Addendum to 'Teaching Touchy Transformations'

Martin Gogolla

University of Bremen (D), CS Department, Database Systems Group

Abstract: This paper is an addendum to the paper 'Teaching Touchy Transformations' presented at the Educator's Symposium during the MODELS conference in 2008 by the same author. That paper reports on a teaching unit on model transformations in which one example model is first developed and afterwards transformed into various other models. The current paper collects the material used for the described teaching unit.

Context

The paper at the Educator's Symposium during the MODELS conference in 2008 describes a library system with different models in different sections. The models and sections are abbreviated and numbered as follows:

- Informal (Section 3.1)
- MaxInvsMinPrepos (Section 3.2)
- MaxPrepos (Section 3.3)
- Assoc2Attr (Section 3.4)
- RelDB1NF (Section 3.5)
- Invs2Super (Section 3.6)
- CompFrame (Section 3.7)

In the following we present the material used for the respective section using the above numbering scheme thus allowing an easy reference to the original paper.

3.1 Informal

3.1.1 Cloze Text

```
The example describes a digital support system for a library. The
library offers book copies to users. A user can borrow a copy or in
other words, an exemplar, of a book. A book is characterized by an
author list, a year of publication, and a unique title. A copy is
determined by the number of return actions of the copy, the book of
which the copy is an exemplar of, and a unique signature. A user has
an address and a unique name. At most one user can borrow a copy of a
book at one particular point in time. Book, copy, and user properties
are first manipulated by initialization actions. Both users and copies
are able to perform actions for borrowing and returning.
```

Additionally, certain conditions must hold. If properties such as author, title, ---------, address, and ---- are described by strings, the string is not allowed to be undefined or to be equal to the empty string. A year of ----------- is equal to or greater than 1455 (the year in which the Gutenberg bible was published). A ---- having borrowed a copy of a particular ---- is not allowed to borrow another copy of the same book at the same time. An ------ can appear at most once in an ------ list. Finally, as already indicated above, certain properties such as -----, ---------, and ---- are unique.

Initialization, borrow and ------ actions have to respect the above ----------. They can only be performed meaningfully in reasonable situations. They have to fulfill their expected functionality.

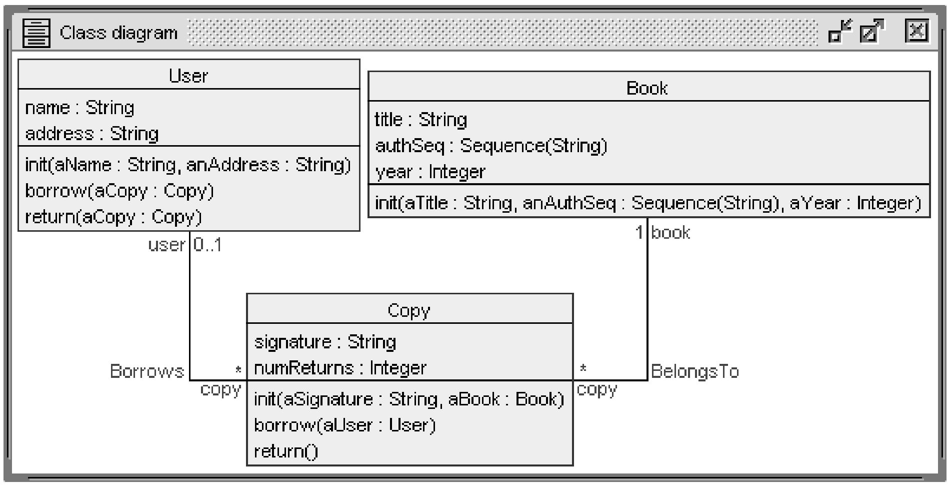
3.1.2 Cloze Text with Missing Words Substituted (Last Paragraphs Only)

Additionally, certain conditions must hold. If properties such as author, title, ***signature***, address, and ***name*** are described by strings, the string is not allowed to be undefined or to be equal to the empty string. A year of ***publication*** is equal to or greater than 1455 (the year in which the Gutenberg bible was published). A ***user*** having borrowed a copy of a particular ***book*** is not allowed to borrow another copy of the same book at the same time. An ***author*** can appear at most once in an ***author*** list. Finally, as already indicated above, certain properties such as ***title***, ***signature***, and ***name*** are unique.

Initialization, borrow and ***return*** actions have to respect the above ***conditions***. They can only be performed meaningfully in reasonable situations. They have to fulfill their expected functionality.

3.2 MaxInvsMinPrepos

3.2.1 Class Diagram



3.2.2 USE Model (Classes, Associations, Invariants, Pre- and postconditions)

```
---------------------------------------------------------------- Library
model Library
-------------------------------------------------------------- class User
class User
attributes
  name:String -- key
  address:String
operations
  init(aName:String, anAddress:String)
  borrow(aCopy:Copy)
  return(aCopy:Copy)
end
-------------------------------------------------------------- class Copy
class Copy
attributes
  signature:String -- key
  numReturns:Integer
operations
  init(aSignature:String, aBook:Book)
  borrow(aUser:User)
  return()
end
-------------------------------------------------------------- class Book
class Book
attributes
  title:String -- key
  authSeq:Sequence(String)
  year:Integer
operations
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
end
----------------------------------------------------- association Borrows
association Borrows between
  User[0..1] role user
  Copy[0..*] role copy
end
-- - - - - - - - - - - - - - - - - - - - - - - - - - association BelongsTo
association BelongsTo between
  Copy[0..*] role copy
  Book[1] role book
end
------------------------------------------------------------- constraints
constraints
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - User
context u:User inv nameAddressFormatOk:
  u.name<>oclUndefined(String) and u.name<>'' and
  u.address<>oclUndefined(String) and u.address<>''
context u1:User inv nameIsKey: User.allInstances->forAll(u2 |
  u1<>u2 implies u1.name<>u2.name)
context u:User inv noDoubleBorrowings:
  not(u.copy->exists(c1,c2|c1<>c2 and c1.book=c2.book))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy
context c:Copy inv signatureFormatOk:
  c.signature<>oclUndefined(String) and c.signature<>''
context c1:Copy inv signatureIsKey: Copy.allInstances->forAll(c2 |
  c1<>c2 implies c1.signature<>c2.signature)
```

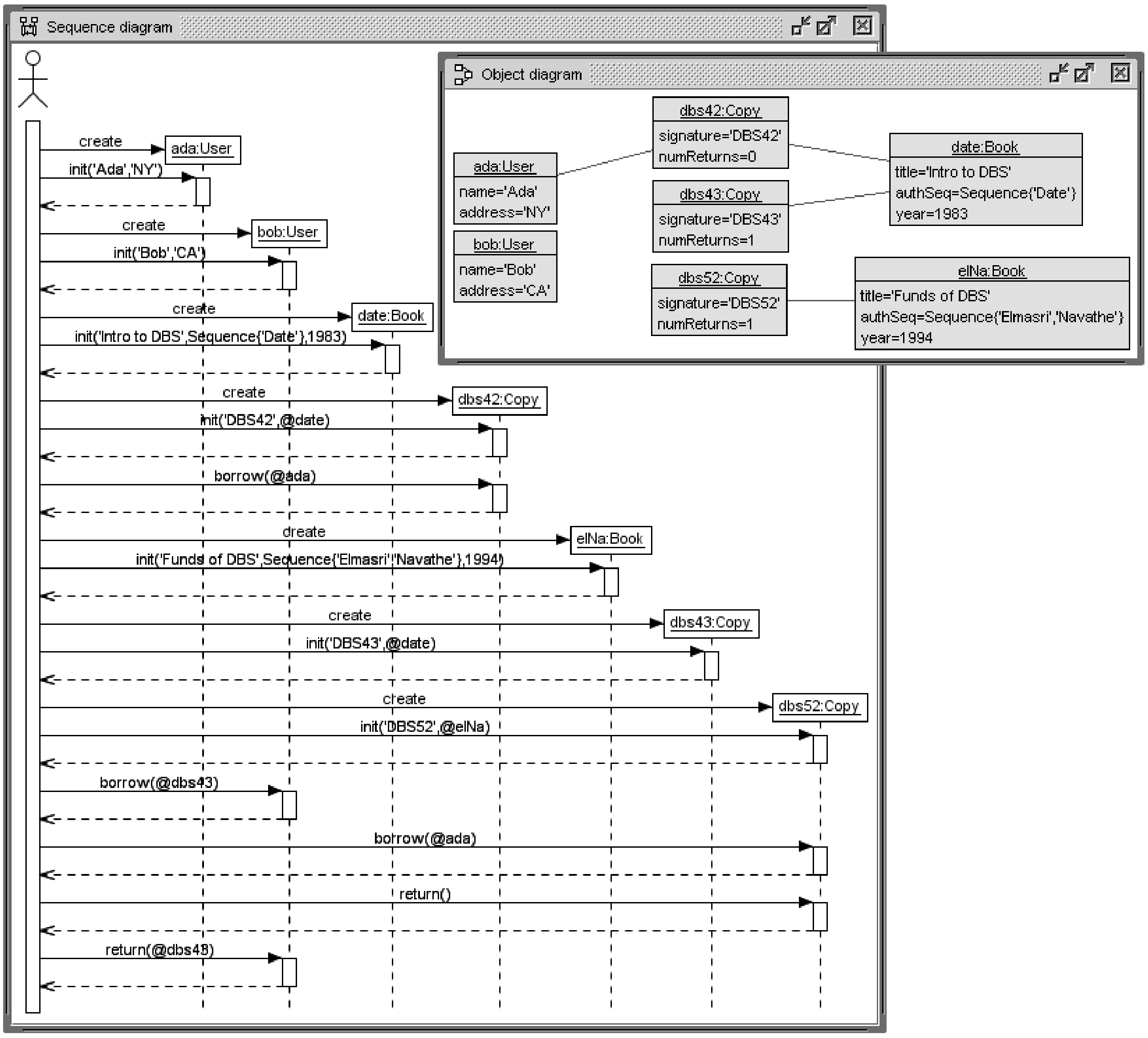
```
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Book
context b:Book inv titleFormatOk:
  b.title<>oclUndefined(String) and b.title<>''
context b1:Book inv titleIsKey: Book.allInstances->forAll(b2 |
  b1<>b2 implies b1.title<>b2.title)
context b:Book inv authSeqFormatOk: Set{1..b.authSeq->size()}->forAll(i|
  authSeq->at(i)<>oclUndefined(String) and authSeq->at(i)<>'')
context b:Book inv authSeqExistsAndUnique: b.authSeq->size()>0 and
  Set{1..b.authSeq->size()-1}->forAll(i|
    Set{i+1..b.authSeq->size()}->forAll(j|
      authSeq->at(i)<>authSeq->at(j)))
context b:Book inv yearPlausible:
  1455<=b.year
------------------------------------------------------------ User::init
context User::init(aName:String, anAddress:String)
pre freshUser:
  self.name=oclUndefined(String) and
  self.address=oclUndefined(String) and self.copy->isEmpty()
post attrsAssigned:
  aName=self.name and anAddress=self.address
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - User::borrow
context User::borrow(aCopy:Copy)
pre copyOk:
  aCopy<>oclUndefined(Copy) and aCopy.user->isEmpty()
post linkAssigned:
  self.copy@pre->including(aCopy)=self.copy
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - User::return
context User::return(aCopy:Copy)
pre aCopyOk:
  aCopy<>oclUndefined(Copy) and self.copy->includes(aCopy)
post linkRemoved:
  self.copy@pre->excluding(aCopy)=self.copy
post numReturnsIncreased:
  aCopy.numReturns@pre+1=aCopy.numReturns
------------------------------------------------------------ Copy::init
context Copy::init(aSignature:String, aBook:Book)
pre freshCopy:
  self.signature=oclUndefined(String) and
  self.numReturns=oclUndefined(Integer) and
  self.user->isEmpty() and self.book->isEmpty()
pre bookOk:
  aBook<>oclUndefined(Book)
post attrsAndLinkAssigned:
  aSignature=self.signature and 0=self.numReturns and
  aBook=self.book
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy::borrow
context Copy::borrow(aUser:User)
pre userOk:
  aUser<>oclUndefined(User)
pre notBorrowed:
  self.user->isEmpty()
post linkAssigned:
  aUser=self.user
```

```
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy::return
context Copy::return()
pre copyOk:
  self.user->notEmpty()
post linkRemoved:
  self.user->isEmpty()
post numReturnsIncreased:
  self.numReturns@pre+1=self.numReturns
------------------------------------------------------------ Book::init
context Book::
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
pre freshBook:
  self.title=oclUndefined(String) and
  self.authSeq=oclUndefined(Sequence(String)) and
  self.year=oclUndefined(Integer) and
  self.copy->isEmpty()
post attrsAssigned:
  aTitle=self.title and anAuthSeq=self.authSeq and aYear=self.year
-----------------------------------------------------------------------
```

3.2.3 Operation Implementations with Command Files

```
-----------------------------------------------------------------------
-- - - - - - - - - - - - - - -  User::init(aName:String, anAddress:String)
!set self.name:=aName
!set self.address:=anAddress

-----------------------------------------------------------------------
-- - - - - - - - - - - - - - - - - - - - - - - - -  User::borrow(aCopy:Copy)
!insert (self,aCopy) into Borrows

-----------------------------------------------------------------------
-- - - - - - - - - - - - - - - - - - - - - - - - -  User::return(aCopy:Copy)
!set aCopy.numReturns:=aCopy.numReturns+1
!delete (self,aCopy) from Borrows

-----------------------------------------------------------------------
-- - - - - - - - - - - - - - - - Copy::init(aSignature:String, aBook:Book)
!set self.signature:=aSignature
!set self.numReturns:=0
!insert (self,aBook) into BelongsTo

-----------------------------------------------------------------------
-- - - - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow(aUser:User)
!insert (aUser,self) into Borrows

-----------------------------------------------------------------------
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::return()
!set self.numReturns:=self.numReturns+1
!delete (self.user,self) from Borrows

-----------------------------------------------------------------------
--  Book::init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
!set self.title:=aTitle
!set self.authSeq:=anAuthSeq
!set self.year:=aYear
-----------------------------------------------------------------------
```

3.2.4 Sequence and Object Diagram



3.2.5 Complete Command Line Protocol

```
use> ------------------------------------------------------------ library.use
use> open library.use

use> --------------------------------------------------------------- ada:User
use> !create ada:User
use> ?Tuple{name:ada.name,address:ada.address,copy:ada.copy}
     Tuple{name:Undefined,address:Undefined,copy:Set{}} :
       Tuple(name:String,address:String,copy:Set(Copy))
use> !openter ada init('Ada','NY')
     precondition `freshUser' is true
use> read User_init.cmd
```

```
     -- - - - - - - - - - - - - -  User::init(aName:String, anAddress:String)
     !set self.name:=aName
     !set self.address:=anAddress
use> !opexit
     postcondition `attrsAssigned' is true
use> ?Tuple{name:ada.name,address:ada.address,copy:ada.copy}
     Tuple{name:'Ada',address:'NY',copy:Set{}} :
       Tuple(name:String,address:String,copy:Set(Copy))

use> -------------------------------------------------------------- bob:User
use> !create bob:User
use> !openter bob init('Bob','CA')
     precondition `freshUser' is true
use> read User_init.cmd
     -- - - - - - - - - - - - - -  User::init(aName:String, anAddress:String)
     !set self.name:=aName
     !set self.address:=anAddress
use> !opexit
     postcondition `attrsAssigned' is true

use> -------------------------------------------------------------date:Book
use> !create date:Book
use> !openter date init('Intro to DBS',Sequence{'Date'},1983)
     precondition `freshBook' is true
use> read Book_init.cmd
     --  Book::init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
     !set self.title:=aTitle
     !set self.authSeq:=anAuthSeq
     !set self.year:=aYear
use> !opexit
     postcondition `attrsAssigned' is true

use> ------------------------------------------------------------ dbs42:Copy
use> !create dbs42:Copy
use> !openter dbs42 init('DBS42',date)
     precondition `freshCopy' is true
     precondition `bookOk' is true
use> read Copy_init.cmd
     -- - - - - - - - - - - - - - - Copy::init(aSignature:String, aBook:Book)
     !set self.signature:=aSignature
     !set self.numReturns:=0
     !insert (self,aBook) into BelongsTo
use> !opexit
     postcondition `attrsAndLinkAssigned' is true

use> ---------------------------------------------------------- Copy::borrow
use> ?Tuple{name:ada.name,address:ada.address,copy:ada.copy}
     Tuple{name:'Ada',address:'NY',copy:Set{}} :
       Tuple(name:String,address:String,copy:Set(Copy))
use> !openter dbs42 borrow(ada)
     precondition `userOk' is true
     precondition `notBorrowed' is true
use> read Copy_borrow.cmd
     -- - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow(aUser:User)
     !insert (aUser,self) into Borrows
use> !opexit
     postcondition `linkAssigned' is true
use> ?Tuple{name:ada.name,address:ada.address,copy:ada.copy}
     Tuple{name:'Ada',address:'NY',copy:Set{@dbs42}} :
       Tuple(name:String,address:String,copy:Set(Copy))
```

```
use> -------------------------------------------------------------- elNa:Book
use> !create elNa:Book
use> !openter elNa init('Funds of DBS',Sequence{'Elmasri','Navathe'},1994)
     precondition `freshBook' is true
use> read Book_init.cmd
     --  Book::init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
     !set self.title:=aTitle
     !set self.authSeq:=anAuthSeq
     !set self.year:=aYear
use> !opexit
     postcondition `attrsAssigned' is true

use> ------------------------------------------------------------- dbs43:Copy
use> !create dbs43:Copy
use> !openter dbs43 init('DBS43',date)
     precondition `freshCopy' is true
     precondition `bookOk' is true
use> read Copy_init.cmd
     -- - - - - - - - - - - - - - - - Copy::init(aSignature:String, aBook:Book)
     !set self.signature:=aSignature
     !set self.numReturns:=0
     !insert (self,aBook) into BelongsTo
use> !opexit
     postcondition `attrsAndLinkAssigned' is true

use> ------------------------------------------------------------- dbs52:Copy
use> !create dbs52:Copy
use> !openter dbs52 init('DBS52',elNa)
     precondition `freshCopy' is true
     precondition `bookOk' is true
use> read Copy_init.cmd
     -- - - - - - - - - - - - - - - - Copy::init(aSignature:String, aBook:Book)
     !set self.signature:=aSignature
     !set self.numReturns:=0
     !insert (self,aBook) into BelongsTo
use> !opexit
     postcondition `attrsAndLinkAssigned' is true

use> ----------------------------------------------------------- User::borrow
use> !openter bob borrow(dbs43)
     precondition `copyOk' is true
use> read User_borrow.cmd
     -- - - - - - - - - - - - - - - - - - - - - - -  User::borrow(aCopy:Copy)
     !insert (self,aCopy) into Borrows
use> !opexit
     postcondition `linkAssigned' is true

use> ----------------------------------------------------------- Copy::borrow
use> !openter dbs52 borrow(ada)
     precondition `userOk' is true
     precondition `notBorrowed' is true
use> read Copy_borrow.cmd
     -- - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow(aUser:User)
     !insert (aUser,self) into Borrows
use> !opexit
     postcondition `linkAssigned' is true

use> ----------------------------------------------------------- Copy::return
use> ?Tuple{signature:dbs52.signature,numReturns:dbs52.numReturns,
       user:dbs52.user,book:dbs52.book}
     Tuple{signature:'DBS52',numReturns:0,user:@ada,book:@elNa} :
       Tuple(signature:String,numReturns:Integer,user:User,book:Book)
use> !openter dbs52 return()
     precondition `copyOk' is true
use> read Copy_return.cmd
```

```
     -- - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::return()
     !set self.numReturns:=self.numReturns+1
     !delete (self.user,self) from Borrows
use> !opexit
     postcondition `linkRemoved' is true
     postcondition `numReturnsIncreased' is true
use> ?Tuple{signature:dbs52.signature,numReturns:dbs52.numReturns,
       user:dbs52.user,book:dbs52.book}
     Tuple{signature:'DBS52',numReturns:1,user:Undefined,book:@elNa} :
       Tuple(signature:String,numReturns:Integer,user:User,book:Book)

use> ----------------------------------------------------------- User::return
use> !openter dbs43.user return(dbs43)
     precondition `aCopyOk' is true
use> read User_return.cmd
     -- - - - - - - - - - - - - - - - - - - - - - - - -  User::return(aCopy:Copy)
     !set aCopy.numReturns:=aCopy.numReturns+1
     !delete (self,aCopy) from Borrows
use> !opexit
     postcondition `linkRemoved' is true
     postcondition `numReturnsIncreased' is true
use> ---------------------------------------------------------------------------
```

3.3 MaxPrepos

3.3.1 Class Diagram

Identical to class diagram in MaxInvsMinPrepos.

3.3.2 USE Model

Changes with respect to MaxInvsMinPrepos are indicated by '-- inv'.

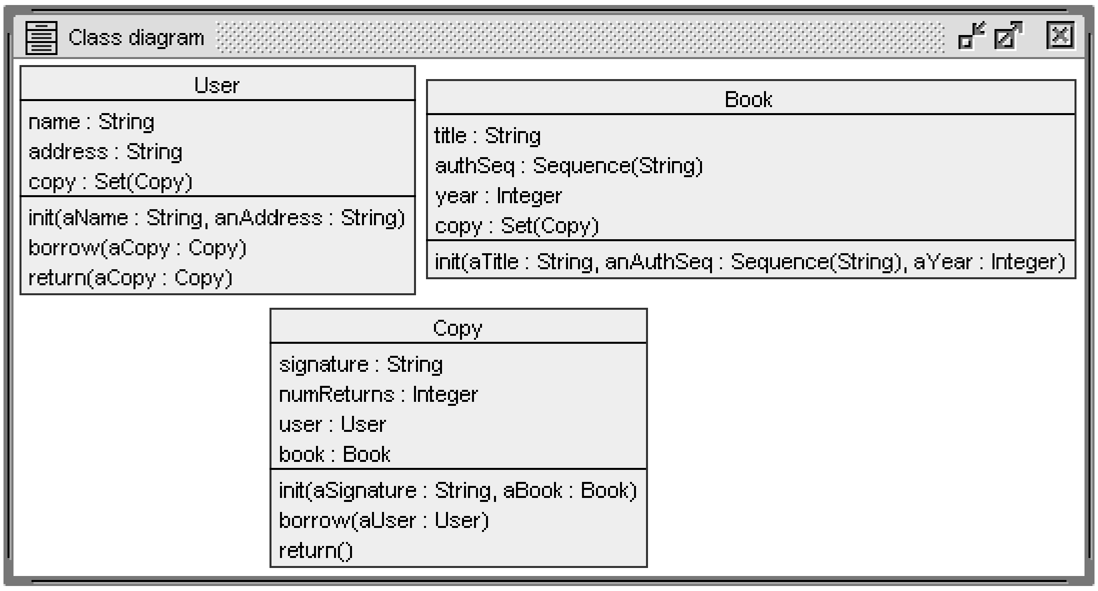
```
---------------------------------------------------------------- Library
model Library
------------------------------------------------------------- class User
class User
attributes
  name:String -- key
  address:String
operations
  init(aName:String, anAddress:String)
  borrow(aCopy:Copy)
  return(aCopy:Copy)
end
------------------------------------------------------------- class Copy
class Copy
attributes
  signature:String -- key
  numReturns:Integer
operations
  init(aSignature:String, aBook:Book)
  borrow(aUser:User)
  return()
end
```

```
------------------------------------------------------------ class Book
class Book
attributes
  title:String -- key
  authSeq:Sequence(String)
  year:Integer
operations
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
end
----------------------------------------------------- association Borrows
association Borrows between
  User[0..1] role user
  Copy[0..*] role copy
end
-- - - - - - - - - - - - - - - - - - - - - - - - - association BelongsTo
association BelongsTo between
  Copy[0..*] role copy
  Book[1] role book
end
----------------------------------------------------------- constraints
constraints
-- invariants transformed into pre-conditions of operations
------------------------------------------------------------ User::init
context User::init(aName:String, anAddress:String)
pre nameAddressFormatOk:                                          -- inv
  aName<>oclUndefined(String) and aName<>'' and
  anAddress<>oclUndefined(String) and anAddress<>''
pre nameIsKey:                                                    -- inv
  User.allInstances->collect(u|u.name)->excludes(aName)
pre freshUser:
  self.name=oclUndefined(String) and
  self.address=oclUndefined(String) and self.copy->isEmpty()
post attrsAssigned:
  aName=self.name and anAddress=self.address
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::borrow
context User::borrow(aCopy:Copy)
pre noDoubleBorrowings:                                           -- inv
  self.copy.book->excludes(aCopy.book)
pre copyOk:
  aCopy<>oclUndefined(Copy) and aCopy.user->isEmpty()
post linkAssigned:
  self.copy@pre->including(aCopy)=self.copy
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::return
context User::return(aCopy:Copy)
pre aCopyOk:
  aCopy<>oclUndefined(Copy) and self.copy->includes(aCopy)
post linkRemoved:
  self.copy@pre->excluding(aCopy)=self.copy
post numReturnsIncreased:
  aCopy.numReturns@pre+1=aCopy.numReturns
```

```
------------------------------------------------------------ Copy::init
context Copy::init(aSignature:String, aBook:Book)
pre signatureFormatOk:                                            -- inv
  aSignature<>oclUndefined(String) and aSignature<>''
pre signatureIsKey:                                               -- inv
  Copy.allInstances->collect(c|c.signature)->excludes(aSignature)
pre freshCopy:
  self.signature=oclUndefined(String) and
  self.numReturns=oclUndefined(Integer) and
  self.user->isEmpty() and self.book->isEmpty()
pre bookOk:
  aBook<>oclUndefined(Book)
post attrsAndLinkAssigned:
  aSignature=self.signature and 0=self.numReturns and
  aBook=self.book
-- - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow
context Copy::borrow(aUser:User)
pre noDoubleBorrowings:                                           -- inv
  aUser.copy.book->excludes(self.book)
pre userOk:
  aUser<>oclUndefined(User)
pre notBorrowed:
  self.user->isEmpty()
post linkAssigned:
  aUser=self.user
-- - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::return
context Copy::return()
pre copyOk:
  self.user->notEmpty()
post linkRemoved:
  self.user->isEmpty()
post numReturnsIncreased:
  self.numReturns@pre+1=self.numReturns
------------------------------------------------------------ Book::init
context Book::
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
pre titleFormatOk:
  aTitle<>oclUndefined(String) and aTitle<>''                    -- inv
pre titleIsKey:                                                  -- inv
  Book.allInstances->collect(b|b.title)->excludes(aTitle)
pre authSeqFormatOk: Set{1..anAuthSeq->size()}->forAll(i|        -- inv
  anAuthSeq->at(i)<>oclUndefined(String) and anAuthSeq->at(i)<>'')
pre authSeqExistsAndUnique:                                      -- inv
  anAuthSeq->size()>0 and
  Set{1..anAuthSeq->size()-1}->forAll(i|
    Set{i+1..anAuthSeq->size()}->forAll(j|
      anAuthSeq->at(i)<>anAuthSeq->at(j)))
pre yearPlausible:                                               -- inv
  1455<=aYear
pre freshBook:
  self.title=oclUndefined(String) and
  self.authSeq=oclUndefined(Sequence(String)) and
  self.year=oclUndefined(Integer) and
  self.copy->isEmpty()
post attrsAssigned:
  aTitle=self.title and anAuthSeq=self.authSeq and aYear=self.year
-----------------------------------------------------------------------
```

3.4 Assoc2Attr

3.4.1 Class Diagram



3.4.2 USE Model

```
--------------------------------------------------------------- Library
model Library
------------------------------------------------------------ class User
class User
attributes
  name:String -- key
  address:String
  copy:Set(Copy)
operations
  init(aName:String, anAddress:String)
  borrow(aCopy:Copy)
  return(aCopy:Copy)
end
------------------------------------------------------------ class Copy
class Copy
attributes
  signature:String -- key
  numReturns:Integer
  user:User
  book:Book
operations
  init(aSignature:String, aBook:Book)
  borrow(aUser:User)
  return()
end
```

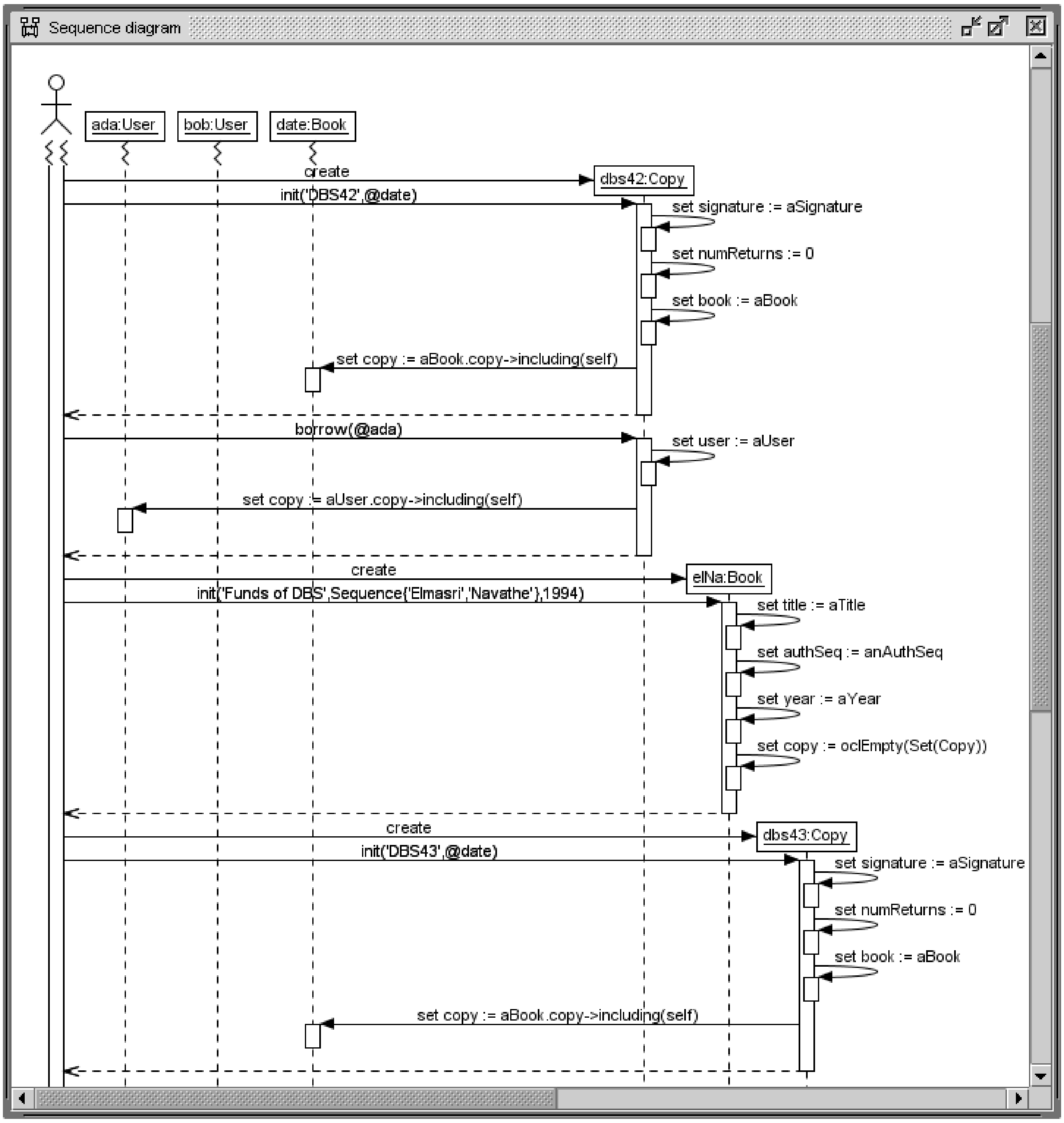
```
-------------------------------------------------------------- class Book
class Book
attributes
  title:String -- key
  authSeq:Sequence(String)
  year:Integer
  copy:Set(Copy)
operations
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
end
------------------------------------------------------------- constraints
constraints
-- - - - - - - - - - - - - - - - -  guarantee for multiplicity consistency
context c:Copy inv bookIsDefined:
  c.book<>oclUndefined(Book)
-- - - - - - - - - - - - - - - - - - guarantee for association consistency
context u:User inv userCopyUserEQuser:
  u.copy<>oclEmpty(Set(Copy)) implies u.copy.user->asSet()=Set{u}
context c:Copy inv copyUserCopyEQcopy:
  c.user<>oclUndefined(User)  implies c.user.copy->includes(c)
context b:Book inv bookCopyBookEQbook:
  b.copy<>oclEmpty(Set(Copy)) implies b.copy.book->asSet()=Set{b}
context c:Copy inv copyBookCopyEQcopy:
  c.book.copy->includes(c)
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User
context u:User inv nameAddressFormatOk:
  u.name<>oclUndefined(String) and u.name<>'' and
  u.address<>oclUndefined(String) and u.address<>''
context u1:User inv nameIsKey: User.allInstances->forAll(u2 |
  u1<>u2 implies u1.name<>u2.name)
context u:User inv noDoubleBorrowings:
  not(u.copy->exists(c1,c2|c1<>c2 and c1.book=c2.book))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy
context c:Copy inv signatureFormatOk:
  c.signature<>oclUndefined(String) and c.signature<>''
context c1:Copy inv signatureIsKey: Copy.allInstances->forAll(c2 |
  c1<>c2 implies c1.signature<>c2.signature)
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Book
context b:Book inv titleFormatOk:
  b.title<>oclUndefined(String) and b.title<>''
context b1:Book inv titleIsKey: Book.allInstances->forAll(b2 |
  b1<>b2 implies b1.title<>b2.title)
context b:Book inv authSeqFormatOk: Set{1..b.authSeq->size()}->forAll(i|
  authSeq->at(i)<>oclUndefined(String) and authSeq->at(i)<>'')
context b:Book inv authSeqExistsAndUnique: b.authSeq->size()>0 and
  Set{1..b.authSeq->size()-1}->forAll(i|
    Set{i+1..b.authSeq->size()}->forAll(j|
      authSeq->at(i)<>authSeq->at(j)))
context b:Book inv yearPlausible:
  1455<=b.year
-------------------------------------------------------------- User::init
context User::init(aName:String, anAddress:String)
pre freshUser:
  self.name=oclUndefined(String) and
  self.address=oclUndefined(String) and
  self.copy=oclUndefined(Set(Copy))                    -- forced change
post attrsAssigned:
  aName=self.name and anAddress=self.address
```

```
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::borrow
context User::borrow(aCopy:Copy)
pre copyOk:
  aCopy<>oclUndefined(Copy) and
  aCopy.user=oclUndefined(User)                          -- forced change
post linkAssigned:
  self.copy@pre->including(aCopy)=self.copy
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::return
context User::return(aCopy:Copy)
pre aCopyOk:
  aCopy<>oclUndefined(Copy) and self.copy->includes(aCopy)
post linkRemoved:
  self.copy@pre->excluding(aCopy)=self.copy
post numReturnsIncreased:
  aCopy.numReturns@pre+1=aCopy.numReturns
------------------------------------------------------------ Copy::init
context Copy::init(aSignature:String, aBook:Book)
pre freshCopy:
  self.signature=oclUndefined(String) and
  self.numReturns=oclUndefined(Integer) and
  self.user=oclUndefined(User) and                       -- forced change
  self.book=oclUndefined(Book)                           -- forced change
pre bookOk:
  aBook<>oclUndefined(Book)
post attrsAndLinkAssigned:
  aSignature=self.signature and 0=self.numReturns and
  aBook=self.book
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow
context Copy::borrow(aUser:User)
pre userOk:
  aUser<>oclUndefined(User)
pre notBorrowed:
  self.user=oclUndefined(User)                           -- forced change
post linkAssigned:
  aUser=self.user
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::return
context Copy::return()
pre copyOk:
  self.user<>oclUndefined(User)                          -- forced change
post linkRemoved:
  self.user=oclUndefined(User)                           -- forced change
post numReturnsIncreased:
  self.numReturns@pre+1=self.numReturns
------------------------------------------------------------ Book::init
context Book::
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
pre freshBook:
  self.title=oclUndefined(String) and
  self.authSeq=oclUndefined(Sequence(String)) and
  self.year=oclUndefined(Integer) and
  self.copy=oclUndefined(Set(Copy))                      -- forced change
post attrsAssigned:
  aTitle=self.title and anAuthSeq=self.authSeq and aYear=self.year
-----------------------------------------------------------------------
```

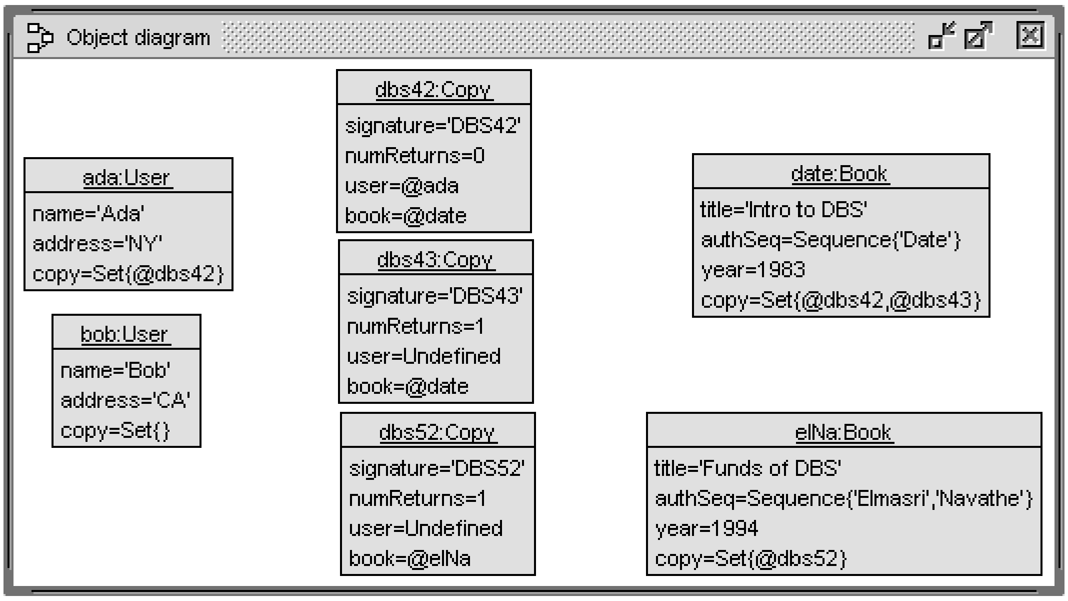
3.4.3 Operation Implementations with Command Files

```
-- - - - - - - - - - - - - - - User::init(aName:String, anAddress:String)
!set self.name:=aName
!set self.address:=anAddress
!set self.copy:=oclEmpty(Set(Copy))

-- - - - - - - - - - - - - - - - - - - - - - - - User::borrow(aCopy:Copy)
-- !insert (self,aCopy) into Borrows
!set self.copy:=self.copy->including(aCopy)
!set aCopy.user:=self

-- - - - - - - - - - - - - - - - - - - - - - - - User::return(aCopy:Copy)
!set aCopy.numReturns:=aCopy.numReturns+1
-- !delete (self,aCopy) from Borrows
!set self.copy:=self.copy->excluding(aCopy)
!set aCopy.user:=oclUndefined(User)

-- - - - - - - - - - - - - - - - Copy::init(aSignature:String, aBook:Book)
!set self.signature:=aSignature
!set self.numReturns:=0
-- !insert (self,aBook) into BelongsTo
!set self.book:=aBook
!set aBook.copy:=aBook.copy->including(self)

-- - - - - - - - - - - - - - - - - - - - - - - - Copy::borrow(aUser:User)
-- !insert (aUser,self) into Borrows
!set self.user:=aUser
!set aUser.copy:=aUser.copy->including(self)

-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy::return()
!set self.numReturns:=self.numReturns+1
-- !delete (self.user,self) from Borrows
!set self.user.copy:=self.user.copy->excluding(self)
!set self.user:=oclUndefined(User)

-- Book::init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
!set self.title:=aTitle
!set self.authSeq:=anAuthSeq
!set self.year:=aYear
!set self.copy:=oclEmpty(Set(Copy))
------------------------------------------------------------------------
```

3.4.4 Sequence Diagram (Excerpt)

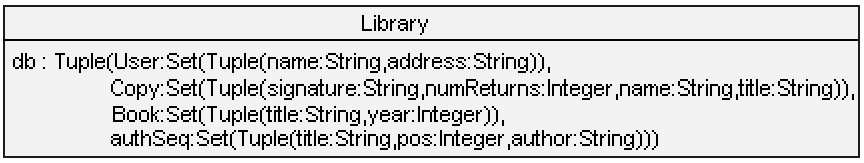


3.4.5 Object Diagram



3.5 RelDB1NF

3.5.1 Class Diagram


Library
db : Tuple(User:Set(Tuple(name:String,address:String)),
Copy:Set(Tuple(signature:String,numReturns:Integer,name:String,title:String)),
Book:Set(Tuple(title:String,year:Integer)),
authSeq:Set(Tuple(title:String,pos:Integer,author:String)))

3.5.2 USE Model

```
--------------------------------------------------------------- Library
model Library
-----------------------------------------------------------------------
class Library
attributes
  db:Tuple(User:Set(Tuple(name:String,
                          address:String)),
           Copy:Set(Tuple(signature:String,
                          numReturns:Integer,
                          name:String,
                          title:String)),
           Book:Set(Tuple(title:String,
                          year:Integer)),
           authSeq:Set(Tuple(title:String,
                             pos:Integer,
                             author:String)))
```

```
operations
  ---------------------------------------------------------------------
  Library_init()
  User_init(aName:String, anAddress:String)
  User_borrow(aName:String, aSignature:String)
  User_return(aName:String, aSignature:String)
  Copy_init(aSignature:String, aTitle:String)
  Copy_borrow(aSignature:String, aName:String)
  Copy_return(aSignature:String)
  Book_init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
  ---------------------------------------------------------------------
  User_name2tuple(aName:String):
    Tuple(name:String,address:String)=
    self.db.User->select(name=aName)->any(true)
  Copy_signature2tuple(aSignature:String):
    Tuple(signature:String,numReturns:Integer,name:String,title:String)=
    self.db.Copy->select(signature=aSignature)->any(true)
  Book_title2tuple(aTitle:String):
    Tuple(title:String,year:Integer)=
    self.db.Book->select(title=aTitle)->any(true)
  authSeq_titlePos2tuple(aTitle:String,aPos:Integer):
    Tuple(title:String,pos:Integer,author:String)=
    self.db.authSeq->select(title=aTitle and pos=aPos)->any(true)
  ---------------------------------------------------------------------
end
-----------------------------------------------------------------------
constraints
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User
context Library inv nameAddressFormatOk:
  self.db.User->forAll(u:Tuple(name:String,address:String)|
    u.name<>oclUndefined(String) and u.name<>'' and
    u.address<>oclUndefined(String) and u.address<>'')
context Library inv nameIsKey:
  self.db.User->forAll(u1,u2:Tuple(name:String,address:String)|
    u1<>u2 implies u1.name<>u2.name)
context Library inv noDoubleBorrowings:
  self.db.User->forAll(u:Tuple(name:String,address:String)|
    not(self.db.Copy->exists(c1,c2:
    Tuple(signature:String,numReturns:Integer,name:String,title:String)|
      c1<>c2 and c1.name=u.name and c2.name=u.name and
      c1.title=c2.title)))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy
context Library inv signatureFormatOk:
  self.db.Copy->forAll(c:
    Tuple(signature:String,numReturns:Integer,name:String,title:String)|
    c.signature<>oclUndefined(String) and c.signature<>'')
context Library inv signatureIsKey:
  self.db.Copy->forAll(c1,c2:
    Tuple(signature:String,numReturns:Integer,name:String,title:String)|
      c1<>c2 implies c1.signature<>c2.signature)
```

```
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Book
context Library inv titleFormatOk:
  self.db.Book->forAll(b:Tuple(title:String,year:Integer)|
    b.title<>oclUndefined(String) and b.title<>'')
context Library inv titleIsKey:
  self.db.Book->forAll(b1,b2:Tuple(title:String,year:Integer)|
    b1<>b2 implies b1.title<>b2.title)
context Library inv authSeqFormatOk:
  self.db.authSeq->forAll(aS:
    Tuple(title:String,pos:Integer,author:String)|
      aS.author<>oclUndefined(String) and aS.author<>'')
context Library inv authSeqExistsAndUnique:
  self.db.Book->forAll(b:Tuple(title:String,year:Integer)|
    self.db.authSeq->exists(aS:
      Tuple(title:String,pos:Integer,author:String)|
        b.title=aS.title and aS.pos=1) and
    self.db.authSeq->forAll(aS1,aS2:
      Tuple(title:String,pos:Integer,author:String)|
        b.title=aS1.title and b.title=aS2.title and aS1.pos<>aS2.pos
        implies aS1.author<>aS2.author) and
    self.db.authSeq->forAll(aS1:
      Tuple(title:String,pos:Integer,author:String)|
        b.title=aS1.title and 1<aS1.pos implies
        self.db.authSeq->exists(aS2:
          Tuple(title:String,pos:Integer,author:String)|
            aS2.title=aS1.title and aS2.pos=aS1.pos-1)))
context Library inv yearPlausible:
  self.db.Book->forAll(b:Tuple(title:String,year:Integer)|
    1455<=b.year)
------------------------------------------------------------------------
```

3.5.3 Operation Implementations with Command Files

```
-- Library_init()
!set self.db:=
  Tuple{User:oclEmpty(Set(Tuple(name:String,
                                address:String))),
        Copy:oclEmpty(Set(Tuple(signature:String,
                                numReturns:Integer,
                                name:String,
                                title:String))),
        Book:oclEmpty(Set(Tuple(title:String,
                                year:Integer))),
        authSeq:oclEmpty(Set(Tuple(title:String,
                                   pos:Integer,
                                   author:String)))}

-- User_init(aName:String, anAddress:String)
!set self.db:=
  Tuple{User:self.db.User->
             including(Tuple{name:aName,address:anAddress}),
        Copy:self.db.Copy,
        Book:self.db.Book,
        authSeq:self.db.authSeq}
```

```
-- User_borrow(aName:String, aSignature:String)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy->
               reject(t|t.signature=aSignature)->
               including(Tuple{signature:aSignature,
                               numReturns:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).numReturns,
                               name:aName,
                               title:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).title}),
        Book:self.db.Book,
        authSeq:self.db.authSeq}

-- User_return(aName:String, aSignature:String)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy->
               reject(t|t.signature=aSignature)->
               including(Tuple{signature:aSignature,
                               numReturns:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).numReturns+1,
                               name:oclUndefined(String),
                               title:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).title}),
        Book:self.db.Book,
        authSeq:self.db.authSeq}

-- Copy_init(aSignature:String, aTitle:String)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy->including(Tuple{signature:aSignature,
                                           numReturns:0,
                                           name:oclUndefined(String),
                                           title:aTitle}),
        Book:self.db.Book,
        authSeq:self.db.authSeq}

-- Copy_borrow(aSignature:String, aName:String)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy->
               reject(t|t.signature=aSignature)->
               including(Tuple{signature:aSignature,
                               numReturns:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).numReturns,
                               name:aName,
                               title:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).title}),
        Book:self.db.Book,
        authSeq:self.db.authSeq}
```

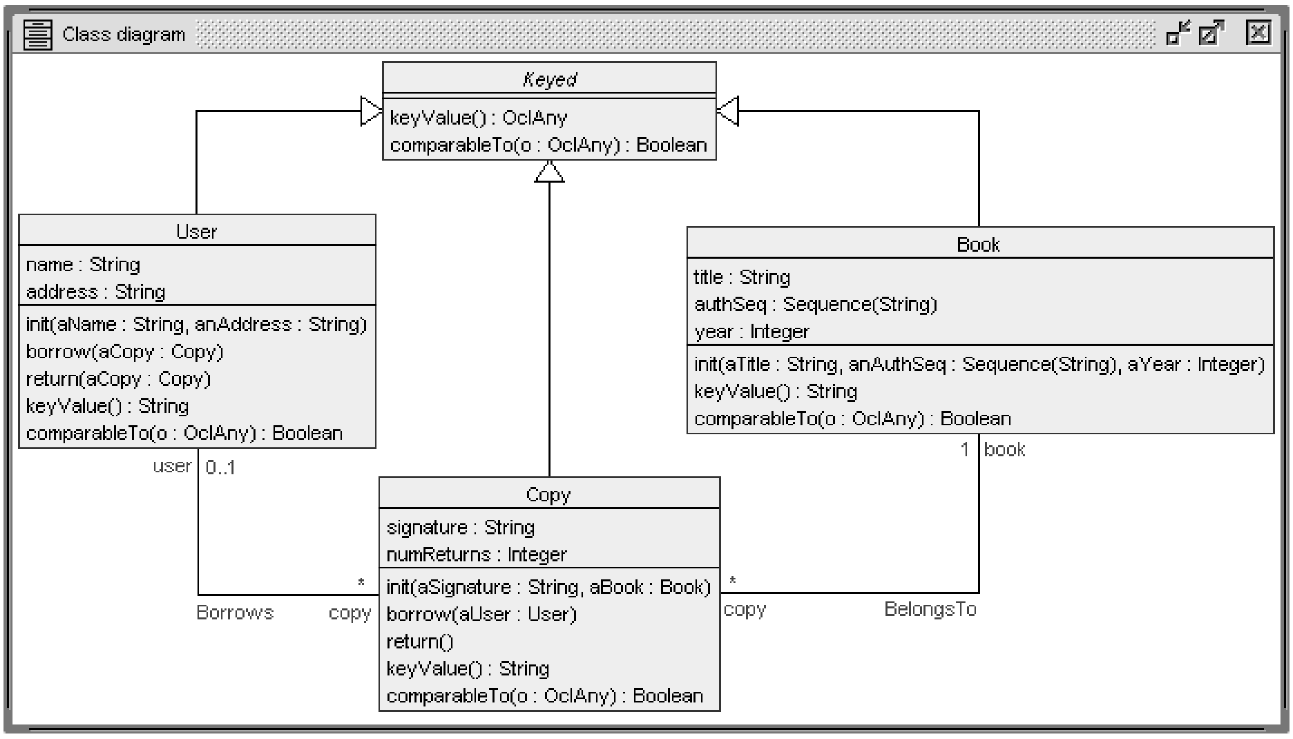
```
-- Copy_return(aSignature:String)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy->
               reject(t|t.signature=aSignature)->
               including(Tuple{signature:aSignature,
                               numReturns:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).numReturns+1,
                               name:oclUndefined(String),
                               title:self.db.Copy->
                                 select(signature=aSignature)->
                                 any(true).title}),
        Book:self.db.Book,
        authSeq:self.db.authSeq}

-- Book_init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
!set self.db:=
  Tuple{User:self.db.User,
        Copy:self.db.Copy,
        Book:self.db.Book->including(Tuple{title:aTitle,year:aYear}),
        authSeq:Set{1..anAuthSeq->size()}->
          iterate(i:Integer;
                  res:Set(Tuple(title:String,
                                pos:Integer,
                                author:String))=self.db.authSeq|
                  res->including(Tuple{title:aTitle,
                                       pos:i,
                                       author:anAuthSeq->at(i)})))}
```

3.5.4 System State (Object Diagram)

```
Tuple{
  User=Set{Tuple{name='Ada',address='NY'},
           Tuple{name='Bob',address='CA'}},
  Copy=Set{Tuple{signature='DBS42',numReturns=0,
                 name='Ada',title='Intro to DBS'},
           Tuple{signature='DBS43',numReturns=1,
                 name=Undefined,title='Intro to DBS'},
           Tuple{signature='DBS52',numReturns=1,
                 name=Undefined,title='Funds of DBS'}},
  Book=Set{Tuple{title='Funds of DBS',year=1994},
           Tuple{title='Intro to DBS',year=1983}},
  authSeq=Set{Tuple{title='Funds of DBS',pos=1,author='Elmasri'},
              Tuple{title='Funds of DBS',pos=2,author='Navathe'},
              Tuple{title='Intro to DBS',pos=1,author='Date'}}} :
  Tuple(User:Set(Tuple(name:String,address:String)),
        Copy:Set(Tuple(signature:String,numReturns:Integer,
                       name:String,title:String)),
        Book:Set(Tuple(title:String,year:Integer)),
        authSeq:Set(Tuple(title:String,pos:Integer,author:String)))
```

3.6 Invs2Super

3.6.1 Class Diagram



Class diagram
Keyed
keyValue() : OclAny
comparableTo(o : OclAny) : Boolean
User
name : String
address : String
init(aName : String, anAddress : String)
borrow(aCopy : Copy)
return(aCopy : Copy)
keyValue() : String
comparableTo(o : OclAny) : Boolean
Book
title : String
authSeq : Sequence(String)
year : Integer
init(aTitle : String, anAuthSeq : Sequence(String), aYear : Integer)
keyValue() : String
comparableTo(o : OclAny) : Boolean
Copy
signature : String
numReturns : Integer
init(aSignature : String, aBook : Book)
borrow(aUser : User)
return()
keyValue() : String
comparableTo(o : OclAny) : Boolean
user
0..1
*
Borrows
copy
1
book
*
copy
BelongsTo

3.6.2 USE Model

```
--------------------------------------------------------------- Library
model Library
----------------------------------------------------------- class Keyed
abstract class Keyed
operations
  keyValue():OclAny=oclUndefined(OclAny)
  comparableTo(o:OclAny):Boolean=oclUndefined(Boolean)
constraints
  inv self:diffObjectsDiffKeys:
    Keyed.allInstances->forAll(self2|
      self<>self2 and self.comparableTo(self2) implies
        self.keyValue()<>self2.keyValue())
end
------------------------------------------------------------ class User
class User < Keyed
attributes
  name:String -- key
  address:String
operations
  init(aName:String, anAddress:String)
  borrow(aCopy:Copy)
  return(aCopy:Copy)
  keyValue():String=name
  comparableTo(o:OclAny):Boolean=o.oclIsTypeOf(User)
end
```

```
------------------------------------------------------------- class Copy
class Copy < Keyed
attributes
  signature:String -- key
  numReturns:Integer
operations
  init(aSignature:String, aBook:Book)
  borrow(aUser:User)
  return()
  keyValue():String=signature
  comparableTo(o:OclAny):Boolean=o.oclIsTypeOf(Copy)
end
------------------------------------------------------------- class Book
class Book < Keyed
attributes
  title:String -- key
  authSeq:Sequence(String)
  year:Integer
operations
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
  keyValue():String=title
  comparableTo(o:OclAny):Boolean=o.oclIsTypeOf(Book)
end
---------------------------------------------------- association Borrows
association Borrows between
  User[0..1] role user
  Copy[0..*] role copy
end
-- - - - - - - - - - - - - - - - - - - - - - - - - association BelongsTo
association BelongsTo between
  Copy[0..*] role copy
  Book[1] role book
end
------------------------------------------------------------- invariants
constraints
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User
context u:User inv nameAddressFormatOk:
  u.name<>oclUndefined(String) and u.name<>'' and
  u.address<>oclUndefined(String) and u.address<>''
-- context u1:User inv nameIsKey: User.allInstances->forAll(u2 |      --
--   u1<>u2 implies u1.name<>u2.name)                                 --
context u:User inv noDoubleBorrowings:
  not(u.copy->exists(c1,c2|c1<>c2 and c1.book=c2.book))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy
context c:Copy inv signatureFormatOk:
  c.signature<>oclUndefined(String) and c.signature<>''
-- context c1:Copy inv signatureIsKey: Copy.allInstances->forAll(c2 | --
--   c1<>c2 implies c1.signature<>c2.signature)                      --
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Book
context b:Book inv titleFormatOk:
  b.title<>oclUndefined(String) and b.title<>''
-- context b1:Book inv titleIsKey: Book.allInstances->forAll(b2 |     --
--   b1<>b2 implies b1.title<>b2.title)                              --
context b:Book inv authSeqFormatOk: Set{1..b.authSeq->size()}->forAll(i|
  authSeq->at(i)<>oclUndefined(String) and authSeq->at(i)<>'')
```

```
context b:Book inv authSeqExistsAndUnique: b.authSeq->size()>0 and
  Set{1..b.authSeq->size()-1}->forAll(i|
    Set{i+1..b.authSeq->size()}->forAll(j|
      authSeq->at(i)<>authSeq->at(j)))
context b:Book inv yearPlausible:
  1455<=b.year
------------------------------------------------ pre- and postconditions
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::init
context User::init(aName:String, anAddress:String)
pre freshUser:
  self.name=oclUndefined(String) and
  self.address=oclUndefined(String) and self.copy->isEmpty()
post attrsAssigned:
  aName=self.name and anAddress=self.address
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::borrow
context User::borrow(aCopy:Copy)
pre copyOk:
  aCopy<>oclUndefined(Copy) and aCopy.user->isEmpty()
post linkAssigned:
  self.copy@pre->including(aCopy)=self.copy
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  User::return
context User::return(aCopy:Copy)
pre aCopyOk:
  aCopy<>oclUndefined(Copy) and self.copy->includes(aCopy)
post linkRemoved:
  self.copy@pre->excluding(aCopy)=self.copy
post numReturnsIncreased:
  aCopy.numReturns@pre+1=aCopy.numReturns
------------------------------------------------------------- Copy::init
context Copy::init(aSignature:String, aBook:Book)
pre freshCopy:
  self.signature=oclUndefined(String) and
  self.numReturns=oclUndefined(Integer) and
  self.user->isEmpty() and self.book->isEmpty()
pre bookOk:
  aBook<>oclUndefined(Book)
post attrsAndLinkAssigned:
  aSignature=self.signature and 0=self.numReturns and
  aBook=self.book
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::borrow
context Copy::borrow(aUser:User)
pre userOk:
  aUser<>oclUndefined(User)
pre notBorrowed:
  self.user->isEmpty()
post linkAssigned:
  aUser=self.user
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Copy::return
context Copy::return()
pre copyOk:
  self.user->notEmpty()
post linkRemoved:
  self.user->isEmpty()
post numReturnsIncreased:
  self.numReturns@pre+1=self.numReturns
```

```
------------------------------------------------------------ Book::init
context Book::
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
pre freshBook:
  self.title=oclUndefined(String) and
  self.authSeq=oclUndefined(Sequence(String)) and
  self.year=oclUndefined(Integer) and
  self.copy->isEmpty()
post attrsAssigned:
  aTitle=self.title and anAuthSeq=self.authSeq and aYear=self.year
-----------------------------------------------------------------------
```

3.7 CompFrame

3.7.1 Class Diagram

Identical to class diagram in MaxInvsMinPrepos.

3.7.2 USE Model

```
--------------------------------------------------------------- Library
model Library
------------------------------------------------------------ class User
class User
attributes
  name:String -- key
  address:String
operations
  init(aName:String, anAddress:String)
  borrow(aCopy:Copy)
  return(aCopy:Copy)
  doNothing()
end
------------------------------------------------------------ class Copy
class Copy
attributes
  signature:String -- key
  numReturns:Integer
operations
  init(aSignature:String, aBook:Book)
  borrow(aUser:User)
  return()
end
------------------------------------------------------------ class Book
class Book
attributes
  title:String -- key
  authSeq:Sequence(String)
  year:Integer
operations
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
end
--------------------------------------------------- association Borrows
association Borrows between
  User[0..1] role user
  Copy[0..*] role copy
end
```

```
-- - - - - - - - - - - - - - - - - - - - - - - - - - association BelongsTo
association BelongsTo between
  Copy[0..*] role copy
  Book[1] role book
end
------------------------------------------------------------- constraints
constraints
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - User
context u:User inv nameAddressFormatOk:
  u.name<>oclUndefined(String) and u.name<>'' and
  u.address<>oclUndefined(String) and u.address<>''
context u1:User inv nameIsKey: User.allInstances->forAll(u2 |
  u1<>u2 implies u1.name<>u2.name)
context u:User inv noDoubleBorrowings:
  not(u.copy->exists(c1,c2|c1<>c2 and c1.book=c2.book))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy
context c:Copy inv signatureFormatOk:
  c.signature<>oclUndefined(String) and c.signature<>''
context c1:Copy inv signatureIsKey: Copy.allInstances->forAll(c2 |
  c1<>c2 implies c1.signature<>c2.signature)
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -  Book
context b:Book inv titleFormatOk:
  b.title<>oclUndefined(String) and b.title<>''
context b1:Book inv titleIsKey: Book.allInstances->forAll(b2 |
  b1<>b2 implies b1.title<>b2.title)
context b:Book inv authSeqFormatOk: Set{1..b.authSeq->size()}->forAll(i|
  authSeq->at(i)<>oclUndefined(String) and authSeq->at(i)<>'')
context b:Book inv authSeqExistsAndUnique: b.authSeq->size()>0 and
  Set{1..b.authSeq->size()-1}->forAll(i|
    Set{i+1..b.authSeq->size()}->forAll(j|
      authSeq->at(i)<>authSeq->at(j)))
context b:Book inv yearPlausible:
  1455<=b.year
--------------------------------------------------------- User::doNothing
context User::doNothing() -- systematic description of 'unchanged'
pre neverCalled: false
post userUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    u.copy@pre=u.copy)
post copyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and c.numReturns@pre=c.numReturns and
    c.user@pre=c.user and c.book@pre=c.book)
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
------------------------------------------------------------- User::init
context User::init(aName:String, anAddress:String)
pre freshUser:
  self.name=oclUndefined(String) and
  self.address=oclUndefined(String) and self.copy->isEmpty()
post attrsAssigned:
  aName=self.name and anAddress=self.address
```

```
post userNearlyUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    (u<>self implies u.name@pre=u.name) and
    (u<>self implies u.address@pre=u.address) and
    u.copy@pre=u.copy)
post copyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and c.numReturns@pre=c.numReturns and
    c.user@pre=c.user and c.book@pre=c.book)
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - User::borrow
context User::borrow(aCopy:Copy)
pre copyOk:
  aCopy<>oclUndefined(Copy) and aCopy.user->isEmpty()
post linkAssigned:
  self.copy@pre->including(aCopy)=self.copy
post userNearlyUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    (u<>self implies u.copy@pre=u.copy))
post copyNearlyUnchanged: -- attention!
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and c.numReturns@pre=c.numReturns and
    (c<>aCopy implies c.user@pre=c.user) and c.book@pre=c.book)
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - User::return
context User::return(aCopy:Copy)
pre aCopyOk:
  aCopy<>oclUndefined(Copy) and self.copy->includes(aCopy)
post linkRemoved:
  self.copy@pre->excluding(aCopy)=self.copy
post numReturnsIncreased:
  aCopy.numReturns@pre+1=aCopy.numReturns
post userNearlyUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    (u<>self implies u.copy@pre=u.copy))
post copyNearlyUnchanged: -- attention!
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and
    (c<>aCopy implies c.numReturns@pre=c.numReturns) and
    (c<>aCopy implies c.user@pre=c.user) and c.book@pre=c.book)
```

```
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
------------------------------------------------------------- Copy::init
context Copy::init(aSignature:String, aBook:Book)
pre freshCopy:
  self.signature=oclUndefined(String) and
  self.numReturns=oclUndefined(Integer) and
  self.user->isEmpty() and self.book->isEmpty()
pre bookOk:
  aBook<>oclUndefined(Book)
post attrsAndLinkAssigned:
  aSignature=self.signature and 0=self.numReturns and
  aBook=self.book
post userUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    u.copy@pre=u.copy)
post copyNearlyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    (c<>self implies c.signature@pre=c.signature) and
    (c<>self implies c.numReturns@pre=c.numReturns) and
    c.user@pre=c.user and
    (c<>self implies c.book@pre=c.book))
post bookNearlyUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and
    (b<>self.book implies b.copy@pre=b.copy))
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy::borrow
context Copy::borrow(aUser:User)
pre userOk:
  aUser<>oclUndefined(User)
pre notBorrowed:
  self.user->isEmpty()
post linkAssigned:
  aUser=self.user
post userNearylyUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    (u<>aUser implies u.copy@pre=u.copy))
post copyNearlyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and c.numReturns@pre=c.numReturns and
    (c<>self implies c.user@pre=c.user) and
    c.book@pre=c.book)
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
```

```
-- - - - - - - - - - - - - - - - - - - - - - - - - - - - - Copy::return
context Copy::return()
pre copyOk:
  self.user->notEmpty()
post linkRemoved:
  self.user->isEmpty()
post numReturnsIncreased:
  self.numReturns@pre+1=self.numReturns
post userNearlyUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    (u<>self.user@pre implies u.copy@pre=u.copy))
post copyNearlyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and
    (c<>self implies c.numReturns@pre=c.numReturns) and
    (c<>self implies c.user@pre=c.user) and
    c.book@pre=c.book)
post bookUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    b.title@pre=b.title and b.authSeq@pre=b.authSeq and
    b.year@pre=b.year and b.copy@pre=b.copy)
------------------------------------------------------------ Book::init
context Book::
  init(aTitle:String, anAuthSeq:Sequence(String), aYear:Integer)
pre freshBook:
  self.title=oclUndefined(String) and
  self.authSeq=oclUndefined(Sequence(String)) and
  self.year=oclUndefined(Integer) and
  self.copy->isEmpty()
post attrsAssigned:
  aTitle=self.title and anAuthSeq=self.authSeq and aYear=self.year
post userUnchanged:
  User.allInstances@pre=User.allInstances and
  User.allInstances->forAll(u|
    u.name@pre=u.name and u.address@pre=u.address and
    u.copy@pre=u.copy)
post copyUnchanged:
  Copy.allInstances@pre=Copy.allInstances and
  Copy.allInstances->forAll(c|
    c.signature@pre=c.signature and c.numReturns@pre=c.numReturns and
    c.user@pre=c.user and c.book@pre=c.book)
post bookNearlyUnchanged:
  Book.allInstances@pre=Book.allInstances and
  Book.allInstances->forAll(b|
    (b<>self implies b.title@pre=b.title) and
    (b<>self implies b.authSeq@pre=b.authSeq) and
    (b<>self implies b.year@pre=b.year) and
    b.copy@pre=b.copy)
------------------------------------------------------------------------
```

3.7.3 Command Line Protocol Showing Difference to MaxInvsMinPrepos

```
use> ------------------------------------------------------------------
use> open libraryWithoutFrameConditions.use
use> ---------------------------------------------------------- ada:User
use> !create ada:User
use> !openter ada init('Ada','NY')
     precondition `freshUser' is true
use> !set self.name:=aName
use> !set self.address:=anAddress
use> !opexit
     postcondition `attrsAssigned' is true
use> ---------------------------------------------------------- bob:User
use> !create bob:User
use> !openter bob init('Bob','CA')
     precondition `freshUser' is true
use> !set self.name:=aName
use> !set self.address:=anAddress
use> !set ada.address:='TX'
use> !opexit
     postcondition `attrsAssigned' is true
use> ------------------------------------------------------------------

use> ------------------------------------------------------------------
use> open libraryWithFrameConditions.use
use> ---------------------------------------------------------- ada:User
use> !create ada:User
use> !openter ada init('Ada','NY')
     precondition `freshUser' is true
use> !set self.name:=aName
use> !set self.address:=anAddress
use> !opexit
     postcondition `attrsAssigned' is true
     postcondition `userNearlyUnchanged' is true
     postcondition `copyUnchanged' is true
     postcondition `bookUnchanged' is true
use> ---------------------------------------------------------- bob:User
use> !create bob:User
use> !openter bob init('Bob','CA')
     precondition `freshUser' is true
use> !set self.name:=aName
use> !set self.address:=anAddress
use> !set ada.address:='TX'
use> !opexit
     postcondition `attrsAssigned' is true
     postcondition `userNearlyUnchanged' is false -- postcondition fails
     postcondition `copyUnchanged' is true
     postcondition `bookUnchanged' is true
use> ------------------------------------------------------------------
```

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