Consider the following database schema:

Define in SQL Server a set of triggers that ensure the following constraints:

**Exercise 1.** A PhD student must work in the same laboratory as his/her supervisor.

**Exercise 2.** A PhD student must take at least one course.

**Exercise 3.** A PhD student must take all courses taught by his/her supervisor.
Details of the database for the exercises

Table creation script

create table Professor (  
    ProfNo char(5) not null,  
    Name varchar(25) not null,  
    Laboratory varchar(25) not null,  
    constraint PK_Professor primary key (ProfNo)  
)  
create table PhDStudent (  
    StudentNo char(9) not null,  
    Name varchar(25) not null,  
    Laboratory varchar(25),  
    Supervisor char(5),  
    constraint PK_PhDStudent primary key (StudentNo),  
    constraint FK_PhDStudent_Professor  
    foreign key (Supervisor) references Professor(ProfNo)  
)  
create table Course (  
    CourseNo char(7) not null,  
    Title varchar(30) not null,  
    ProfNo char(5),  
    constraint PK_Course primary key (CourseNo),  
    constraint FK_Course_Professor  
    foreign key (ProfNo) references Professor(ProfNo)  
)  
create table CourseTaken (  
    StudentNo char(9) not null,  
    CourseNo char(7) not null,  
    constraint PK_CourseTaken primary key (StudentNo,CourseNo),  
    constraint FK_CourseTaken_Student  
    foreign key (StudentNo) references PhDStudent(StudentNo),  
    constraint FK_CourseTaken_Course  
    foreign key (CourseNo) references Course(CourseNo)  
)

Initial data in the tables

<table>
<thead>
<tr>
<th>Professor</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>12345</td>
<td>John B. Smith</td>
</tr>
<tr>
<td>33344</td>
<td>Franklin T. Wong</td>
</tr>
<tr>
<td>99988</td>
<td>Alicia J. Zelaya</td>
</tr>
<tr>
<td>98765</td>
<td>Jennifer S. Wallace</td>
</tr>
<tr>
<td>66688</td>
<td>Ramesh K. Narayan</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PhDStudent</th>
<th>Supervisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4534534533</td>
<td>Joyce A. English</td>
</tr>
<tr>
<td>987987987</td>
<td>Ahmad V. Jabbar</td>
</tr>
<tr>
<td>8886655555</td>
<td>James A. Borg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>ProfNo</th>
</tr>
</thead>
<tbody>
<tr>
<td>INFO364</td>
<td>Introduction to Databases</td>
<td>12345</td>
</tr>
<tr>
<td>INFO365</td>
<td>Advanced Databases</td>
<td>33344</td>
</tr>
<tr>
<td>INFO378</td>
<td>XML</td>
<td>66688</td>
</tr>
<tr>
<td>INFO379</td>
<td>Web Services</td>
<td>66688</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CourseTaken</th>
</tr>
</thead>
<tbody>
<tr>
<td>4534534533</td>
</tr>
<tr>
<td>987987987</td>
</tr>
<tr>
<td>8886655555</td>
</tr>
</tbody>
</table>
Solution to Exercise 1

**Constraint**

“A PhD student must work in the same laboratory as his/her supervisor.”

**Events** that may violate the constraint

a) Insert into PhDStudent

b) Update of Laboratory or Supervisor in PhDStudent

c) Update of Laboratory in Professor

d) Delete from Professor

**Actions**

For each event, we have to choose whether to *abort* the transaction (by rolling back and generating a message) or to *repair* it (applying modifications that ensure that the constraint is satisfied). Note that for the latter, there are often several ways to ensure constraint satisfaction; choosing the way of applying changes that enforce the database's consistency therefore depends on the actual implementation context. In the following, we propose one of the often many possible ways of repairing the violated constraints.

For the present exercises, when applicable, a trigger creation statement for both scenarios – *aborting* or *repairing* – is proposed.

⚠️ CAUTION Beware, however, that, for each constraint, only one single rule should be active at any given time. Thus, ensure that the first trigger does not exist or has been deactivated or deleted before testing the second one, and vice-versa.

**Events a) and b)**

1. *Abortting* the transaction

```sql
create trigger StudSameLabAsSuperv_PhDStud_InsUpd_Abort
on PhDStudent
after insert, update
as
if exists ( 
    select * from Inserted I, Professor P
    where P.ProfNo = I.Supervisor
    and P.Laboratory <> I.Laboratory
)
begin
    raiserror 13000 'Constraint Violation:
    A PhD student must work in the same
    laboratory as his/her supervisor'
    rollback
end
```
2. Repairing the transaction

```sql
create trigger StudSameLabAsSuperv_PhDStud_InsUpd_Repair
on PhDStudent
after insert, update
as
begin
    update PhDStudent
    set Laboratory = ( 
        select P.Laboratory 
        from Professor P 
        where P.ProfNo = Supervisor 
    )
    where StudentNo in ( 
        select I.StudentNo 
        from Inserted I 
    )
end
```

In this case, repairing by making the necessary updates in PhDStudent will probably be the better choice, as the value that Laboratory should take is univocally determined by the consistency rule.

Event c)

1. Aborting the transaction

```sql
create trigger StudSameLabAsSuperv_Prof_Upd_Abort
on Professor
after update
as
if exists ( select * from Inserted I, PhDStudent S 
    where I.ProfNo = S.Superv
    and I.Laboratory <> S.Laboratory )
begin
    raiserror 13000 'Constraint Violation: 
    A PhD student must work in the same laboratory as his/her supervisor'
    rollback
end
```

2. Repairing the violated constraints

```sql
create trigger StudSameLabAsSuperv_Prof_Upd_Repair
on Professor
after update
as
begin
    update PhDStudent
    set Laboratory = ( 
        select I.Laboratory 
        from Inserted I 
    )
    where Supervisor in ( 
        select I2.ProfNo 
        from Inserted I2 
    )
end
```

Again, repairing the violated constraints should be preferred in this case too. The assumption is that, when a professor leaves her lab for another one, her PhD students are following.
Event d)

In this case, there are several possibilities.

- The professor is deleted and the attributes Laboratory and Supervisor of the PhD students who worked for the deleted professor are set to null.

- The transaction is rolled back, preventing a professor to be deleted when there are PhD students associated to her. This is taken care of by the referential integrity.

- The professor is deleted and all PhD students associated with him are also deleted. This is taken care of by the referential integrity with the option on update cascade.

We here provide the trigger corresponding to the first of these cases.

```sql
alter table PhDStudent
drop constraint FK_PhDStudent_Professor

create trigger StudSameLabAsSuperv_Prof_Del_Repair
on Professor
after delete
as
begin
update PhDStudent
set Laboratory = null,
    Supervisor = null
where Supervisor in (
    select ProfNo
    from Deleted )
end
```

⚠️ CAUTION As SQL Server does not implement the option on delete set null for the referential integrity, it is necessary to drop the foreign key constraint in the table PhDStudent.

▶ Solution to Exercise 2

**Constraint**

“A PhD student must take at least one course.”

Contrarily to Exercise 1, this constraint is a “negative” one, in the sense that it prevents that there does not exist any PhD student that does not take any course, but it provides no information about a way of automatically determining the one course that should be taken “by default”, should no other be provided. Consequently, it will not be possible without any additional assumption, to repair violated constraints. All violating events will thus simply result in aborting the transaction.

**Events** that may violate the constraint

a) Insert into PhDStudent

b) Update of StudentNo in CourseTaken

c) Delete from CourseTaken

d) Delete from Course
Actions

Event a)

create trigger PhDStudMinOneCourse_PhDStud_Ins_Abort
on PhDStudent
after insert
as
if exists ( 
  select * from Inserted I
  where not exists ( 
    select *
    from CourseTaken
    where StudentNo = I.StudentNo ) )
begin
  raiserror 13000 'Constraint Violation:
  A PhD student must take at least one course'
  rollback
end

⚠️ CAUTION  This does not work in SQL Server, since a trigger is executed immediately after the triggering instruction. Thus, embedding several inserts (into PhDStudent and CourseTaken) into one transaction would not help. Practically, thus, and without any further assumption, it will not be possible to ensure that this constraint verified, as the aborting trigger would prevent any insertion into the table PhDStudent.

Events b) and c)

create trigger PhDStudMinOneCourse_PhDStud_Ins_Abort
on CourseTaken
after update, delete
as
if exists ( 
  select * from Deleted D
  where D.StudentNo not in ( 
    select StudentNo
    from CourseTaken
    ) )
begin
  raiserror 13000 'Constraint Violation:
  A PhD student must take at least one course'
  rollback
end

Event d)

Removing an entry from Course could indirectly affect the number of courses taken by one or several PhD students. This case, however, should be handled with the on update cascade option of the referential integrity constraint on the CourseNo field of CourseTaken.

➤ Solution to Exercise 3

Constraint

“A PhD student must take all courses taught by his/her supervisor.”

Events that may violate the constraint

a) Insert into PhDStudent
b) Update of Supervisor in PhDStudent

c) Insert into Course

d) Update of ProfNo in Course

e) Update of StudentNo or CourseNo in CourseTaken

f) Delete from CourseTaken

Actions

Events a) and b)

1. **Aborting** the transaction

```sql
create trigger StudAllCoursesOfSuperv_Stud_InsUpd_Abort
on PhDStudent
after insert, update
as
if exists {
    select * from Inserted I
    where exists ( select *
        from Course C
        where C.ProfNo = I.Supervisor
        and C.CourseNo not in ( select T.CourseNo
            from CourseTaken T
            where T.StudentNo = I.StudentNo ) )

    begin
        raiserror 13000 'Constraint Violation:
            A PhD student must take all the courses
            given by his supervisor'
        rollback
    end
}
```

2. **Repairing** the transaction

```sql
create trigger StudAllCoursesOfSuperv_Stud_InsUpd_Repair
on PhDStudent
after insert, update
as
begin
    insert into CourseTaken (StudentNo, CourseNo)
    select I.StudentNo, C.CourseNo
    from Inserted I,
    Professor P,
    Course C
    where I.Supervisor = P.ProfNo
    and C.ProfNo = P.ProfNo
    and C.CourseNo not in ( select T.CourseNo
        from CourseTaken T
        where T.StudentNo = I.StudentNo )
end
```

The rules implemented by this trigger can be challenged, for instance, with the following change of supervisor for the student named Joyce. The lab she belongs to will automatically be changed to “Web Technologies” by the trigger.

```sql
begin transaction
    update PhDStudent
    set Supervisor = 66688
    where StudentNo = 453453453
commit transaction
```
Events c) and d)

Aborting the transaction, particularly in SQL Server (where triggers are executed immediately after the triggering instruction), would not work (well).

The repairing rule being implicitly defined, or at least suggested, by the constraint (namely to automatically enrol the student in the added course), it will be the method of choice for this case.

Note that the update case, where a Professor would abandon a course, has not to be handled here explicitly, since letting a Student take courses from Professors that are not his supervisor is not forbidden.

```sql
create trigger StudAllCoursesOfSuperv_Course_InsUpd_Repair
on Course
after insert, update
as
begin
  insert into CourseTaken (StudentNo, CourseNo)
  select S.StudentNo, I.CourseNo
  from Inserted I,
       Professor P,
       PhDStudent S
  where C.ProfNo = P.ProfNo
       and S.Supervisor = P.ProfNo
       and I.CourseNo not in ( select T.CourseNo 
                                 from CourseTaken T
                                 where T.StudentNo = C.StudentNo )
end
```

Events e) and f)

```sql
create trigger StudAllCoursesOfSuperv_CourseTaken_UpdDel_Abort
on CourseTaken
after update, delete
as
if exists ( select *
            from Deleted D,
                 Course C,
                 PhDStudent S
            where D.CourseNo = C.CourseNo
            and C.ProfNo = S.Supervisor
            and D.StudentNo = S.StudentNo )
begin
  raiserror 13000 'Constraint Violation:
  A PhD student must take all the courses
given by his supervisor'
end
```