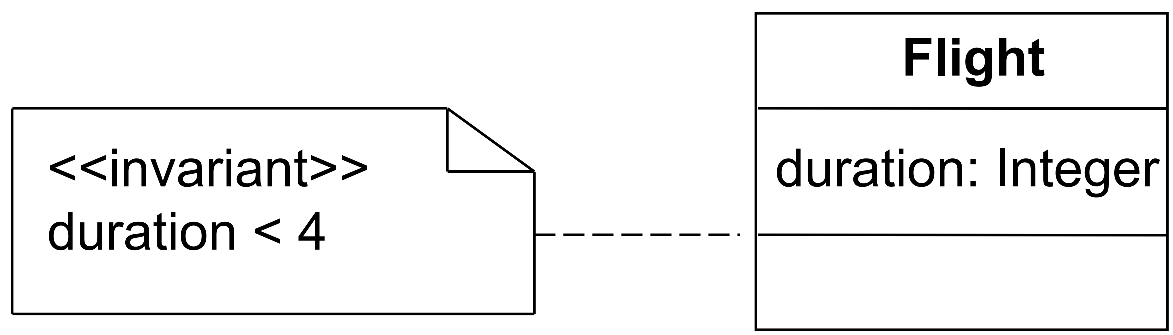
- Every OCL expression is bound to a specific context.
  - The context is often the element that the constraint is attached to
- The context may be denoted within the expression using the keyword ‘self’.
  - ‘self’ is implicit in all OCL expressions
  - Similar to`this’ in C++

Notation

- Constraints may be denoted within the UML model or in a separate document.
  - the expression:

    context Flight inv: self.duration < 4
  - is identical to:

    context Flight inv: duration < 4
  - is identical to:



Elements of an OCL expression

- In an OCL expression these elements may be used:
  - basic types: String, Boolean, Integer, Real.
  - classifiers from the UML model and their features
    - attributes, and class attributes
    - query operations, and class query operations (i.e., those operations that do not have side effects)
  - associations from the UML model

Example: OCL basic types

```
context Airline inv:
name.toLower = ‘klm’

context Passenger inv:
age >= ((9.6 - 3.5)* 3.1).floor implies
mature = true
```

Model classes and attributes

- "Normal" attributes

  context Flight inv:

  self.maxNrPassengers <= 1000

- Class attributes

  context Passenger inv:

  age >= Passenger.minAge

Example: Using query operations

context Flight inv:

self.departTime.difference
(self.arrivalTime) .equals(self.duration)

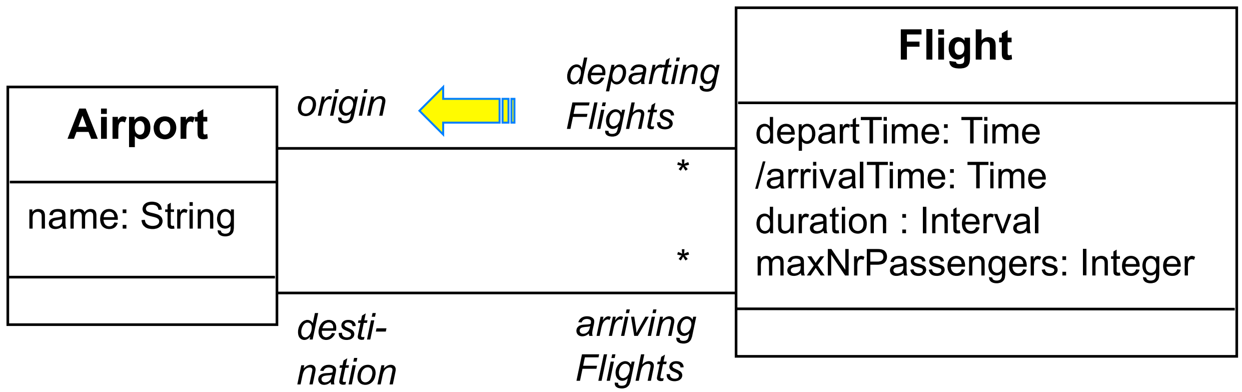
Time
$midnight: Time month : String day : Integer year : Integer hour : Integer minute : Integer
difference(t:Time):Interval before(t: Time): Boolean plus(d : Interval) : Time

Interval
nrOfDays : Integer nrOfHours : Integer nrOfMinutes : Integer
equals(i:Interval):Boolean $Interval(d, h, m : Integer) : Interval

Associations and navigations

- Every association in the model is a navigation path.
- The context of the expression is the starting point.
- Role names are used to identify the navigated association.

Example: navigations



context Flight

inv: origin <> destination

inv: origin.name = ‘Amsterdam’

context Flight

inv: airline.name = ‘KLM’

Association classes

context Person inv:

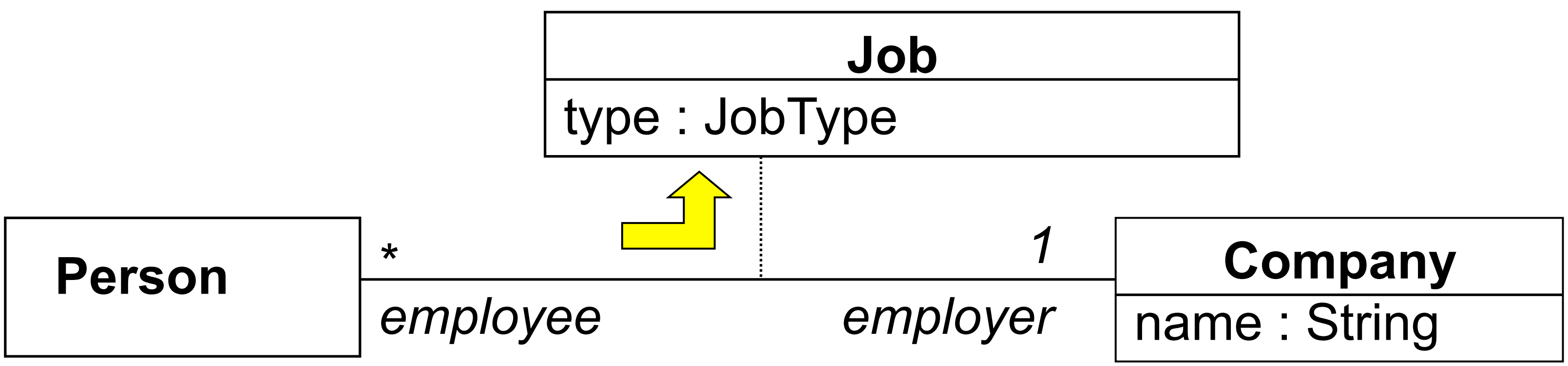
if employer.name = ‘Klasse Objecten’ then

  job.type = JobType::trainer

else

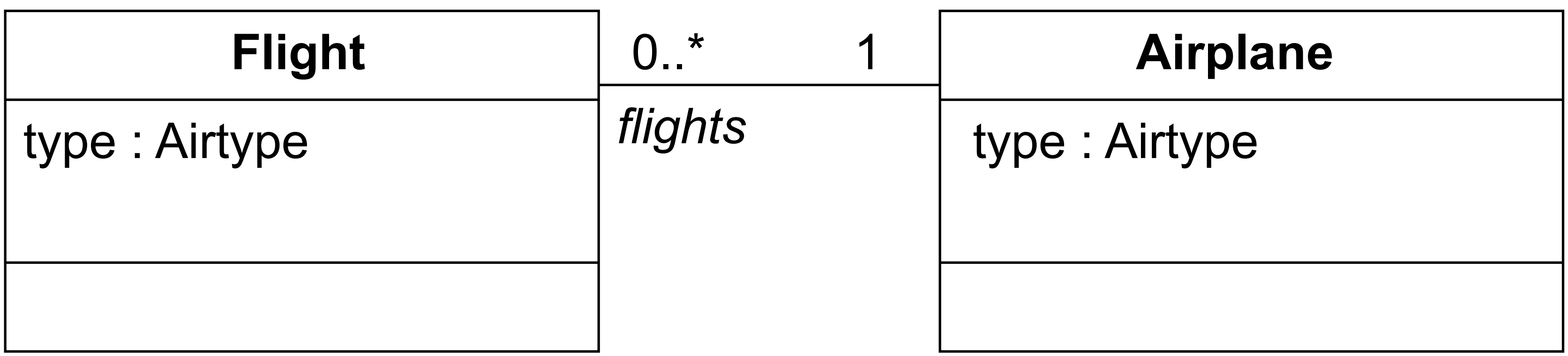
  job.type = JobType::programmer

endif



Significance of Collections in OCL

- Most navigations return collections rather than single elements



Three Subtypes of Collection

- Set:
  - arrivingFlights(from the context Airport)
  - Non-ordered, unique
- Bag:
  - arrivingFlights.duration (from the context Airport)
  - Non-ordered, non-unique
- Sequence:
  - passengers (from the context Flight)
  - Ordered, non-unique

Collection operations

- OCL has a great number of predefined operations on the collection types.
- Syntax:
  - collection->operation

Use of the “->” (arrow) operator instead of the “.” (dot) operator

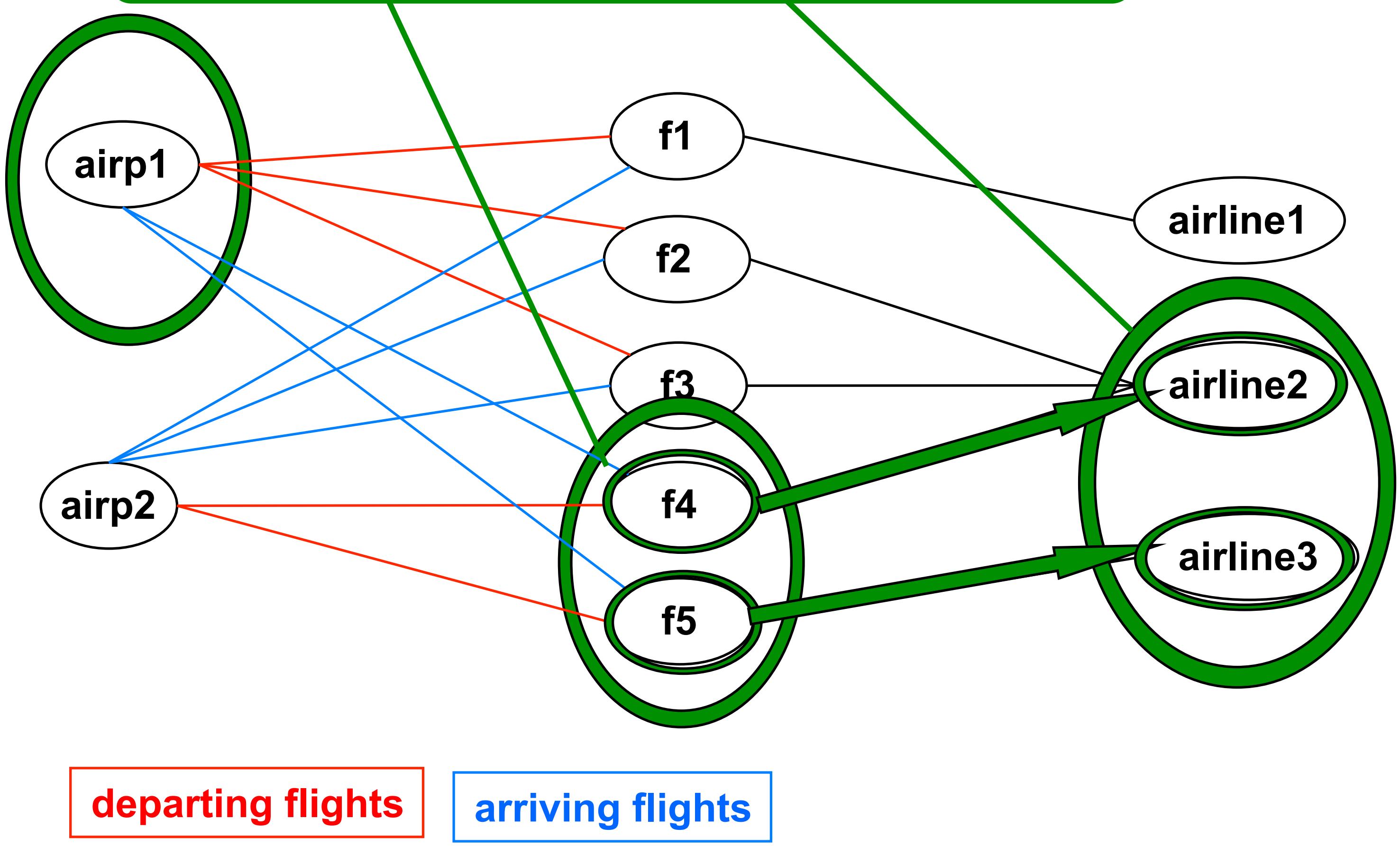
The collect operation

- The *collect* operation results in the collection of the values obtained by evaluating an expression for all elements in the collection

The collect operation

context Airport inv:

self.arrivingFlights -> collect(airLine) ->notEmpty



The collect operation syntax

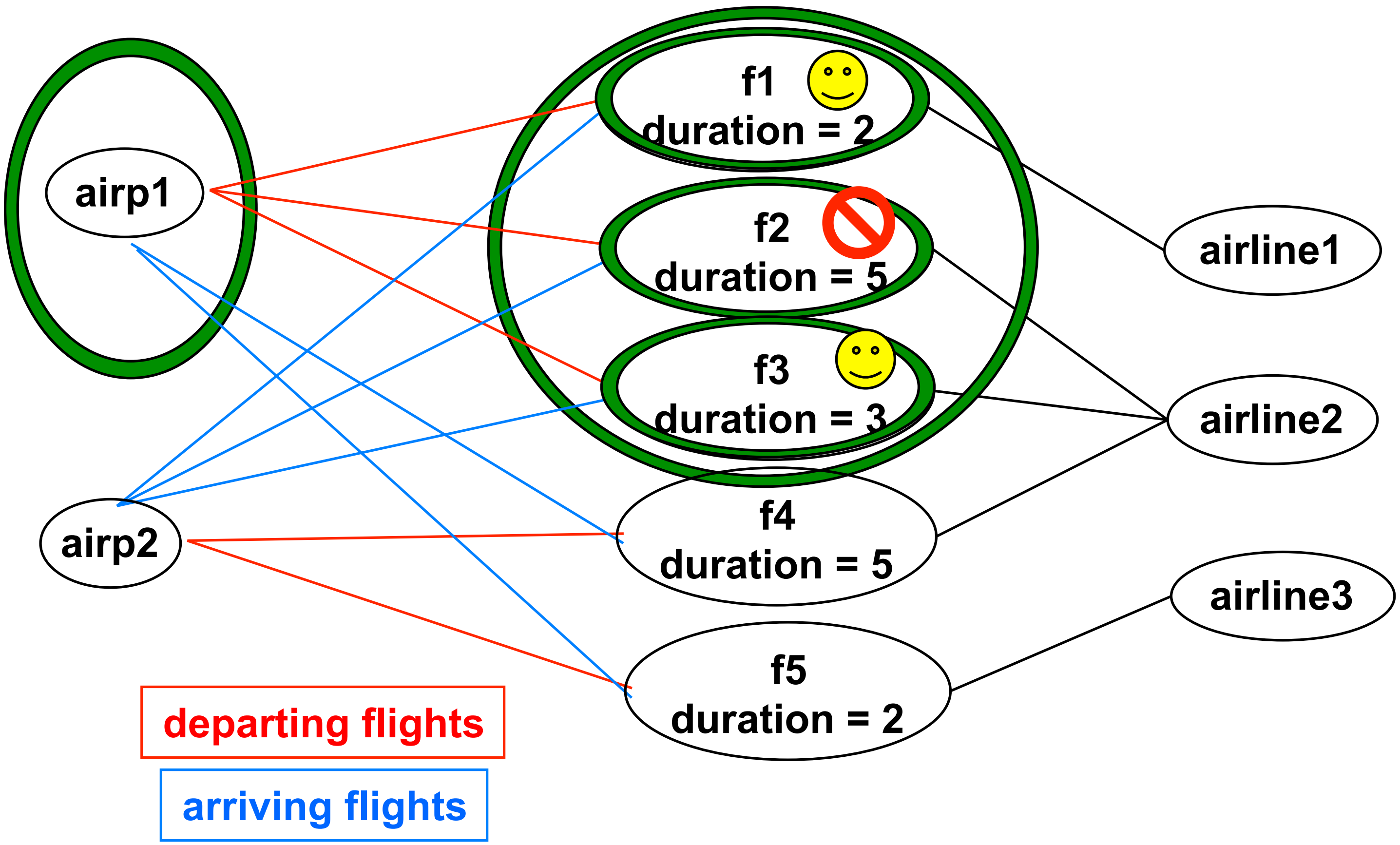
- Syntax:
  ```
  collection->collect(elem : T | expr)
  collection->collect(elem | expr)
  collection->collect(expr)
  ```
- Shorthand:
  ```
  collection.expr
  ```
- Shorthand often trips people up. Be Careful!

The select operation

The *select* operation results in the subset of all elements for which a boolean expression is true

context Airport inv:

self.departingFlights->select(duration<4)->notEmpty



The select operation syntax

- Syntax:

  collection->select(elem : T | expression)

  collection->select(elem | expression)

  collection->select(expression)

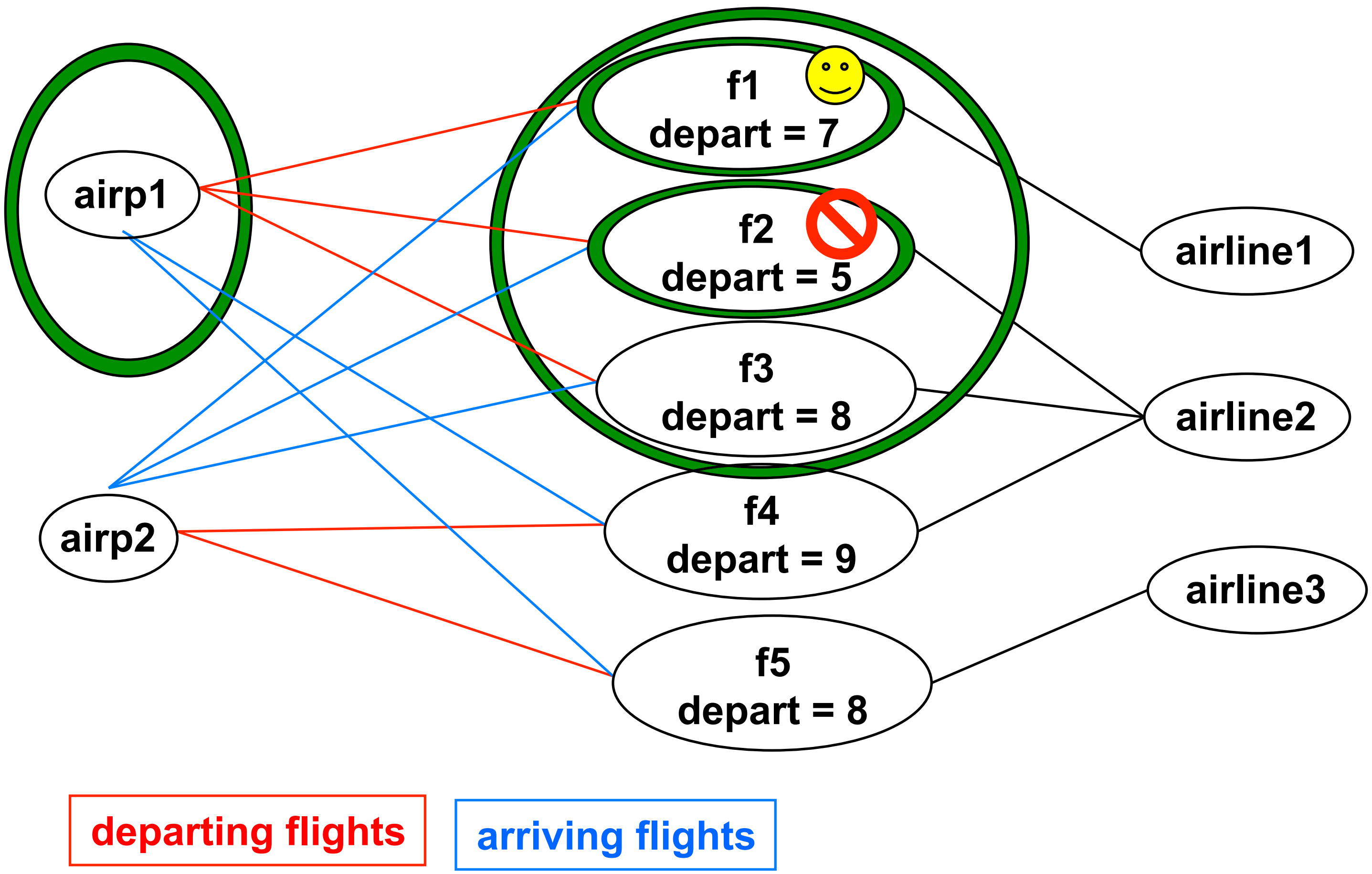
The forAll operation

- The forAll operation results in true if a given expression is true for all elements of the collection

Example: forAll operation

context Airport inv:

self.departingFlights->forAll(departTime.hour>6)



The forAll operation syntax

- Syntax:
  - collection->forAll(elem : T | expr)
  - collection->forAll(elem | expr)
  - collection->forAll(expr)

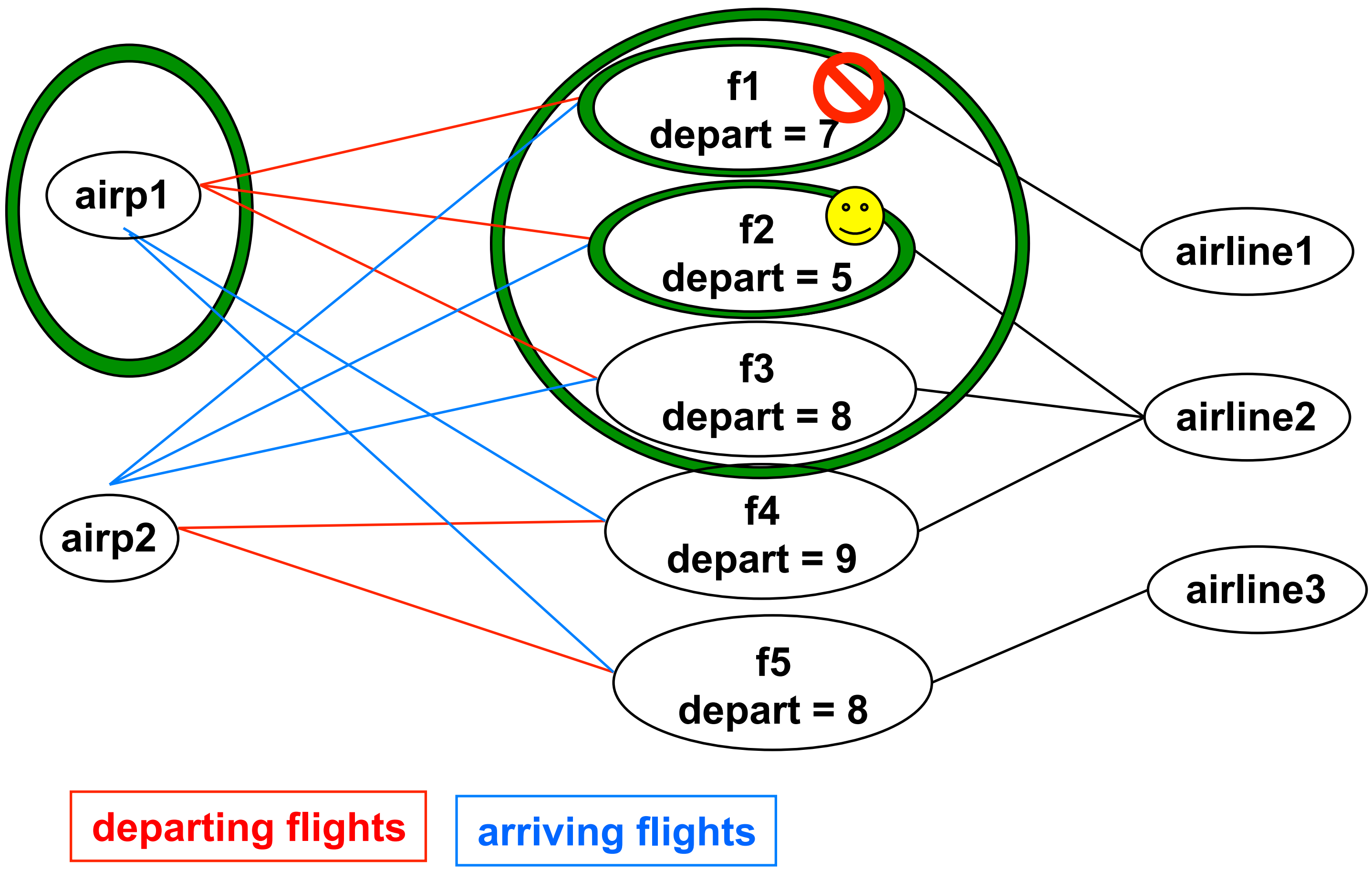
The exists operation

- The *exists* operation results in true if there is at least one element in the collection for which a given expression is true.

Example: exists operation

context Airport inv:

self.departingFlights->exists(departTime.hour<6)



The exists operation syntax

- Syntax:

```
collection->exists(elem : T | expr)
collection->exists(elem | expr)
collection->exists(expr)
```

Other collection operations

- *isEmpty*: true if collection has no elements
- *notEmpty*: true if collection has at least one element
- *size*: number of elements in collection
- *count(elem)*: number of occurences of elem in collection
- *includes(elem)*: true if elem is in collection
- *excludes(elem)*: true if elem is not in collection
- *includesAll(coll)*: true if all elements of coll are in collection

Local variables

- The *let* construct defines variables local to one constraint:

  Let var : Type = <expression1> in
  <expression2>

- Example:

  context Airport inv:

  Let supportedAirlines : Set (Airline) =
  self.arrivingFlights -> collect(airLine) in
  (supportedAirlines ->notEmpty) and
  (supportedAirlines ->size < 500)

Iterate

- The *iterate* operation for collections is the most generic and complex building block.

```
collection->iterate(elem : Type;
                    answer : Type = <value> |
        <expression-with-elem-and-answer>)
```

Iterate example

- Example iterate:

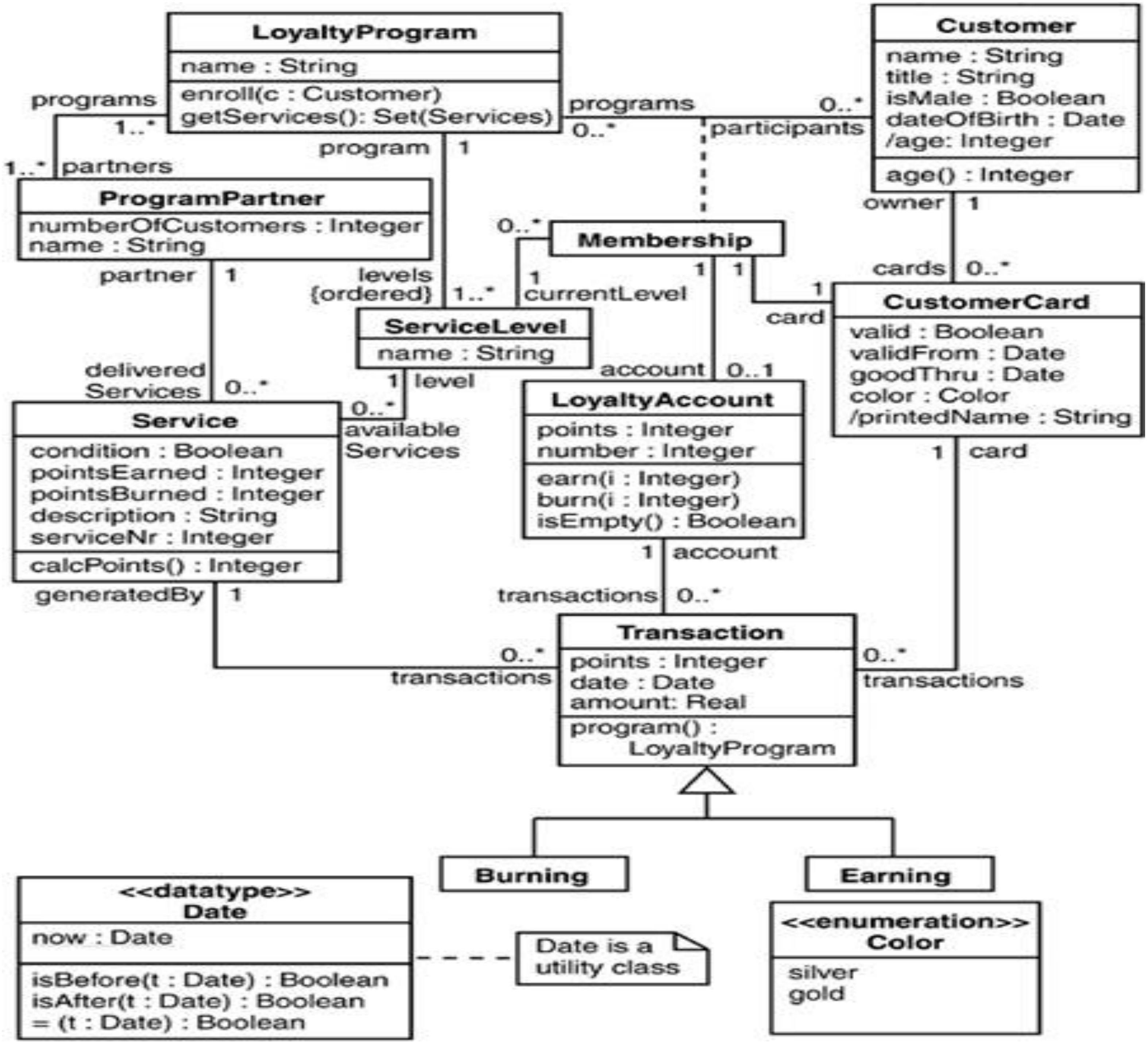
```
context Airline inv:
flights->select(maxNrPassengers > 150)->notEmpty
```

- Is identical to:

```
context Airline inv:
flights->iterate (f : Flight;
    answer : Set(Flight) = Set{ } |
    if f.maxNrPassengers > 150 then
            answer->including(f)
    else
            answer endif )->notEmpty
```

An Example: Royal and Loyal Model

Taken from “The Object Constraint Language” by Warmer and Kleppe


LoyaltyProgram
name : String
enroll(c : Customer)
getServices(): Set(Services)
programs
1..*
1..*
partners
ProgramPartner
numberOfCustomers : Integer
name : String
partner
1
program
1
levels
{ordered}
1..*
programs
0..*
0..*
participants
Customer
name : String
title : String
isMale : Boolean
dateOfBirth : Date
/age: Integer
age() : Integer
owner
1
0..*
Membership
1
currentLevel
1
1
1
card
cards
0..*
CustomerCard
valid : Boolean
validFrom : Date
goodThru : Date
color : Color
/printedName : String
1
card
ServiceLevel
name : String
1
level
0..*
available
Services
delivered
Services
0..*
Service
condition : Boolean
pointsEarned : Integer
pointsBurned : Integer
description : String
serviceNr : Integer
calcPoints() : Integer
generatedBy
1
account
0..1
LoyaltyAccount
points : Integer
number : Integer
earn(i : Integer)
burn(i : Integer)
isEmpty() : Boolean
1
account
transactions
0..*
Transaction
points : Integer
date : Date
amount: Real
program() :
LoyaltyProgram
0..*
transactions
0..*
transactions
Burning
Earning
<<datatype>>
Date
now : Date
isBefore(t : Date) : Boolean
isAfter(t : Date) : Boolean
= (t : Date) : Boolean
Date is a
utility class
<<enumeration>>
Color
silver
gold

Defining initial values & derived attributes

context LoyaltyAccount::points
init:0

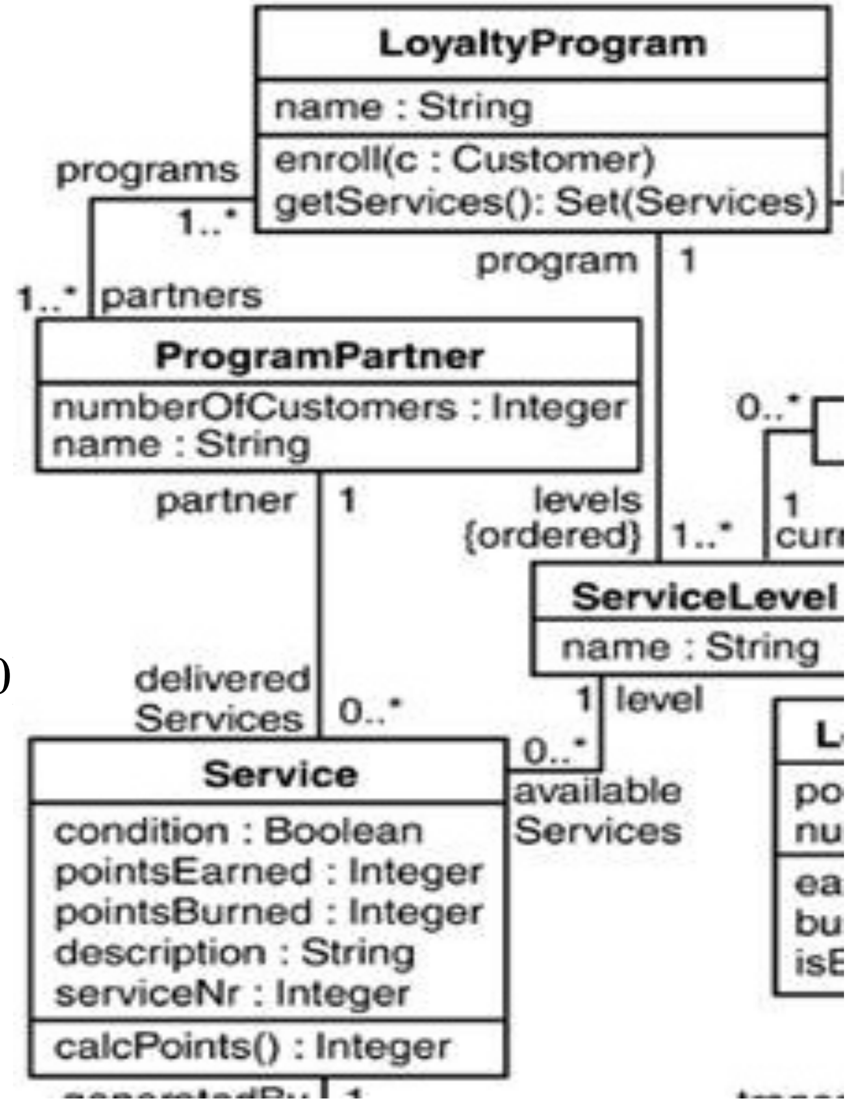
context CustomerCard::valid
init: true

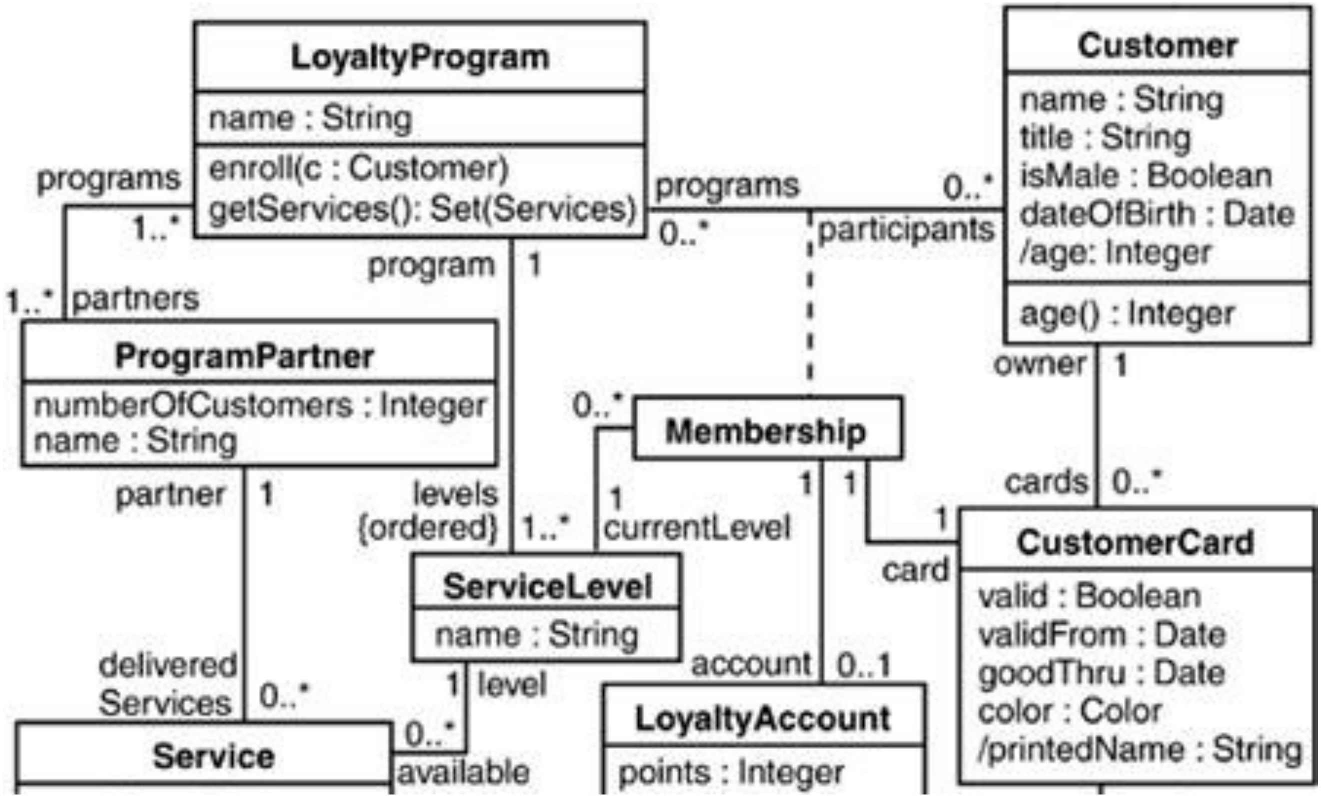
context CustomerCard::printedName
Derive: owner.title.concat(‘ ’).concat(owner.name)

context LoyaltyProgram
inv: partners.deliveredServices -> size() >= 1

context LoyaltyProgram
inv: partners.deliveredServices ->
forAll(pointsEarned = 0 and pointsBurned = 0
implies Membership.account -> isEmpty()

A note on the collect operation
partners -> collect(numberIOfCustomers)
can also be written as
partners.numberOfCustomers



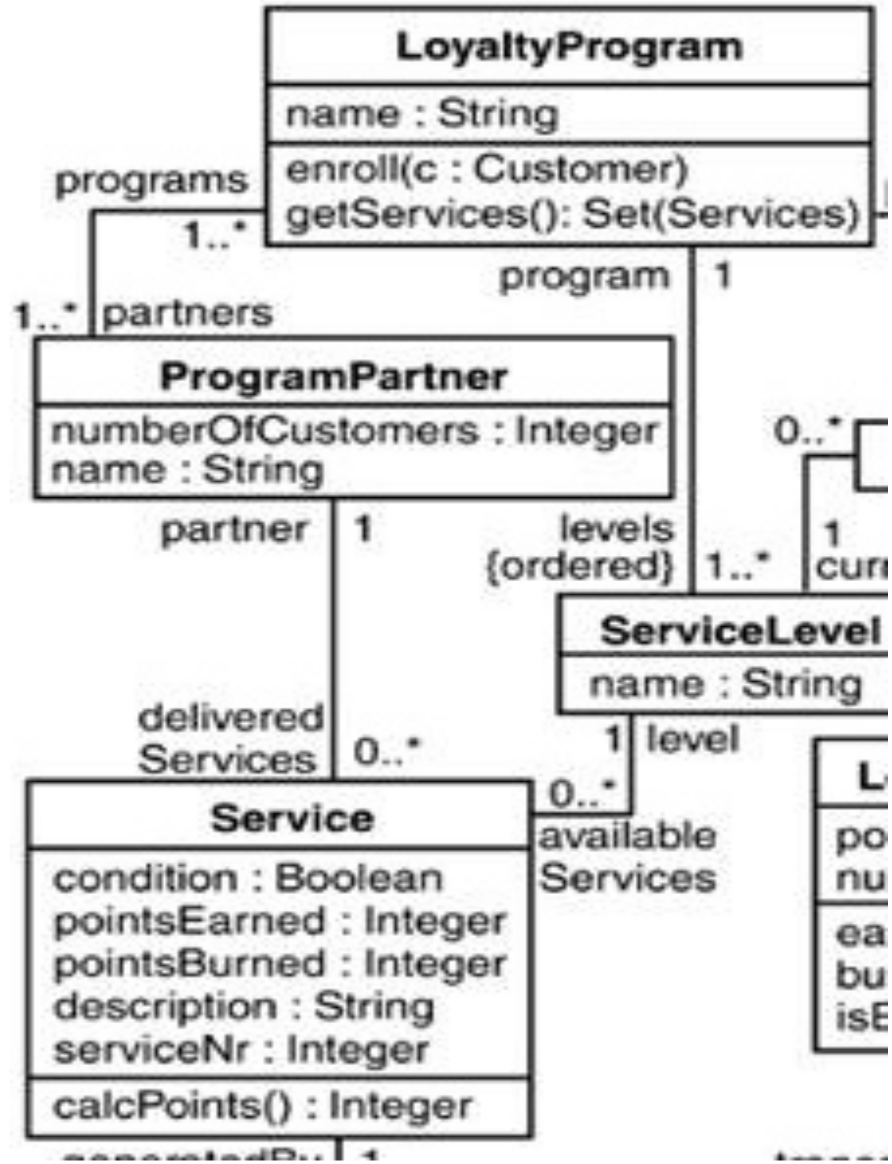


context Customer
inv: programs -> size() = cards -> select (valid = true) -> size()

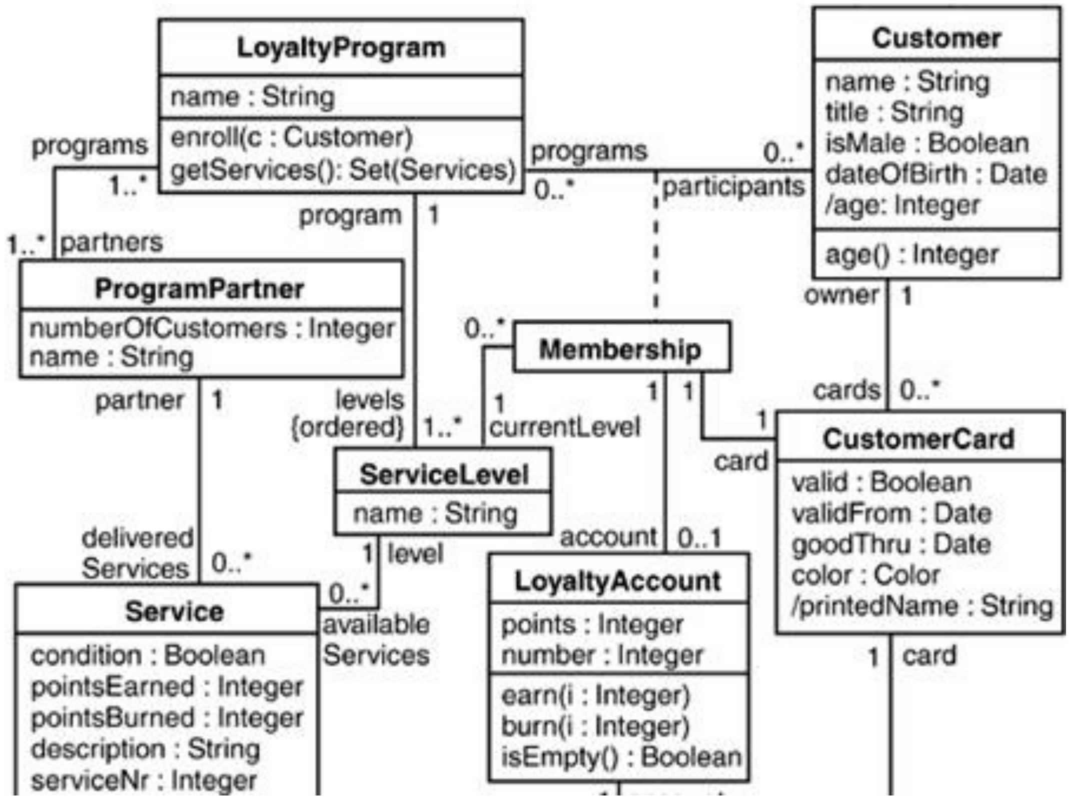
context ProgramPartner
inv: numberOfCustomers = programs.participants ->
asSet() -> size()

Defining Query Operations in OCL

context
LoyaltyProgram::getServices
(pp:ProgramPartner:Set(Service)
body: if partners -> includes(pp)
then pp.deliveredServices
else Set{}
endif



Defining new attributes and operations



context LoyaltyAccount
def: turnover :
Real = transactions.amount -> sum()
//Attributes introduced in this manner are always derived attributes

context LoyaltyProgram
def: getServicesByLevel(levelName:String): Set(Service)
= levels -> select (name = levelName).availableServices ->asSet()

Specifying Operations

context LoyaltyAccount::isEmpty():Boolean
pre: true
post: result = (points = 0)

context Customer::birthdayHappens()
post: age = age@pre +1

context LoyaltyProgram::enroll(c:Customer)
pre: c.name <> ‘ ’
post: participants @pre -> including(c)

context Service::upgradePointsEarned(amount: Integer)
post: calcPoints() = calcPoints@pre() + amount

Inheritance of constraints

- Guiding principle Liskov's Substitution Principle (LSP):
  - "Whenever an instance of a class is expected, one can always substitute an instance of any of its subclasses."

Inheritance of constraints

- Consequences of LSP for invariants:
  - An invariant is always inherited by each subclass.
  - Subclasses may strengthen the invariant.
- Consequences of LSP for preconditions and postconditions:
  - A precondition may be *weakened* (contravariance)
  - A postcondition may be strengthened (covariance)

OCL Tips

- OCL invariants allow you to
  - model more precisely
  - remain implementation independent
- OCL pre- and post-conditions allow you to
  - specify contracts (design by contract)
  - specify interfaces of components more precisely
- OCL usage tips
  - keep constraints simple
  - always give natural language comments for OCL exptressions
  - use a tool to check your OCL