CIS 771: Software Specifications

Lecture 13: More OCL

Outline

- OCL type hierarchy
- Collection operations
- Using collection operations in invariants

...with the Academia model as the running example.

Subtyping

- If T_1, T_2 are model types then $T_1 < T_2$ holds exactly when T_1 is a subclass of T_2 in a class diagram
- Integer < Real
- For all type expressions T, not denoting a collection type,
  - Set(T) < Collection(T)
  - Sequence(T) < Collection(T)
  - Bag(T) < Collection(T)
- If T is a model, basic, or enumeration type then $T < OclAny$
- If $T_1 < T_2$ and C is any of the type constructors Collection, Set, Bag, Sequence, then $C(T_1) < C(T_2)$
- The relation < is transitive
- For any OCL type T, $T:OclType$

Examples

- Grad < Student < Person, so Grad < Person
  - ... *because < is transitive*
- Collection(Grad) < Collection(Person)
  - ... *because Grad < Person*
- Set(Grad) < Collection(Grad)
  - ... *because Set is a Collection type*
- Set(Grad) < Collection(Person)
  - ... *because Set is a Collection type and Grad < Person*

Examples

- Grad < OclAny
  - *... because OclAny is a supertype of any model type*
- Integer < OclAny
  - *... because OclAny is the supertype of any basic type*
- Set(Grad) !< OclAny
  - *... because OclAny is NOT the supertype of a collection type*
- Grad: OclType, Set(Grad):OclType, OclAny:OclType
  - *... because OclType is the type of every OCL type*

For You To Do…

- Is Bag(Grad) < Set(Person)?
- Is Grad: OclAny?
- Is 5: OclAny?
- Is Sequence(Student) < Set(Person)?
- Is 5 < Integer?
- Is Bag(Grad) < Collection(OclAny)?
- Is Sequence(Grad) < Bag(Grad)?
- Is Set(Integer): OclType?

Basic Collection Operations

Membership tests

- *collection*->includes(*object*: OclAny): Boolean
- *collection*->excludes(*object*: OclAny): Boolean

Examples

(robby, cis771)
(oksana, cis771)
(william, cis771)

cis771.enrolled->includes(robby)
...is true

cis771.enrolled->excludes(adam)
...is true

robby.taking->includes(cis775)
...is false

Basic Collection Operations

Inclusion tests

- *collection*->includesAll(*c2*: Collection(*T*)): Boolean
- *collection*->excludesAll(*c2*: Collection(*T*)): Boolean

Examples

(robby, cis771)
(oksana, cis771)
(william, cis771)

cis771.enrolled
->includesAll(Set {robby,oksana})
...is true

Notation for set and bag literals

cis771.enrolled
->excludesAll(Bag {adam, adam})
...is true

(see OMG-UML v1.3 Section 7.6.1 pp. 7.22-7.23)

Select

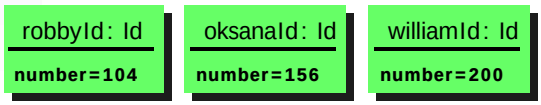
Select

- *collection*->select(*exp*: Boolean)
  - *...yields the sub-collection of components satisfying the condition* exp

Example

(robby, robbyId)
(oksana, oksanaId)
(william, williamId)

Id.allInstances->select(number > 150)
...Set{oksanaId,williamId}: Set(Id)



Reject

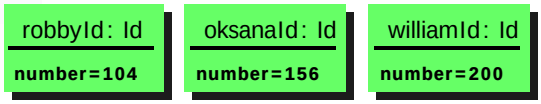
Select

- *collection*->reject(*exp*: Boolean)
  - *...returns a collection with the components satisfying the condition* exp *removed from the original collection*

Example

(robby, robbyId)
(oksana, oksanaId)
(william, williamId)

Id.allInstances->reject(number > 150)
...Set{robbyId}: Set(Id)



Alternate Forms

- A variable (called the *iterator*) can be introduced to refer to the items in the resulting collection directly
  - *collection*->select(*v* | *exp-with-v*: Boolean)
  - *collection*->select(*v* : *Type* | *exp-with-v*: Boolean)
- *v* iterates over the *collection* and the *exp-with-v* is evaluated for each *v*. The result is the collection containing the items for which *exp-with-v* is true.
  - Id.allInstances->select(id | id.number > 150)
- ..similarly for 'reject'

Collect

- select and reject always result in sub-collections of the original collection
- When we we want to specify a collection which is derived from some other collection, but which is not a sub-collection, we can use a collect operation.
  - *collection*->collect(*exp*)
  - *collection*->collect(*v* | *exp-with-v*)
  - *collection*->collect(*v* : *Type* | *exp-with-v*)
- Example
  - robby.taking->collect(number)
  - robby.taking.number *...abbreviation (matches Alloy)*
- The result of the collect operation is always a *bag!*

(see OMG-UML v1.3 Section 7.6.2 pp. 7.24-7.25)

Example

Consider the Academia constraint...

No one is taking or waiting for a course unless they have already taken all the prerequisites

```
context s:Student
   inv PrerequisitesRequired:
     s.transcript
         ->includesAll(s.taking.prerequisites
                       ->union(s.waitingFor.prerequisites))
```

Collection operation applied to obtain the bag of prerequisites for all courses that s is taking (waitingFor)

*This is the union operation for **bags***

Note: the prerequisite bags above may contain duplicate courses, e.g., if the same course is a prerequisite for multiple courses being taken.

For You To Do…

- Pause the lecture
- Download the academia-4.use file
- Add to this file the class, association and invariant declarations for the extension to the Academia model described on the next two slides
- Load the resulting model into USE
- Create some system snapshots
  - some that satisfy your invariants
  - some that violate your invariants
  - you can build off of the academia-basic-instantiation.cmd script
- Use the USE command line to enter in some expressions for USE to evaluate (type 'help' to see syntax), e.g.,
  - `use> ? cis771.enrolled->includes(robby)`
- In your examples, explore the differences between sets and bags
- You may notice the appearance of the 'undefined' value in your results. What implications does that have for us?

I. Academia State

- Add an unique ID attribute for students
  - since we have integers and strings in OCL, there is more than one way to model IDs
- Add student transcripts
  - a transcript gives a set of courses associated with a student (the courses that a student has completed)
- Add prerequisite structure for courses
  - relates a course to courses that are prerequisites for it

I. Academia Constraints

- Enforce the uniqueness constraint for IDs
- A student can only take a course for which they have already taken the prereqs
- A course does not have itself as a prerequisite
  - An even stronger requirement is that there are no cycles in the prerequisite structure (can you do this one?)
- Realism: that there exists a course with prerequisites that someone is enrolled in

ForAll

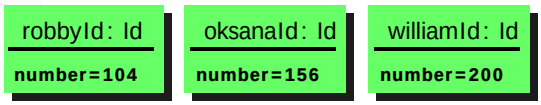
Select

- *collection*->forAll(*exp*: Boolean)
  - *...returns true if exp holds for all objects in the collection*

Example

(robby, robbyId)
(oksana, oksanaId)
(william, williamId)

Id.allInstances->forAll(number > 150)
...false



Exists

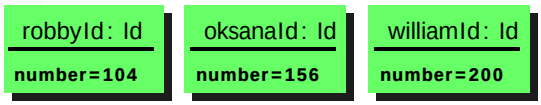
Select

- *collection*->exists(*exp*: Boolean)
  - *...returns true if there is at least one object in the collection for which exp holds*

Example

(robby, robbyId)
(oksana, oksanaId)
(william, williamId)

Id.allInstances->exists(number > 150)
...true



Example

Consider the Academia constraint...

Only faculty members teach required courses

```
context d:Department
   inv FacultyTeachReqCourses:
     d.required.taughtby
         ->forAll(i:Instructor |
                  i.instructor.oclIsKindOf(Faculty))
```

Collection operation applied to obtain the bag of all instructors that teach required courses in department d

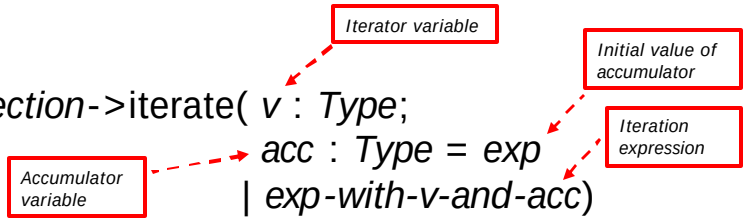
Alternate Forms

- We have the same sort of alternate forms as before
  - *collection*->forAll(*exp*: Boolean)
  - *collection*->forAll(*v* | *exp-with-v*: Boolean)
  - *collection*->forAll(*v* : *Type* | *exp-with-v*: Boolean)
- In addition, if we need two quantified variables, we can use an abbreviation as in the following example...
  - Id.allInstances
    ->forAll(id1, id2 | id1 = id2 implies id1.number = id2.number)
- The above is semantically equivalent to...
  - Id.allInstances
    ->forAll(id1 | Id.allInstances
    ->forAll(id2 | id1 = id2 implies id1.number = id2.number))

(see OMG-UML v1.3 Section 7.6.3 pp. 7.25-7.26)

Iterate

Generic iteration scheme that can be used to define all of the collection operations that we have seen so far.



- *collection*->iterate(*v* : *Type*;
  acc : *Type* = *exp*
  | *exp-with-v-and-acc*)
  - *v* iterates over the *collection* and the *exp-with-v-and-acc* is evaluated for each value of *v*.
  - After each evaluation of *exp-with-v-and-acc*, its value is assigned to *acc*.
  - In this way, the value of *acc* is built up during the iteration of the collection.

Iterate

Example

collection->collect(x : T | x.property)

...is semantically equivalent to...

collection->iterate(x : T; acc : T2 = Bag {} |
acc->including(x.property))

Iterate

As it would be coded in Java-like pseudo-code

```
iterate(v : T, acc : T2 = value)
{
    acc = value;
    for (Enumeration e = collection.elements();
         e.hasMoreElements();) {
            v = e.nextElement();
            acc = <exp-with-v-and-acc>
     }
}
```


For You To Do…

- Pause the lecture
- Download the academia-5.use file
- Add to this file the class, association and invariant declarations for the extension to the Academia model described on the next four slides
- Load the resulting model into USE
- Create some system snapshots
  - some that satisfy your invariants
  - some that violate your invariants
  - you can build off of the academia-extension1-instantiation.cmd script
- Use the USE command line to enter in some expressions for USE to evaluate (type 'help' to see syntax), e.g.,
  - `use> ? cis771.enrolled->includes(robby)`
- In your examples, code up some of your collection operations using the *iterate* operation

II. Academia State

- Add Departments
  - Instructors per
  - Courses per
  - Required courses
  - Student majors
- Add Faculty-Grad student relationships
  - Advisor
  - Thesis committee

II. Department Associations

- Each *faculty* is in a single *department*.
  - Each *department* has at least one *faculty*.
- Each *department* offers some *courses*
  - Courses are offered in exactly one department
- Each *department* requires some *courses*
  - Courses are required in at most one department
- Each *student* has a single *department* as his/her *major*
  - i.e., a department

II. Faculty-Student Associations

- A *graduate* student has exactly one *faculty* member as an *advisor*.
- A *faculty* member serves on five or fewer *graduate* student *committees*.

II. Academia Constraints

- Advisors are on their student's committees
- Students are advised by faculty in their major
- Only faculty teach required courses
- Required courses are a subset of the courses for a major
- Students must take at least one course from their major each semester
- Realism: There are at least two departments and some required courses.

Acknowledgements

- Material for this lecture is based on the following sources
  - Chapter 7 (the OCL chapter) of the OMG-UML specification (version 1.3 – March 2000)