CS660: Intro to Database Systems

Class 4: SQL, The Query Language – Part II

Instructor: Manos Athanassoulis

https://bu-disc.github.io/CS660/

Nested Queries

WHERE clause can itself contain an SQL query!

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.sid IN (SELECT R.sid
                 FROM  Reserves R
                 WHERE  R.bid=103)
```

Nested Queries with Correlation

Subquery must be recomputed for each Sailors tuple.

Think of subquery as a function call that runs a query!

```
SELECT  S.sname
FROM  Sailors S
WHERE EXISTS (SELECT  *
              FROM  Reserves R
              WHERE R.bid=103 AND S.sid=R.sid)
```

Let's revisit Query #3

3. Find all sailors who have <u>not</u> reserved a red boat

```
SELECT S.sid
FROM   Sailors S
EXCEPT
SELECT R.sid
FROM   Boats B,Reserves R
WHERE  R.bid=B.bid
       AND B.color='red'
```

Reserves (sid, bid, day) **Sailors** (sid, sname, rating, age)

Boats (bid, bname, color)

Set-Difference using NOT IN

Find all sailors who have not reserved a red boat

```
SELECT S.sid
FROM   Sailors S
WHERE  S.sid NOT IN
           (SELECT R.sid
            FROM Reserves R, Boats B
            WHERE R.bid = B.bid
                  AND B.color = ‘red’)
```

Nested – NO correlation!

Reserves (sid, bid, day) **Sailors** (sid, sname, rating, age)

Boats (bid, bname, color)

Set-Difference using NOT EXISTS

Find all sailors who have not reserved a red boat

```
SELECT S.sid
FROM   Sailors S
WHERE  NOT EXISTS
           (SELECT *
            FROM Reserves R, Boats B
            WHERE R.sid = S.sid
                  AND R.bid = B.bid
                  AND B.color = 'red')
```

Nested – correlation!

Reserves (sid, bid, day) **Sailors** (sid, sname, rating, age)

Boats (bid, bname, color)

Set Operations

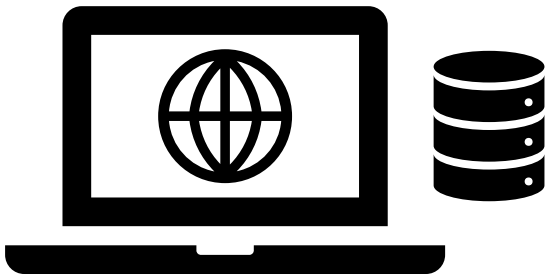
```
SELECT R.sid
FROM   Boats B, Reserves R
WHERE  R.bid=B.bid
       AND B.color='red'
UNION
SELECT R.sid
FROM   Boats B, Reserves R
WHERE  R.bid=B.bid
       AND B.color='green'
```

```
SELECT S.sid
FROM Sailors S, Boats B,
     Reserves R
WHERE S.sid=R.sid
      AND R.bid=B.bid
      AND B.color='red'
INTERSECT
SELECT S.sid
FROM Sailors S, Boats B,
     Reserves R
WHERE S.sid=R.sid
     AND R.bid=B.bid
     AND B.color='green'
```

Let's revisit UNION

we said they are equivalent

but do they always give the same result?



example

```
SELECT R.sid
FROM Boats B,Reserves R
WHERE R.bid=B.bid AND
(B.color='red' OR B.color='green')
```

VS.

example

```
SELECT  R.sid
FROM Boats B, Reserves R
WHERE R.bid=B.bid AND B.color='red'
UNION SELECT R.sid
      FROM Boats B, Reserves R
      WHERE  R.bid=B.bid AND
             B.color='green'
```

ANY and ALL Set-Comparison Operators

Find sailors with rating greater than the rating of at least one sailor called ‘Horatio’:

```
SELECT  *
FROM  Sailors S
WHERE  S.rating > ANY (SELECT  S2.rating
                       FROM  Sailors S2
                      WHERE S2.sname=‘Horatio’)
```

Find sailors with rating greater than the rating of all 20-year old sailors:

```
SELECT  *
FROM  Sailors S
WHERE  S.rating > ALL (SELECT  S2.rating
                       FROM  Sailors S2
                      WHERE S2.age = 20)
```

Division ("for all") in SQL

Find sailors who have reserved all boats.

Sailors S for which …

```
SELECT S.sname
FROM   Sailors S
WHERE  NOT EXISTS (SELECT B.bid
                   FROM Boats B
                   WHERE NOT EXISTS (SELECT R.bid
                                     FROM Reserves R
                                     WHERE R.bid=B.bid
                                     AND R.sid=S.sid))
```

there is no boat B without …

a Reserves tuple showing S reserved B

Division ("for all") in SQL - alternative

Find sailors who have reserved all boats.

Sailors S for which …

```
SELECT S.sname
FROM   Sailors S
WHERE  NOT EXISTS  (SELECT  B.bid
                    FROM  Boats B
                    EXCEPT
                                  (SELECT  R.bid
                                   FROM  Reserves R
                                   WHERE  R.bid=B.bid
                                AND R.sid=S.sid))
```

there is no boat B without …

a Reserves tuple showing S reserved B

Aggregate Operators

Significant extension of relational algebra.

COUNT (*)
COUNT ([DISTINCT] A)
SUM ([DISTINCT] A)
AVG ([DISTINCT] A)
MAX (A)
MIN (A)

single column

```
SELECT  COUNT (*)
FROM  Sailors S

SELECT  AVG (S.age)
FROM  Sailors S
WHERE  S.rating=10

SELECT  COUNT (DISTINCT S.rating)
FROM  Sailors S
WHERE S.sname='Bob'
```

Aggregate Operators

COUNT (*)
COUNT ([DISTINCT] A)
SUM ([DISTINCT] A)
AVG ([DISTINCT] A)
MAX (A)
MIN (A)

single column

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.rating = (SELECT  MAX(S2.rating)
                   FROM  Sailors S2)
```

```
SELECT  AVG (DISTINCT S.age)
FROM  Sailors S
WHERE  S.rating=10
```

Find name and age of the oldest sailor(s)

The first query is incorrect!

```
SELECT  S.sname, MAX (S.age)
FROM  Sailors S
```

Third query equivalent to second query

allowed in SQL/92 standard, but not supported in some systems.

```
SELECT  S.sname, S.age
FROM  Sailors S
WHERE  S.age =
       (SELECT  MAX (S2.age)
        FROM    Sailors S2)
```

```
SELECT  S.sname, S.age
FROM  Sailors S
WHERE  (SELECT  MAX (S2.age)
        FROM    Sailors S2)
               = S.age
```

ARGMAX?

The Sailor with the highest rating

What about ties for highest?

```
SELECT *
FROM   Sailors S
WHERE  S.rating >= ALL
   (SELECT  S2.rating
    FROM    Sailors S2)
```

```
SELECT *
FROM   Sailors S
WHERE  S.rating =
(SELECT  MAX(S2.rating)
   FROM  Sailors S2)
```

```
SELECT *
FROM   Sailors S
ORDER BY rating DESC
LIMIT 1;
```

JOINS

Joins

```
SELECT (column_list)
FROM  table_name
 [INNER | NATURAL | {LEFT | RIGHT | FULL} | {OUTER}]
JOIN table_name
    ON qualification_list
WHERE …
```

INNER is default

SELECT sname FROM sailors S JOIN reserves R ON S.sid=R.sid;

SELECT sname FROM sailors S NATURAL JOIN reserves R

WHERE R.bid = 102;

Inner Joins

```
SELECT s.sid, s.sname, r.bid
  FROM Sailors s, Reserves r
 WHERE s.sid = r.sid
```

```
SELECT s.sid, s.sname, r.bid
 FROM Sailors s INNER JOIN Reserves r
              ON s.sid = r.sid
```

They are equivalent!

Left Outer Join

Returns all matched rows, plus all unmatched rows from the table on the **left** of the join clause

(use nulls in fields of non-matching tuples)

```
SELECT s.sid, s.sname, r.bid
  FROM Sailors s LEFT OUTER JOIN
       Reserves r
        ON s.sid = r.sid;
```

Returns all sailors & bid for boat in any of their reservations

Note: no match for s.sid? r.sid `IS NULL`!

```
SELECT s.sid, s.sname, r.bid
  FROM Sailors s LEFT OUTER JOIN Reserves r
                 ON s.sid = r.sid;
```

sid	sname	rating	age
22	Dustin	7	45.0
31	Lubber	8	55.5
95	Bob	3	63.5

sid	bid	day
22	101	10/10/96
95	103	11/12/96

s.sid	s.name	r.bid
22	Dustin	101
95	Bob	103
31	Lubber	

NULL

Right Outer Join

Returns all matched rows, plus all unmatched rows from the table on the **right** of the join clause

(use nulls in fields of non-matching tuples)

```
SELECT r.sid, b.bid, b.bname
  FROM Reserves r RIGHT OUTER JOIN
       Boats b
        ON r.bid = b.bid;
```

Returns all boats & information on which ones are reserved

Note: no match for b.bid? r.bid `IS NULL`!

Full Outer Join

Full Outer Join returns all (matched or unmatched) rows from the tables on both sides of the join clause

```
SELECT r.sid, b.bid, b.bname
  FROM Reserves2 r FULL OUTER JOIN
       Boats2 b
        ON r.bid = b.bid;
```

Returns all boats & all information on reservations

No match for r.bid?

- b.bid IS NULL AND b.bname is NULL

No match for b.bid?

- r.sid is NULL

GROUP BY AND HAVING

GROUP BY and HAVING

So far, we've applied aggregate operators to all (qualifying) tuples.

Sometimes, we want to apply them to each of several *groups* of tuples.

Consider: *Find the age of the youngest sailor for each rating level.*

In general, we don't know how many rating levels exist, and what the rating values for these levels are!

Suppose we know that rating values go from 1 to 10; we can write 10 queries that look like this (!):

For $i = 1, 2, \ldots, 10$:

```
SELECT MIN (S.age)
FROM   Sailors S
WHERE  S.rating = i
```

Queries With GROUP BY and HAVING

```
SELECT      [DISTINCT]  target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
[HAVING     group-qualification]
```

Group rows by columns in *grouping-list*

Every column from *target-list* mast appear in the *grouping-list*

HAVING restricts through an *aggregate* which group-rows are part of the result

Conceptual Evaluation

(1) Cross-product of *relation-list*

(2) Select only tuples that follow the where clause *qualification*)

(3) Partition rows by the value of attributes in *grouping-list*

(4) Select only groups that follow the *group-qualification*

Attributes in *target-list* must also be in *grouping-list*.

(5) One answer tuple is generated per qualifying group, showing *target-list*

Expressions in *group-qualification* must have a *single value per group*! That is, attributes in *group-qualification* must be part of an aggregate op / must appear in the *grouping-list*.

Find the age of the youngest sailor with age ≥ 18,
for each rating with at least 2 such sailors

```
SELECT  S.rating,  MIN (S.age)
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
71	zorba	10	16.0
64	horatio	7	35.0
29	brutus	1	33.0
58	rusty	10	35.0

2

rating	age
1	33.0
7	45.0
7	35.0
8	55.5
10	35.0

3

rating	m-age	count
1	33.0	1
7	35.0	2
8	55.0	1
10	35.0	1

4

rating	
7	35.0

```
SELECT   S.sname, S.sid
FROM     Sailors S, reserves R
WHERE    S.sid = R.sid
GROUP BY S.sname, S.sid
HAVING   COUNT(DISTINCT R.bid) =
         (Select COUNT (*) FROM Boats)
```

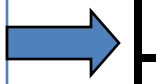
s.sname	s.sid	r.sid	r.bid
Dustin	22	22	101
Lubber	31	22	101
Bob	95	22	101
Dustin	22	95	102
Lubber	31	95	102
Bob	95	95	102

bid	bname	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

Count (*) from boats = 4

s.sname	s.sid	bcount
Dustin	22	1
Bob	95	1

Apply having clause to groups



s.sname	s.sid

```
SELECT  S.rating,  MIN (S.age)
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

can I ask…

```
SELECT  S.rating,  MIN (S.age)
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  S.name = 'Horatio'
```

what about …

```
SELECT  S.rating,  MIN (S.age)
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  S.rating < 9
```

or…

```
...
GROUP BY  S.rating
HAVING  MIN (S.age) < 30
```

Sorting the Results of a Query

ORDER BY *column* [ASC | DESC] [, ...]

```
SELECT   S.rating, S.sname, S.age
FROM     Sailors S, Boats B, Reserves R
WHERE    S.sid=R.sid AND R.bid=B.bid
         AND B.color='red'
ORDER BY S.rating, S.sname;
```

Extra reporting power obtained by combining with aggregation.

```
SELECT   S.sid, COUNT (*) AS redrescnt
FROM     Sailors S, Boats B, Reserves R
WHERE    S.sid=R.sid AND R.bid=B.bid
         AND B.color='red'
GROUP BY S.sid
ORDER BY redrescnt DESC;
```

Summary: The SQL Query

```
SELECT      [DISTINCT]  target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
ORDER BY    attribute-list
```

Remember? Division ("for all") in SQL

Find sailors who have reserved all boats.

Sailors S for which …

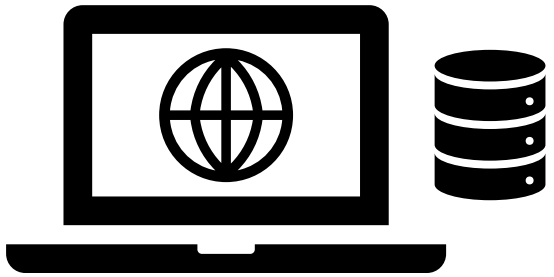
```
SELECT S.sname
FROM   Sailors S
WHERE  NOT EXISTS (SELECT B.bid
                   FROM   Boats B
                   WHERE  NOT EXISTS (SELECT R.bid
                                      FROM   Reserves R
                                      WHERE  R.bid=B.bid
                                      AND R.sid=S.sid))
```

there is no boat B without …

a Reserves tuple showing S reserved B

Can you do this using Group By and Having?

Find sailors who have reserved all boats.



```
SELECT   S.sname
FROM     Sailors S, Reserves R
WHERE    S.sid = R.sid
GROUP BY S.sname, S.sid
HAVING   COUNT(DISTINCT R.bid) =
         (Select COUNT (*) FROM Boats)
```

Note: must have both sid and name in the GROUP BY clause. Why?

(1) Attributes in *target-list* must also be in *grouping-list*.
(2) Expressions in *group-qualification* must have a *single value per group*!
(3) Without sid we are grouping together sailors with the same name!

An Illustration

```
SELECT  S.name
FROM  Sailors S, reserves R
WHERE  S.sid = R.sid
GROUP BY S.name, S.sid
HAVING COUNT(DISTINCT R.bid) =
        ( Select COUNT (*) FROM
                        Boats)
```

Sailors

sid	sname	rating	age
1	Frodo	7	22
2	Bilbo	2	39
3	Sam	8	27

Boats

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

Reserves

sid	bid	day
1	102	9/12
2	102	9/12
2	101	9/14
1	102	9/10
2	103	9/13

sname	sid	bid
Frodo	1	102
Bilbo	2	101
Bilbo	2	102
Frodo	1	102
Bilbo	2	103

sname	sid	count
Frodo	1	1
Bilbo	2	3

count
3

sname	sid	bid
Frodo	1	102,102
Bilbo	2	101, 102, 103

REVISITING DDL, NULL, AND MORE

INSERT [INTO] *table_name* [(*column_list*)]
VALUES (value_list)

INSERT [INTO] *table_name* [(*column_list*)]
<select statement>

INSERT INTO Boats VALUES (105, ‘Clipper’, ‘purple’)
INSERT INTO Boats (bid, color) VALUES (99, ‘yellow’)

You can also do a “bulk insert” of values from one table into another:

```
INSERT INTO TEMP(bid)
SELECT r.bid FROM Reserves R WHERE r.sid = 22;
```

(must be type compatible)

DELETE [FROM] *table_name*
[WHERE *qualification*]

DELETE FROM Boats WHERE color = ‘red’

DELETE FROM Boats b
WHERE b. bid =
(SELECT r.bid FROM Reserves R WHERE r.sid = 22)

Can also modify tuples using UPDATE statement.

```
UPDATE Boats
SET Color = “green”
WHERE bid = 103;
```

Null Values

Field values in a tuple are sometimes *unknown* (e.g., a rating has not been assigned) or *inapplicable* (e.g., no spouse's name).

- SQL provides a special value *null* for such situations.

The presence of *null* complicates many issues. E.g.:

- Special operators needed to check if value is/is not *null*. IS NULL/IS NOT NULL
- Is *rating>8* true or false when *rating* is equal to *null*? What about AND, OR and NOT connectives?
- We need a 3-valued logic (true, false and *unknown*).
- Meaning of constructs must be defined carefully. (e.g., WHERE clause eliminates rows that don't evaluate to true.)
- New operators (in particular, *outer joins*) possible/needed.

NULLs

example

branch2=

bname	bcity	assets
Downtown	Boston	9M
Perry	Horse	1.7M
Mianus	Horse	.4M
Kenmore	Boston	NULL

What does this mean?

We don't know Kenmore's assets?
Kenmore has no assets?
.....

Effect on Queries:

SELECT * FROM branch2 WHERE assets = NULL

bname	bcity	assets

SELECT * FROM branch2 WHERE assets IS NULL

bname	bcity	assets
Kenmore	Boston	NULL

NULLs

Arithmetic with nulls:

- n <op> null = null

  <op> : + , - , *, /, mod, ...

"Booleans" with nulls: One can write:

3-valued logic (true, false, unknown)

```
SELECT   .....
FROM     .....
WHERE boolexpr IS UNKNOWN
```

What expressions evaluate to UNKNOWN?

1. Comparisons with NULL (e.g., assets = NULL)
2. FALSE OR UNKNOWN (but: TRUE OR UNKNOWN = TRUE)
3. TRUE AND UNKNOWN
4. UNKNOWN AND/OR UNKNOWN

NULLs

Aggregate operations:

SELECT SUM(assets)
FROM branch2

returns

SUM

11.1M

branch2=

bname	bcity	assets
Downtown	Boston	9M
Perry	Horse	1.7M
Mianus	Horse	.4M
Kenmore	Boston	NULL

NULL is ignored
Same for AVG, MIN, MAX

Let branch3 an empty relation
Then: SELECT SUM(assets)
FROM branch3 returns NULL

but SELECT COUNT(*) FROM branch3 returns 0

Views

Makes development **simpler**
Often used for **security**
Not instantiated - makes updates tricky

CREATE VIEW *view_name*
AS *select_statement*

```
CREATE VIEW Reds
AS SELECT  B.bid,  COUNT (*) AS scount
    FROM Boats B, Reserves R
    WHERE  R.bid=B.bid AND   B.color='red'
     GROUP BY  B.bid
```

An illustration

```
CREATE VIEW Reds
AS SELECT  B.bid,  COUNT (*) AS scount
    FROM Boats B, Reserves R
    WHERE  R.bid=B.bid AND   B.color='red'
     GROUP BY  B.bid
```

bid	bname	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

b.bid	scount
102	1

Reds

Views Instead of Relations in Queries

```
CREATE VIEW Reds
AS SELECT  B.bid,  COUNT (*) AS scount
    FROM Boats B, Reserves R
    WHERE  R.bid=B.bid AND   B.color='red'
     GROUP BY  B.bid
```

```
SELECT  bname, scount
    FROM Reds R, Boats B
    WHERE  R.bid=B.bid
        AND scount < 10
```

b.bid	scount
102	1

Reds

Views vs INTO

(1)
```
SELECT bname, bcity
FROM   branch
INTO   branch2
```

vs

(2)
```
CREATE VIEW branch2 AS
SELECT  bname, bcity
FROM    branch
```

(1) creates a new table that gets stored on disk

(2) creates a “virtual table” (materialized when needed)

Therefore: **changes** in branch are **seen** in (2) but **not** in (1)

Discretionary Access Control

GRANT *privileges* ON *object* TO *users* [WITH GRANT OPTION]

Object can be a Table or a View

Privileges can be:

- Select/Insert/Delete
- References (cols) – to create a foreign key references to <cols>
- All

Can later be REVOKED

Users can be single users or groups

See Chapter 17 for more details.

Assertions and Triggers

CONSTRAINTS

Integrity Constraints

- predicates on the database
- must always be true (checked whenever db gets updated)

There are the following 4 types of IC's:

Key constraints (1 table)

e.g., 2 accts can't share the same acct_no

Attribute constraints (1 table)

e.g., 2 accts must have nonnegative balance

Referential Integrity constraints (2 tables)

E.g. bnames associated w/ loans must be names of real branches

Global Constraints (n tables)

E.g., a loan must be carried by at least 1 customer with a svngs acct

Global Constraints

Idea: two kinds

1) **single relation** (constraints spans multiple columns)

   E.g.: CHECK (total = svngs + check) declared in the CREATE TABLE

2) **multiple relations**: CREATE ASSERTION

SQL examples:

1) **single relation**: All BOSTON branches must have assets > 5M

```
CREATE TABLE branch (
        .....
        bcity  CHAR(15),
        assets INT,
        CHECK (NOT(bcity = 'BOS') OR assets > 5M))
```

Affects:

insertions into branch

updates of bcity or **assets** in branch

Global Constraints

SQL example:

2) **Multiple relations**: every loan has a borrower with a savings account

```
CHECK (NOT EXISTS (
                SELECT   *
                FROM      loan AS L
                WHERE  NOT EXISTS(
                          SELECT   *
                          FROM borrower B, depositor D, account A
                          WHERE B.cname = D.cname  AND
                                    D.acct_no = A.acct_no  AND  L.lno  = B.lno)))
```

Problem: Where to put this constraint? At depositor? Loan? ....

Ans: None of the above:

```
CREATE ASSERTION loan-constraint
      CHECK(  ..... )
```

Checked with EVERY DB update!
very expensive.....

Global Constraints

Issues:

1) How does one decide what global constraint to impose?
2) How does one minimize the cost of checking the global constraints?

Ans: Semantics of application and Functional dependencies.

Summary: Integrity Constraints

Constraint Type	Where declared	Affects...	Expense
Key Constraints	CREATE TABLE (PRIMARY KEY, UNIQUE)	Insertions, Updates	Moderate
Attribute Constraints	CREATE TABLE CREATE DOMAIN (Not NULL, CHECK)	Insertions, Updates	Cheap
Referential Integrity	Table Tag (FOREIGN KEY …. REFERENCES ….)	1.Insertions into referencing rel'n 2. Updates of referencing rel'n of relevant attrs 3. Deletions from referenced rel'n 4. Update of referenced rel'n	1,2: like key constraints. Another reason to index/sort on the primary keys 3,4: depends on a. update/delete policy chosen b. existence of indexes on foreign key
Global Constraints	Table Tag (CHECK) or outside table (CREATE ASSERTION)	1. For single rel'n constraint, with insertion, deletion of relevant attrs 2. For assesrtions w/ every db modification	1. cheap 2. very expensive

Triggers (Active database)

- Trigger: A procedure that starts automatically if specified changes occur to the DBMS
- Analog to a "daemon" that monitors a database for certain events to occur
- Three parts:
  - Event (activates the trigger)
  - Condition (tests whether the triggers should run) [Optional]
  - Action (what happens if the trigger runs)
- Semantics:
  - When event occurs, and condition is satisfied, the action is performed.

An example of Trigger

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor
FOR EACH ROW
WHEN (new.salary < 100,000)
BEGIN
    RAISE_APPLICATION_ERROR (-20004, 'Violation of Minimum Professor Salary');
END;
```

Conditions can refer to **old/new** values of tuples modified by the statement activating the trigger.

Triggers – Event, Condition, Action

Events could be :

```
BEFORE|AFTER INSERT|UPDATE|DELETE ON <tableName>
```

e.g.: `BEFORE INSERT ON Professor`

Condition is SQL expression or even an SQL query (query with non-empty result means TRUE)

Action can be many different choices :

- SQL statements, and even DDL and transaction-oriented statements like “commit”.

Example Trigger

Assume our DB has a relation schema :

Professor (pNum, pName, salary)

We want to write a trigger that :

Ensures that any new professor inserted has salary >= 70000

Example Trigger

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor

     for what context  ?

BEGIN

    check for violation here ?

END;
```

Example Trigger

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor

     FOR EACH ROW

BEGIN

    check for violation here ?

END;
```

Example Trigger

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor

      FOR EACH ROW

BEGIN

  IF (:new.salary < 70000)
     THEN RAISE_APPLICATION_ERROR (-20004,
     'Violation of Minimum Professor Salary');
  END IF;

END;
```

Details of Trigger Example

BEFORE INSERT ON Professor

- This trigger is checked before the tuple is inserted

FOR EACH ROW

- specifies that trigger is performed for each row inserted

:new

- refers to the new tuple inserted

If (:new.salary < 70000)

- then an application error is raised and hence the row is not inserted; otherwise the row is inserted.

Use error code: -20004;

- this is in the valid range

Example Trigger Using Condition

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor
   FOR EACH ROW
WHEN (new.salary < 70000)
BEGIN
   RAISE_APPLICATION_ERROR (-20004,
   'Violation of Minimum Professor Salary');
END;
```

Conditions can refer to **old/new** values of tuples modified by the statement activating the trigger.

Triggers: REFERENCING

```
CREATE TRIGGER minSalary BEFORE INSERT ON Professor

REFERENCING NEW as newTuple

FOR EACH ROW

WHEN (newTuple.salary < 70000)

BEGIN
   RAISE_APPLICATION_ERROR (-20004,
   'Violation of Minimum Professor Salary');
END;
```

Example Trigger

```
CREATE TRIGGER updSalary
     BEFORE UPDATE ON Professor
REFERENCING OLD AS oldTuple NEW as newTuple
FOR EACH ROW
WHEN (newTuple.salary < oldTuple.salary)
BEGIN
   RAISE_APPLICATION_ERROR (-20004, 'Salary
   Decreasing !!');
END;
```

Ensure that salary does not decrease

Another Trigger Example (SQL:99)

```
CREATE TRIGGER  youngSailorUpdate
    AFTER  INSERT ON SAILORS
REFERENCING NEW TABLE AS NewSailors
FOR EACH STATEMENT
    INSERT
        INTO YoungSailors(sid, name, age, rating)
        SELECT sid, name, age, rating
        FROM NewSailors N
        WHERE N.age <= 18
```

Row vs Statement Level Trigger

- Row level: activated once per modified tuple
- Statement level: activate once per SQL statement

- Row level triggers can access new data, statement level triggers cannot always do that (depends on DBMS).

- Statement level triggers will be more efficient if we do not need to make row-specific decisions

Row vs Statement Level Trigger

Example: Consider a relation schema

Account (num, amount)

where we will allow creation of new accounts only during normal business hours.

Example: Statement level trigger

```
CREATE TRIGGER MYTRIG1
BEFORE INSERT ON Account
FOR EACH STATEMENT                  --- is default
BEGIN
   IF (TO_CHAR(SYSDATE,'dy') IN ('sat','sun'))
   OR
   (TO_CHAR(SYSDATE,'hh24:mi') NOT BETWEEN '08:00' AND '17:00')
    THEN
      RAISE_APPLICATION_ERROR(-20500,'Cannot   create new account now !!');
   END IF;
END;
```

When to use BEFORE/AFTER

Based on efficiency considerations or semantics.

Suppose we perform statement-level after insert,

➔all the rows are inserted first,

➔if the condition fails ➔ all inserts must be "rolled back"

Not very efficient !!

Combining multiple events into one trigger

```
CREATE TRIGGER salaryRestrictions
AFTER INSERT OR UPDATE ON Professor
FOR EACH ROW
BEGIN
IF (INSERTING AND :new.salary < 70000) THEN
  RAISE_APPLICATION_ERROR (-20004, 'below min salary');
END IF;
IF (UPDATING AND :new.salary < :old.salary) THEN
  RAISE_APPLICATION_ERROR (-20004, 'Salary Decreasing !!');
END IF;
END;
```

Summary : Trigger Syntax

```
CREATE TRIGGER <triggerName>
BEFORE|AFTER   INSERT|DELETE|UPDATE
   [OF <columnList>] ON <tableName>|<viewName>
   [REFERENCING [OLD AS <oldName>] [NEW AS <newName>]]
[FOR EACH ROW] (default is “FOR EACH STATEMENT”)
[WHEN (<condition>)]
<PSM body>;
```

Constraints versus Triggers

- Constraints are useful for database consistency
  - Use IC when sufficient
  - More opportunity for optimization
  - Not restricted into insert/delete/update

- Triggers are flexible and powerful
  - Alerters
  - Event logging for auditing
  - Security enforcement
  - Analysis of table accesses (statistics)
  - Workflow and business intelligence …

But can be **hard** to understand ……

- Several triggers (Arbitrary order → unpredictable!)
- Chain triggers (When to stop ?)
- Recursive triggers (Termination?)

Links for Examples

Schema is available at:
https://gist.github.com/manathan1984/35b189ae92fd996cce7816e2d7f9e40f

Lightweight online SQL frontend:
http://sqlfiddle.com/