Ders # 6

Veri Bütünlüğü Programlama ve Güvenlik

From Standford's The complete Book

Sciore's textbook, Ch 9-10

From Raghu&Johennes DB textbook

Outline:

- General Constraints as Assertions
- Triggers
- Security

Objective:

- ❑Specification of more general **constraints** via assertions, triggers
- ❑Coordination of users access to data. Authorization issues on dabases.

Constraints as Assertions

- General constraints: constraints that do not fit in the basic SQL categories (*such as unique, primary key, not null, foreign key..*)
- Mechanism: **CREAT ASSERTION**
  - a constraint name,
  - followed by CHECK,
  - followed by a condition

- "The salary of an employee must not be greater than the salary of the manager of the department that the employee works for''

```
CREAT ASSERTION SALARY_CONSTRAINT
CHECK (NOT EXISTS ( SELECT *
                    FROM EMPLOYEE E, EMPLOYEE M, DEPARTMENT D
                    WHERE E.SALARY > M.SALARY AND
                    E.DNO=D.NUMBER AND
                    D.MGRSSN=M.SSN))
```

Examples on student record database:

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

```
create assertion SmallSections
   check (not exists
          select e.SectionId
          from ENROLL e
          group by e.SectionId
          having count(e.EId) > 30)
```

Figure 5-1
The SQL specification of the integrity constraint
"No section can have more than 30 students"

Examples on student record database:

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

```
create assertion ValidGradYear
   check (not exists
          select s.*
          from STUDENT s
          where s.GradYear < 1863)
```

Figure 5-2
The SQL specification of the integrity constraint
"A student's graduation year must be at least 1863"

Examples on student record database:

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

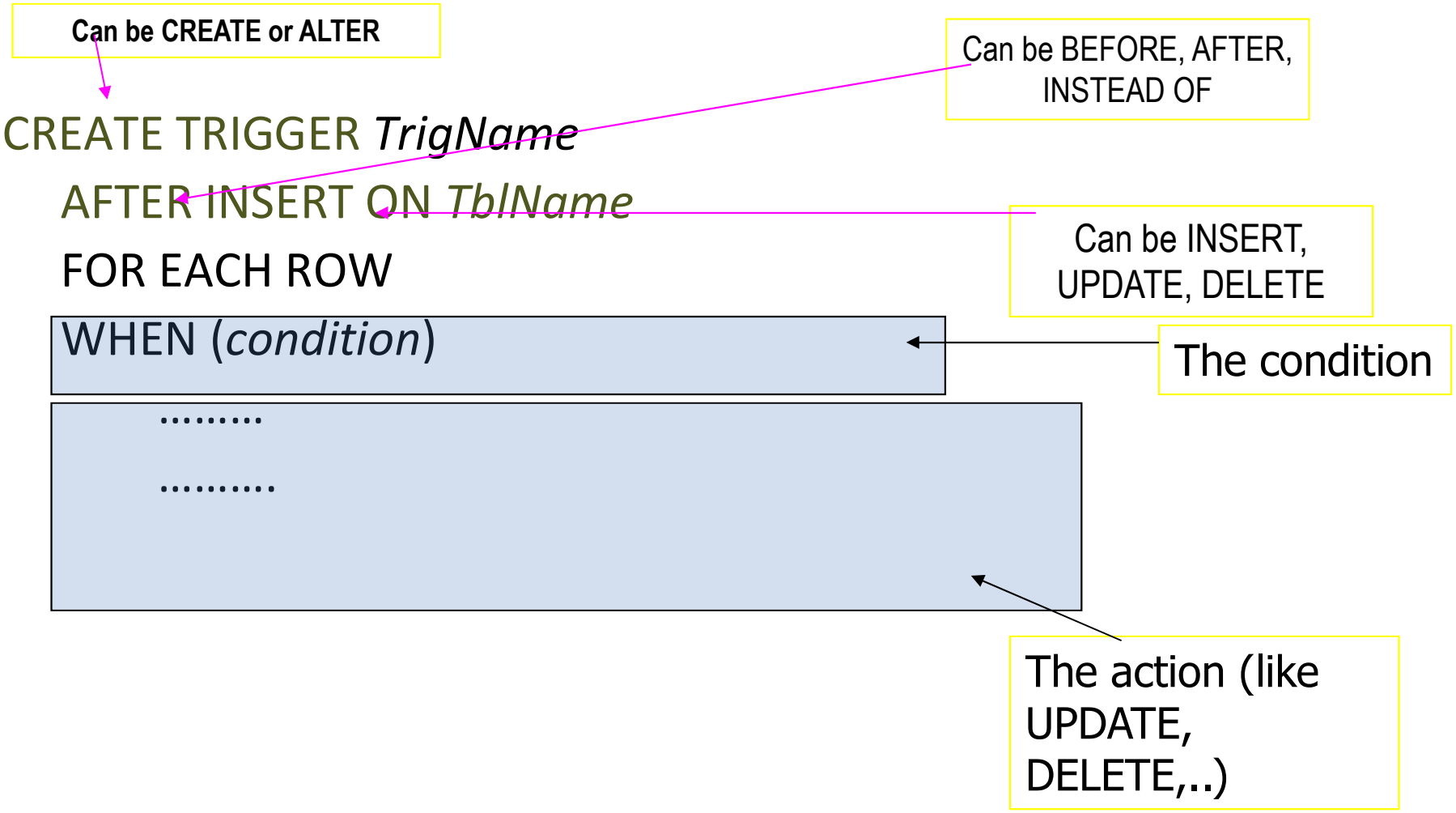
```
create assertion NoTakeTwice
   check (not exists
          select e.StudentId, k.CourseId
          from SECTION k, ENROLL e
          where k.SectId=e.SectionId
          group by e.StudentId, k.CourseId
          having count(k.SectId)>1)
```

Figure 5-3
The SQL specification of the integrity constraint
"Students can take a course at most once"

SQL Triggers

- Objective: to monitor a database and take initiate action when a condition occurs
- Triggers are action that fire automatically based on these conditions
- Triggers are expressed in a syntax similar to assertions and include the following:
  - Event : Such as an insert, deleted, or update operation
  - Condition : optional
  - Action:To be taken when the condition is satisfied
- CREATE TRIGGER <name>: Creates a trigger
- ALTER TRIGGER <name> : Alters a trigger (assuming one exists)
- CREATE OR ALTER TRIGGER <name>
  - Creates a trigger if one does not exist
  - Alters a trigger if one does exist

implementing a trigger



Valid Trigger Types

Triggered by INSERT:

- BEFORE INSERT statement-level.
- BEFORE INSERT row-level.
- AFTER INSERT statement-level.
- AFTER INSERT row-level.

Triggered by UPDATE:

- BEFORE UPDATE statement-level.
- BEFORE UPDATE row-level.
- AFTER UPDATE statement-level.
- AFTER UPDATE row-level.

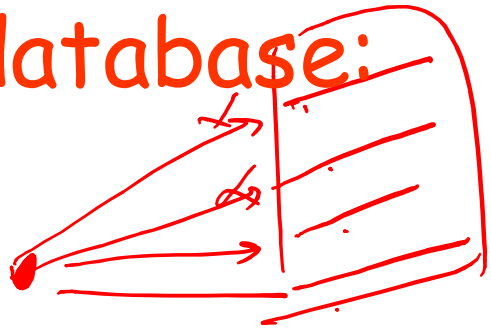
Triggered by DELETE:

- BEFORE DELETE statement-level.
- BEFORE DELETE row-level.
- AFTER DELETE statement-level.
- AFTER DELETE row-level.

To replace the triggering event:

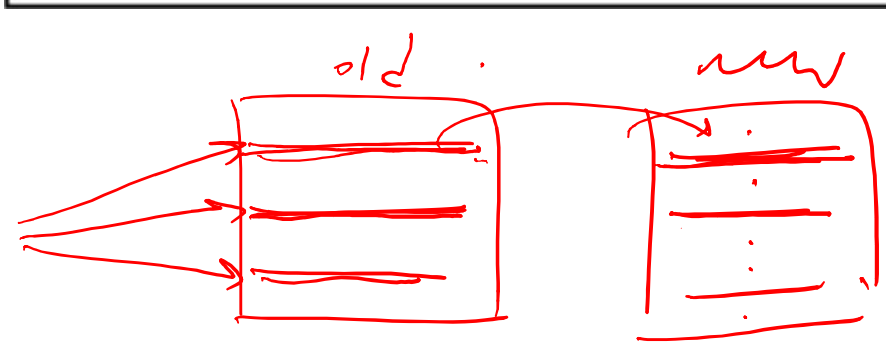
- INSTEAD OF statement-level.
- INSTEAD OF row-level.

Examples on student record database:



```
create trigger LogGradeChange
   after update of Grade in ENROLL
   for each row
   referencing old row as oldrow, new row as newrow
   when oldrow.Grade <> newrow.Grade
      insert into GRADE_LOG(UserName, DateChanged, EId,
                            OldGrade, NewGrade)
      values(current_user, current_date, newrow.EId,
             oldrow.Grade, newrow.Grade)
```

Figure 5-4
An SQL trigger that logs changes to student grades



Examples on student record database:

```
create trigger FixBadGradYear
   after insert in STUDENT
   for each row
   referencing new row as newrow
   when newrow.GradYear > 4 + extract(YEAR, current_date)
      set newrow.GradYear = null
```

Figure 5-5
An SQL trigger that replaces inappropriate graduation years with nulls

fig_05_05

Triggers on Simplified COMPANY DB

- EMPLOYEE (NAME, SSN, SALARY, DNO, SUPERVİSOR_SSN)
- DEPARTMENT (DNAME, DNO, TOTAL_SAL, MANAGER _SSN)

- **EXAMPLE 1:** A trigger to compare an employee's salary to his/her supervisor during insert or update operations:

```
CREATE TRIGGER INFORM_SUPERVISOR
BEFORE INSERT OR UPDATE OF
    SALARY, SUPERVISOR_SSN ON EMPLOYEE
    FOR EACH ROW
       WHEN
       NEW.SALARY> (SELECT SALARY FROM EMPLOYEE
            WHERE SSN=NEW.SUPERVISOR_SSN))
       INFORM_SUPERVISOR (NEW.SUPERVISOR_SSN,NEW.SSN);
```

Triggers on Simplified COMPANY DB

EMPLOYEE (NAME, SSN, SALARY, DNO, SUPERVİSOR_SSN)

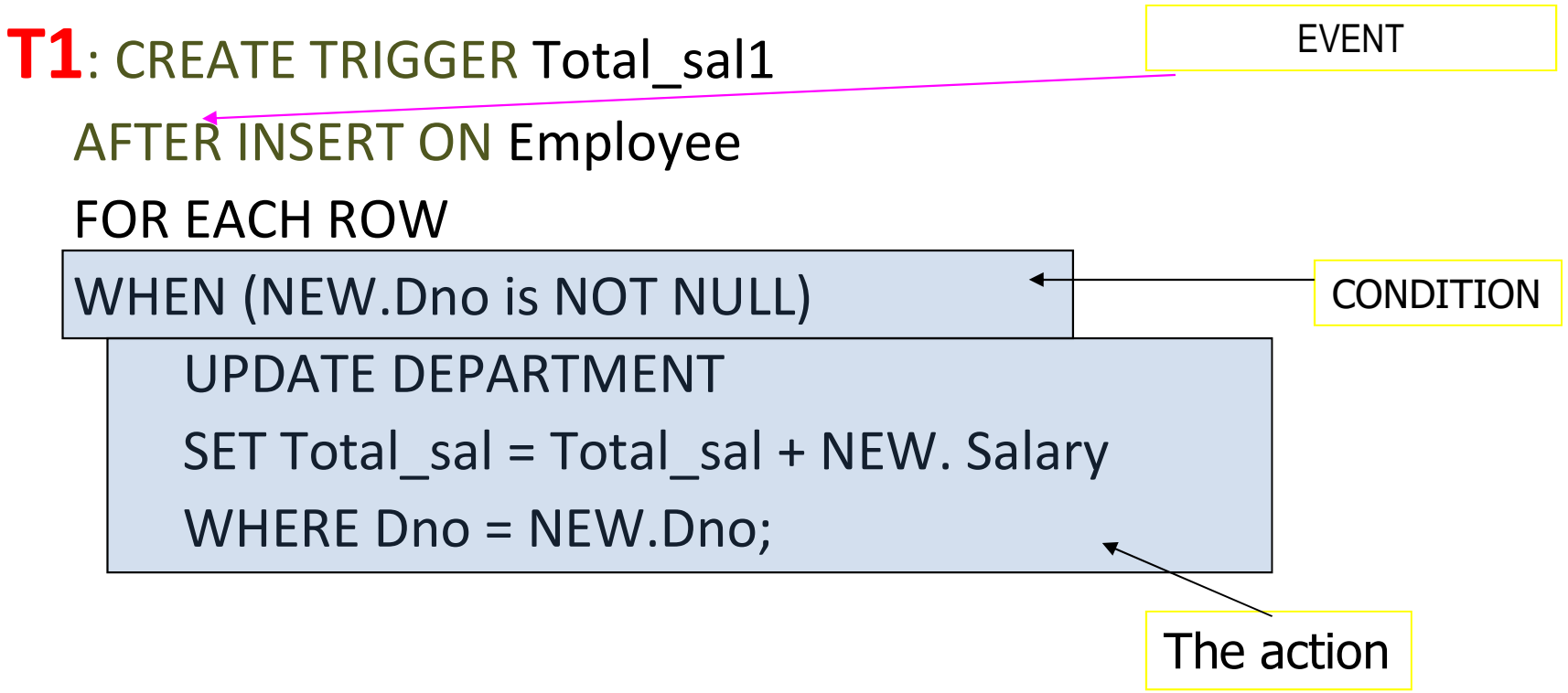
DEPARTMENT (DNAME, DNO, TOTAL_SAL, MANAGER _SSN)

- keep updated the DEPARTMENT.TOTAL_SAL

4 events runs the trigger:

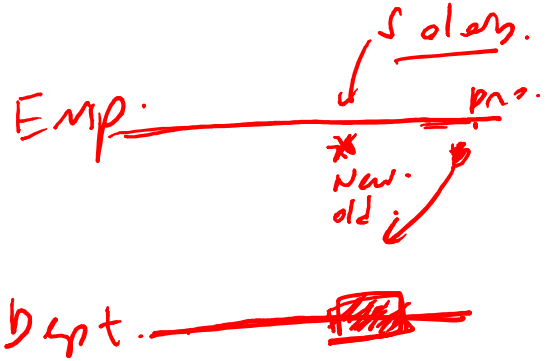
- T1: Total_sal1 *(When a new employees is added to a department, modify the Total_sal of the Department to include the new employees salary)*
  - This trigger will execute **AFTER INSERT ON** Employee table
  - It will do the following FOR EACH ROW
    - WHEN NEW.Dno is NOT NULL
    - The trigger will UPDATE DEPARTMENT
    - By SETting the new Total_sal to be the sum of
      - » old Total_sal and NEW. Salary
      - » WHERE the Dno matches the NEW.Dno;
- T2:Total_sal2: (*changing salary of existing Emp.)*
- T3: (*Deleting an employee.)*
- T4: *(Changing department of an employee.)*

Implementing T1: «adding a new Employee»

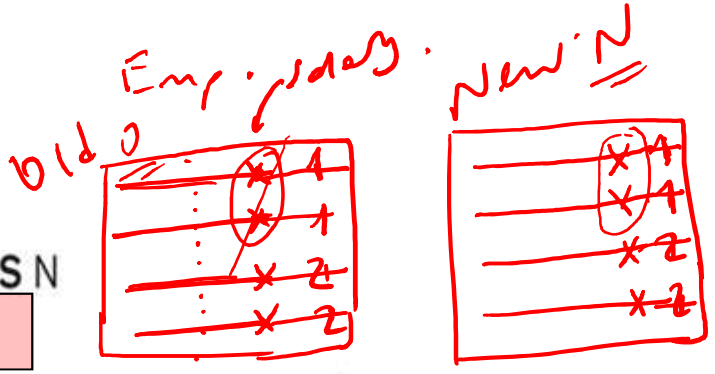


Implementing T2: «changing salary of existing Emp»

```
T2: CREATE TRIGGER Total_sal2
    AFTER UPDATE OF Salary ON EMPLOYEE
    REFERENCING OLD ROW AS O, NEW ROW AS N
    FOR EACH ROW
    WHEN  ( N.Dno IS NOT NULL )
    UPDATE DEPARTMENT
    SET Total_sal = Total_sal + N.salary – O.salary
    WHERE Dno = N.Dno;
```




```
T2: CREATE TRIGGER Total_sal2
    AFTER UPDATE OF Salary ON EMPLOYEE
    REFERENCING OLD TABLE AS O, NEW TABLE AS N
    FOR EACH STATEMENT
    WHEN  EXISTS  ( SELECT * FROM N WHERE N.Dno IS NOT NULL ) OR
          EXISTS  ( SELECT * FROM O WHERE O.Dno IS NOT NULL )
    UPDATE DEPARTMENT AS D
    SET D.Total_sal = D.Total_sal
    + ( SELECT SUM (N.Salary) FROM N WHERE D.Dno=N.Dno )
    – ( SELECT SUM (O.Salary) FROM O WHERE D.Dno=O.Dno )
    WHERE Dno IN ( ( SELECT Dno FROM N ) UNION ( SELECT Dno FROM O ) );
```



Cont... *T2 (for each statement)*

	Salary	DNO
	200	1
	300	2

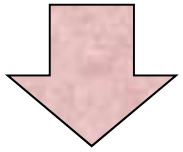
EVENT: ONLY «SAL» changes !

Old O

	Salary	DNO
	200	1
	300	2

New N

	Salary	DNO
	700	1
	900	2



ACTION !

Cont... *T2 (for each statement)*

	Salary	DNO
	200	1
	300	2

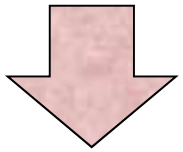
EVENT: Both «SAL» and «DNO» changes !

Old O

	Salary	DNO
	200	1
	300	2

New N

	Salary	DNO
	700	2
	900	1



ACTION !

Cont... *T2 (for each statement)*

	Salary	DNO
	200	
	300	

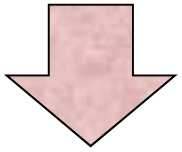
EVENT: ONLY «SAL» changes and All DNOs are NULL !

Old O

	Salary	DNO
	200	Null
	300	Null

New N

	Salary	DNO
	700	Null
	900	Null



No action !

GÜVENLİK

- **Authentication** (**Kimlik doğrulama**), kullanıcının iddia ettiği kişi olduğunun ve DBMS'nin de kullanılmak istenen sistem olduğunun doğrulanması.
  - Kimlik doğrulama, belirli görevler için herhangi bir ayrıcalık/yetki vermez. **Authorization** (**Yetkilendirme**) için bir önkoşuldur.

- **Authorization (yetkilendirme);** hangi kullanıcının, hangi veriler üzerinde, neler yapabileceğinin, belirlenmesi.

- **Authentication «SERVER», Authorization «SERVER», Auditing «SERVER», …**

Authorization methods (yetkilendirme metodları)

- Discretionary access control *(takdire dayalı)*
  - Privileges are associated with tables
  - Based on the assumption that the users are trustworthy.
  - Privilege may propagate from one subject to another
  - Provided by SQL and flexible..
- Mandotary access control *(zorlayıcı)*
  - Privileges are associated with data
  - Eliminates the loopholes of dicreationary method, thus suited for high-security systems (like military)
  - Less flexible

Discretionary access control

Privileges (hak, yetki)

- The table's owner grants privileges on it to other users.
- Kinds of privileges:
  - ***Select, Insert, Delete, Update***, *References, Usage, Trigger,Execute,Under*
- SQL **GRANT/REVOKE** *statement* assigns/removes priveleges to users:

  SYNTAX : **GRANT** <*priv list*> **ON** <DB element> **TO** ***<users/roles>***

  Example: GRANT *select* on COURSE to public

UNIVERSITY database

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

```
grant select on STUDENT to dean, admissions
grant insert on STUDENT to admissions
grant delete on STUDENT to dean
grant update on STUDENT to dean

grant select on COURSE to public
grant insert on COURSE to registrar
grant delete on COURSE to registrar
grant update on COURSE to registrar

grant select on DEPT  to public

grant select on ENROLL to dean, professor
grant insert on ENROLL to registrar
grant delete on ENROLL to registrar
grant update on ENROLL to professor

grant select on SECTION to public
grant insert on SECTION to registrar
grant delete on SECTION to registrar
grant update on SECTION to registrar
```

Figure 5-6
Some SQL grant statements for the university database

users / roles

- A “user” is the person who logged into the database. The “role” is the category of users.
- For a better feasibility, privileges are granted to “roles”. Thus the admin should
  - define “roles” in the database.
  - define “users” in the database.
  - assign one or more roles to the user. *(In case of more than one role, the user is granted the union of priveleges from each role)*
- The owner of an db-object (table, *view, idx*,..) automatically gets all previliges on that object.

Fine-tuning: Column privileges

GRANT select on ENROLL to dean, professor

- The purpose of this privilege was for keeping student enrollments and grades private.
- Instead of “all or nothing” aspect, it is better to use column priveleges.
- Study the following column privileges:

GRANT *select(StudentId,grade)* on ENROLL to dean, professor

GRANT *update(Grade)* on ENROLL to professor

GRANT *insert(Sname,MajorId)* on STUDENT to admissions

Privileges required by SQL statements:

- **Select** requires "*select privilege*" on every field mentioned in the query.
- **Insert (update)** requires "*Insert* (*update*) privilege" for the field to be inserted (modified), **plus the "select privilege" on every field mentioned in its where clause.**
- **delete** requires "*delete privilege*" for the field to be deleted, plus the "select privilege" on every field mentioned in its where clause.

Statement	Required Privileges
select s.SId, s.SName, count(e.EId) from STUDENT s, ENROLL e where s.SId = e.StudentId and e.Grade = 'A' group by s.SId, s.SName	select(SId, SName) on STUDENT select(EId, StudentId, Grade) on ENROLL
select c.* from COURSE c where c.DeptId in (select d.DId from Dept d where d.DName = 'math')	select on COURSE select(DId, DName) on DEPT
delete from SECTION where SectId not in (select e.SectionId from ENROLL e)	select(SectId) on SECTION delete on SECTION select(SectionId) on ENROLL

Example: Determine Who is authorized to execute the SQL statements in the table.

GRANT *update(Grade)* on ENROLL to professor

Can a professor do the followings ?
UPDATE ENROLL e SET e.Grade= 100
UPDATE ENROLL e SET e.Grade=e.Grade+1

More Fine-tuning: Privileges on **Views**

GRANT *update(Grade)* on ENROLL to professor

- Column privileges gives roles(users) too much power. A professor can change a grade given by another professor.
- Solution: Revoke the previous privileges of professors on ENROLL table. Give the privileges on the following view.

```
create view PROF_ENROLLMENTS as
   select e.*
   from ENROLL e
   where e.SectionId in
        (select k.SectId
         from Section k
         where k.Prof=current_user)
```

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

```
grant select         on PROF_ENROLLMENTS to professor
grant update(Grade)  on PROF_ENROLLMENTS to professor
```

Create view **CurrYearGrades** AS
S YearOffered, Grades
F ENROLL e, SECTION s
W e.SectionId=s.SectId and YearOffered = extact(YEAR,current_date);

GRANT *select* ON **CurrYearGrades** to DEAN

Privileges on constraints

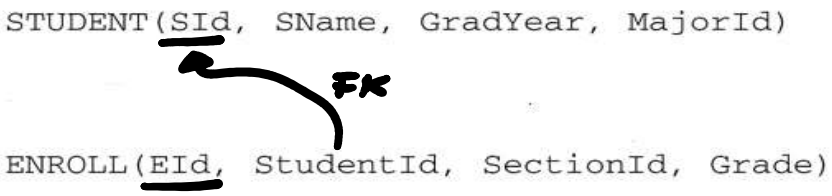
- “assertions” restricts the contents, limits what the user can do.
- It is not difficult for a malicious user to define an assertion that would make a table useless.

```
create assertion MakeTableUseless
check (not exist
    select s.*
    from STUDENT
    where SName !=‘abc’ and GradYear != 0)
```

- Thus, allowing to define assertions should be under authorization. We should control to use constraints (assertions, **Foreign keys**,…) that mentions STUDENT table.

GRANT *references* on STUDENT to dean

Reference vs. *Select* Privilege



User U: CREATE TABLE STUDENT (…..)

U: GRANT ***SELECT (SId)*** on STUDENT to **V**

V: CREATE TABLE ENROLL (…….PK (Eıd), **FK(StudentId) REFERENCES STUDENT**, FK(SectionId) ….) ➔ **REJECTED !!**

U: GRANT ***REFERENCES(SId***) on STUDENT to **V**

V: CREATE TABLE ENROLL (…….PK (Eıd), **FK(StudentId) REFERENCES STUDENT**, FK(SectionId) ….) ➔ **ACCEPTED!!**

Why SELECT privilege is not ENOUGH ?

Remember FK enforcements: (CASCADE, SET NULL, SET DEFAULT, **NO ACTION**)

V: CREATE TABLE ENROLL (…….PK (Eıd), FK(StudentId) REFERENCES STUDENT ON DELETE **NO ACTION**, FK(SectionId) ….)

Grant-option Privileges

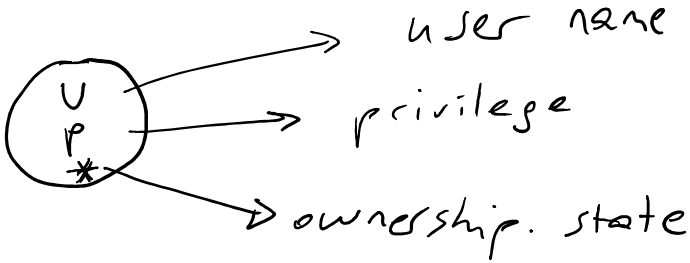
GRANT <*priv list*> **ON** <DB element> **TO** <***users/roles***>

GRANT insert **ON** student **TO** admission WITH GRANT OPTİON

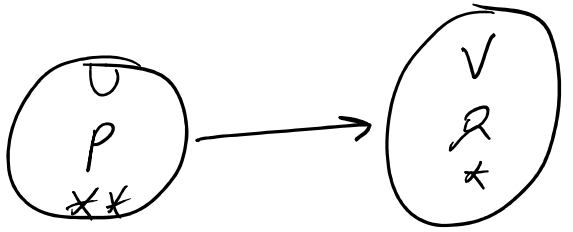
- The above grant grants the following previliges to admission:
  - To insert records on STUDENT table
  - To grant that privilege to others.
- Since it is a powerful, it is critical to grant that kind of privileges..

GRANT Diagrams

- Useful to represent «sequence of GRANTs» by a GRAPH.
- SQL system keeps track of all users privileges with «access matrices», Access Control Lists (ACL).



{ ** : privilege is from ownership.
* : " is granted from s/w else. It includes "with grant option"



U grants Q to V w/ grant option ($Q \subset P$)

Example:

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

User «**admin**» grants following privileges:

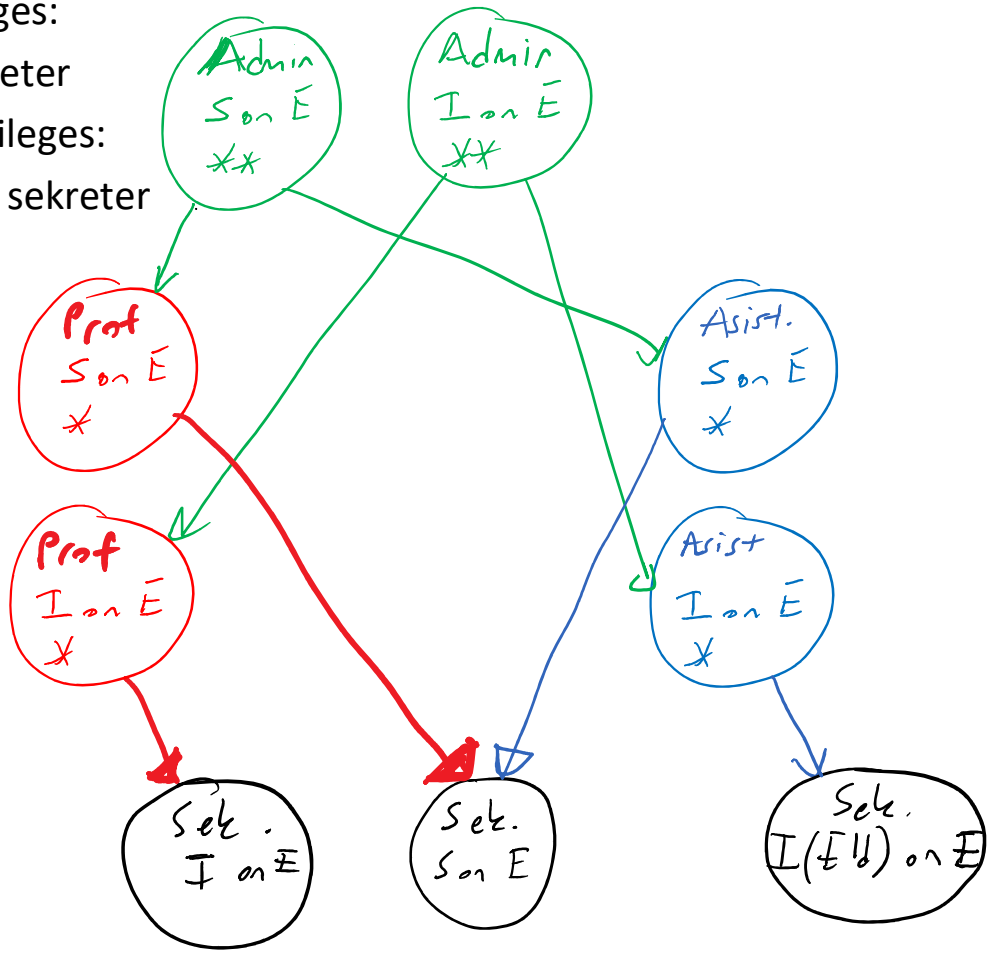
- GRANT *select,insert* ON ENROLL to prof,asistan WITH GRANT OPTION

User in «prof» role, grants following privileges:

- GRANT *select,insert* ON ENROLL to sekreter

User in «asistan» role, grants following privileges:

- GRANT *select,insert(EId)* ON ENROLL to sekreter



GRANT Diagrams/ REVOKE

REVOKE <*priv list*> **ON** <DB element> **FROM** <***users/roles***> **<CASCADE/RESTRICT>**

CASCADE : specified privileges revoked **AND** privileges that were granted ONLY because of the granted priviliges. **At last, any node that is not accessible from some ownership node is also deleted.**

RESTRICT: If the privileges that are being tried to be revoked have been passed to others, then REJECT this present REVOKE.

REVOKE GRANT OPTION FOR <DB element> **FROM** <***users/roles***> **<CASCADE/RESTRICT>**

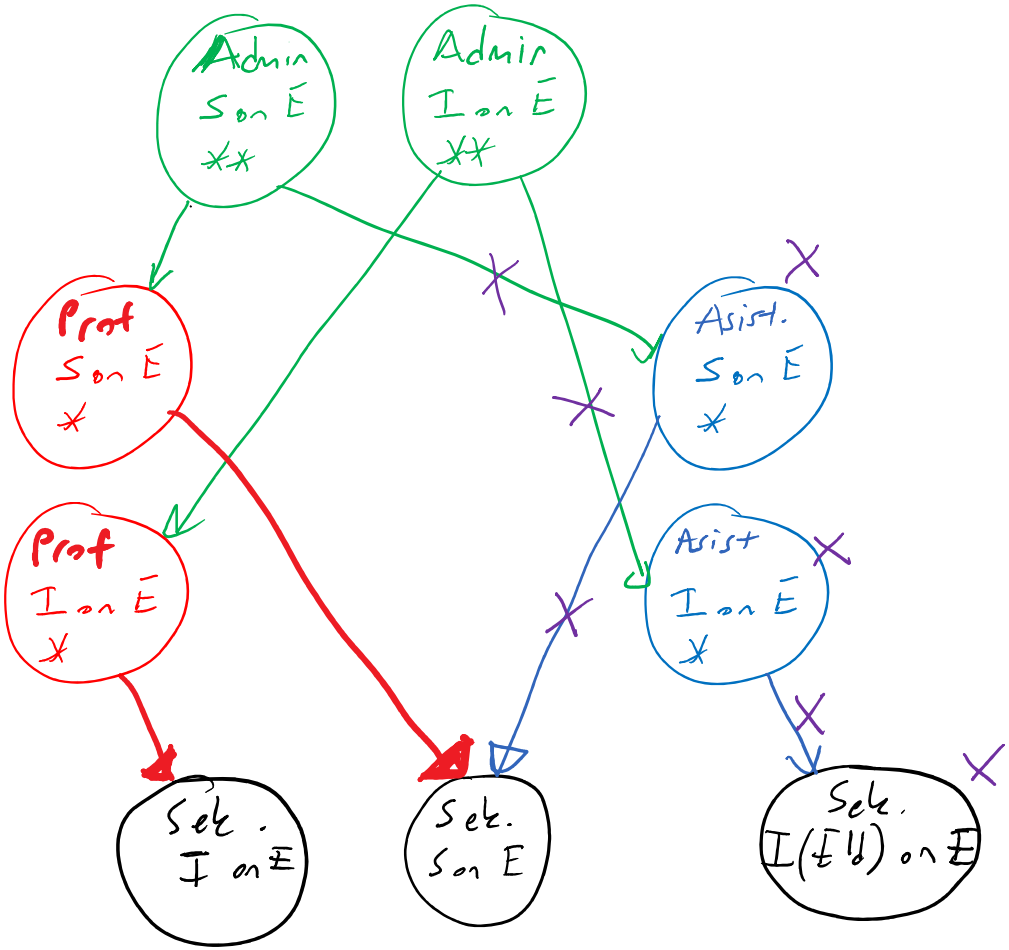
Privileges themselves remain but, the option to grant them is revoked.

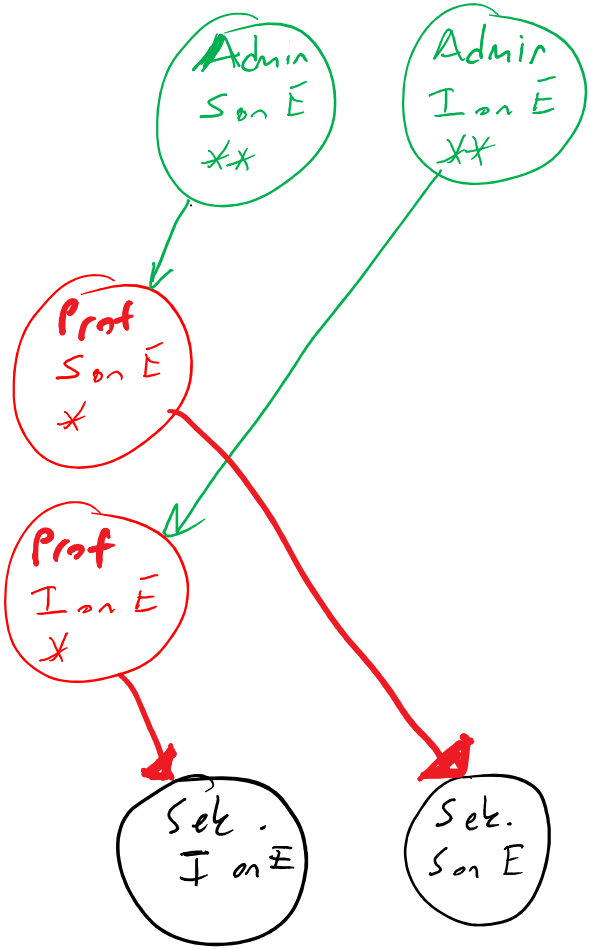
Example:

```
STUDENT(SId, SName, GradYear, MajorId)
DEPT(DId, DName)
COURSE(CId, Title, DeptId)
SECTION(SectId, CourseId, Prof, YearOffered)
ENROLL(EId, StudentId, SectionId, Grade)
```

User «**admin**» grants following privileges:

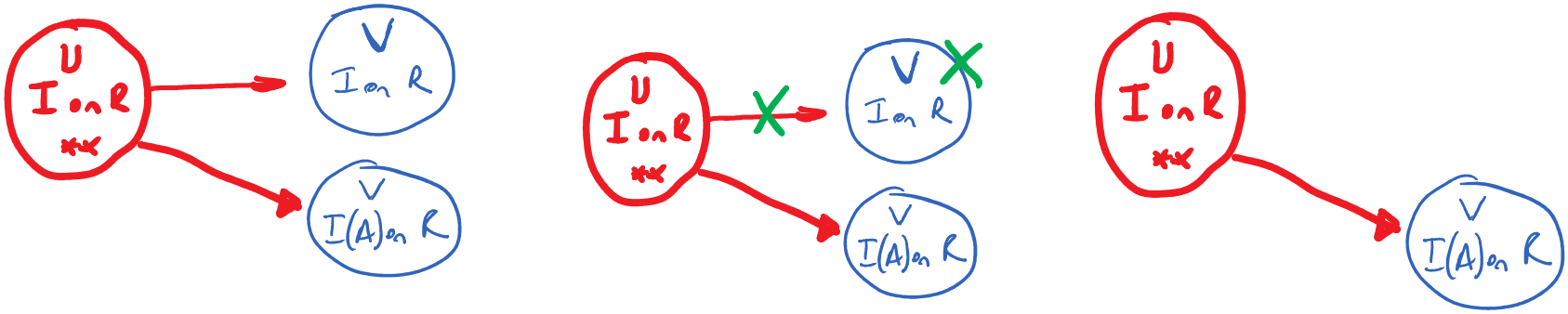
- REVOKE *select,insert* ON ENROLL FROM asistan CASCADE





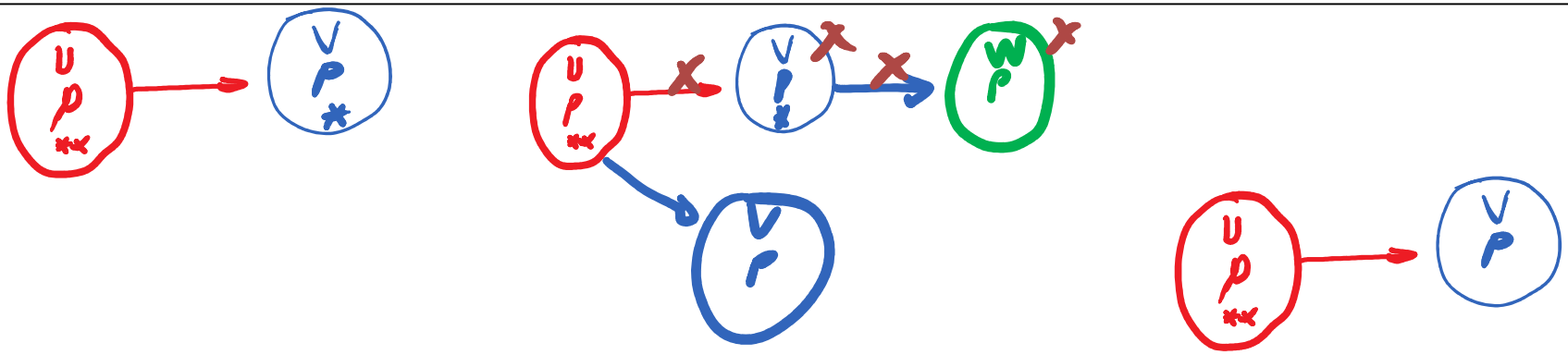
Example:

- U: GRANT *insert* ON R to V
- U: GRANT *insert(A)* ON R to V
- U: REVOKE *insert* ON R from V RESTRICT

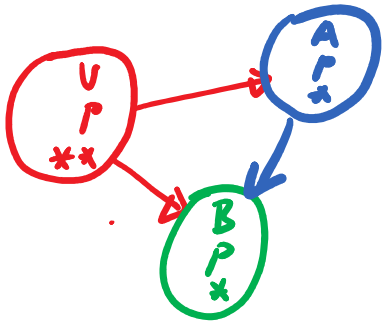


Example:

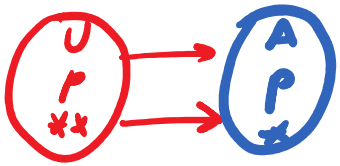
- U: GRANT *p* to V WITH GRANT OPTION
- V : GRANT *p* to W
- U: REVOKE **GRANT OPTION FOR** *p* from V CASCADE



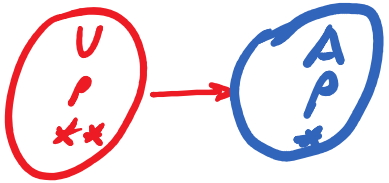
Examples:



U: REVOKE *p* FROM A CASCADE

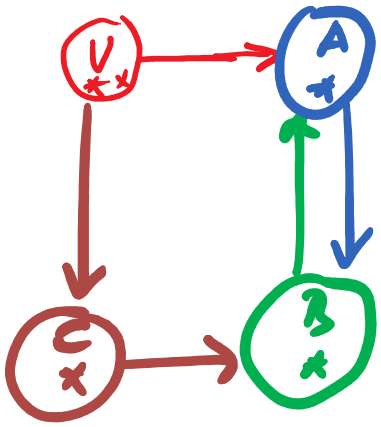


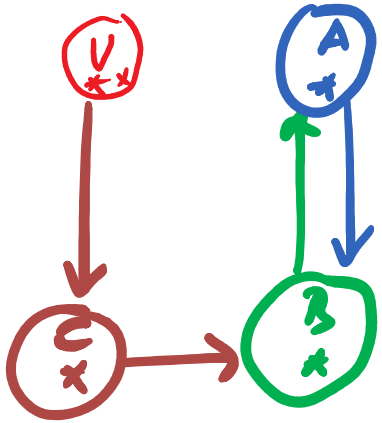
U: REVOKE *p* FROM A CASCADE



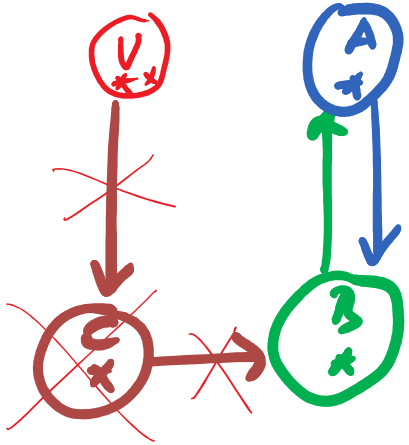
U: REVOKE **GRANT OPTION FOR** *p* FROM A CASCADE

U: REVOKE *p* FROM A CASCADE





U: REVOKE *p* FROM C CASCADE



Example

- A: GRANT *p* to B WITH GRANT OPTION
- A : GRANT *p* to C
- B : GRANT *p* to D WITH GRANT OPTION
- D : GRANT *p* to B, C, E WITH GRANT OPTION
- B : REVOKE *p* from D CASCADE
- A : REVOKE *p* from C CASCADE

Show the GRANT diagram steps..

Mandatory access control

- Remember that **discretionary controls** assume that **the users are trustworthy**.
- A LOOPHOLE scneario:
- A «malicious» professor can easily violate confidentiality.

```
create table TakeAPeek(StudentId int, Title varchar(20),
                       Grade varchar(2));

grant select on TakeAPeek to public;

insert into table TakeAPeek(StudentId, Title, Grade)
   select e.StudentId, c.Title, e.Grade
   from ENROLL e, SECTION k, COURSE c
   where e.SectionId=k.SectId and k.CourseId=c.CId;
```

- Since the professor is the owner, she can authorize anybody to look at “student grades” which is supposed to be private.
- Mandatory access control ensure confidentiality by assigning privileges to data, rather than to users.
- The IDEA in Mandatory access control : **When private data is copied to other tables, it still remains confidential.**
- This idea is implemented by **classification levels**. It may be built with security database software and additional discretionary SQL tools.

Security levels

- Each user,**S** and every object,**O** *(table,record,…)* and is assigned a clearances and security level.
  - Top secret **(TS)**
  - Secret **(S)**
  - Classified **(C)**
  - Unclassfied **(UC)**
- BELL-LaPADULA Model:
  - **Read Property: S** can **read** O; IFF **class(S) ≥ class(O):** A user is authorized to READ an object «only if» his level is at least as **HİGH** as the security level of the object.
  - **Write Property: S** can **write** O; IFF **class(S) ≤ class(O):** A user is authorized to WRITE an object «only if» his level is at least as **LOW** as the security level of the object. *(Information MUST flow from lower security level to higher)*

```
create table TakeAPeek(StudentId int, Title varchar(20),
                       Grade varchar(2));
insert into table TakeAPeek(StudentId, Title, Grade)
   select e.StudentId, c.Title, e.Grade
   from ENROLL e, SECTION k, COURSE c
   where e.SectionId=k.SectId and k.CourseId=c.CId;
```

  - class(Prof) = S, class(TakeAPeek)= S
  - Other users (like students,..) class(student) = C. They cannot READ due to Read prop.

Examples:

- A LOOPHOLE scneario:

  User «Tricky» : CREATE TABLE T (….)

  «Tricky» : GRANT *insert* on **T** to Prof;

  Tricky modify app code of User «Prof» that enters Student Grades by writing(copying) grades into table **T.**

  «Prof» enters grades that is supposed to be secret. However, it is seen by «Tricky».

- In case of Mandatory Model:

  class(Prof) = S ➔ class(Application)=S

  class(Tricky) = C ➔ class(T) = C

  Due to Write prop. Prof's application CANNOT write to T.

```
select c.Title
from ENROLL e, SECTION k, COURSE c
where e.SectionId=k.SectId and k.CourseId=c.CId
and e.Grade='F'
```

- Suppose ENROLL's level is *secret*, SECTION's level is *classified* and COURSE's level is *unclassified*. In such a case,
  - the user that has at least a level of *secret* is able to execute the query.
  - The **query's output table** has **the highest level** of its input tables = **S**

Covert Channels

- **«Inference» of information** about DB objects
  - that have higher security levels. (mandatory model)
  - in statistical DBs. (s.a. OLAP, Data warehouse)
  - Distributed databases. (more complex scenarios..)

Eid	SectionId	StudentId	Grade	Security Class
101	10	1234	A	**S**
102	11	1235	B	**C**

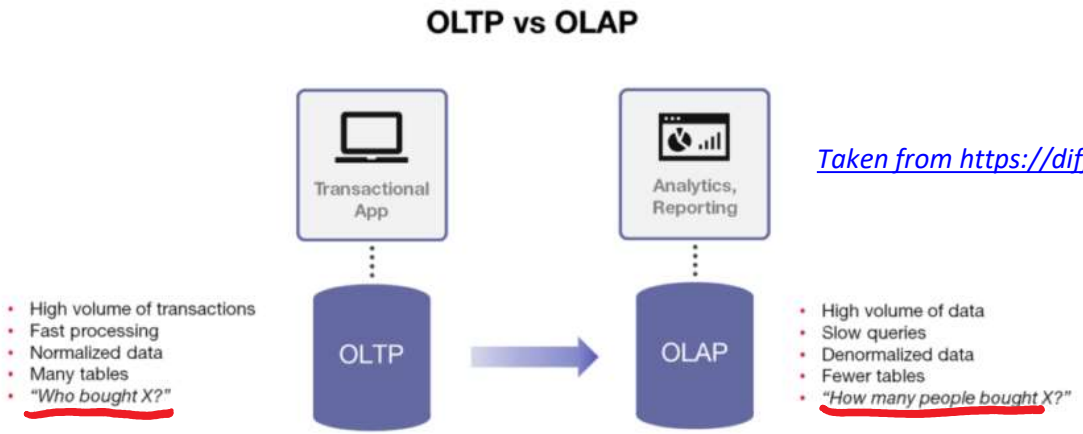
- Users with **U** clearance can see 0 tuple.
- Users with **S** or **TS** clearance can see 2 tuple.
- Users with **C** clearance can see 1 tuple.

Scenario: Users with **C** clearance: **insert <101, …..>**

If Accept: PK violation !

If Reject: Covert Channel !

Statistical DBs (OLAP)



[Taken from https://diffzi.com/oltp-vs-olap/](https://diffzi.com/oltp-vs-olap/)

Sid	SName	Major	Age	GPA
101	Mehmet	10	24	2,36
102	Ahmet	12	**35**	**3,7**

- OLAP can allow **only** statistical queries.
  - Everyone knows Ahmet is the oldest student. Can «User-Tricky» know Ahmet's age, GPA ..?
  - Tricky repeatedly ask : **Q1:** «**How many** students are there whose **age** is greater_equal **(≥)** than X?» **(increment X until the answer is 1) ➔ X=35 !!**
  - Tricky ask : **Q2:** «What is the **max** GPA of students whose **age** is greater_equal **(≥)** than **X=35?**» ➔ Tricky gets Ahmet's GPA=3,7

Preventing inference in OLAP

- «Each query MUST involve at least **N** rows to run»
  - Q1 runs. But Q2 fails. Tricky is decisive, does not give up :)..
  - Tricky repeatedly ask : **Q1:** «**How many** students are there whose **age** is greater_equal **(≥)** than X?» **(increment X until Result is N) , Say, X=28**
  - **Q3:** «What is the **sum of** GPA of all students whose **age** is greater_equal **(≥)** than X=28?» ➔ **The result includes «Ahmet»'s GPA.**
  - **Q4:** «What is the **sum of** GPA of all students **other than «Ahmet»,** whose age is greater_equal **(≥)** than X=28 and **including «himself(Tricky)?»**
  - **Ahmet's GPA= Q3- (Q4-Tricky's own GPA)** ➔ Tricky gets Ahmet's GPA=3,7

SUMMARY on Authorization methods

Prefered in commercial databases

- Discretionary access control
  - Privileges are associated with tables
  - Based on the assumption that the users are trustworthy.
  - Provided by SQL and flexible
- Mandotary access control
  - Privileges are associated with data
  - Eliminates the loopholes of dicreationary method, thus suited for high-security systems (like military)
  - Less flexible