

02

Advanced SQL



Intro to Database Systems
15-445/15-645
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AP

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RELATIONAL LANGUAGES

User only needs to specify the answer that they want, not how to compute it.

The DBMS is responsible for efficient evaluation of the query.

→ Query optimizer: re-orders operations and generates query plan

SQL HISTORY

Originally “SEQUEL” from IBM’s
System R prototype.

- Structured English Query Language
- Adopted by Oracle in the 1970s.

IBM releases DB2 in 1983.

ANSI Standard in 1986. ISO in 1987
→ Structured Query Language



SQL HISTORY

Current standard is **SQL:2016**

- **SQL:2016** → JSON, Polymorphic tables
- **SQL:2011** → Temporal DBs, Pipelined DML
- **SQL:2008** → **TRUNCATE**, Fancy sorting
- **SQL:2003** → XML, windows, sequences, auto-gen IDs.
- **SQL:1999** → Regex, triggers, OO

Most DBMSs at least support **SQL-92**

- System Comparison: <http://troels.arvin.dk/db/rdbms/>

RELATIONAL LANGUAGES

Data Manipulation Language (DML)

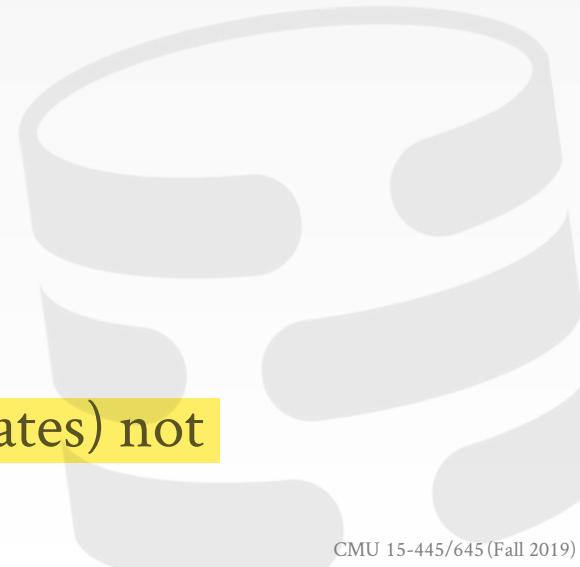
Data Definition Language (DDL)

Data Control Language (DCL)

Also includes:

- View definition
- Integrity & Referential Constraints
- Transactions

Important: SQL is based on **bags** (duplicates) not **sets** (no duplicates).



TODAY'S AGENDA

Aggregations + Group By

String / Date / Time Operations

Output Control + Redirection

Nested Queries

Common Table Expressions

Window Functions



EXAMPLE DATABASE

student(sid,name,login,gpa)

sid	name	login	age	gpa
53666	Kanye	kayne@cs	39	4.0
53688	Bieber	jbieber@cs	22	3.9
53655	Tupac	shakur@cs	26	3.5

course(cid,name)

cid	name
15-445	Database Systems
15-721	Advanced Database Systems
15-826	Data Mining
15-823	Advanced Topics in Databases

enrolled(sid,cid,grade)

sid	cid	grade
53666	15-445	C
53688	15-721	A
53688	15-826	B
53655	15-445	B
53666	15-721	C

AGGREGATES

Functions that return a single value from a bag of tuples:

- **AVG(col)** → Return the average col value.
- **MIN(col)** → Return minimum col value.
- **MAX(col)** → Return maximum col value.
- **SUM(col)** → Return sum of values in col.
- **COUNT(col)** → Return # of values for col.



AGGREGATES

Aggregate functions can only be used in the
SELECT output list.

Get # of students with a "@cs" login:

```
SELECT COUNT(login) AS cnt
FROM student WHERE login LIKE '%@cs'
```

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Get # of students with a "@cs" login:

```
SELECT COUNT(login) AS cnt  
FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(*) AS cnt  
FROM student WHERE login LIKE '%@cs'
```

AGGREGATES

Aggregate functions can only be used in the **SELECT** output list.

Get # of students with a "@cs" login:

```
SELECT COUNT(login) AS cnt  
FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(*) AS cnt  
FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(1) AS cnt  
FROM student WHERE login LIKE '%@cs'
```

MULTIPLE AGGREGATES

Get the **number of students** and their **average GPA** that have a “@cs” login.

```
SELECT AVG(gpa), COUNT(sid)  
FROM student WHERE login LIKE '%@cs'
```

AVG(gpa)	COUNT(sid)
3.25	12

DISTINCT AGGREGATES

COUNT, SUM, AVG support DISTINCT

Get the number of unique students that have an "@cs" login.

```
SELECT COUNT(DISTINCT login)
FROM student WHERE login LIKE '%@cs'
```

COUNT(DISTINCT login)
10

AGGREGATES

Output of other columns outside of an aggregate is undefined.

Get the average GPA of students enrolled in each course.

```
SELECT AVG(s.gpa), e.cid  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid
```

AVG(s.gpa)	e.cid
3.5	???

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid  
GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445



AVG(s.gpa)	e.cid
2.46	15-721
3.39	15-826
1.89	15-445

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
FROM enrolled AS e, student AS s
WHERE e.sid = s.sid
GROUP BY e.cid
```

e.sid	s.sid	s.gpa	e.cid
53435	53435	2.25	15-721
53439	53439	2.70	15-721
56023	56023	2.75	15-826
59439	59439	3.90	15-826
53961	53961	3.50	15-826
58345	58345	1.89	15-445



AVG(s.gpa)	e.cid
2.46	15-721
3.39	15-826
1.89	15-445

GROUP BY

Non-aggregated values in **SELECT** output clause
must appear in **GROUP BY** clause.

```
SELECT AVG(s.gpa), e.cid, s.name
  FROM enrolled AS e, student AS s
 WHERE e.sid = s.sid
 GROUP BY e.cid
```



GROUP BY

Non-aggregated values in **SELECT** output clause must appear in **GROUP BY** clause.

```
SELECT AVG(s.gpa), e.cid, s.name  
  FROM enrolled AS e, student AS s  
 WHERE e.sid = s.sid  
 GROUP BY e.cid, s.name
```

HAVING

Filters results based on aggregation computation.

Like a **WHERE** clause for a **GROUP BY**

```
SELECT AVG(s.gpa) AS avg_gpa, e.cid  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid  
AND avg_gpa > 3.9  
GROUP BY e.cid
```



HAVING

Filters results based on aggregation computation.

Like a **WHERE** clause for a **GROUP BY**

```
SELECT AVG(s.gpa) AS avg_gpa, e.cid  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid  
GROUP BY e.cid  
HAVING avg_gpa > 3.9;
```

HAVING

Filters results based on aggregation computation.

Like a **WHERE** clause for a **GROUP BY**

```
SELECT AVG(s.gpa) AS avg_gpa, e.cid  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid  
GROUP BY e.cid  
HAVING avg_gpa > 3.9;
```

AVG(s.gpa)	e.cid
3.75	15-415
3.950000	15-721
3.900000	15-826



avg_gpa	e.cid
3.950000	15-721

STRING OPERATIONS

	String Case	String Quotes
SQL-92	Sensitive	Single Only
Postgres	Sensitive	Single Only
MySQL	Insensitive	Single/Double
SQLite	Sensitive	Single/Double
DB2	Sensitive	Single Only
Oracle	Sensitive	Single Only

WHERE UPPER(name) = UPPER('KaNyE') **SQL-92**

WHERE name = "KaNyE" **MySQL**

STRING OPERATIONS

LIKE is used for string matching.

String-matching operators

- '%' Matches any substring (including empty strings).
- '_' Match any one character

```
SELECT * FROM enrolled AS e  
WHERE e.cid LIKE '15-%'
```

```
SELECT * FROM student AS s  
WHERE s.login LIKE '%@c_'
```

STRING OPERATIONS

SQL-92 defines string functions.

→ Many DBMSs also have their own unique functions

Can be used in either output and predicates:

```
SELECT SUBSTRING(name,0,5) AS abbrv_name  
FROM student WHERE sid = 53688
```

```
SELECT * FROM student AS s  
WHERE UPPER(e.name) LIKE 'KAN%'
```

STRING OPERATIONS

SQL standard says to use **||** operator to concatenate two or more strings together.

```
SELECT name FROM student           SQL-92  
WHERE login = LOWER(name) || '@cs'
```

```
SELECT name FROM student           MSSQL  
WHERE login = LOWER(name) + '@cs'
```

```
SELECT name FROM student           MySQL  
WHERE login = CONCAT(LOWER(name), '@cs')
```

DATE/TIME OPERATIONS

Operations to manipulate and modify **DATE/TIME** attributes.

Can be used in either output and predicates.

Support/syntax varies wildly...

Demo: Get the # of days since the beginning of the year.

OUTPUT REDIRECTION

Store query results in another table:

- Table must not already be defined.
- Table will have the same # of columns with the same types as the input.

```
SELECT DISTINCT cid INTO CourseIds SQL-92
      FROM enrolled;
```

```
CREATE TABLE CourseIds (
    SELECT DISTINCT cid FROM enrolled); MySQL
```

OUTPUT REDIRECTION

Insert tuples from query **into another table**:

- Inner **SELECT** must generate the same columns as the **target table**.
- DBMSs have **different options/syntax** on what to do with duplicates.

```
INSERT INTO CourseIds
```

SQL-92

```
(SELECT DISTINCT cid FROM enrolled);
```

OUTPUT CONTROL

ORDER BY <column*> [ASC|DESC]

→ Order the output tuples by the values in one or more of their columns.

```
SELECT sid, grade FROM enrolled  
WHERE cid = '15-721'  
ORDER BY grade
```

sid	grade
53123	A
53334	A
53650	B
53666	D

OUTPUT CONTROL

ORDER BY <column*> [ASC|DESC]

→ Order the output tuples by the values in one or more of their columns.

```
SELECT sid, grade FROM enrolled  
WHERE cid = '15-721'  
ORDER BY grade
```

sid	grade
53123	A
53334	A
53650	B
53666	D

```
SELECT sid FROM enrolled  
WHERE cid = '15-721'  
ORDER BY grade DESC, sid ASC
```

sid
53666
53650
53123
53334

OUTPUT CONTROL

LIMIT <count> [offset]

- Limit the # of tuples returned in output.
- Can set an offset to return a “range”

```
SELECT sid, name FROM student  
WHERE login LIKE '%@cs'  
LIMIT 10
```

OUTPUT CONTROL

LIMIT <count> [offset]

- Limit the # of tuples returned in output.
- Can set an offset to return a “range”

```
SELECT sid, name FROM student  
WHERE login LIKE '%@cs'  
LIMIT 10
```

```
SELECT sid, name FROM student  
WHERE login LIKE '%@cs'  
LIMIT 20 OFFSET 10
```

NESTED QUERIES

Queries containing other queries.

They are often difficult to optimize.

Inner queries can appear (almost) anywhere in query.

Outer Query → **SELECT name FROM student WHERE sid IN (SELECT sid FROM enrolled)** ← Inner Query

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student  
WHERE ...
```



sid in the set of people that take 15-445

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student  
WHERE ...
```

```
    SELECT sid FROM enrolled  
    WHERE cid = '15-445'
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
WHERE sid IN (
    SELECT sid FROM enrolled
    WHERE cid = '15-445'
)
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
WHERE sid IN (
    SELECT sid FROM enrolled
    WHERE cid = '15-445'
)
```

NESTED QUERIES

ALL→ Must satisfy expression for all rows in sub-query

ANY→ Must satisfy expression for at least one row in sub-query.

IN→ Equivalent to '**=ANY()**' .

EXISTS→ At least one row is returned.



NESTED QUERIES

Get the names of students in '15-445'

```
SELECT name FROM student
WHERE sid = ANY(
    SELECT sid FROM enrolled
    WHERE cid = '15-445'
)
```

NESTED QUERIES

Get the names of students in '15-445'

```
SELECT (SELECT S.name FROM student AS S  
        WHERE S.sid = E.sid) AS sname  
      FROM enrolled AS E  
     WHERE cid = '15-445'
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT MAX(e.sid), s.name
FROM enrolled AS e, student AS s
WHERE e.sid = s.sid;
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT MAX(e.sid), s.name  
FROM enrolled AS e, student AS s  
WHERE e.sid = s.sid;
```



Won't work in SQL-92. This runs in SQLite, but not Postgres or MySQL (v5.7 with strict mode).

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student  
WHERE ...
```

"Is greater than every other sid"

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student  
WHERE sid is greater than every  
    SELECT sid FROM enrolled
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
WHERE sid => ALL(
    SELECT sid FROM enrolled
)
```

sid	name
53688	Bieber

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
WHERE sid = (
    SELECT sid
    FROM student
    WHERE sid = (
        SELECT MAX(sid)
        FROM enrolled
    )
)
```

NESTED QUERIES

Find student record with the highest id that is enrolled in at least one course.

```
SELECT sid, name FROM student
  WHERE sid = (
    SELECT sid, name FROM student
      WHERE sid = (
        SELECT sid, name FROM student
          WHERE sid IN (
            SELECT sid FROM enrolled
              ORDER BY sid DESC LIMIT 1
          )
      )
  )
```

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course  
WHERE ...
```

"with no tuples in the 'enrolled' table"

cid	name
15-445	Database Systems
15-721	Advanced Database Systems
15-826	Data Mining
15-823	Advanced Topics in Databases

sid	cid	grade
53666	15-445	C
53688	15-721	A
53688	15-826	B
53655	15-445	B
53666	15-721	C

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course  
WHERE NOT EXISTS(  
    tuples in the 'enrolled' table  
)
```

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
WHERE NOT EXISTS(
    SELECT * FROM enrolled
    WHERE course.cid = enrolled.cid
)
```

cid	name
15-823	Advanced Topics in Databases

NESTED QUERIES

Find all courses that has no students enrolled in it.

```
SELECT * FROM course
WHERE NOT EXISTS(
    SELECT * FROM enrolled
    WHERE course.cid = enrolled.cid
)
```

cid	name
15-823	Advanced Topics in Databases

WINDOW FUNCTIONS

Performs a "sliding" calculation across a set of tuples that are related.

Like an aggregation but tuples are not grouped into a single output tuples.

```
SELECT ... FUNC-NAME(...) OVER (...)  
FROM tableName
```

WINDOW FUNCTIONS

Performs a "sliding" calculation across a set of tuples that are related.

Like an aggregation but tuples are not grouped into a single output tuples.

```
SELECT ... FUNC-NAME(...) OVER (...)  
FROM tableName
```

How to "slice" up data
Can also sort

Aggregation Functions
Special Functions

WINDOW FUNCTIONS

Aggregation functions:

- Anything that we discussed earlier

Special window functions:

- **ROW_NUMBER()** → # of the current row
- **RANK()** → Order position of the current row.

sid	cid	grade	row_num
53666	15-445	C	1
53688	15-721	A	2
53688	15-826	B	3
53655	15-445	B	4
53666	15-721	C	5

```
SELECT *, ROW_NUMBER() OVER () AS row_num
FROM enrolled
```

WINDOW FUNCTIONS

Aggregation functions:

- Anything that we discussed earlier

Special window functions:

- **ROW_NUMBER()** → # of the current row
- **RANK()** → Order position of the current row.

sid	cid	grade	row_num
53666	15-445	C	1
53688	15-721	A	2
53688	15-826	B	3
53655	15-445	B	4
53666	15-721	C	5

```
SELECT *, ROW_NUMBER() OVER () AS row_num
FROM enrolled
```

WINDOW FUNCTIONS

The **OVER** keyword specifies how to group together tuples when computing the window function.

Use **PARTITION BY** to specify group.

cid	sid	row_number
15-445	53666	1
15-445	53655	2
15-721	53688	1
15-721	53666	2
15-826	53688	1

```
SELECT cid, sid,  
       ROW_NUMBER() OVER (PARTITION BY cid)  
    FROM enrolled  
   ORDER BY cid
```

WINDOW FUNCTIONS

The **OVER** keyword specifies how to group together tuples when computing the window function.

Use **PARTITION BY** to specify group.

cid	sid	row_number
15-445	53666	1
15-445	53655	2
15-721	53688	1
15-721	53666	2
15-826	53688	1

```
SELECT cid, sid,  
       ROW_NUMBER() OVER (PARTITION BY cid)  
    FROM enrolled  
   ORDER BY cid
```

WINDOW FUNCTIONS

You can also include an **ORDER BY** in the window grouping to sort entries in each group.

```
SELECT *,  
    ROW_NUMBER() OVER (ORDER BY cid)  
FROM enrolled  
ORDER BY cid
```

WINDOW FUNCTIONS

Find the student with the highest grade for each course.

```
SELECT * FROM (
    SELECT *,  
        RANK() OVER (PARTITION BY cid  
                      ORDER BY grade ASC)  
    AS rank  
    FROM enrolled) AS ranking  
WHERE ranking.rank = 1
```

WINDOW FUNCTIONS

Find the student with the highest grade for each course.

```
SELECT * FROM (
    SELECT *,  
        RANK() OVER (PARTITION BY cid  
                      ORDER BY grade ASC)  
    AS rank  
    FROM enrolled) AS ranking  
WHERE ranking.rank = 1
```

Group tuples by cid
Then sort by grade



WINDOW FUNCTIONS

Find the student with the highest grade for each course.

```
SELECT * FROM (
    SELECT *,  
        RANK() OVER (PARTITION BY cid  
                      ORDER BY grade ASC)  
    AS rank  
    FROM enrolled) AS ranking  
WHERE ranking.rank = 1
```

Group tuples by cid
Then sort by grade

COMMON TABLE EXPRESSIONS

Provides a way to write **auxiliary** statements for use in a larger query.

→ Think of it like **a temp table just for one query**.

Alternative to nested queries and views.

```
WITH cteName AS (
    SELECT 1
)
SELECT * FROM cteName
```

COMMON TABLE EXPRESSIONS

Provides a way to write auxiliary statements for use in a larger query.

→ Think of it like a temp table just for one query.

Alternative to nested queries and views.

```
WITH cteName AS (
    SELECT 1
)
SELECT * FROM cteName
```

COMMON TABLE EXPRESSIONS

You can bind output columns to names before the **AS** keyword.

```
WITH cteName (col1, col2) AS (
    SELECT 1, 2
)
SELECT col1 + col2 FROM cteName
```

COMMON TABLE EXPRESSIONS

Find student record with the highest id that is enrolled in at least one course.

```
WITH cteSource (maxId) AS (
    SELECT MAX(sid) FROM enrolled
)
SELECT name FROM student, cteSource
WHERE student.sid = cteSource.maxId
```

COMMON TABLE EXPRESSIONS

Find student record with the highest id that is enrolled in at least one course.

```
WITH cteSource (maxId) AS (←  
    SELECT MAX(sid) FROM enrolled  
)  
SELECT name FROM student, cteSource  
WHERE student.sid = cteSource.maxId
```

CTE – RECURSION

Print the sequence of numbers from 1 to 10.

```
WITH RECURSIVE cteSource (counter) AS (
    (SELECT 1)
    UNION ALL
    (SELECT counter + 1 FROM cteSource
     WHERE counter < 10)
)
SELECT * FROM cteSource
```

Demo: Postgres CTE!

CONCLUSION

SQL is not a dead language.

You should (almost) always strive to compute your answer as a single SQL statement.



NEXT CLASS

Storage Management

