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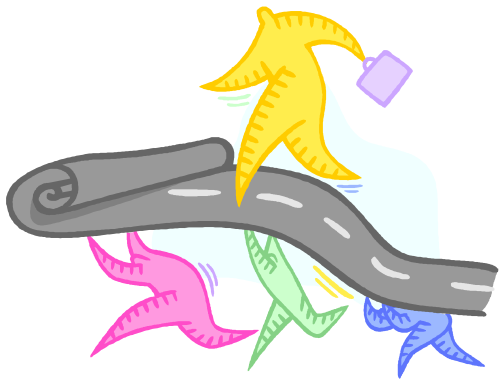
Computer Science Department

The Object Constraint Language (OCL)

Robert B. France
Dept. of Computer Science
Colorado State University
USA
france@cs.colostate.edu



Semantics and UML models

- UML models often treated as informal descriptions
  - Useful if you use UML as a sketching language – this is not the focus of the course
  - Focus is on using as a formal language that can be used to create machine analyzable models
- UML models can be treated formally
  - Necessary if we are to use UML as a software engineering language

Defining semantics

- Three key concepts
  - **Syntactic domain**: Syntactic elements of the language (e.g., class symbol)
  - **Semantic domain**: Elements representing meaningful concepts described by statements in the language (e.g., objects)
  - **Semantic mapping**: Mapping of syntactic elements to semantic elements; the semantic elements denote the meaning of the syntactic elements that are mapped to it

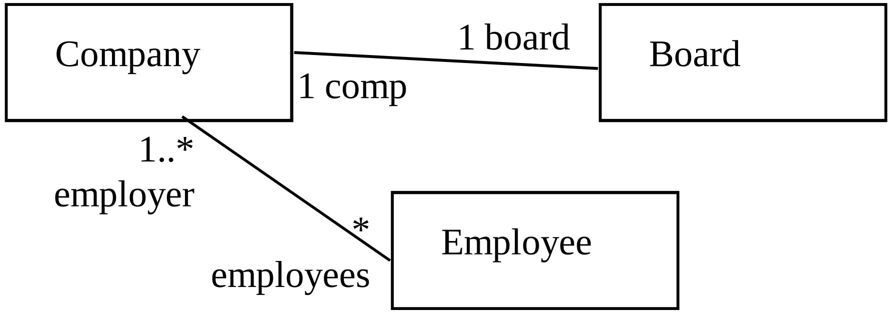
Semantics of class models

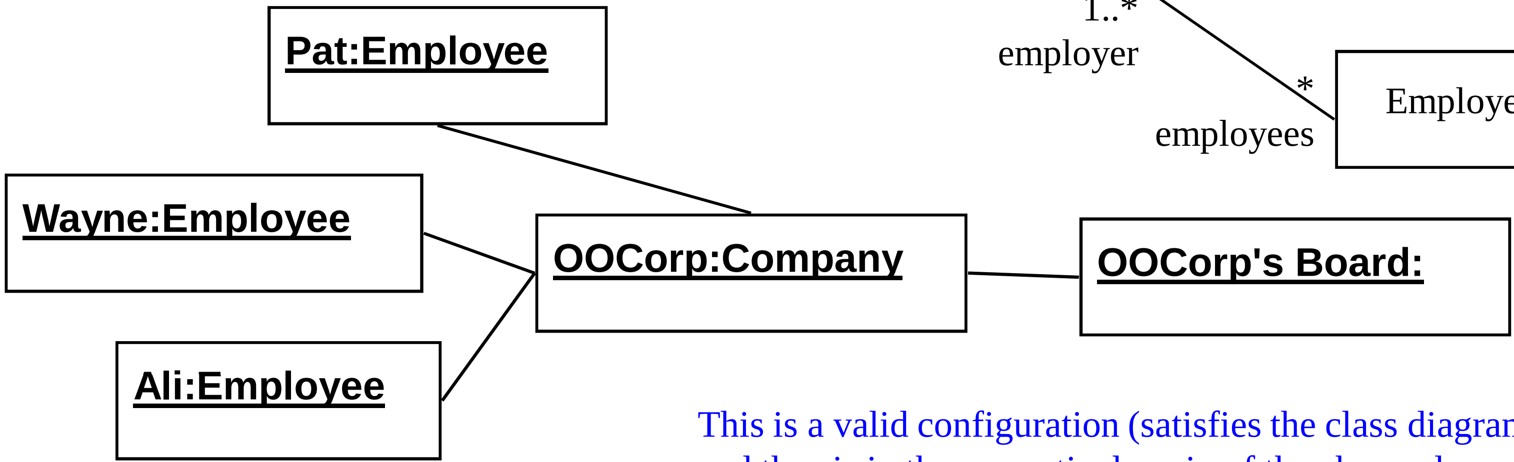
- A class model characterizes a set of valid object configurations
- Syntactic domain: UML class diagram notation (e.g., class, association)
- Semantic domain: Object configurations
- Example:
  - A class is a set of objects
  - An abstract class is the set of all objects of its concrete subclasses
  - A subclass is a subset of the set of all objects of its superclass
  - An association is a set of links between objects of the associated classes

A class model is a specification of valid object configurations.

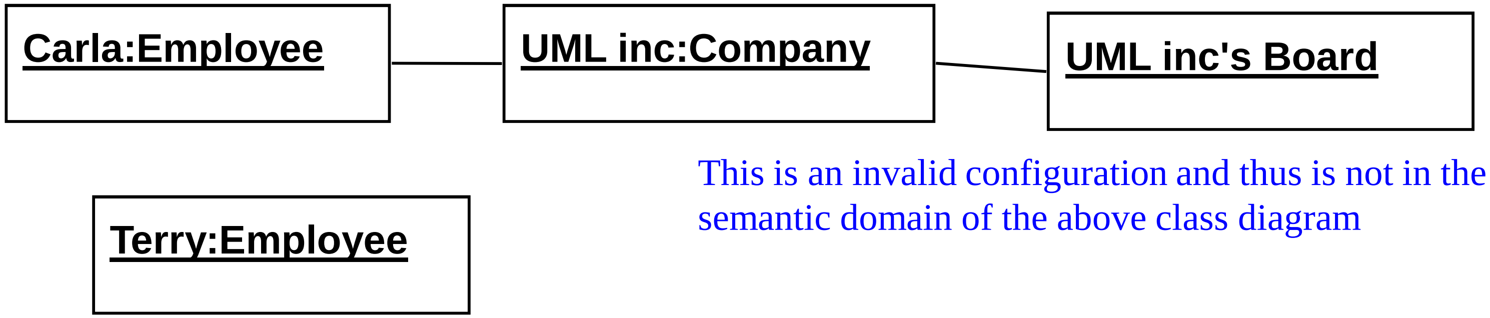
Example

Class diagram





This is a valid configuration (satisfies the class diagram) and thus is in the semantic domain of the above class diagram



This is an invalid configuration and thus is not in the semantic domain of the above class diagram

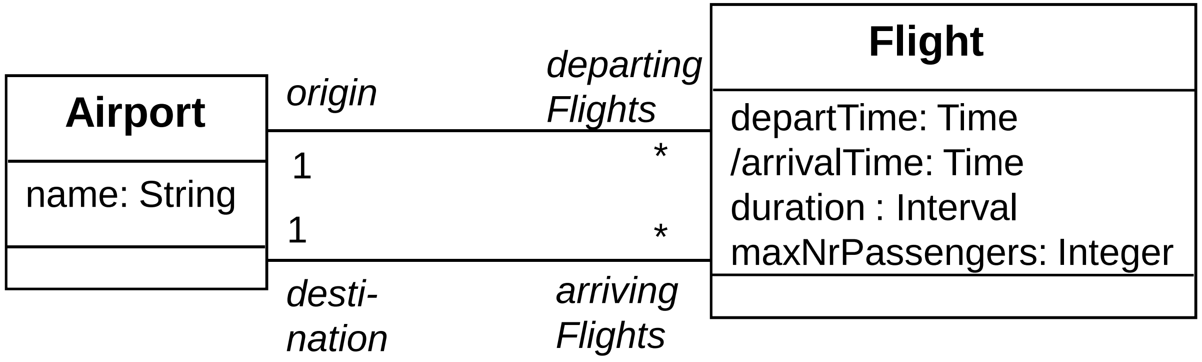
How are constraints expressed in a class model?

- Association multiplicities constrain the number of elements that can participate in an association
  - Note: the multiplicity * is **not** a constraint. Why? If you can answer this then you know what it means to be constrained (or restricted)
- Attribute types restrict the type of values that can be associated with an attribute.
- Are the above enough? What if you defined an attribute age: Integer, and wanted to restrict the value to integers greater than 18?
  - You can write it in natural language but you won't be able to mechanically reason using this information

What is OCL?

- OCL can be used
  - to describe constraints
    - A constraint is a restriction on one or more values of a model or system.
    - A constraint is an expression that evaluate to true or false
  - as a query language
    - Queries are expressions that evaluate to a value (true, false and other values)
    - Can be used to define new attributes and operations
- OCL expressions are always associated with a UML model
  - OCL expressions can be associated with any model element in UML

Constraints vs. Queries



- Examples of constraints:
  - Duration of a flight is the same as the difference between the arrival and departure times
  - The maximum number of passengers on a flight must be less than 1,001
  - The origin of a flight must be different than its destination
- Examples of queries:
  - Return all the departing flights from a given airport
  - Return all the flights departing from a given airport with a departure time after 4p.m.
  - Derive the arrival time by adding the duration of the flight to the departure time.

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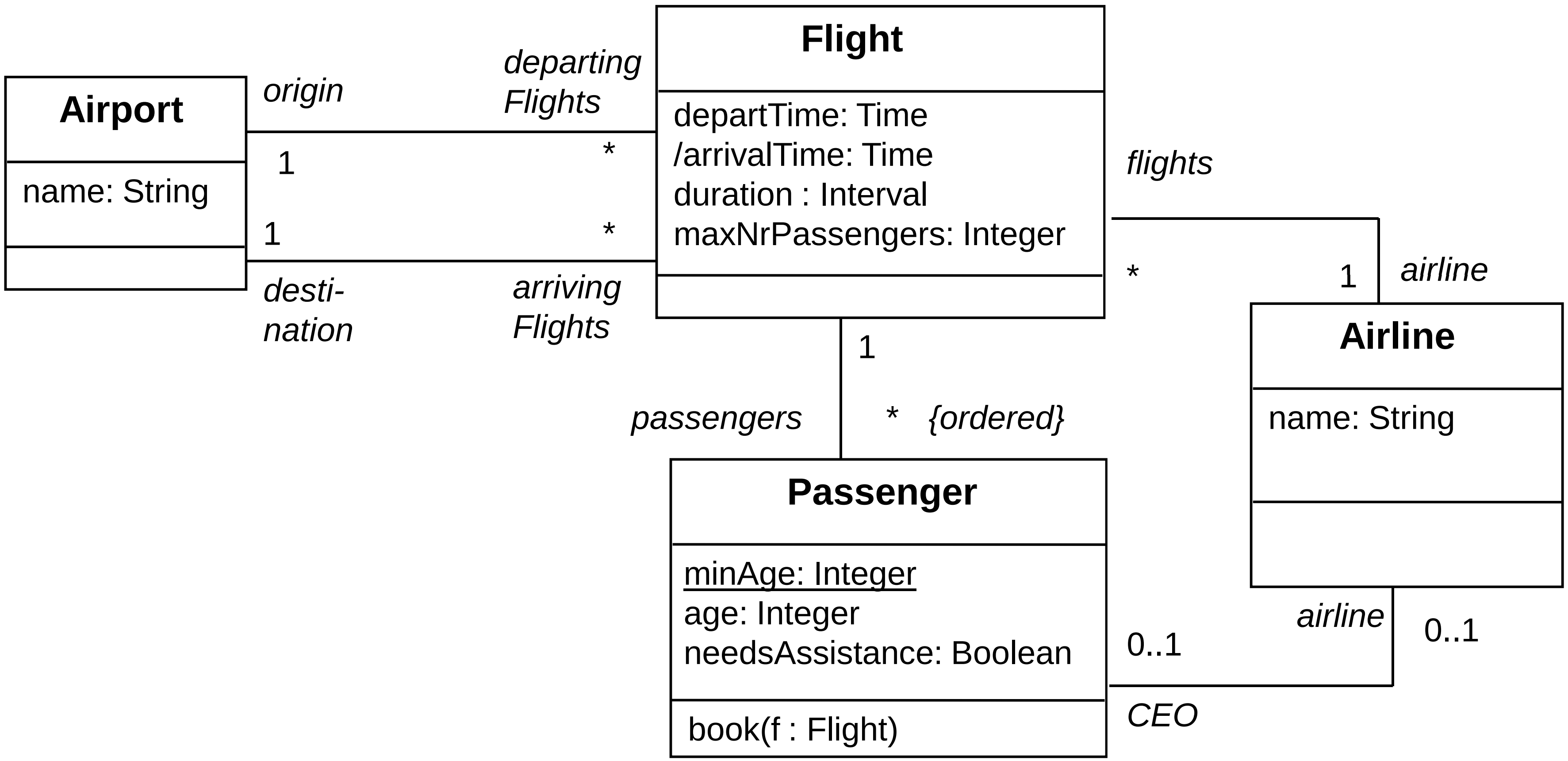
Specifying Constraints - Invariants

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

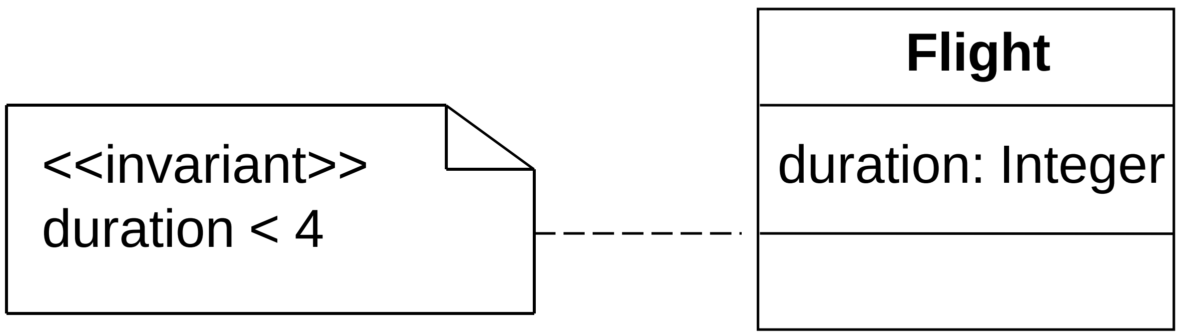
- Every OCL expression is bound to a specific context.
  - The context is often the element that the constraint is attached to
- The context may be denoted within the expression using the keyword ‘self’.
  - ‘self’ is implicit in all OCL expressions
  - Similar to`this’ in C++

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)

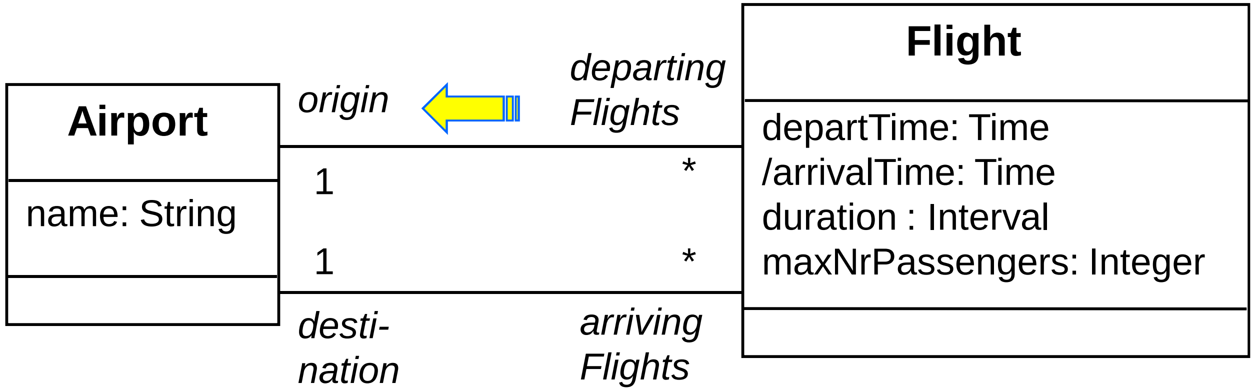
Time
midnight: Time
month : String
day : Integer
year : Integer
hour : Integer
minute : Integer
difference(t:Time):Interval
before(t: Time): Boolean
plus(d : Interval) : Time

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:

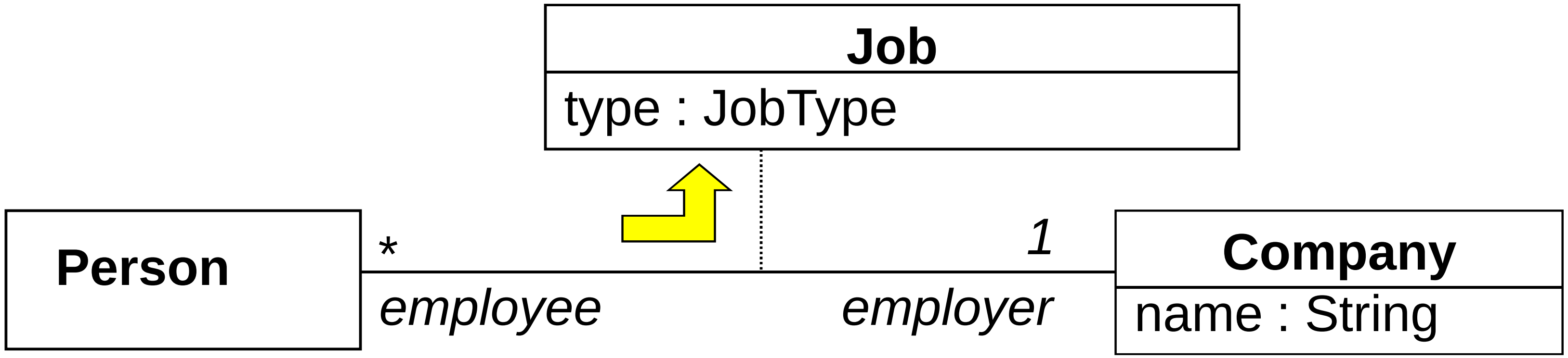
if employer.name = ‘Klasse Objecten’ then

   job.type = JobType::trainer

else

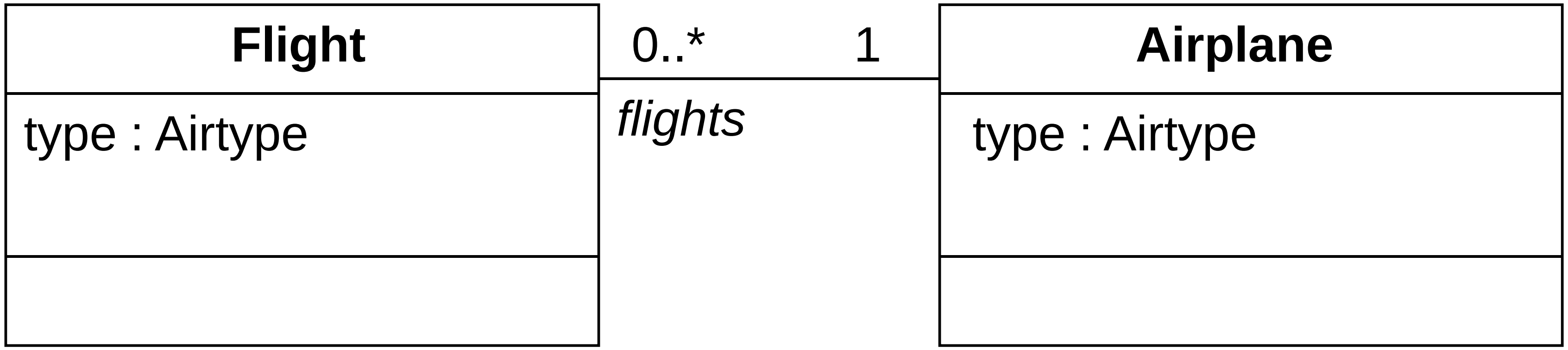
   job.type = JobType::programmer

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

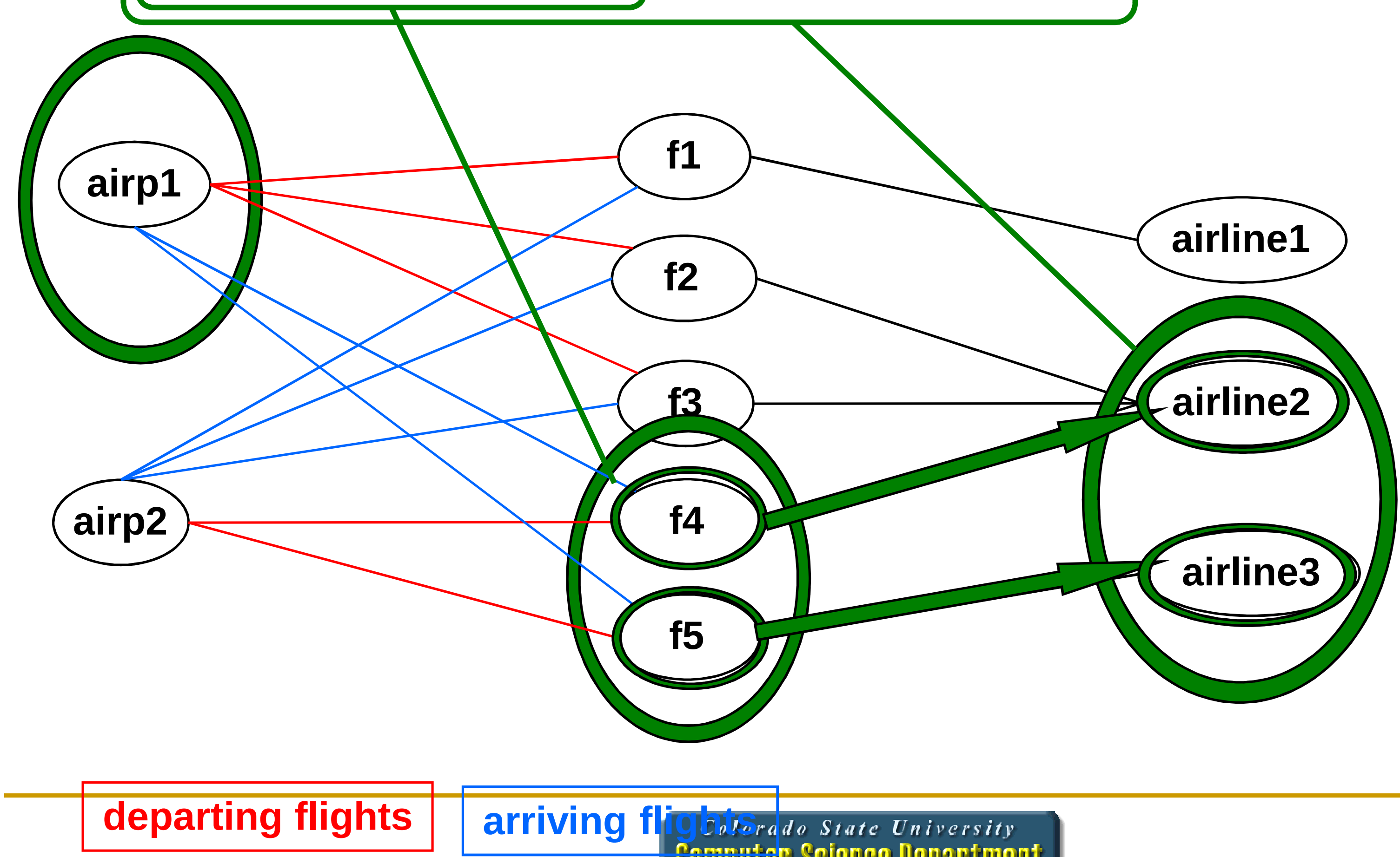
The collect operation

- 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

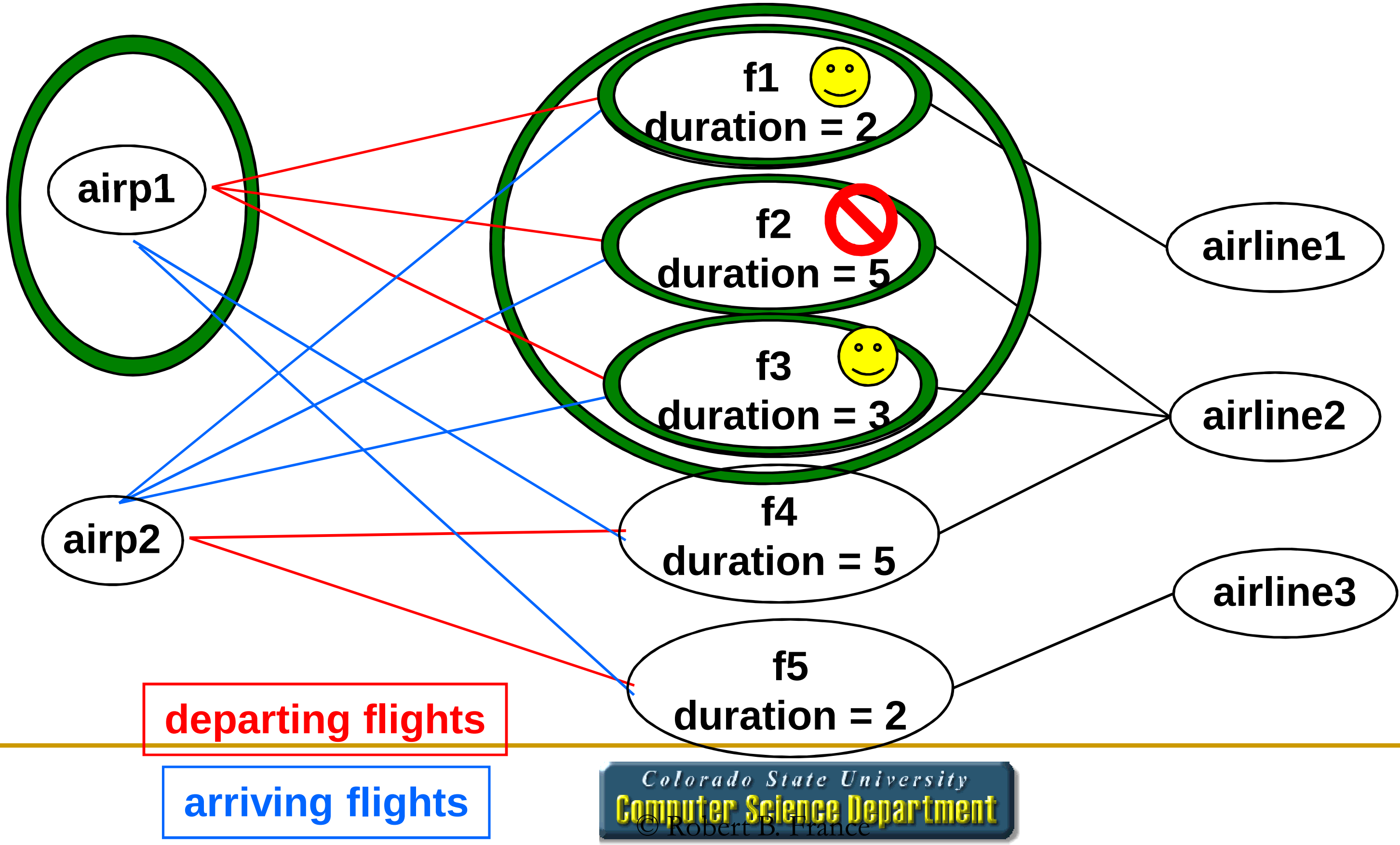
- Shorthand often trips people up. Be Careful!

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)

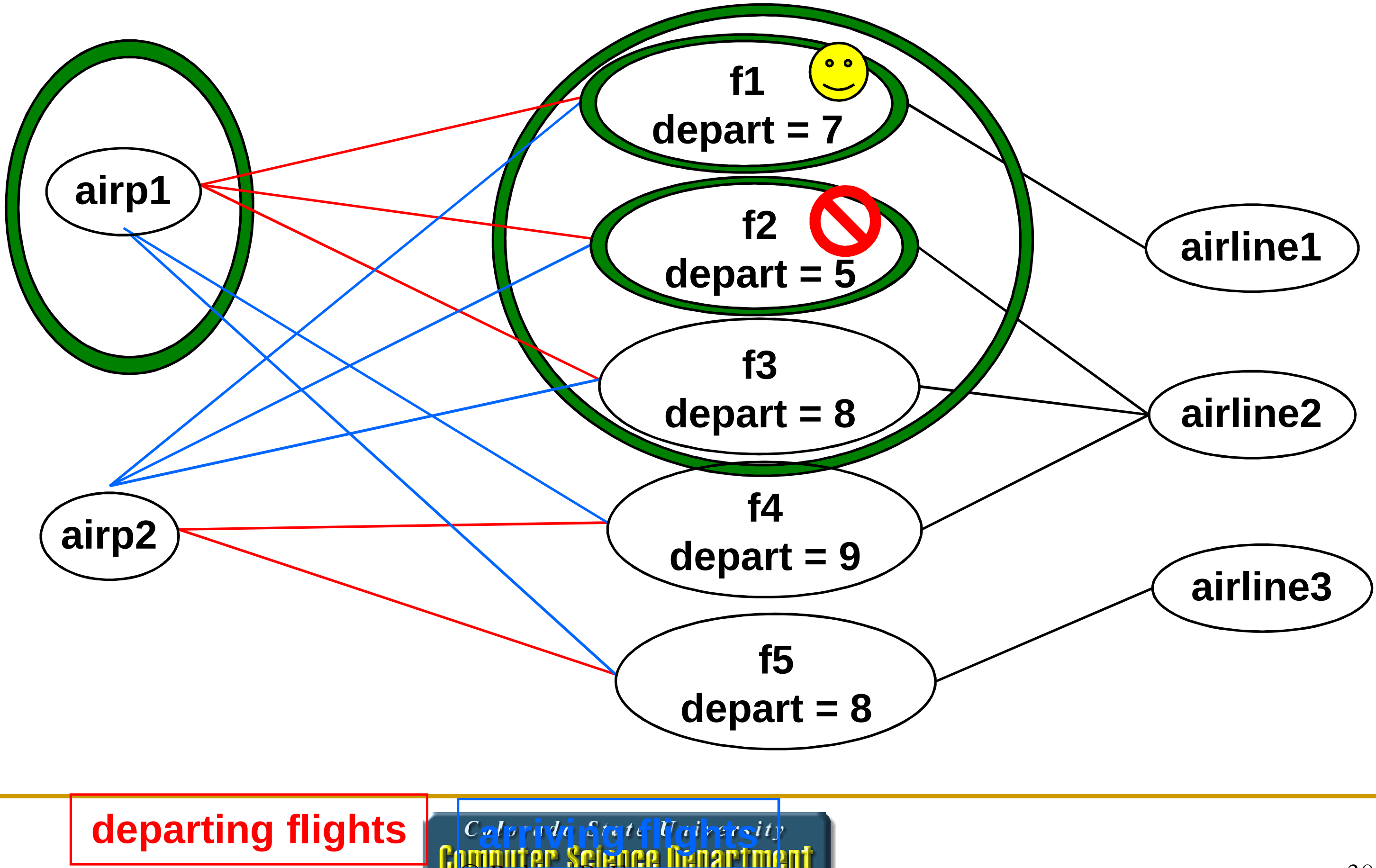
The forAll operation

- 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)

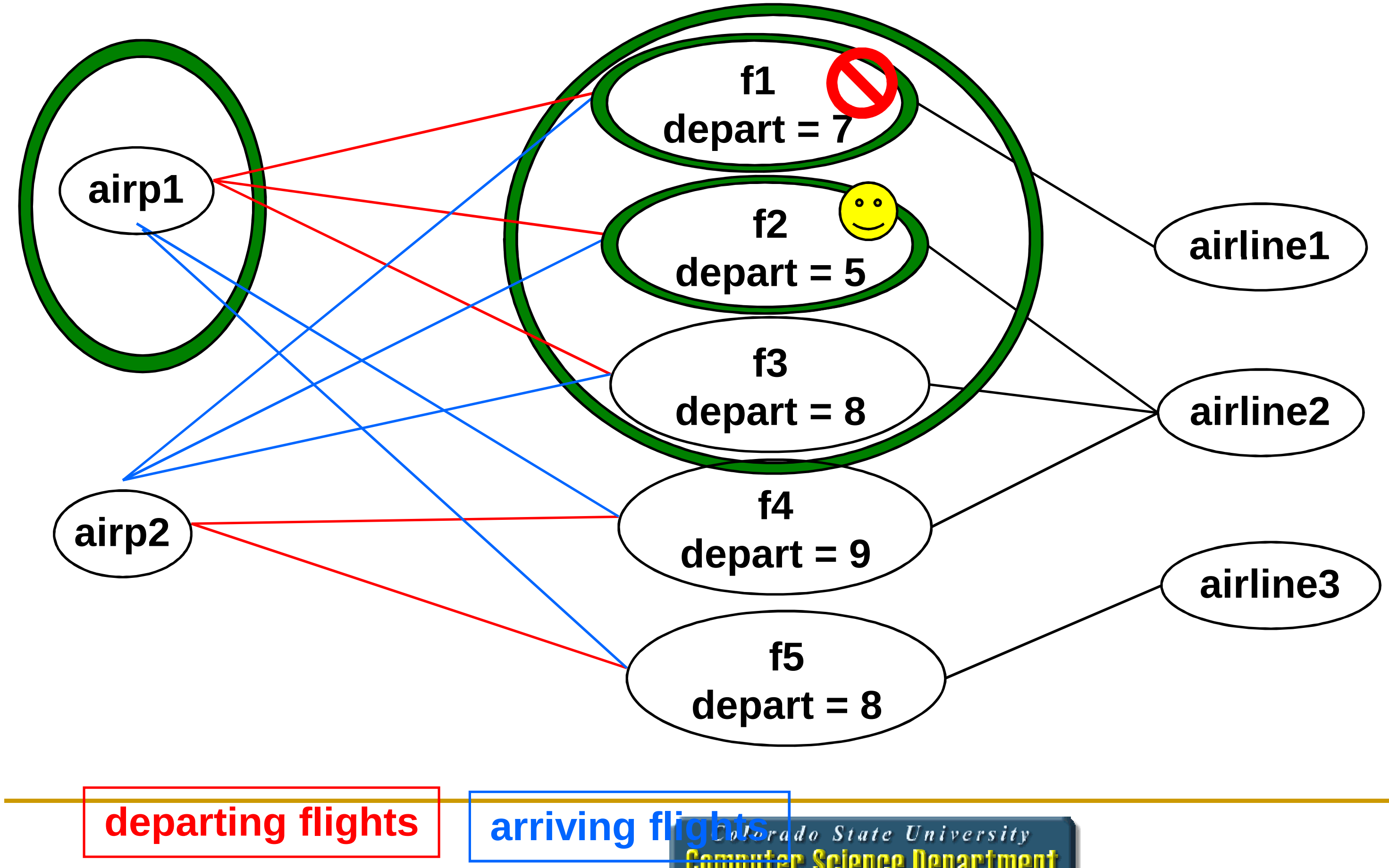
The exists operation

- 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

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Specifying Constraints: Operation Specifications

Pre- and PostCondition Example

A class named Account has an attribute balance and an operation overdraft() that returns true if the balance is less than 0 and false otherwise.

```
context Account::overdraft():Boolean
pre : -- none
post : result = (balance < 0)
```

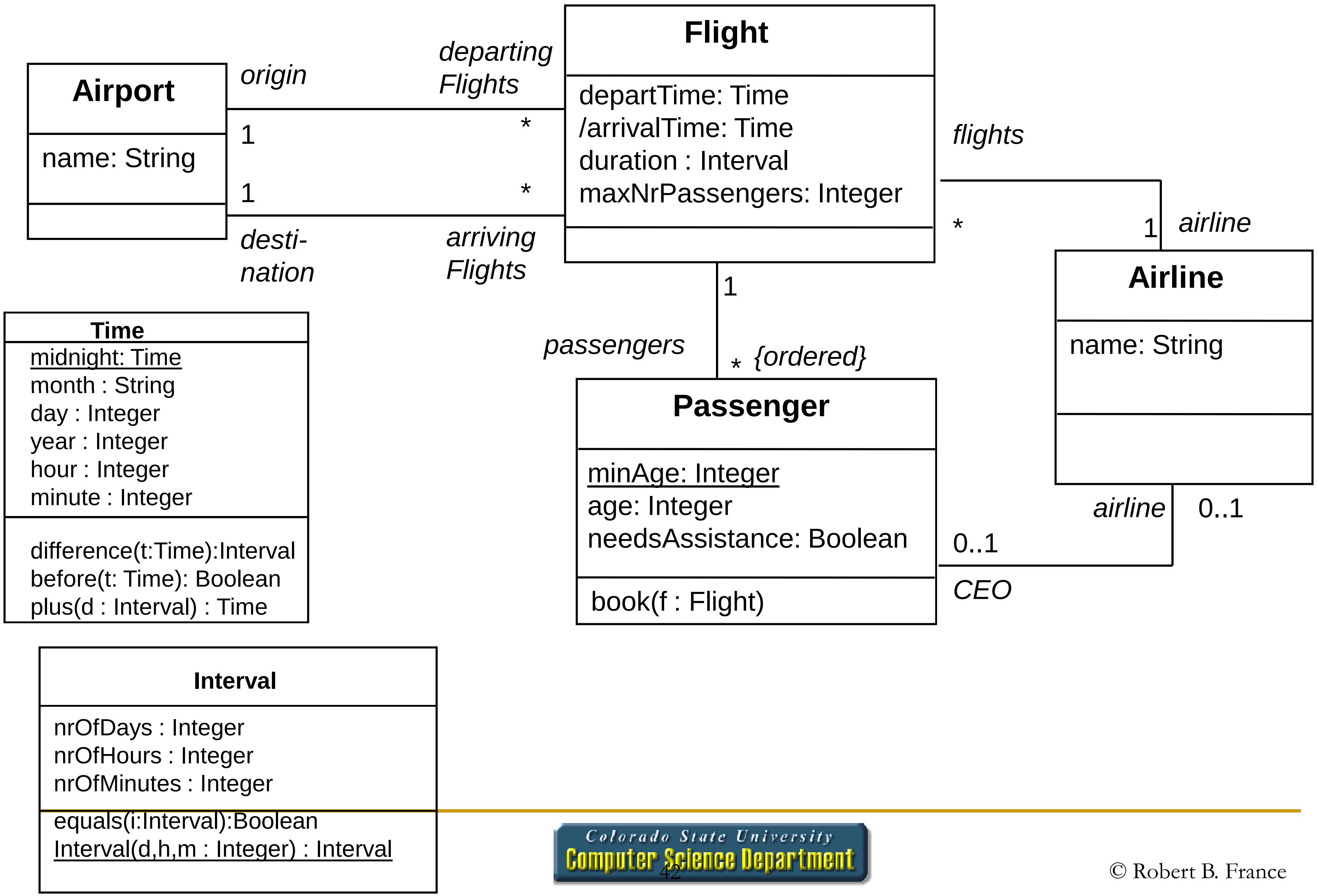
More complex operation specifications

The operation birthdayOccurs() adds 1 to the customer age.

```
context Customer::birthdayOccurs()
pre : -- none
post : age = age@pre + 1

context Account::safeWithdraw(amt:Integer)
pre : balance > amt
post : balance = balance@pre - amt
```

Example model



Derived Attribute & Initial Value Example

Defining derived attributes

```
context Flight::arrivalTime:Time
derive:departTime.plus(duration)
```

Defining initial attribute value

```
context Flight::maxNrPassengers:Integer
init: 100
```

Defining initial association end value

```
context Flight::passengers:Set(Passenger)
init: Set{}
```

Query operation examples

Return all the departing flights from a given airport

context `Airport::departures():Set(Flight)`

body: `result=departingFlights`

Query operation example: Return all the airports served by an airline

context `Airline::served():Set(Airport)`

body: `result=flights.destination->asSet`

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)

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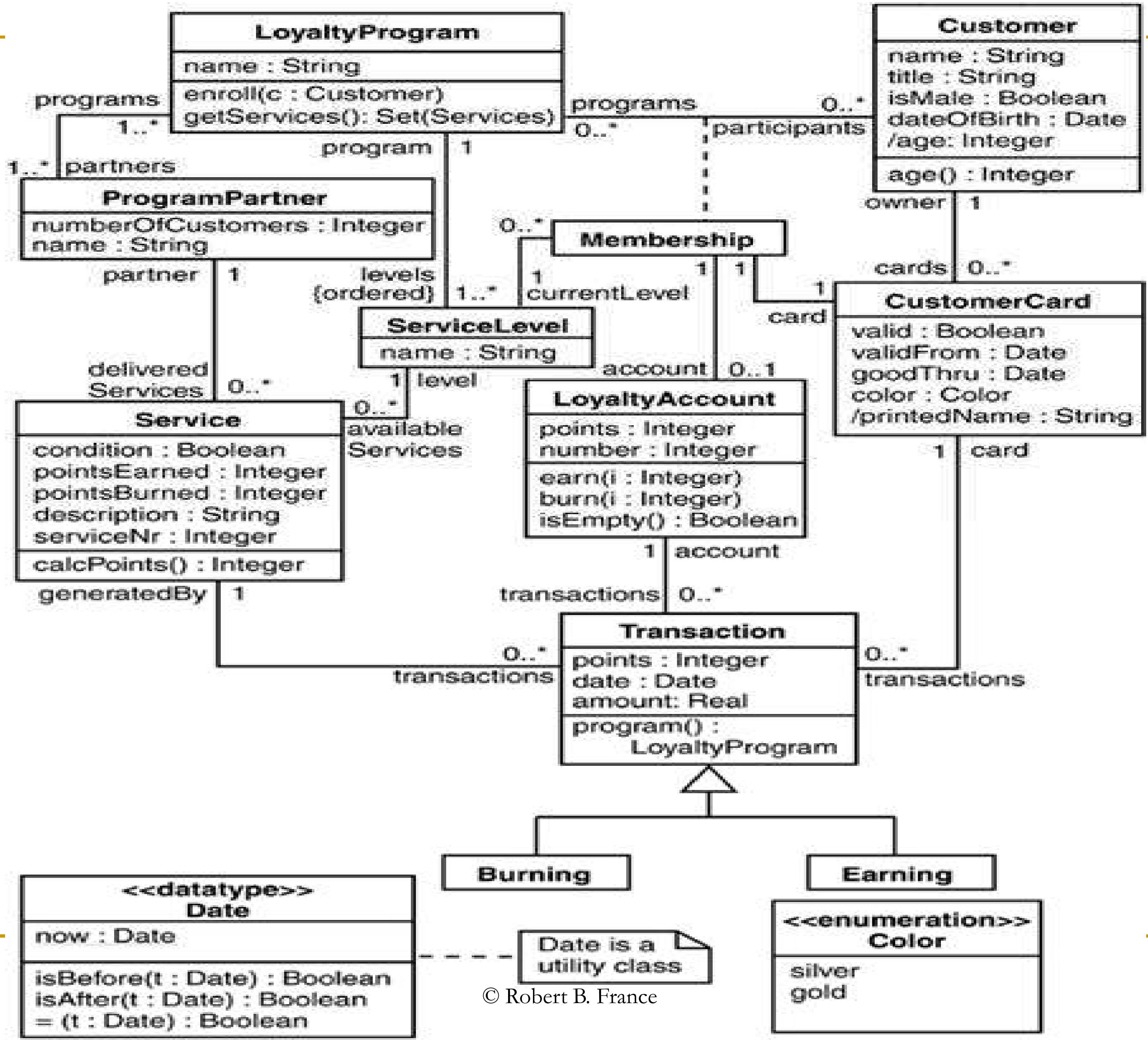
An Example: Royal and Loyal Model

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


LoyaltyProgram
name : String
enroll(c : Customer)
getServices(): Set(Services)
Customer
name : String
title : String
isMale : Boolean
dateOfBirth : Date
/age: Integer
age() : Integer
programs
1..*
1..* partners
programs
0..*
0..*
participants
program
1
ProgramPartner
numberOfCustomers : Integer
name : String
owner
1
0..*
Membership
1
currentLevel
1
1
cards
0..*
partner
1
levels
{ordered}
1..*
ServiceLevel
name : String
card
1
CustomerCard
valid : Boolean
validFrom : Date
goodThru : Date
color : Color
/printedName : String
delivered
Services
0..*
1 level
account
0..1
0..*
available
Services
Service
condition : Boolean
pointsEarned : Integer
pointsBurned : Integer
description : String
serviceNr : Integer
calcPoints() : Integer
LoyaltyAccount
points : Integer
number : Integer
earn(i : Integer)
burn(i : Integer)
isEmpty() : Boolean
1 card
1 account
generatedBy 1
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

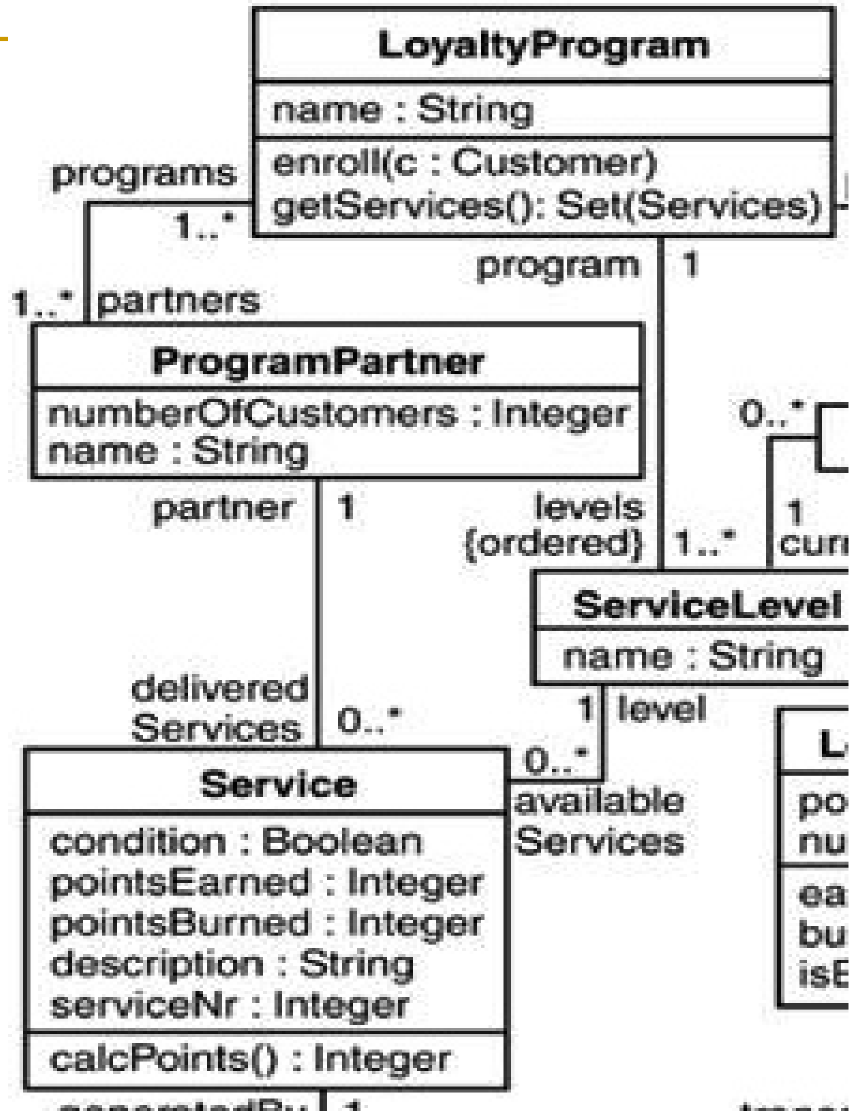
context CustomerCard::valid
init: true

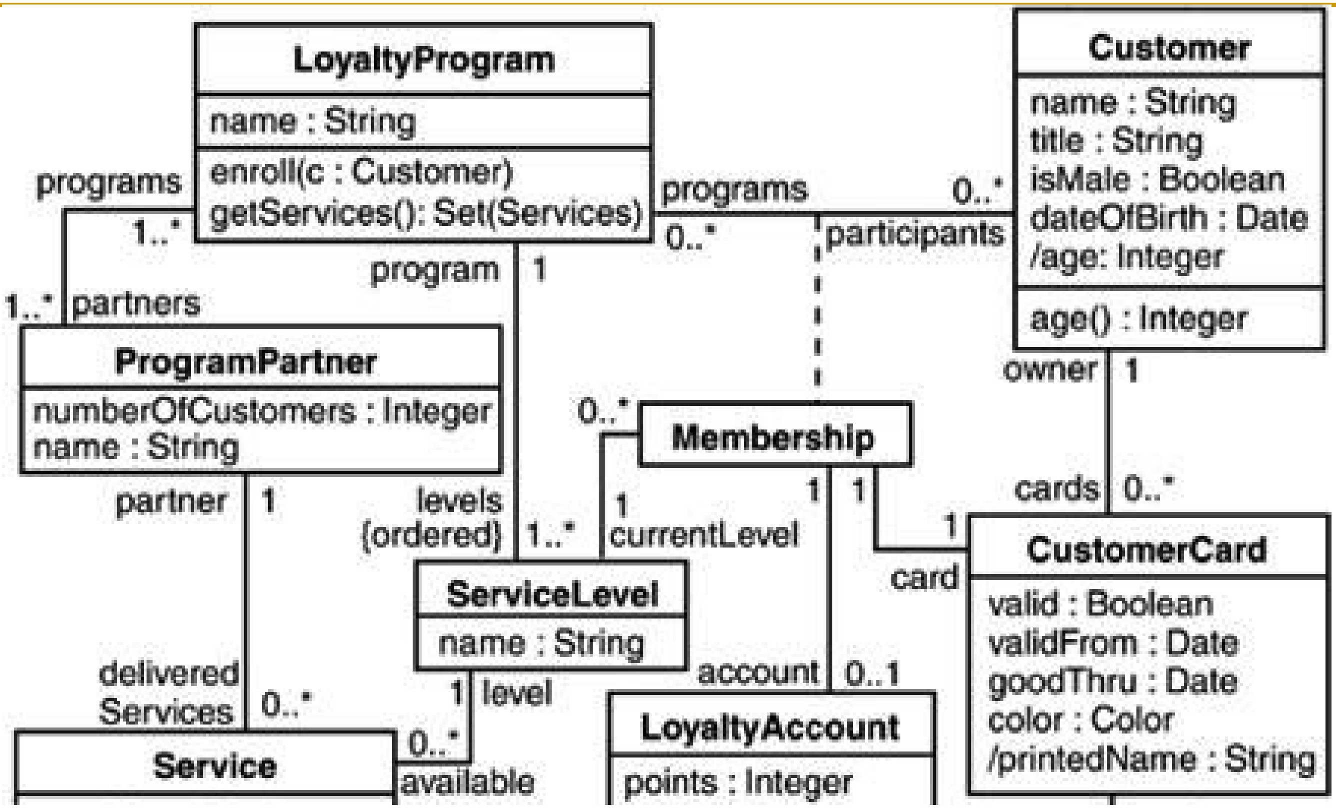
context CustomerCard::printedName
Derive: owner.title.concat(‘ ’).concat(owner.name)

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

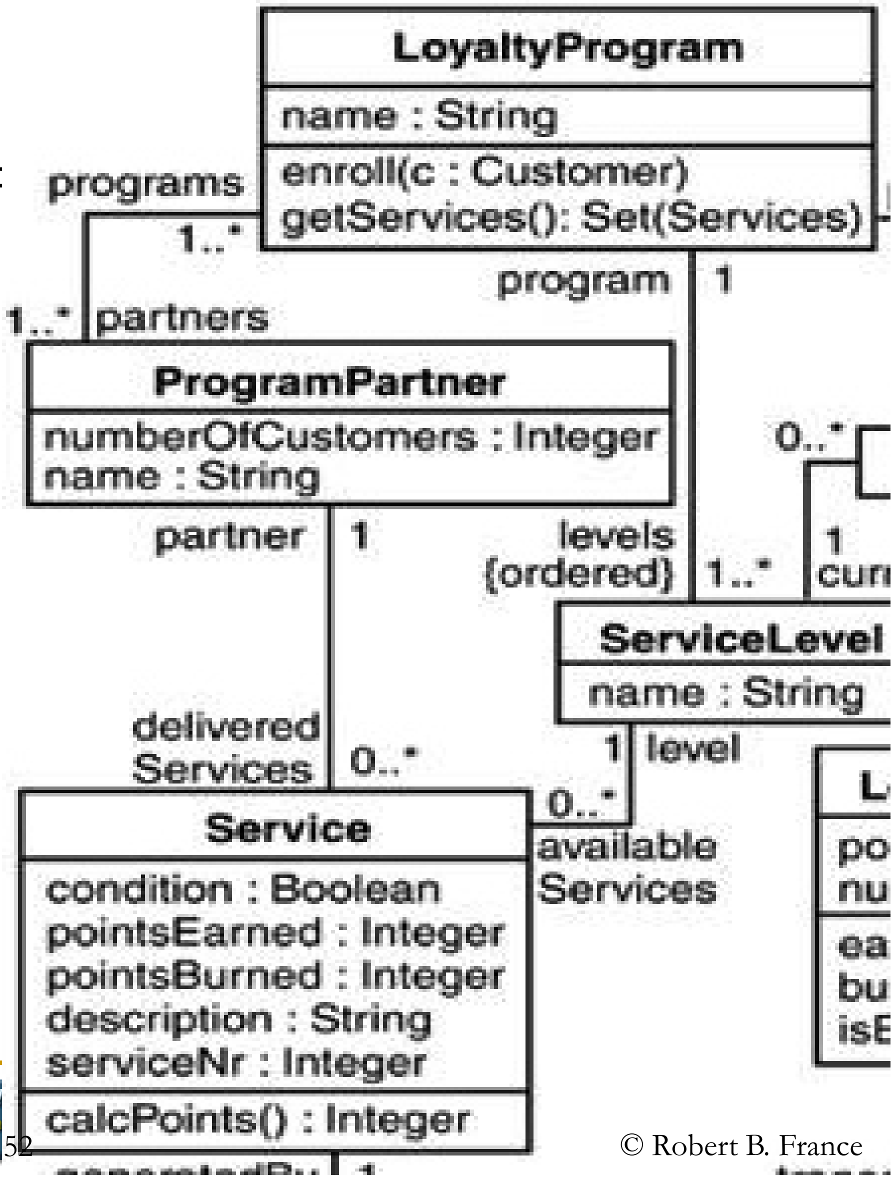
inv: programs -> size() = cards -> select (valid = true) -> size()

context ProgramPartner

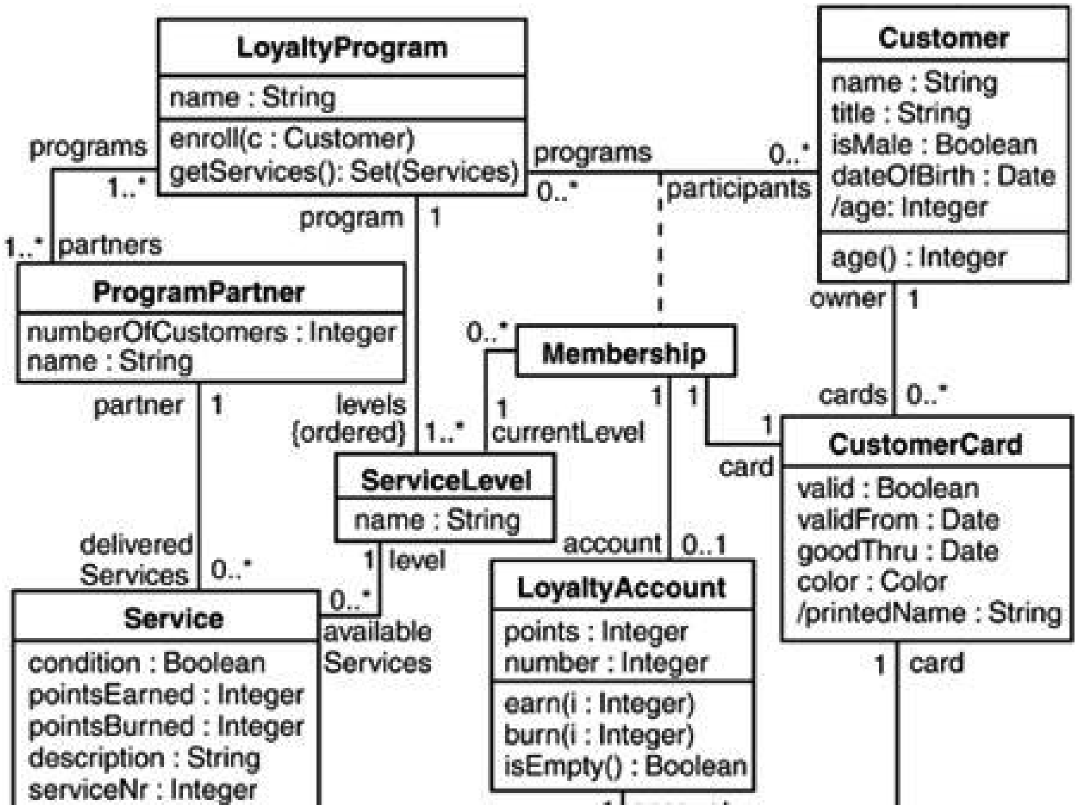
inv: numberOfCustomers = programs.participants -> asSet() -> size()

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

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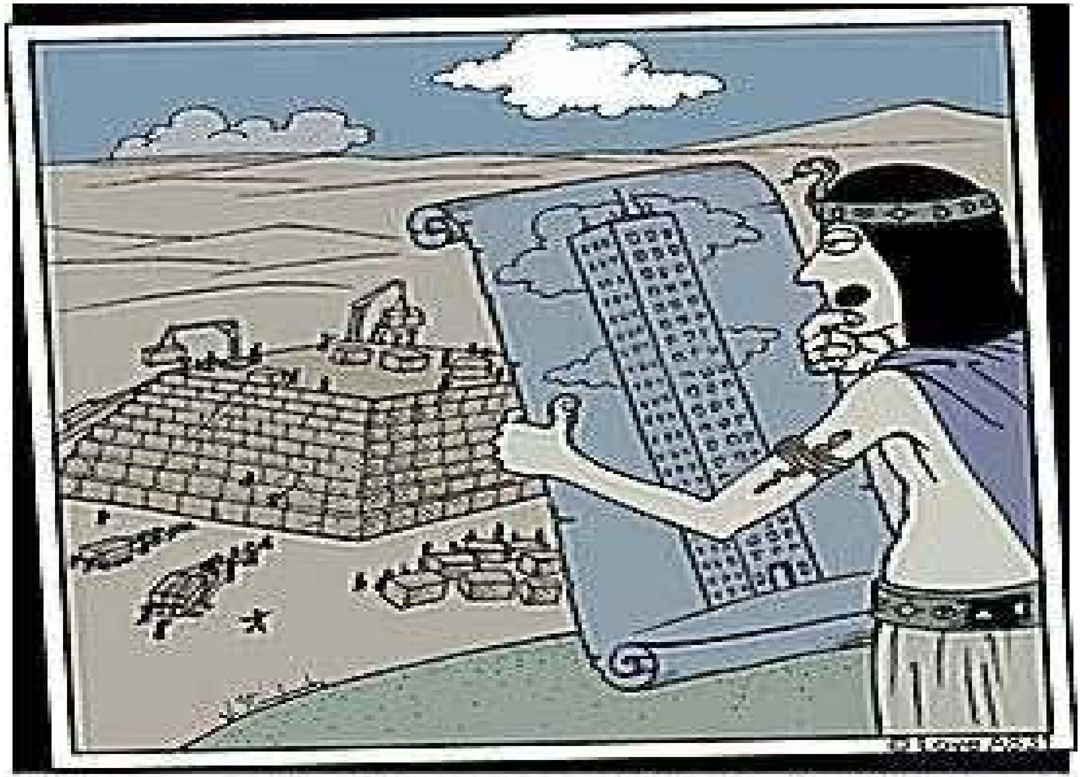
OCL Summary

- 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 expressions
  - use a tool to check your OCL

Conclusion



"I *knew* we didn't have enough blocks for this thing."