Databases

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SQL Overview

Overview

1. `SELECT-FROM-WHERE` Blocks, Tuple Variables
2. Subqueries, Non-Monotonic Constructs
3. Aggregations I: Aggregation Functions
4. Aggregations II: `GROUP BY`, `HAVING`
5. `UNION`, Conditional Expressions
6. `ORDER BY`
7. SQL-92 Joins, Outer Join

Basic SQL Query Syntax

Basic SQL query (extensions follow)

SELECT $A_1, \ldots, A_n$
FROM $R_1, \ldots, R_m$
WHERE C

- The **`FROM` clause** declares which **table(s)** are accessed.
- The **`WHERE` clause** specifies a **condition** for rows in these tables that are considered in this query.

  The absence of C is equivalent to `TRUE`.
- The **`SELECT` clause** specifies the attributes of the **result**.

  Here $*$ means output all attributes occurring in $R_1, \ldots, R_m$.

Example Database

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

EXERCISES

CAT	ENO	TOPIC	MAXPT
H	1	Rel.Alg.	10
H	2	SQL	10
M	1	SQL	14

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

Tuple Variables

The FROM clause can be understood as **declaring variables** that **range over tuples** of a relation.

EXERCISES

CAT	ENO	TOPIC	MAXPT
H	1	Rel.Alg.	10
H	2	SQL	10
M	1	SQL	14

```
SELECT  E.ENO, E.TOPIC
FROM    EXERCISES E
WHERE   E.CAT = 'H'
```

1	Rel.Alg.
2	SQL

- The query may be thought of as

```
for all E ∈ EXERCISES do
   if E.CAT = 'H' then
      print E.ENO, E.TOPIC
   end if
end for
```

- **Tuple variable** E represents a **single row** of EXERCISES.

  The loop assigns each row in succession.

Tuple Variables

```
EXERCISES(CAT,ENO,TOPIC,MAXPT)
```

- For each table in the `FROM` clause there is a tuple variable.
- If the the name of the tuple variable is not given explicitly, the variable will have the name of the relation:

```
SELECT  EXERCISES.ENO, EXERCISES.TOPIC
FROM    EXERCISES
WHERE   EXERCISES.CAT = 'H'
```

  In other words, `FROM EXERCISES` is understood as:

```
FROM EXERCISES EXERCISES
```

- If a tuple variable is explicitly declared, e.g.:

```
FROM EXERCISES E
```

  then the implicit tuple variable `EXERCISES` is **not** declared and `EXERCISES.ENO` will yield an error.

Attribute References

`STUDENTS(SID,FIRST,LAST,EMAIL)` `RESULTS(SID,CAT,ENO,POINTS)`

Attributes are referenced in the form

$$R.A$$

A reference to attribute A of variable R may be written as

$$A$$

if R is **the only tuple variable** with an attribute named A.

For example,

```
SELECT  CAT, ENO, POINTS
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID
    AND FIRST = 'Ann' AND LAST = 'Smith'
```

- `FIRST`, `LAST` can only refer to `S`
- `CAT`, `ENO`, `POINTS` can only refer to `R`
- `SID` on its own is **ambiguous** (may refer to `S` or `R`)

Attribute References

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Consider this query:

```
SELECT  ENO, SID, POINTS, MAXPT
FROM    RESULTS R, EXERCISES E
WHERE   R.ENO = E.ENO
    AND R.CAT = 'H' AND E.CAT = 'H'
```

Here `ENO` in the `SELECT` clause is ambiguous.

Although forced to be equal by the join condition, SQL requires the user to specify unambiguously which of the `ENO` attributes (bound to `R` or `E`) is meant.

The unambiguity rule thus is purely **syntactic** and does not depend on the query semantics.

Joins

STUDENTS(SID,FIRST,LAST,EMAIL) RESULTS(SID,CAT,ENO,POINTS)

Consider a query with two tuple variables:

```
SELECT  A_1, ..., A_n
FROM    STUDENTS S, RESULTS R
WHERE   C
```

- S ranges over 4 tuples in STUDENTS
- R ranges over 8 tuples in RESULTS

In principle, all $4 \times 8 = 32$ combinations will be considered:

```
for all S ∈ STUDENTS do
  for all R ∈ RESULTS do
    if C then
      print A_1, ..., A_n
    end if
  end for
end for
```

Joins

A good DBMS will use a **better evaluation algorithm** (depending on the condition *C*).

- This is the task of the **query optimiser.**

For understanding the **semantics** of a query, the simple nested `foreach` algorithm suffices:

- The query optimizer may use any algorithm that produces the **exact same output** (except possibly the tuple order).

For example, if *C* contains the join condition

```
S.SID = R.SID
```

then the DBMS might execute the query efficiently by:

- looping over the tuples in `RESULTS`,
- finding the matching `STUDENTS` tuple via an **index** on `STUDENT.SID`

DBMS typically create an index over the key attributes.

Joins

A **join** needs to be explicitly specified in the `WHERE` clause:

```
SELECT  R.CAT, R.ENO, R.POINTS
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID       -- Join Condition
    AND S.FIRST = 'Ann' AND S.LAST = 'Smith'
```

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

Output of this query?

```
SELECT  S.FIRST, S.LAST
FROM    STUDENTS S, RESULTS R
WHERE   R.CAT = 'H' AND R.ENO = 1
```

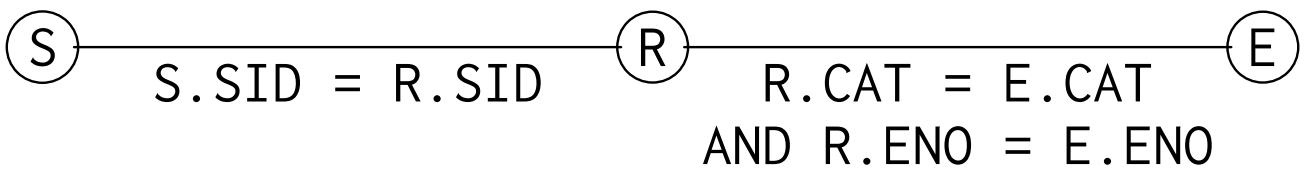
Joins

Guideline: it is almost always an **error** if there are two tuples variables which are **not linked** (directly or indirectly) via join conditions.

In this query, all three tuple variables are connected:

```
SELECT E.CAT, E.ENO, R.POINTS, E.MAXPT
FROM   STUDENTS S, RESULTS R, EXERCISES E
WHERE  S.SID = R.SID
   AND R.CAT = E.CAT AND R.ENO = E.ENO
   AND S.FIRST = 'Ann' AND S.LAST = 'Smith'
```

- The tuple variable connection works as follows:



- Often (like in this example), the conditions correspond to the **foreign key relationships** between the tables.

Query Formulation

Formulate the following query in SQL

Which are the topics of all exercises solved by Ann Smith?

To formulate this query:

- consider that Ann Smith is a student, we need
  - tuple variable `S` over `STUDENTS`
  - identifying condition in the `WHERE` clause
    `S.FIRST = 'Ann' AND S.LAST = 'Smith'`
- exercise topics are of interest, so we need
  - tuple variable `E` over `EXERCISES`

Thus we start from:

```
SELECT DISTINCT E.TOPIC
FROM STUDENTS S, EXERCISES E
WHERE S.FIRST = 'Ann' AND S.LAST = 'Smith'
```

(`DISTINCT` since several exercises may have the same topic.)

Query Formulation

```
SELECT DISTINCT E.TOPIC
FROM STUDENTS S, EXERCISES E
WHERE S.FIRST = 'Ann' AND S.LAST = 'Smith'
```

Note: S and E are still **unconnected**:

- The **connection graph** of the tables in a database schema (connections are foreign key relations) helps in understanding the connection requirements:


```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

- We see that the S–E connection is **indirect** and needs to be established via a tuple variable R over RESULTS:

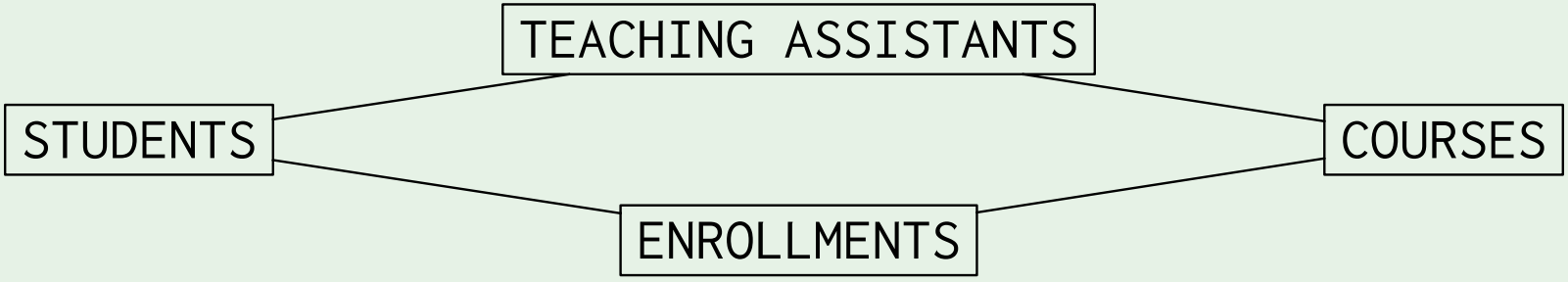
```
S.SID = R.SID AND R.CAT = E.CAT AND R.ENO = E.ENO
```

Query Formulation

It is not always that trivial. . .

The connection graph may contain **cycles**, which makes the selection of the “right path” more difficult (and error-prone).

Consider a course registration database that also contains teaching assistants assignments:



Unnecessary Joins

Do not join **more** tables than needed.

Query will run slowly if the optimizer overlooks the redundancy.

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Results for homework 1

```
SELECT  R.SID, R.POINTS
FROM    RESULTS R, EXERCISES E
WHERE   R.CAT = E.CAT AND R.ENO = E.ENO
    AND E.CAT = 'H' AND E.ENO = 1
```

Will the following query produce the same results?

```
SELECT  SID, POINTS
FROM    RESULTS R
WHERE   R.CAT = 'H' AND R.ENO = 1
```

Unnecessary Joins

EXERCISES

CAT	ENO	TOPIC	MAXPT
H	1	Rel.Alg.	10
H	2	SQL	10
M	1	SQL	14

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

What will be the result of this query?

```
SELECT  R.SID, R.POINTS
FROM    RESULTS R, EXERCISES E
WHERE   R.CAT = 'H' AND R.ENO = 1
```

Unnecessary Joins

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

Is there any difference between these two queries?

```
SELECT  S.FIRST, S.LAST
FROM    STUDENTS S

SELECT  DISTINCT S.FIRST, S.LAST
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID
```

Self Joins

In some query scenarios, we might have to consider **more than one tuple of the same relation** to generate a result tuple.

Is there a student with 9 points for both, homework 1 & 2?

```
SELECT  S.FIRST, S.LAST
FROM    STUDENTS S, RESULTS H1, RESULTS H2
WHERE   S.SID = H1.SID AND S.SID = H2.SID
    AND H1.CAT = 'H' AND H1.ENO = 1
    AND H2.CAT = 'H' AND H2.ENO = 2
    AND H1.POINTS = 9 AND H2.POINTS = 9
```

Self Joins

Find students who solved at least two exercises.

(This may also be solved using aggregations.)

```
SELECT  S.FIRST, S.LAST
FROM    STUDENTS S, RESULTS E1, RESULTS E2
WHERE   S.SID = E1.SID AND S.SID = E2.SID
```

“Unexpected” result

What is going wrong here?

We need to ensure that `E1` and `E2` refer to distinct exercises:

```
        ⋮
        AND (E1.CAT <> E2.CAT OR E1.ENO <> E2.ENO)
```

Duplicate Elimination

A core difference between SQL and relational algebra is that **duplicates have to explicitly eliminated** in SQL.

Which exercises have been solved by at least one student?

```
SELECT  CAT, ENO
FROM    RESULTS
```

CAT	ENO
H	1
H	2
M	1
H	1
⋮	⋮

The **DISTINCT** modifier may be applied to the SELECT clause to request explicit duplicate row elimination

```
SELECT  DISTINCT CAT, ENO
FROM    RESULTS
```

CAT	ENO
H	1
H	2
M	1

Duplicate Elimination

Intuition behind the algorithm: think of $\mathcal{K}$ as the set of attributes that are uniquely determined by the result.

Sufficient condition for superfluous `DISTINCT`

Assumption: `WHERE` clause is a conjunction (`AND`).

1. Let $\mathcal{K}$ be the set of attributes in the `SELECT` clause.
2. Add to $\mathcal{K}$ attributes A such that
   - $A = c$ for a constant c is in the `WHERE` clause, or
   - $A = B$ for $B \in \mathcal{K}$ is in the `WHERE` clause, or
   - if $\mathcal{K}$ contains a key of a tuple variable, add all attributes of that variable.

   Repeat 2 until $\mathcal{K}$ is stable.

If $\mathcal{K}$ **contains a key of every tuple variable** listed under `FROM`, then `DISTINCT` is superfluous.

Duplicate Elimination

```
SELECT  DISTINCT S.FIRST, S.LAST, R.ENO, R.POINTS
FROM    STUDENTS S, RESULTS R
WHERE   R.CAT = 'H' AND R.SID = S.SID
```

Let us assume that (FIRST, LAST) is a key for STUDENTS.

1. Initialize $\mathcal{K} = \{$S.FIRST, S.LAST, R.ENO, R.POINTS$\}$.
2. $\mathcal{K} + \{$R.CAT$\}$ because of R.CAT = 'H'
2. $\mathcal{K} + \{$S.SID, S.EMAIL$\}$ as $\mathcal{K}$ contains a key of STUDENTS
2. $\mathcal{K} + \{$R.SID$\}$ because of the conjunct S.SID = R.SID

$\mathcal{K}$ contains a key of

- STUDENTS S (S.FIRST, S.LAST) and
- RESULTS R (R.SID, R.CAT, R.ENO)

Thus DISTINCT is superfluous.

If FIRST, LAST were no key of STUDENTS, this test would not succeed (and rightly so).

Query Formulation Traps

Typical mistakes

- **Missing join conditions** (very common).
- **Unnecessary joins** (may slow query down significantly).
- **Self joins:** incorrect treatment of multiple tuple variables which range over the same relation (**missing (in)equality conditions**).
- **Unexpected duplicates**, often an indicator for faulty queries (adding `DISTINCT` is no cure here).
- **Unnecessary `DISTINCT`.**

  Although today's query optimizer are probably more "clever" than the average SQL user in proving the absence of duplicates.

SQL Overview

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Non-Monotonic Behaviour

SQL queries using only the constructs introduced so far compute **monotonic functions** on the database state:

- if further rows gets **inserted**,
  these queries yield a **superset** of rows.

However, not all queries behave monotonically in this way.

Example of a non-monotonic query

Query: find students who have not submitted any homework.

- In the current DB state, `Maria Brown` would be a correct answer.
- `INSERT INTO RESULTS VALUES (104, 'H', 1, 8)` would invalidate this answer.

Such queries **cannot** be formulated with the SQL constructs introduced so far.

Non-Monotonic Behaviour

In natural language, queries that contain formulations like

- "**there is no**",
- "**does not exists**",
- ...

indicate non-monotonic behaviour.

$\Longrightarrow$ **negated existential quantification**

Furthermore,

- "**for all**",
- "**the minimum/maximum**"

also indicate non-monotonic behaviour.

$\Longrightarrow$ **universally quantification**

In an equivalent SQL formulation of such queries, this boils down to a test whether a **query yields a (non-)empty result.**

NOT IN

With

- `IN`
- `NOT IN`

it is possible to check whether an attribute value appears in a set of values computed by another SQL **subquery.**

Students without any homework result

```
SELECT  FIRST, LAST
FROM    STUDENTS
WHERE   SID NOT IN (SELECT  SID
                    FROM    RESULTS
                    WHERE   CAT = 'H')
```

FIRST	LAST
Maria	Brown

NOT IN

```
SELECT  FIRST, LAST
FROM    STUDENTS
WHERE   SID NOT IN (SELECT  SID
                    FROM    RESULTS
                    WHERE   CAT = 'H')
```

At least conceptually, the **subquery** is evaluated before the evaluation of the **main query** starts:

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

Subquery result

SID
101
101
102
102
103

Then, for every `STUDENTS` tuple, a matching `SID` is searched in the subquery result. If there is none, the tuple is output.

NOT IN

EXERCISES(CAT,ENO,TOPIC,MAXPT) RESULTS(SID,CAT,ENO,POINTS)

Topics of homeworks solved by at least one student.

```
SELECT  TOPIC
FROM    EXERCISES
WHERE   CAT = 'H' AND ENO IN (SELECT  ENO
                              FROM    RESULTS
                              WHERE   CAT = 'H')
```

Is there a difference to this query?
(with or without `DISTINCT`)

```
SELECT  DISTINCT TOPIC
FROM    EXERCISES E, RESULTS R
WHERE   E.CAT = 'H'
    AND E.ENO = R.ENO
    AND R.CAT = 'H'
```

NOT IN

- In SQL-86,
  subquery is required to deliver a **single output column**

- In SQL-92,
  comparisons where extended to the tuple level.

  It is thus valid to write, e.g.:

```
⋮
WHERE (A,B) NOT IN (SELECT C,D FROM . . . )
```

NOT EXISTS

The construct `NOT EXISTS` enables the main (or outer) query to check whether the **subquery result is empty**.

Students that have not submitted any homework

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   R.CAT = 'H'
                    AND     R.SID = S.SID)
```

- In the subquery, tuple variables declared in the `FROM` clause of the outer query may be referenced.

  You may also do so for `IN` *subqueries.*
- In this case, the outer query and subquery are **correlated**.
- The subquery is "**parameterized**".

NOT EXISTS

Students that have not submitted any homework

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   R.CAT = 'H'
                    AND     R.SID = S.SID)
```

Tuple variable `S` loops over the four rows in `STUDENTS`.

Conceptually, the subquery is evaluated four times (with `S.SID` bound to the current `SID` value).

The DBMS is free to choose a more efficient equivalent evaluation strategy (cf. query unnesting).

NOT EXISTS

Students that have not submitted any homework

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   R.CAT = 'H'
                    AND     R.SID = S.SID)
```

- "First," `S` is bound to the `STUDENTS` tuple

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...

- In the subquery, `S.SID` is "replaced by" `101`:

```
SELECT  *
FROM    RESULTS R
WHERE   R.CAT = 'H'
AND     R.SID = 101
```

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8

- Since the result is non-empty, the `NOT EXISTS` in the outer query is not satisfied for **this** `S`.

NOT EXISTS

Students that have not submitted any homework

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   R.CAT = 'H'
                    AND     R.SID = S.SID)
```

- "Finally," `S` is bound to the `STUDENTS` tuple

SID	FIRST	LAST	EMAIL
104	Maria	Brown	...

- In the subquery, `S.SID` is "replaced by" `104`:

```
SELECT  *
FROM    RESULTS R
WHERE   R.CAT = 'H'
AND     R.SID = 104
```

SID	CAT	ENO	POINTS
(no rows selected)			

- Since the result is empty, the `NOT EXISTS` in the outer query is satisfied and `Maria Brown` is output.

NOT EXISTS

While in the subquery tuple variables from outer query may be referenced, the **converse is illegal**!

Wrong!

```
SELECT  FIRST, LAST, R.ENO
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   R.CAT = 'H'
                    AND     R.SID = S.SID)
```

- Compare this to **variable scoping** (global/local variables) in block-structured programming languages (Java, C). Subquery tuple variables declarations are “local.”

NOT EXISTS

Non-correlated subqueries with `NOT EXISTS` are almost always an indication of an error!

Wrong!

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS (SELECT  *
                    FROM    RESULTS R
                    WHERE   CAT = 'H')
```

- If there is at least one tuple in `RESULTS`, the overall result will be empty.

Non-correlated subqueries evaluate to a set/relation **constant** and may make perfect sense (e.g., when used with (`NOT`) `IN`).

NOT EXISTS

It is legal SQL syntax to use `EXISTS` without negation:

Who has submitted at least one homework?

```
SELECT  SID, FIRST, LAST
FROM    STUDENTS S
WHERE   EXISTS (SELECT *
                FROM   RESULTS R
                WHERE  R.SID = S.SID
                AND    R.CAT = 'H')
```

Can we reformulate the above without using `EXISTS`?

“For all”

```
EXERCISES(CAT,ENO,TOPIC,MAXPT)      RESULTS(SID,CAT,ENO,POINTS)
```

Who got the best result for homework 1?

```
SELECT  FIRST, LAST, POINTS
FROM    STUDENTS S, RESULTS X
WHERE   S.SID = X.SID
    AND X.CAT = 'H' AND X.ENO = 1
    AND NOT EXISTS
        (SELECT  *
         FROM    RESULTS Y
         WHERE   Y.CAT = 'H' AND Y.ENO = 1
         AND     Y.POINTS > X.POINTS)
```

In natural language:

- **A result `X` for homework 1 is selected if there is no result `Y` for this exercise with more points than `X`.**

“For all”

In mathematical logic there are **quantifiers:**

- $\exists X(\varphi)$ **existential quantifier**
  - Meaning: There is an X that satisfies formula φ.
- $\forall X(\varphi)$ **universal quantifier**
  - Meaning: For all X, formula φ is satisfied (true).

In **tuple relational calculus (TRC)** the maximum number of points for homework 1 reads:

$$\{\, \texttt{X.POINTS} \mid \texttt{X} \in \texttt{RESULTS} \wedge \texttt{X.CAT} = \texttt{'H'} \wedge \texttt{X.ENO} = 1 \wedge \forall \texttt{Y} \big((\texttt{Y} \in \texttt{RESULTS} \wedge \texttt{Y.CAT} = \texttt{'H'} \wedge \texttt{Y.ENO} = 1) \Rightarrow \texttt{Y.POINTS} \leqslant \texttt{X.POINTS} \big) \,\}$$

“For all”

- SQL does **not** offer a universal quantifier ($\forall$, “for all”).

  SQL offers only the existential quantifier `EXISTS`.

  However, see `>= ALL` *below.*

This is no problem because

$$\forall X\,(\varphi) \quad \Longleftrightarrow \quad \neg\exists X\,(\neg\varphi)$$

The following two statements are equivalent:

- All cars are red.
- There exists no car that is not red.

“For all”

SQL does not have $\Rightarrow$. Thus commonly used pattern

$$\forall X\,(\varphi_1 \Rightarrow \varphi_2)$$

becomes

$$\neg\exists X\,(\varphi_1 \wedge \neg\varphi_2)$$

The following example:

$$\{\,\mathtt{X.POINTS} \mid \mathtt{X} \in \mathtt{RESULTS} \wedge \mathtt{X.CAT} = \mathtt{'H'} \wedge \mathtt{X.ENO} = 1 \wedge \forall \mathtt{Y}\,((\mathtt{Y} \in \mathtt{RESULTS} \wedge \mathtt{Y.CAT} = \mathtt{'H'} \wedge \mathtt{Y.ENO} = 1) \Rightarrow \mathtt{Y.POINTS} \leqslant \mathtt{X.POINTS})\,\}$$

is thus logically equivalent to:

$$\{\,\mathtt{X.POINTS} \mid \mathtt{X} \in \mathtt{RESULTS} \wedge \mathtt{X.CAT} = \mathtt{'H'} \wedge \mathtt{X.ENO} = 1 \wedge \neg\exists \mathtt{Y}\,((\mathtt{Y} \in \mathtt{RESULTS} \wedge \mathtt{Y.CAT} = \mathtt{'H'} \wedge \mathtt{Y.ENO} = 1) \wedge \mathtt{Y.POINTS} > \mathtt{X.POINTS})\,\}$$

“For all”

$$\{\, \mathtt{X.POINTS} \mid \mathtt{X} \in \mathtt{RESULTS} \;\wedge\; \mathtt{X.CAT} = \mathtt{'H'} \;\wedge\; \mathtt{X.ENO} = 1 \;\wedge \neg\exists\, \mathtt{Y} \big((\mathtt{Y} \in \mathtt{RESULTS} \wedge \mathtt{Y.CAT} = \mathtt{'H'} \wedge \mathtt{Y.ENO} = 1) \wedge \mathtt{Y.POINTS} > \mathtt{X.POINTS} \big) \,\}$$

Can be written in SQL as follows:

```
SELECT  X.POINTS
FROM    RESULTS X
WHERE   X.CAT = 'H' AND X.ENO = 1
AND     NOT EXISTS
        (SELECT  *
         FROM    RESULTS Y
         WHERE   Y.CAT = 'H' AND Y.ENO = 1
         AND     Y.POINTS > X.POINTS)
```

Nested Subqueries

Subqueries may be nested!

List the students who solved all homeworks

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS
        (SELECT  *
         FROM    EXERCISES E
         WHERE   CAT = 'H'
         AND     NOT EXISTS
                 (SELECT  *
                  FROM    RESULTS R
                  WHERE   R.SID = S.SID
                  AND     R.ENO = E.ENO
                  AND     R.CAT = 'H'))
```

- Inner query: all results for a given student and homework
- Middle query: homeworks of the student without results
- Outer query: students that have no homework without results

Common Errors

Does this query compute the student with the best result for homework 1?

```
SELECT  DISTINCT S.FIRST, S.LAST, X.POINTS
FROM    STUDENTS S, RESULTS X, RESULTS Y
WHERE   S.SID = X.SID
AND     X.CAT = 'H' AND X.ENO = 1
AND     Y.CAT = 'H' AND Y.ENO = 1
AND     X.POINTS > Y.POINTS
```

- If not, what does the query compute?

Common Errors

STUDENTS(SID,FIRST,LAST,EMAIL) RESULTS(SID,CAT,ENO,POINTS)

Return those students which did not solve homework 1

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   NOT EXISTS
        (SELECT  *
         FROM    RESULTS R, STUDENTS S
         WHERE   R.SID = S.SID
         AND     R.CAT = 'H' AND R.ENO = 1)
```

Quiz

What goes wrong here?

Subqueries bring up the concept of **variable scoping** (just like in programming languages) and related pitfalls.

Common Errors

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

What is the error in this query?

"Find those students who have neither submitted a homework nor participated in any exam."

```
SELECT  FIRST, LAST
FROM    STUDENTS
WHERE   SID NOT IN (SELECT  SID
                    FROM    EXERCISES)
```

1. Is this syntactically correct SQL?
2. What is the output of this query?
3. If the query is faulty, correct it.

ALL, ANY, SOME

SQL allows to compare a **single value** with all values in a set (computed by a subquery). Such comparisons may be

- **universally** (ALL), or
- **existentially** (ANY)

quantified.

Who got the best result for homework 1?

```
SELECT  S.FIRST, S.LAST, X.POINTS
FROM    STUDENTS S, RESULTS X
WHERE   S.SID = X.SID AND X.CAT = 'H' AND X.ENO = 1
AND     X.POINTS >= ALL (SELECT Y.POINTS
                         FROM   RESULTS Y
                         WHERE  Y.CAT = 'H'
                         AND    Y.ENO = 1)
```

Note: usage of >= is important here.

ALL, ANY, SOME

This query is equivalent to the previous query:

Using ANY.

```
SELECT  S.FIRST, S.LAST, X.POINTS
FROM    STUDENTS S, RESULTS X
WHERE   S.SID = X.SID AND X.CAT = 'H' AND X.ENO = 1
AND     NOT X.POINTS < ANY (SELECT Y.POINTS
                            FROM   RESULTS Y
                            WHERE  Y.CAT = 'H'
                            AND    Y.ENO = 1)
```

Note that ANY and ALL do **not** extend SQL's expressiveness.

The ANY statement

$$A \texttt{ < ANY (SELECT } B \texttt{ FROM } \cdots \texttt{ WHERE } \cdots \texttt{)}$$

is equivalent to the EXISTS statement

$$\texttt{EXISTS (SELECT * FROM } \cdots \texttt{ WHERE } \cdots \texttt{ AND } A \texttt{ < } B \texttt{)}$$

ALL, ANY, SOME

Syntactical remarks on comparisons with subquery results:

1. `ANY` and `SOME` are synonyms.
2. *x* `IN` *S* is equivalent to *x* `= ANY` *S*.
3. The subquery must yield a single result column.

If none of the keywords `ALL`, `ANY`, `SOME` are present, i.e.

```
. . . WHERE x = (SELECT A FROM . . . ),
```

the subquery must yield a single column and **at most one row.**

- Ensures that the comparison is between atomic values.
- An empty subquery result is equivalent to `NULL`.

Single Value Subqueries

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Who got full points for homework 1?

```
SELECT  S.FIRST, S.LAST
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID AND R.CAT= 'H' AND R.ENO = 1
AND     R.POINTS = (SELECT  MAXPT
                    FROM    EXERCISES
                    WHERE   CAT = 'H' AND ENO = 1)
```

Comparisons with subquery results (note: no `ANY`, `ALL`) are possible if the subquery returns **at most one row**:

Why is this guaranteed here?

- Use constraints to ensure this condition.
- The DBMS will yield a runtime error if the subquery returns two or more rows.

Single Value Subqueries

If the subquery has an **empty result**, the **null value** is returned.

Bad style!

```
SELECT  FIRST, LAST
FROM    STUDENTS S
WHERE   (SELECT 1
         FROM   RESULTS R
         WHERE  R.SID = S.SID
         AND    R.CAT = 'H' AND R.ENO = 1) IS NULL
```

Subqueries under FROM

Since the result of an SQL query is a **table**, it seems natural to use a subquery result wherever a table might be specified, i.e., in the FROM clause.

In the following example, the join of RESULTS and EXERCISES is computed in a subquery.

Points (in %) achieved in homework exercise 1.

```
SELECT  X.SID, (X.POINTS * 100 / X.MAXPT) AS PCT
FROM    (SELECT  E.CAT, E.ENO, R.SID, R.POINTS, E.MAXPT
         FROM    EXERCISES E, RESULTS R
         WHERE   E.CAT = R.CAT AND E.ENO = R.ENO) X
WHERE   X.CAT = 'H' AND X.ENO = 1
```

One use of subqueries under FROM are **nested aggregations**.

Subqueries under FROM

Inside the subquery, tuple variables introduced in the same FROM clause **may not be referenced.**

Not allowed in SQL!

```
SELECT  S.FIRST, S.LAST, X.ENO, X.POINTS
FROM    STUDENTS S, (SELECT  R.ENO, R.POINTS
                     FROM    RESULTS R
                     WHERE   R.CAT = 'H'
                     AND     R.SID = S.SID) X
```

Subqueries under FROM

A **view declaration** registers a **query (not a query result)** under a given identifier in the database.

View: homework points

```
CREATE VIEW HW_POINTS AS
SELECT  S.FIRST, S.LAST, R.ENO, R.POINTS
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID AND R.CAT = 'H'
```

In queries, views may be used like stored tables:

```
SELECT  ENO, POINTS
FROM    HW_POINTS
WHERE   FIRST = 'Michael' AND LAST = 'Jones'
```

- Views may be thought of as **subquery macros**

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Aggregations

Aggregation functions are functions from a set or multiset to a single value, e.g.,

$$\min\{42, 57, 5, 13, 27\} = 5$$

- Aggregation functions are also known as
  - **group functions**, or
  - **column functions**
- Take as input the values of an entire column.

Typical use: statistics, data analysis, report generation.

Aggregations

SQL-92 defines the five main aggregation functions

`COUNT`, `SUM`, `AVG`, `MAX`, `MIN`

How many students in the current database state?

```
SELECT   COUNT(*)
FROM     STUDENTS
```

COUNT(*)
4

- Some DBMS define further aggregation functions:

  `CORRELATION`, `STDDEV`, `VARIANCE`, `...`

- Some aggregation functions are sensitive to **duplicates**:

  `SUM`, `COUNT`, `AVG` ,

  some are insensitive:

  `MIN`, `MAX`

- SQL allows to explicitly request to ignore duplicates, e.g.:

  `···` `COUNT(DISTINCT A)` `···`

Simple Aggregations

Simple aggregations feed the value set of an **entire column** into an aggregation function.

*Below, we will discuss partitioning (or **grouping**) of columns.*

How many students in the current database state?

```
SELECT   COUNT(*)
FROM     STUDENTS
```

COUNT(*)
4

Best and average result for homework 1?

```
SELECT MAX(POINTS), AVG(POINTS)
FROM   RESULTS
WHERE  CAT = 'H' AND ENO = 1
```

MAX(POINTS)	AVG(POINTS)
10	8

Simple Aggregations

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

How many students have submitted a homework?

```
SELECT  COUNT(DISTINCT SID)
FROM    RESULTS
WHERE   CAT = 'H'
```

COUNT(DISTINCT SID)
3

What is the total number of points student 101 got for her homeworks?

```
SELECT  SUM(POINTS) AS "Total Points"
FROM    RESULTS
WHERE   SID = 101 AND CAT = 'H'
```

Total Points
18

Simple Aggregations

What average percentage of the maximum points did the students reach for homework 1?

```
SELECT  AVG(R.POINTS / E.MAXPT) * 100
FROM    RESULTS R, EXERCISES E
WHERE   R.CAT = 'H' AND E.CAT = 'H'
AND     R.ENO  = 1 AND E.ENO = 1
```

Homework points for student 101 plus 3 bonus points.

```
SELECT  SUM(POINTS) + 3 AS "Total Homework Points"
FROM    RESULTS
WHERE   SID = 101 AND CAT = 'H'
```

Restrictions

- Aggregations may not be nested (makes no sense).
- Aggregations may not be used in the `WHERE` clause:

Wrong!

```
··· WHERE SUM(A) > 100 ···
```

- If an aggregation function is used and no `GROUP BY` is used, **no attributes** may appear in the `SELECT` clause.

Wrong!

```
SELECT  CAT, ENO, AVG(POINTS)
FROM    RESULTS
```

Null Values and Aggregations

Usually, null values are **ignored** (filtered out) before the aggregation operator is applied.

Exception:

- `COUNT(*)` counts null values
- `COUNT(*)` counts rows, not attribute values

If the input set is empty, aggregation functions yield `NULL`.

- Exception: `COUNT` returns `0`.

- This seems counter-intuitive, at least for `SUM` (where users might expect `0` in this case)
- However, allows to detect the difference between:
  - all column values `NULL`, or
  - values that sum up to 0.

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GROUP BY

`GROUP BY` **partitions** the tuples of a table into **disjoint groups.**

- Aggregation functions applied for each group separately.

Average points for each homework

```
SELECT    ENO, AVG(POINTS)
FROM      RESULTS
WHERE     CAT = 'H'
GROUP BY  ENO
```

ENO	AVG(POINTS)
1	8
2	8.5

All tuples agreeing in their `ENO` values (i.e., belonging to the same homework) form a group for aggregation.

GROUP BY

The `GROUP BY` partitions the incoming tuples into groups:

- based on **value equality for the `GROUP BY` attributes**

(after evaluation of the `FROM` and `WHERE` clauses)

```
SELECT    ENO, AVG(POINTS)
FROM      RESULTS
WHERE     CAT = 'H'
GROUP BY  ENO
```

`ENO`-based groups formed by above example query:

SID	CAT	ENO	POINTS
101	H	1	10
102	H	1	9
103	H	1	5
101	H	2	8
101	H	2	9

Aggregation is subsequently done for every group (yielding as many rows as groups).

GROUP BY

The `GROUP BY` construction can **never** produce empty groups.

- `COUNT(*)` will never result in `0`

Since the `GROUP BY` attributes have a **unique value for every group**, these attributes may be used in the `SELECT` clause.

- A reference to any other attribute is illegal.

Wrong!

```
SELECT    E.ENO, E.TOPIC, AVG(R.POINTS)
FROM      EXERCISES E, RESULTS R
WHERE     E.CAT = 'H'
      AND R.CAT = 'H'
      AND E.ENO = R.ENO
GROUP BY  E.ENO
```

Wrong! Although `E.ENO` functionally determines `E.TOPIC` which thus is unique (for every group).

GROUP BY

Grouping by `E.ENO` **and** `E.TOPIC` yields the desired result:

```
SELECT    E.ENO, E.TOPIC, AVG(R.POINTS)
FROM      EXERCISES E, RESULTS R
WHERE     E.CAT = 'H'
      AND R.CAT = 'H'
      AND E.ENO = R.ENO
GROUP BY  E.ENO, E.TOPIC
```

E.ENO	E.TOPIC	AVG(POINTS)
1	Rel.Alg.	8
2	SQL	8.5

Now the DBMS has a **syntactic clue** that `E.TOPIC` is unique.

GROUP BY

Is there any semantical difference between these queries?

1.
```
SELECT    TOPIC, AVG(POINTS / MAXPT)
FROM      EXERCISES E, RESULTS R
WHERE     E.CAT='H' AND R.CAT='H' AND E.ENO=R.ENO
GROUP BY  TOPIC
```

2.
```
SELECT    TOPIC, AVG(POINTS / MAXPT)
FROM      EXERCISES E, RESULTS R
WHERE     E.CAT='H' AND R.CAT='H' AND E.ENO=R.ENO
GROUP BY  TOPIC, E.ENO
```

GROUP BY

- The sequence of the `GROUP BY` attributes is not important.
- Duplicates should be eliminated with `DISTINCT`, although such elimination can also be realised via `GROUP BY`:

Grouping without aggregation: `DISTINCT`.

```
SELECT    CAT, ENO
FROM      RESULTS
GROUP BY  CAT, ENO
```

This is an **abuse** of `GROUP BY` and should be avoided.

HAVING

Aggregations may not be used in the `WHERE` clause.

With `GROUP BY`, however, it may make sense to **filter out entire groups** based on some aggregated group property.

This is possible with SQL's `HAVING` clause.

- The condition in the `HAVING` clause may (only) involve aggregation functions.

For example, only groups of size greater than n tuples.

```
SELECT    ...              -- output columns
FROM      ...              -- what tuples
WHERE     ...              -- filter tuples
GROUP BY  ...              -- group tuples
HAVING    COUNT(*) > n     -- filter groups
```

HAVING

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Which students got at least 18 homework points?

```
SELECT    FIRST, LAST
FROM      STUDENTS S, RESULTS R
WHERE     S.SID = R.SID AND R.CAT = 'H'
GROUP BY  S.SID, FIRST, LAST
HAVING    SUM(POINTS) >= 18
```

FIRST	LAST
Ann	Smith
Michael	Jones

The `WHERE` clause refers to single tuples, the `HAVING` condition applies to entire groups (in this case: all tuples containing the homework results of a student).

WHERE vs. HAVING

`HAVING` should not contain direct attribute references, only aggregation functions.

This is wrong

```
SELECT    FIRST, LAST
FROM      STUDENTS S, RESULTS R
GROUP BY  S.SID, R.SID, FIRST, LAST
HAVING    S.SID = R.SID AND SUM(POINTS) >= 18
```

This is correct

```
SELECT    FIRST, LAST
FROM      STUDENTS S, RESULTS R
WHERE     S.SID = R.SID
GROUP BY  S.SID, FIRST, LAST
HAVING    SUM(POINTS) >= 18
```

Aggregation Subqueries

Who has the best result for homework 1?

```
SELECT  S.FIRST, S.LAST, R.POINTS
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID AND R.CAT = 'H' AND R.ENO = 1
AND     R.POINTS = (SELECT  MAX(POINTS)
                    FROM    RESULTS
                    WHERE   CAT = 'H' AND ENO = 1)
```

- The aggregate in the subquery is guaranteed to yield exactly one row as required.
- Remember: earlier we solved this using `ANY/ALL`.

Aggregation Subqueries

Aggregation subqueries may be used in the `SELECT` clause:

- This sometimes can be used to replace `GROUP BY`.

The homework points of the individual students.

```
SELECT  FIRST, LAST, (SELECT  SUM(POINTS)
                      FROM    RESULTS R
                      WHERE   R.SID = S.SID
                      AND     R.CAT = 'H')
FROM    STUDENTS S
```

Nested Aggregations

Nested aggregations require a subquery in the `FROM` clause.

What is the average number of homework points (excluding those students who did not submit anything)?

```
SELECT  AVG(X.HW_POINTS)
FROM    (SELECT    SID, SUM(POINTS) AS HW_POINTS
         FROM      RESULTS
         WHERE     CAT = 'H'
         GROUP BY  SID) X
```

X

SID	HW_POINTS
101	18
102	18
103	5

AVG(X.HW_POINTS)
13.67

Maximizing Aggregations

Who has the best overall homework result? (maximum sum of homework points)

```
SELECT    FIRST, LAST, SUM(POINTS) AS TOTAL
FROM      STUDENTS S, RESULTS R
WHERE     S.SID = R.SID AND R.CAT = 'H'
GROUP BY  S.SID, FIRST, LAST
HAVING    SUM(POINTS)
            >= ALL (SELECT    SUM (POINTS)
                    FROM      RESULTS
                    WHERE     CAT = 'H'
                    GROUP BY  SID)
```

- Alternatively, we could use a view to solve this problem (next slide).

Maximizing Aggregations

View: total number of homework points for each student.

```
CREATE VIEW HW_TOTALS AS
SELECT    SID, SUM(POINTS) AS TOTAL
FROM      RESULTS
WHERE     CAT = 'H'
GROUP BY  SID
```

Alternative formulation of query on previous slide.

```
SELECT  S.FIRST, S.LAST, H.TOTAL
FROM    STUDENTS S, HW_TOTALS H
WHERE   S.SID = H.SID
AND     H.TOTAL = (SELECT MAX(TOTAL)
                   FROM   HW_TOTALS)
```

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UNION

`UNION` allows to combine the results of two queries.

`UNION` is needed since there is no other method to construct one result column that draws from different tables/columns.

- This is necsessary, for example, if specialisations of a concept (“subclasses”) are stored in separate tables.

For instance, if we have tables

- `GRADUATE_COURSES` and
- `UNDERGRADUATE_COURSES`

both of which are specialisations of the concept `COURSE`.

- `UNION` is also commonly used for **case analysis** (cf., the `if...then...` cascades in programming languages).

UNION

Assign student grades based on homework 1.

```
  SELECT  S.SID, S.FIRST, S.LAST, 'A' AS GRADE
  FROM    STUDENTS S, RESULTS R
  WHERE   S.SID = R.SID AND R.CAT = 'H' AND R.ENO=1
  AND     R.POINTS >= 9

UNION ALL

  SELECT  S.SID, S.FIRST, S.LAST, 'B' AS GRADE
  FROM    STUDENTS S, RESULTS R
  WHERE   S.SID = R.SID AND R.CAT = 'H' AND R.ENO=1
  AND     R.POINTS >= 7 AND R.POINTS < 9

UNION ALL

  ...
```

UNION

The `UNION` operand subqueries must return tables with the same number of columns and compatible data types.

*Columns correspondence is by column **position** (1st, 2nd,. . .).*
Column names need not be identical.

SQL distinguishes between

- `UNION`: with **duplicate elimination**, and
- `UNION ALL`: **concatenation** (duplicates retained).

Other SQL-92 set operations:

- `EXCEPT` ($-$)
- `INTERSECT` ($\cap$)

These do **not** add to the expressivity of SQL.

How?

Conditional Expressions

`UNION` is the **portable way** to conduct a case analysis.

Sometimes a **conditional expression** suffices & more efficient.

Conditional expression syntax varies between DBMSs.
Oracle uses `DECODE(···)`*, for example.*

Here, we will use the SQL-92 syntax.

Full exercise category name for the results of `Ann Smith`.

```
SELECT  CASE WHEN CAT = 'H' THEN 'Homework'
             WHEN CAT = 'M' THEN 'Midterm Exam'
             WHEN CAT = 'F' THEN 'Final Exam'
             ELSE 'Unknown Category' END,
        ENO, POINTS
FROM    STUDENTS S, RESULTS R
WHERE   S.SID = R.SID
AND     S.FIRST = 'Ann' AND S.LAST = 'Smith'
```

Conditional Expressions

A typical application is to **replace a null value** by a value Y:

```
··· CASE WHEN X IS NOT NULL THEN X ELSE Y END ···
```

In SQL-92, this may be abbreviated to

```
··· COALESCE (X, Y)···
```

List the e-mail addresses of all students

```
SELECT  FIRST, LAST, COALESCE (EMAIL, '(none)')
FROM    STUDENTS
```

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Sorting Output

If query output is to be read by humans, enforcing a certain **tuple order** helps in interpreting the result.

`ORDER BY` allows to specify a **list of sorting criteria**.

Without such an ordering, the order is **unpredictable**:

- Depends on the internal algorithms of the query optimiser.
- Order may change even query to query.

An `ORDER BY` clause may specify multiple attribute names.

- The second attribute is used for tuple ordering if they agree on the first attribute, and so on (**lexicographic ordering**).
- Sort in **ascending** order (default): `ASC`,
- Sort in **descending** order: `DESC`.

Sorting Output

Homework results sorted by exercise (best result first). In case of a tie, sort alphabetically by student name.

```
SELECT    R.ENO, R.POINTS, S.FIRST, S.LAST
FROM      STUDENTS S, RESULTS R
WHERE     S.SID = R.SID AND R.CAT = 'H'
ORDER BY  R.ENO, R.POINTS DESC, S.LAST, S.FIRST
```

- First, compare `R.ENO`.
- If the first criterion leads to a tie, compare `POINTS` **`DESC`**.
- If we still have a tie, compare `S.LAST`.
- If we still have a tie, compare `S.FIRST`.

ENO	POINTS	FIRST	LAST
1	10	Ann	Smith
1	9	Michael	Jones
1	5	Richard	Turner
2	9	Michael	Jones
2	8	Ann	Smith

Sorting Output

In some application scenarios it is necessary to **add columns** to a table to obtain suitable **sorting criteria**.

If the students names were stored in the form `'Ann␣Smith'`, sorting by last name is more or less impossible. Having separate columns for first and last name is better.

- **Null values** are all listed first or all listed last in the sorted sequence (depending on the database).
- Since the effect of `ORDER BY` is purely “cosmetic”, `ORDER BY` may **not** be applied to a subquery.

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Example Database

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

EXERCISES

CAT	ENO	TOPIC	MAXPT
H	1	Rel.Alg.	10
H	2	SQL	10
M	1	SQL	14

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

Joins

Up to version SQL-86, there were no explicit joins in queries.

- Instead, Cartesian products of relations (`FROM`) are specified and then filtered via `WHERE`.

Natural join of `RESULTS` and `EXERCISES`

```
SELECT  R.CAT AS CAT, R.ENO AS ENO,
        SID, POINTS, TOPIC, MAXPT
FROM    RESULTS R, EXERCISES E
WHERE   R.CAT = E.CAT AND R.ENO = E.ENO
```

Joins

Since SQL-92 there are explicit join operations.

“Natural join” in SQL-92

```
SELECT  SID, ENO, (POINTS / MAXPT) * 100
FROM    RESULTS NATURAL JOIN EXERCISES
WHERE   CAT = 'H'
```

The keywords `NATURAL JOIN` lead the DBMS to automatically add the join predicate to the query:

```
RESULTS.CAT = EXERCISES.CAT
AND RESULTS.ENO = EXERCISES.ENO
```

In a **natural join**, the join predicate arises implicitly by **comparing all columns with the same name** in both tables.

Inner and Outer Joins

SQL-92 supports the following **join types** (`[..]` is optional):

- `[INNER] JOIN`: Usual join.
- `LEFT [OUTER] JOIN`: Preserves rows of left table.
- `RIGHT [OUTER] JOIN`: Preserves rows of right table.
- `FULL [OUTER] JOIN`: Preserves rows of both tables.
- `CROSS JOIN`: Cartesian product (all combinations).

A **join ($\bowtie$) eliminates tuples without partner**.

A	B
a_1	b_1
a_2	b_2

$\bowtie$

B	C
b_2	c_2
b_3	c_3

$=$

A	B	C
a_2	b_2	c_2

The **left outer join** preserves all tuples in its **left** argument:

A	B
a_1	b_1
a_2	b_2

$|\bowtie$

B	C
b_2	c_2
b_3	c_3

$=$

A	B	C
a_1	b_1	(null)
a_2	b_2	c_2

Inner and Outer Joins

The **right outer join** preserves all tuples in its **right** argument:

A	B
a_1	b_1
a_2	b_2

$\bowtie|$

B	C
b_2	c_2
b_3	c_3

$=$

A	B	C
a_2	b_2	c_2
(null)	b_3	c_3

The **full outer join** preserves all tuples in **both** arguments:

A	B
a_1	b_1
a_2	b_2

$|\bowtie|$

B	C
b_2	c_2
b_3	c_3

$=$

A	B	C
a_1	b_1	(null)
a_2	b_2	c_2
(null)	b_3	c_3

The **cross join** is the **Cartesian product**:

A	B
a_1	b_1
a_2	b_2

$\times$

B	C
b_2	c_2
b_3	c_3

$=$

A	B	B	C
a_1	b_1	b_2	c_2
a_1	b_1	b_3	c_3
a_2	b_2	b_2	c_2
a_2	b_2	b_3	c_3

Inner and Outer Joins

The **join predicate** may be specified as follows:

- **`NATURAL`** prepended to join operator name.

  Yields comparison of columns with the same name.

- **`USING`** $(A_1, \ldots, A_n)$ appended to join operator name.

  The A_i must be columns appearing in both tables. The join predicate then is `R.A1=S.A1 AND ...AND R.An=S.An`.

- **`ON`** $\langle Condition \rangle$ appended to join operator name.

- `CROSS JOIN` has no join predicate.

Inner and Outer Joins

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Number of submission per homework (0 if no submission)

```
SELECT    E.ENO, COUNT(SID)
FROM      EXERCISES E LEFT OUTER JOIN RESULTS R
          ON E.CAT = R.CAT AND E.ENO = R.ENO
WHERE     E.CAT = 'H'
GROUP BY  E.ENO
```

All exercises are present in the result of the left outer join.

- In exercises without solutions, columns `SID` and `POINTS` will contain `NULL`.
- `COUNT(SID)` ignores rows where `SID IS NULL`.

Inner and Outer Joins

Equivalent query without `OUTER JOIN` (12 vs. 5 lines).

```
  SELECT    E.ENO, COUNT(*)
  FROM      EXERCISES E, RESULTS R
  WHERE     E.CAT = 'H' AND R.CAT = 'H'
  AND       E.ENO = R.ENO
  GROUP BY  E.ENO

UNION ALL

  SELECT    E.ENO, 0
  FROM      EXERCISES E
  WHERE     E.CAT = 'H'
  AND       E.ENO NOT IN (SELECT  R.ENO
                          FROM    RESULTS R
                          WHERE   R.CAT = 'H')
```

Inner and Outer Joins

```
STUDENTS(SID, FIRST, LAST, EMAIL)
EXERCISES(CAT, ENO, TOPIC, MAXPT)
RESULTS(SID→STUDENTS, (CAT,ENO)→EXERCISES, POINTS)
```

Exercises with corresponding submissions in different ways...

Join with `ON`

```
SELECT *
FROM EXERCISES E LEFT OUTER JOIN RESULTS R
     ON E.CAT = R.CAT AND E.ENO = R.ENO
```

Join with `USING`

```
SELECT *
FROM EXERCISES E LEFT OUTER JOIN RESULTS R
     USING (CAT, ENO)
```

Join with `NATURAL`

```
SELECT *
FROM EXERCISES E NATURAL LEFT OUTER JOIN RESULTS R
```

Inner and Outer Joins

Is there a problem with the following query?

"**Number of homeworks solved per student (including 0).**"

```
SELECT    FIRST, LAST, COUNT(ENO)
FROM      STUDENTS S LEFT OUTER JOIN RESULTS R
          ON S.SID = R.SID
WHERE     R.CAT = 'H'
GROUP BY  S.SID, FIRST, LAST
```

It is generally wise to restrict the outer join inputs **before** the outer join is performed (or move restrictions into the `ON` clause).

Corrected version of last query.

```
SELECT    FIRST, LAST, COUNT(ENO)
FROM      STUDENTS S LEFT OUTER JOIN
          (SELECT  SID, ENO
             FROM  RESULTS
            WHERE  CAT = 'H') R
          ON S.SID = R.SID
GROUP BY  S.SID, FIRST, LAST
```

Inner and Outer Joins

Will tuples with `CAT = 'M'` appear in the output?

```
SELECT  E.CAT, E.ENO, R.SID, R.POINTS
FROM    EXERCISES E LEFT OUTER JOIN RESULTS R
        ON    E.CAT = 'H'
          AND R.CAT = 'H'
          AND E.ENO = R.ENO
```

Conditions filtering the **left table** make little sense in a **left outer join predicate**.

The left outer join will make the “filtered” tuples appear anyway (as join partners for unmatched `RESULTS` tuples).

SQL: Objectives

After completing this chapter, you should be able to:

- write **advanced SQL** queries
  - with multiple tuple variables over different/the same relation
  - with nested queries
  - …
- use **aggregation**, **grouping**, **union**
- be comfortable with the various **join variants**
- evaluate the **correctness** and **equivalence** of SQL queries
  - this includes sometimes tricky issues of deciding the presence of duplicate result tuples