Formal Specification of Software

Role-based Access Control: An Example in OCL Formalisation

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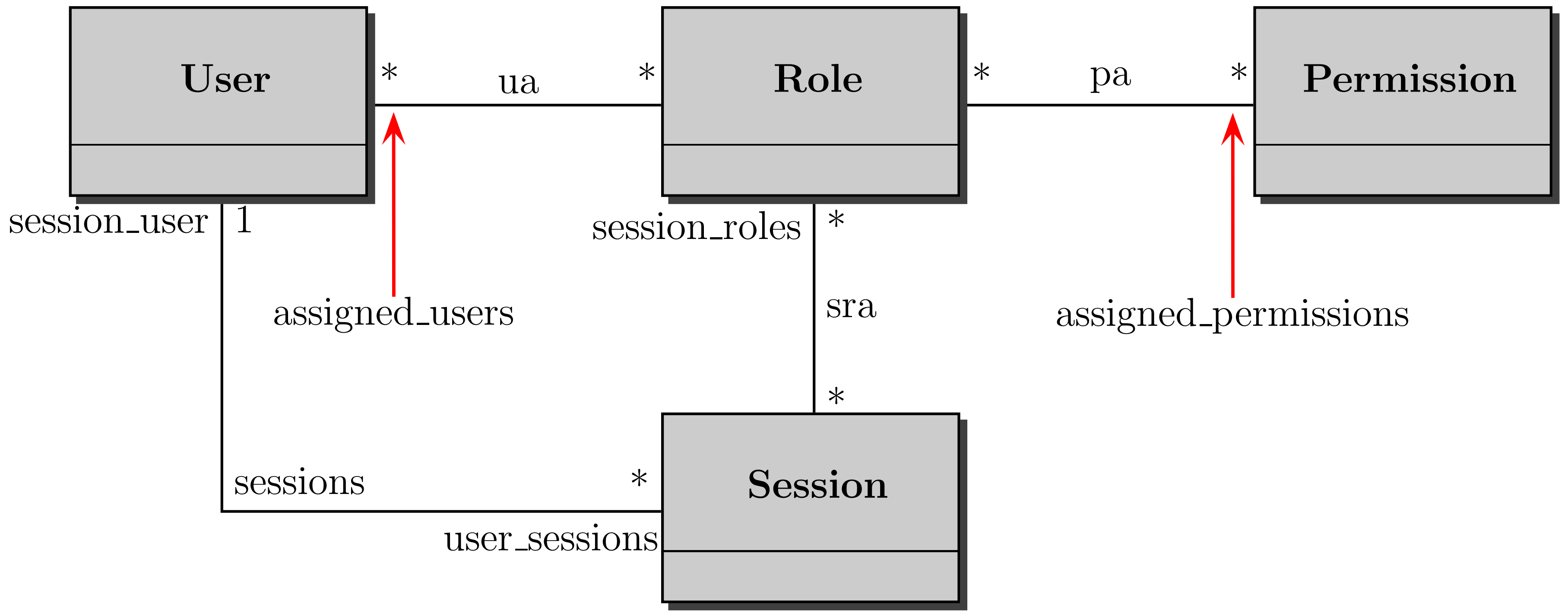
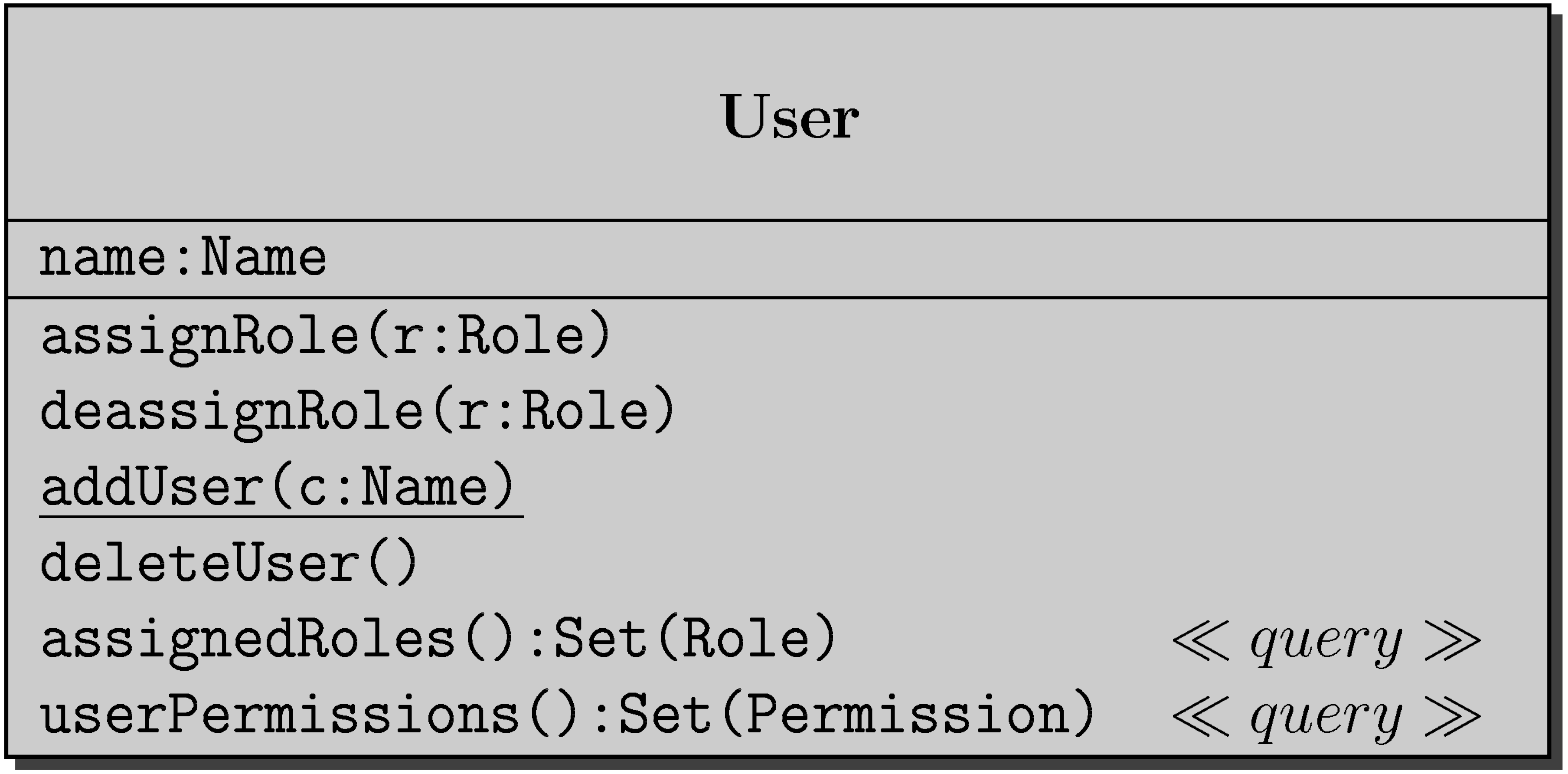
Class Diagram for the RBAC Core



Top Level Constraint

```
context  u:User
   inv   u.role->includesAll(u.user_sessions.session_roles)
```

The Class User



User
name:Name
assignRole(r:Role)
deassignRole(r:Role)
addUser(c:Name)
deleteUser()
assignedRoles():Set(Role) ≪ query ≫
userPermissions():Set(Permission) ≪ query ≫

Constraints on Operations of Class User

assignRole

```
context   u:User::assignRole(r:Role)
   pre    role -> excludes(r)
   post   role = role@pre -> including(r)
```

deassignRole

```
context   u:User::deassignRole(r:Role)
   pre    role -> includes(r)
   post   role = role@pre -> excluding(r)    and
          u.user_sessions =
          u.user_sessions@pre -> reject(
                 s | s.session_roles -> includes(r))
```

Constraints on Operations of Class User

addUser

context u:User::addUser(c:Name)

pre User.allInstances $->$ forAll(u_1 $|$ u_1.name $<>$ c)

post User.allInstances $->$ exists(u_1 $|$
User.allInstances@pre $->$ excludes(u_1) and
u_1.name = c and
User.allInstances = User.allInstances@pre $->$ including(u_1))

deleteUser

context u:User::deleteUser()

pre true

post User.allInstances = User.allInstances@pre $->$ excluding(u) and
Session.allInstances = Session.allInstances@pre $->$
reject(s $|$ u.user_sessions $->$ includes(s))

The Operation oclIsNew

context u:User::addUser(c:Name)

pre User.allInstances $->$ forAll(u_1 | u_1.name $<>$ c)

post User.allInstances $->$ exists(u_1 |
User.allInstances@pre $->$ excludes(u_1) and
u_1.name = c and
User.allInstances = User.allInstances@pre $->$ including(u_1))

is equivalent to

context u:User::addUser(c:Name)

pre User.allInstances $->$ forAll(u_1 | u_1.name $<>$ c)

post User.allInstances $->$ exists(u_1 |
u_1.oclIsNew and
u_1.name = c and
User.allInstances = User.allInstances@pre $->$ including(u_1))

Constraints on Operations of Class User

assignedRoles

context u:User::assignedRoles()

  pre true

  post result = u.role

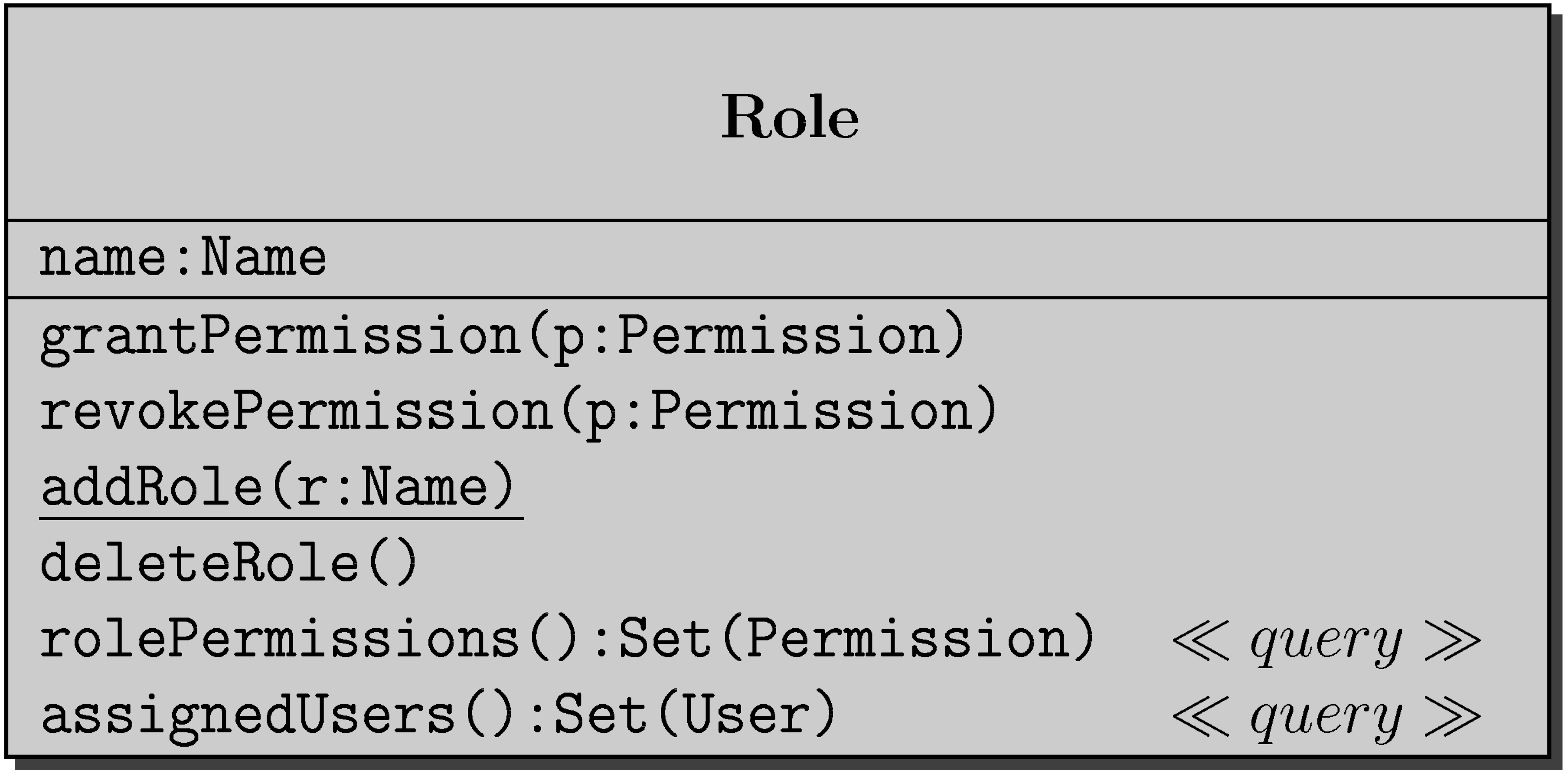
userPermissions

context u:User::userPermissions()

  pre true

  post result = u.role.assigned_permissions −> asSet()

The Class Role


Role
name:Name
grantPermission(p:Permission)
revokePermission(p:Permission)
addRole(r:Name)
deleteRole()
rolePermissions():Set(Permission) ≪ query ≫
assignedUsers():Set(User) ≪ query ≫

Constraints on Operations of Class Role

grantPermission

```
context  r:Role::grantPermission(p:Permission)
   pre   true
   post  r.assigned_permissions =
            r.assigned_permissions@pre -> including(p)
```

revokePermission

```
context  r:Role::revokePermission(p:Permission)
   pre   r.assigned_permissions -> includes(p)
   post  r.assigned_permissions =
            r.assigned_permissions@pre -> excluding(p)
```

Constraints on Operations of Class Role

addRole

```
context  r:Role::addRole(c:Name)

   pre   Role.allInstances –> forAll(r | r.name <> c)

   post  Role.allInstances –> exists( r₁ |
            r₁.oclIsNew and
            r₁.name = c and
            Role.allInstances = Role.allInstances@pre –> including(r₁))
```

deleteRole

```
context  r:Role::deleteRole()

   pre   true

   post  Role.allInstances = Role.allInstances@pre –> excluding(r) and
         Session.allInstances = Session.allInstances@pre –>
               reject(s | s.session_roles –> includes(r))
```

Constraints on Operations of Class Role

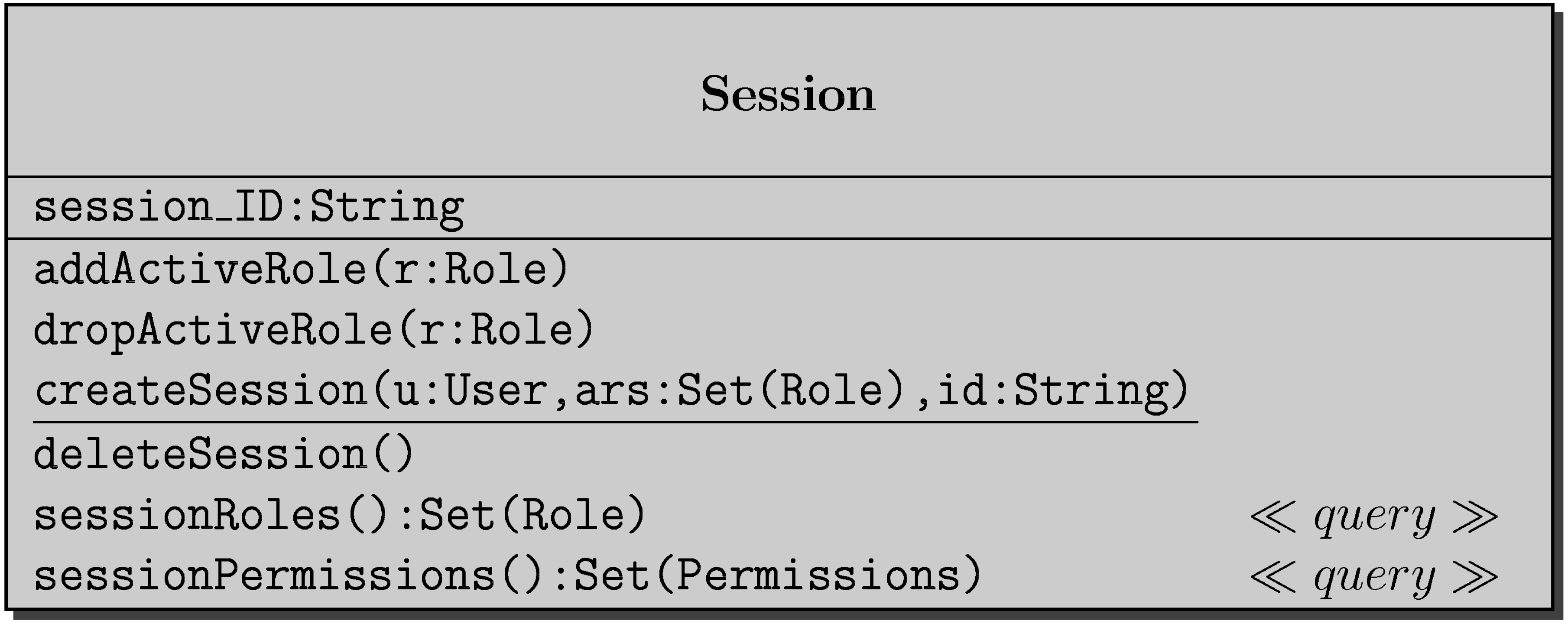
rolePermissions

```
context  r:Role::rolePermissions()
   pre   true
   post  result = r.assigned_permissions
```

assignedUsers

```
context  r:Role::assignedUsers()
   pre   true
   post  result = r.assigned_users
```

The Class Session


Session
session_ID:String
addActiveRole(r:Role)
dropActiveRole(r:Role)
createSession(u:User,ars:Set(Role),id:String)
deleteSession()
sessionRoles():Set(Role) ≪ query ≫
sessionPermissions():Set(Permissions) ≪ query ≫

Constraints on Operations of Class Session

addActiveRole

```
context   s:Session::addActiveRole(r:Role)

    pre    r.assigned_users –> includes(s.session_user)    and
           s.session_roles –> excludes(r)

    post   s.session_roles =
                   s.session_roles@pre –> including(r)
```

dropActiveRole

```
context   s:Session::dropActiveRole(r:Role)

    pre    s.session_roles –> includes(r)

    post   s.session_roles =
                   s.session_roles@pre –> excluding(r)
```

Constraints on Operations of Class Session

createSession

```
context   s:Session::
    createSession(u:User,ars:Set(Role),id:String)

    pre     Session.allInstances –> forAll(s | s.session_ID <> id)    and
            u.role –> includesAll(ars)

    post    u.user_sessions –> exists( s1 |
                    s1.oclIsNew and
                    s1.session_ID = id and
                    s1.session_roles = ars
                    u.user_sessions =
                            u.user_sessions@pre –> including(s1) and
            )
```

Constraints on Operations of Class Session

deleteSession

```
context   s:Session::deleteSession()

    pre   true

    post  Session.allInstances =
                Session.allInstances@pre -> excluding(s)
```

Constraints on Operations of Class Session

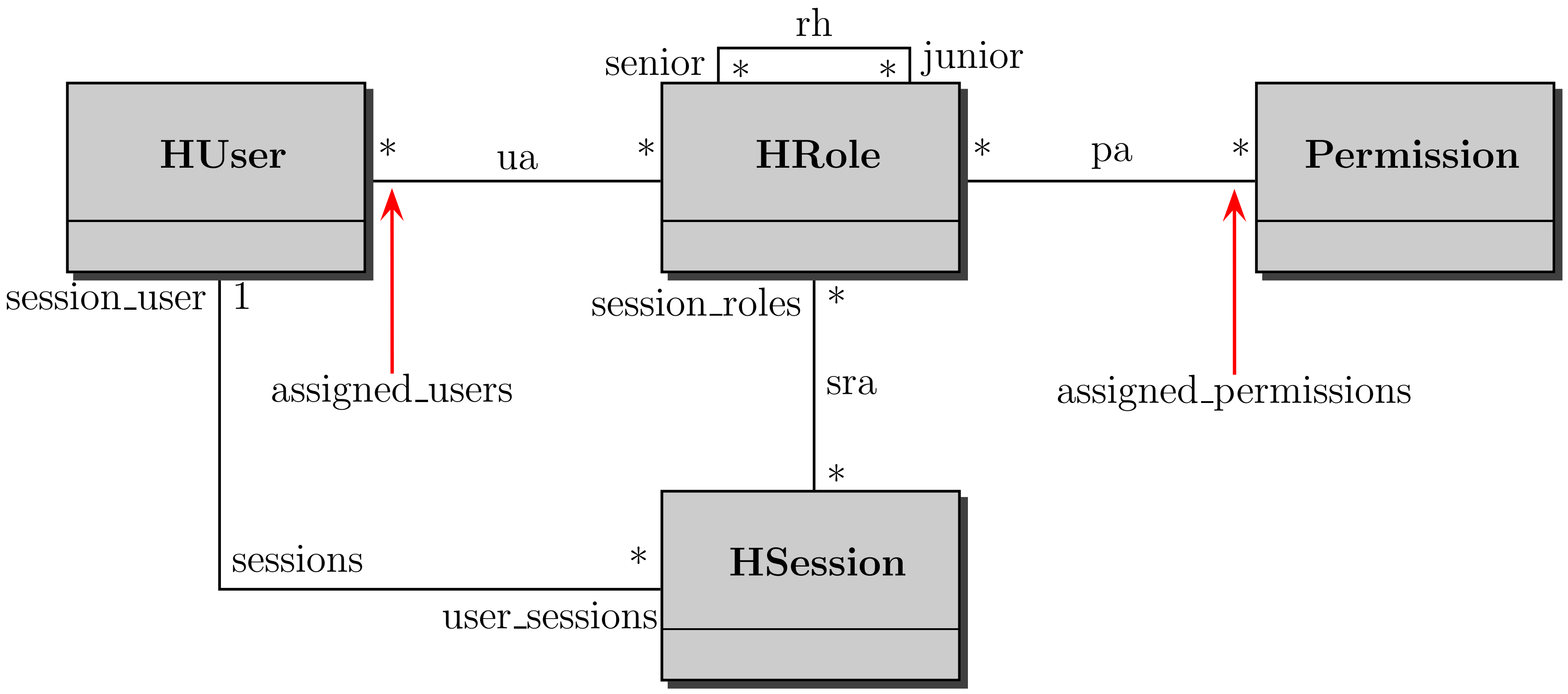
sessionRoles

```
context s:Session::sessionRoles()
    pre  true
    post result = s.session_roles
```

sessionPermissions

```
context s:Session::sessionPermissions()
    pre  true
    post result = s.session_roles.assigned_permissions −> asSet()
```

Class Diagram for RBAC with Hierarchy



Auxilliary Definitions

senior$^+$

r.senior$^+$ abbreviation for

```
HRole.allInstances –>
    iterate(r₁ ; y:Set(HRole) = r.senior | y –> union(y.senior))
```

senior*

r.senior* abbreviation for

```
HRole.allInstances –>
    iterate(r₁ ; y:Set(HRole) = { r } | y –> union(y.senior))
```

junior$^+$

junior*

General Role Hierachies

No skipping of hierarchy levels, no cycles

```
context   r:HRole

   inv     GeneralRH :
      not HRole.allInstances –> exists(r₁,r₂ |
                     r.senior –> includes(r₁) and
                     r.senior –> includes(r₂) and
                     r₁.senior⁺ –> includes(r₂))
      )    and
      r.senior⁺ –> excludes(r)
```

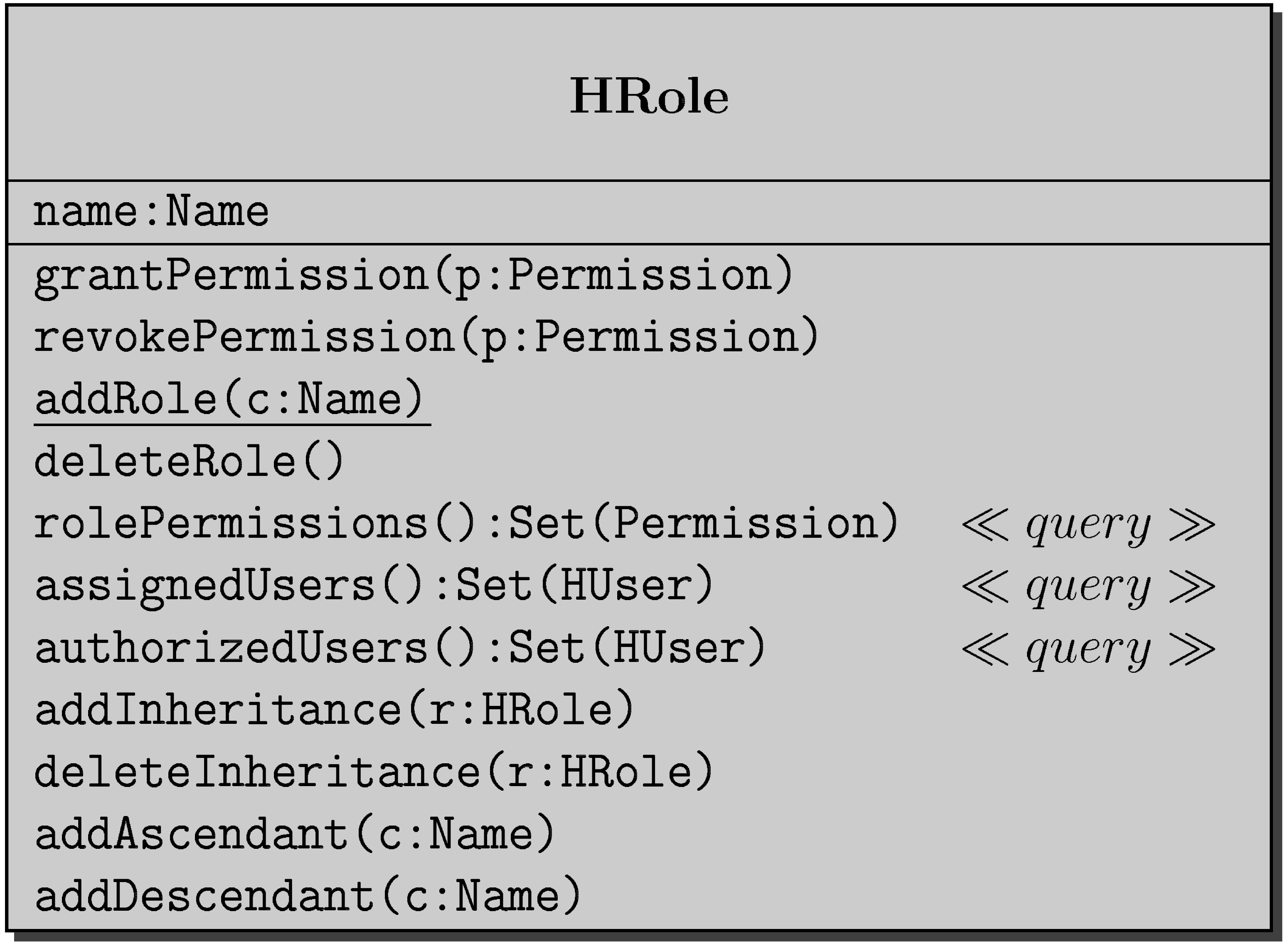
GeneralRH is the name of the invariant

Limited Role Hierachies

Hierarchy a tree structure

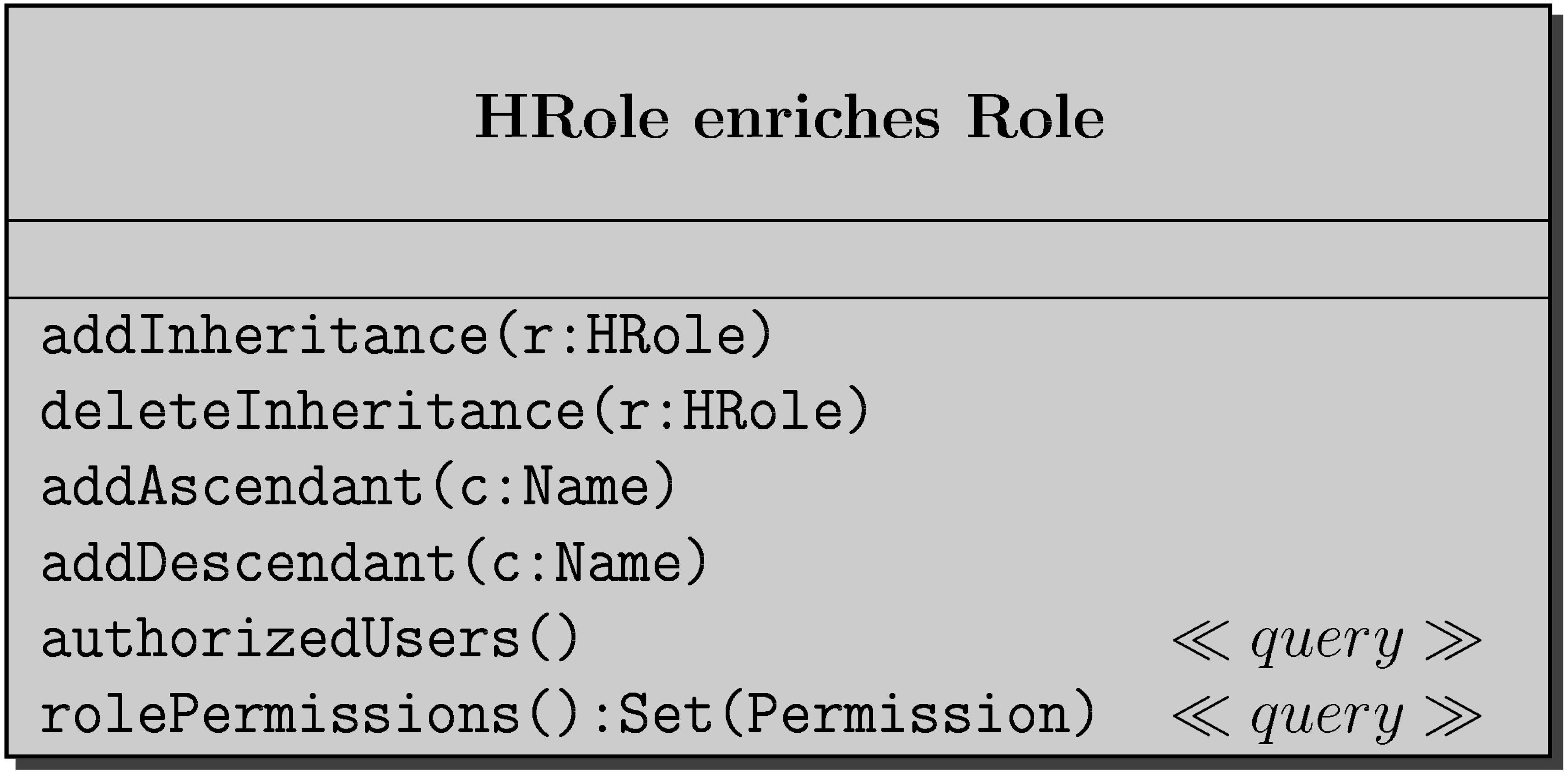
```
context   r,r1,r2:HRole
   inv    LimitedRH :
              GeneralRH   and
              (r.senior –> includes(r1) and r.senior –> includes(r2))
                   implies r1 = r2
```

Class HRole



```
HRole
--------------------------------------------------------------
name:Name
--------------------------------------------------------------
grantPermission(p:Permission)
revokePermission(p:Permission)
addRole(c:Name)
deleteRole()
rolePermissions():Set(Permission)      ≪ query ≫
assignedUsers():Set(HUser)             ≪ query ≫
authorizedUsers():Set(HUser)           ≪ query ≫
addInheritance(r:HRole)
deleteInheritance(r:HRole)
addAscendant(c:Name)
addDescendant(c:Name)
```

Class HRole (Short version)



HRole enriches Role

```
addInheritance(r:HRole)
deleteInheritance(r:HRole)
addAscendant(c:Name)
addDescendant(c:Name)
authorizedUsers()                              ≪ query ≫
rolePermissions():Set(Permission)              ≪ query ≫
```

Constraints on Operations of Class HRole

addInheritance

```
context  r:HRole::addInheritance(r₁:HRole)

  pre    not(r.senior* -> includes(r₁))    and
         not(r₁.senior* -> includes(r))

  post   r.senior -> includes(r₁)    and
         HRole.allInstances -> forAll(r₂,r₃ |
                 ((r₂ <> r or r₃ <> r₁) implies
                 (r₂.senior -> includes(r₃) iff
                         r₂.senior@pre -> includes(r₃))))
```

A iff B   is an abbreviation for   (A implies B) and (B implies A)

Constraints on Operations of Class HRole

deleteInheritance

```
context  r:HRole::deleteInheritance(r1:HRole)

   pre   r.senior -> includes(r1)

   post  r.senior -> excludes(r1)   and
         HRole.allInstances -> forAll(r2,r3 |
                 ((r2 <> r or r3 <> r1) implies
                 (r2.senior -> includes(r3) iff
                         r2.senior@pre -> includes(r3))))
```

Constraints on Operations of Class HRole

addAscendant (combines addRole and addInheritance)

```
context  r:HRole::addAscendant(c:Name)
   pre   HRole –> forAll(r | r.name <> c)
   post  HRole.allInstances –> exists( r₁ |
             r₁.oclIsNew() and
             r₁.name = c and
             r.senior –> includes(r₁) and
             HRole.allInstances = HRole.allInstances@pre including(r₁)
   )
```

Constraints on Operations of Class HRole

addDescendant (combines addRole and addInheritance)

```
context  r:HRole::addDescendant(c:Name)

    pre   HRole –> forAll(r | r.name <> c)

    post  HRole.allInstances –> exists( r1 |
              r1.oclIsNew() and
              r1.name = c and
              r1.senior –> includes(r) and
              HRole.allInstances = HRole.allInstances@pre including(r1)
    )
```

Constraints on Operations of Class HRole

authorizedUsers

context **r:HRole::authorizedUsers():Set(HUser)**

pre **true**

post **result =**
r.senior* –$>$ collect(r$_1$ $|$ r$_1$.assigned_users) –$>$ asSet()

Constraints on Operations of Class HRole

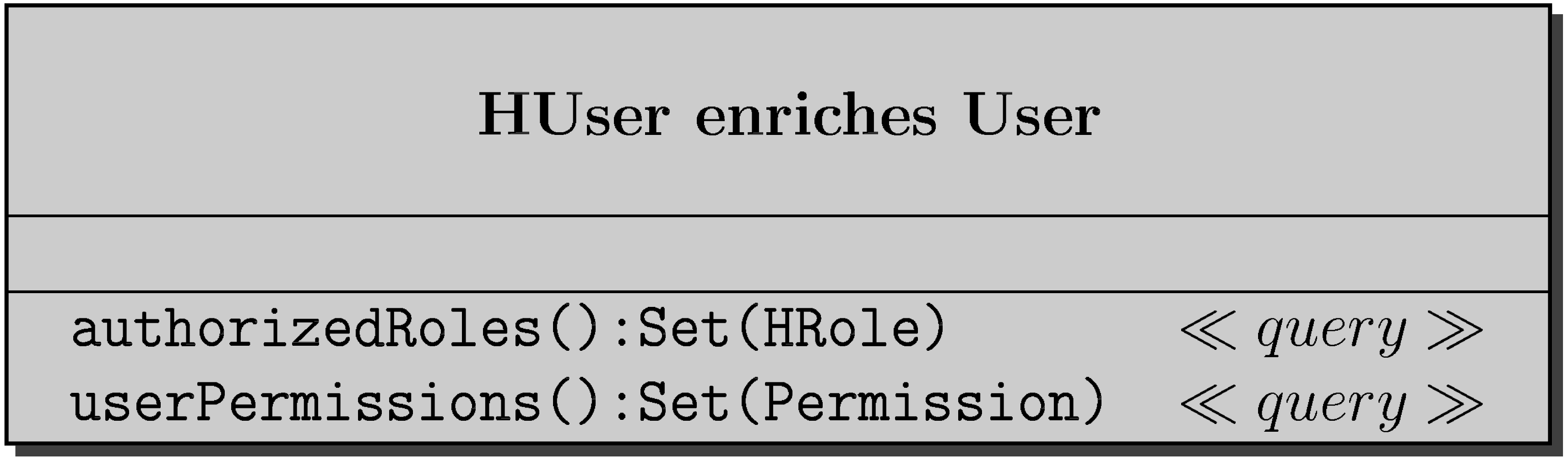
Redefining rolePermissions

context r:HRole::rolePermissions()

pre true

post result = r.junior* –$>$ collect(r$_1$ $\mid$ r$_1$.assigned_permissions)

Class HUser


HUser enriches User
authorizedRoles():Set(HRole) ≪ query ≫
userPermissions():Set(Permission) ≪ query ≫

Constraints on New Operations of Class HUser

authorizedRoles

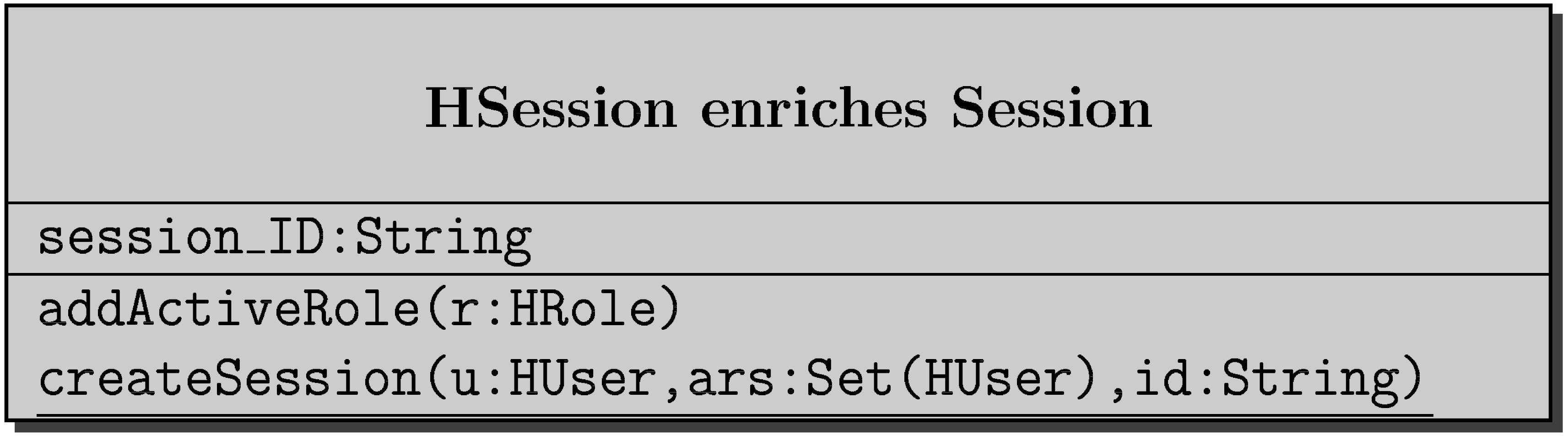
```
context  u:HUser::authorizedRoles():Set(HRole)

   pre   true

   post  result =
              u.role -> collect(r | r.junior*) -> asSet()
```

Constraints on Operations of Class HUser

Redefining userPermissions

```
context  u:HUser::userPermissions():Set(Permission)
   pre   true
   post  result =
         u.authorizedRoles() ->
               collect(r1 | r1.assigned_permissions) -> asSet()
```

Class HSession



HSession enriches Session

```
session_ID:String
```

```
addActiveRole(r:HRole)
createSession(u:HUser,ars:Set(HUser),id:String)
```

Modified Constraints on Class HSession

addActiveRole

```
context s:HSession::addActiveRole(r:HRole)

   pre   r.authorizedUsers() –> includes(s.session_user)   and
         s.session_roles –> excludes(r)

   post  s.session_roles =
                 s.session_roles@pre –> including(r)
```

Modified Constraints on Class HSession

createSession

```
context  s:HSession::
    createSession(u:HUser,ars:Set(HRole),id:String)

    pre     HSessions.allInstances –> forAll(s | s.session_ID <> id)    and
            u.authorizedRoles() –> includesAll(ars)

    post    u.user_sessions –> exists( s1 |
                    s1.oclIsNew and
                    s1.session_ID = id and
                    u.user_sessions =
                            u.user_sessions@pre –> including(s1) and
                    s.session_roles = ars
            )
```

Derived Invariants

User inheritance relation

```
context   r₁, r₂:HRole

    inv   UserInheritance:
              r₁.senior* –> includes(r₂)   implies
              r₁.authorizedUsers() –>
                    includesAll(r₂.authorizedUsers())
```

Permission inheritance relation

```
context   r₁, r₂:HRole
    inv   PermissionInheritance:
              r₁.senior* –> includes(r₂)   implies
              r₂.rolePermissions() –>
                    includesAll(r₁.rolePermissions())
```