Concordia University

Department of Computer Science and Software Engineering

SOEN 331:

Formal Methods for Software Engineering

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Problem 2

1.
```
CL-USER 1 > (defvar *airports* '((YUL.Montreal)(LCY.London_UK)(LHR.London_UK)(MIL.M
*AIRPORTS*

CL-USER 2 > (print *airports*)

((YUL.MONTREAL) (LCY.LONDON_UK) (LHR.LONDON_UK) (MIL.MILAN) (SFO.SAN_FRANCISCO) (SD
((YUL.MONTREAL) (LCY.LONDON_UK) (LHR.LONDON_UK) (MIL.MILAN) (SFO.SAN_FRANCISCO) (SD

CL-USER 3 > *airports*
((YUL.MONTREAL) (LCY.LONDON_UK) (LHR.LONDON_UK) (MIL.MILAN) (SFO.SAN_FRANCISCO) (SD

CL-USER 4 >
```

2. *monitored*=dom(*airports*)

3. *airports* is a variable that holds one to many mappings of objects of type AIRPORT to objects of type CITY. dom(*airports*) = $\mathbb{P}$ AIRPORT. codomain(*airports*) = $\mathbb{P}$ CITY. *airports* = $\mathbb{P}$ AIRPORT$\mapsto$ CITY

4. This should be an unordered structe, because order doesn't matter in this scenario, nor does it make sense. Looking up in an unordered structure would also be a lot faster than in an ordered one $O(1)$ vs $O(n)$. Assuming a Hashmap or any variation is not permitted, a set containing tuples of type (AIRPORT, CITY) should be used. There should be a restriction on the domain of this data structure, indicating no head of tuple can be a duplicate of another head. Lists of strict length 2 with types $\langle$AIRPORT, CITY$\rangle$ could also be used to replace the tuples.

5.

AirportSystem

$codes : \mathbb{P}\ AIRPORT$
$airports : AIRPORT \rightarrow CITY$ `--non-injective, surjective`
$cities : \mathbb{P}\ CITY$

$codes = \text{dom}\ airports$
$deployed = \text{ran}\ airports$

6.

Success

$\Xi AirportSystem$
$response! : MESSAGE$

$response! = 'ok'$

CodeAlreadyInUse

$\Xi AirportSystem$
$code? : AIRPORT$
$response! : Message$

$code? \in \text{dom}\ airports$
$response! = 'Code\ already\ in\ use'$

AddAirportOK

$\Delta AirportSystem$
$code? : AIRPORT$
$city? : CITY$

$code? \notin \text{dom}\ airports$
$airports' = airports \cup \{code? \mapsto city?\}$

$$AddAirport \mathrel{\hat{=}} (AddAirportOK \land Success) \oplus CodeAlreadyInUse$$

7. `CL-USER 1 > (defvar *airports*`

```
  '((YUL . Montreal)
    (LCY .London_UK)
    (LHR . London_UK)
    (MIL . Milan)
    (SFO . San_Francisco)
    (SDQ . Santo_Domingo)))
*AIRPORTS*

CL-USER 2 : 1 > *airports*
((YUL . MONTREAL) (LCY .LONDON_UK) (LHR . LONDON_UK) (MIL . MILAN) (SFO . SAN_FRANC

CL-USER 3 : 1 > (defun addAirport (code city)
  (if (find code *airports* :key #'car)
      (print "Code already in use.")
      (progn
        (push (cons code city) *airports*)
        (print "ok"))))
ADDAIRPORT

CL-USER 4 : 1 >
```

8.

UpdateAirportOK

$\Delta AirportSystem$
$code? : AIRPORT$
$city? : CITY$

$code? \in \mathrm{dom}\ airports$
$airports' = airports \oplus \{code? \mapsto city?\}$

CodeNotInUse

$\Xi AirportSystem$
$code? : AIRPORT$
$response! : Message$

$code? \notin \text{dom } airports$
$response! = \text{'}Code\ not\ in\ use\text{'}$

$$UpdateAirport \mathrel{\hat{=}} (UpdateAirportOK \land Success) \oplus CodeNotInUse$$

9. $airports = \{ YUL \mapsto Dorval,$
   $LCY \mapsto LondonUK,$
   $LHR \mapsto LondonUK,$
   $MIL \mapsto Milan,$
   $SFO \mapsto SanFrancisco,$
   $SDQ \mapsto SantoDomingo$
   $\}$

10. ```
    CL-USER 1 > (defvar *airports*
      '((YUL . Montreal)
        (LCY .London_UK)
        (LHR . London_UK)
        (MIL . Milan)
        (SFO . San_Francisco)
        (SDQ . Santo_Domingo)))
    *AIRPORTS*

    CL-USER 2 > (defun updateAirport (code new-city)
      (let ((existing (assoc code *airports* :test #'equal)))
        (if existing
            (progn
              (setf (cdr existing) new-city)
    ```
    ```

```
          (print  "ok"))
        (print "Code not in use.")))
UPDATEAIRPORT-CITY

CL-USER 3 > (defun updateAirport (code new-city)
  (let ((existing (assoc code *airports* :test #'equal)))
    (if existing
        (progn
          (setf (cdr existing) new-city)
          (print  "ok"))
        (print "Code not in use."))))
UPDATEAIRPORT

CL-USER 4 > (updateAirport 'YUL 'Dorval)

"ok"
"ok"

CL-USER 5 > (updateAirport 'LL 'GG)

"Code not in use."
"Code not in use."

CL-USER 6 >
```

Remove Everything After this line ——————————————————————

Part 1: Temperature monitoring system with the Z specification

Consider a system called 'TempMonitor' that keeps a number of sensors, where each sensor is deployed in a separate location in order to read the location's temperature. Before the system is deployed, all locations are marked on a map, and each location will be addressed by a sensor. The formal specification of the system introduces the following three types:

$$SENSOR\_TYPE, LOCATION\_TYPE, TEMPERATURE\_TYPE$$

We also introduce an enumerated type *MESSAGE* which will assume values that correspond to success and error messages.

Provide a formal specification in Z, with the following operations:

- `DeploySensorOK`: Places a new sensor to a unique location. You may assume that some (default) temperature is also passed as an argument.
- `ReadTemperatureOK`: Obtain the temperature reading from a sensor, given the sensor's location.

Provide appropriate success and error schemata to be combined with the definitions above to produce robust specifications for the following interface:

- `DeploySensor`,
- `ReadTemperature`.

Solution:

TempMonitor

$deployed' : \mathbb{P}\ SENSOR\_TYPE$
$map : SENSOR\_TYPE \pfun LOCATION\_TYPE$ `--partial bijective`
$read : SENSOR\_TYPE \pfun TEMPERATURE\_TYPE$

$deployed = \mathrm{dom}\ map$
$deployed = \mathrm{dom}\ read$

DeploySensorOK

$\Delta TempMonitor$
$sensor? : SENSOR\_TYPE$
$location? : LOCATION\_TYPE$
$temperature? : TEMPERATURE\_TYPE$

$sensor? \notin deployed$
$location? \notin \mathrm{ran}\ map$
$deployed' = deployed \cup \{sensor?\}$
$map' = map \cup \{sensor? \mapsto location?\}$
$read' = read \cup \{sensor? \mapsto temperature?\}$

ReadTemperatureOK

$\Xi TempMonitor$
$location? : LOCATION\_TYPE$
$temperature! : TEMPERATURE\_TYPE$

$location? \in \mathrm{ran}\ map$
$temperature! = read(map^{-1}(location?))$

Success

$\Xi TempMonitor$
$response! : MESSAGE$

$response! = 'ok'$

SensorAlreadyDeployed

$\Xi TempMonitor$
$sensor? : SENSOR\_TYPE$
$response! : Message$

$sensor? \in deployed$
$response! = 'Sensor\ deployed'$

LocationAlreadyCovered

$\Xi TempMonitor$
$location? : LOCATION\_TYPE$
$response! : Message$

$location? \in \operatorname{ran} map$
$response! = 'Location\ already\ covered'$

LocationUnknown

$\Xi TempMonitor$
$location? : LOCATION\_TYPE$
$response! : Message$

$location? \notin \operatorname{ran} map$
$response! = 'Location\ not\ covered'$

$$DeploySensor \mathrel{\hat{=}} (DeploySensorOK \land Success) \oplus (SensorAlreadyDeployed \lor LocationAlreadyCovered)$$

$$ReadTemperature \mathrel{\hat{=}} (ReadTemperatureOK \land Success) \oplus LocationUnknown$$

Part 2: A booking system with the Object Z specification

We introduce the basic types $[Person, SeatType]$. We also introduce an enumerated type *Message* which will assume values (feel free to define your own) that correspond to success and error messages. Consider a system to book seats for a theater play. A customer can book a single seat, and a seat can only accommodate a single customer. The booking system keeps a log of the customers that have booked a seat. The system publishes a plan of the theater and it allows customers to access it online and make a booking or cancel a booking.

Class `Booking`

Define a formal specification in Object-Z for class *Bookingt* to support the following operations:

- `BookOK`: Reserves a seat for a given customer.
- `CancelOK`: Frees a seat for a given customer.

You will also need to provide appropriate success and error schemata to be combined with the definitions above to produce *robust specifications* for the following interface:

- `Book`, and
- `Cancel`.

Class `Booking2`

Subclassify `Booking` to introduce class `Booking2` that behaves exactly like `Booking`, while introducing the following operations:

- `GetNumberOfCustomers` returns the total number of customers who have made a booking.

- `ModifyBookingOK` assigns an existing customer to a different seat. Provide any additional schema(ta) in order to extend the interface to include a robust operation `ModifyBooking`.

The extended interface will now include operations

- `GetNumberOfCustomers`, and
- `ModifyBooking`.

Solution:

The main functionality for class `Booking` together with the success and error schemata are given below:

Booking

$\upharpoonright (Book, Cancel)$

$$
\begin{array}{|l}
\hline
booked : \ \mathbb{P}\ Person \\
booking : Person \rightarrowtail SeatType \\
capacity : \mathbb{N} \\
count : \mathbb{N} \\
\hline
booked = \ dom\ booking \\
capacity > 0 \\
count \geq 0 \\
\hline
\end{array}
$$

Init

$$
\begin{array}{|l}
\hline
booked = \varnothing \\
capacity = 100 \\
count = 0 \\
\hline
\end{array}
$$

BookOK

$$
\begin{array}{|l}
\hline
\Delta(booking, count) \\
customer? : Person \\
seat? : SeatType \\
\hline
customer? \notin booked \\
seat? \notin \operatorname{ran} SeatType \\
count < capacity \\
booking' = booking \cup \{customer? \mapsto seat?\} \\
count' = count + 1 \\
\hline
\end{array}
$$

CancelOK

$$
\begin{array}{|l}
\hline
\Delta(booking, count) \\
customer? : Person \\
\hline
customer? \in booked \\
count > 0 \\
booking' = \{customer?\} \lhd booking \\
count' = count - 1 \\
\hline
\end{array}
$$

...

Booking/cont.

...

Success

$response! : Message$

$response! = 'ok'$

CustomerExists

$customer? : Person$
$response! : Message$

$customer? \in booked$
$response! = 'Customer\ already\ exists'$

CustomerUnknown

$customer? : Person$
$response! : Message$

$customer? \notin booked$
$response! = 'Customer\ unknown'$

SeatTaken

$seat? : SeatType$
$response! : Message$

$seat? \in ran\ booking$
$response! = 'Seat\ taken'$

TheaterFull

$response! : Message$

$count = capacity$
$response! = 'Theater\ full'$

TheaterEmpty

$response! : Message$

$count = 0$
$response! = 'Theater\ empty'$

$Book \mathrel{\hat{=}} (BookOK \land Success) \oplus CustomerExists \oplus (SeatTaken \lor TheaterFull)$

$Cancel \mathrel{\hat{=}} (CancelOK \land Success) \oplus (CustomerUnknown \lor TheaterEmpty)$

*Booking*2

$\upharpoonright (Book, Cancel, GetNumberOfCustomers)$

Booking

GetNumberOfCustomers

$result! : \mathbb{N}$

$result! = count$

ModifyBookingOK

$\Delta(booking)$
$customer? : Person$
$seat? : SeatType$

$customer? \in booked$
$seat? \notin ran\ booking$
$booking' = booking \oplus \{customer? \mapsto seat?\}$

$ModifyBooking \mathrel{\hat{=}} (ModifyBookingOK \land Success) \oplus (CustomerUnknown \lor SeatTaken)$