Carnegie Mellon University

Intro to Database Systems (15-445/645)

Lecture #02

Modern SQL

FALL 2023 » Prof. Andy Pavlo • Prof. Jignesh Patel

LAST CLASS

We introduced the Relational Model as the superior data model for databases.

We then showed how Relational Algebra is the building blocks that will allow us to query and modify a relational database.

SQL HISTORY

In 1971, IBM created its first relational query language called SQUARE.

IBM then created "SEQUEL" in 1972 for IBM System R prototype DBMS.
→ Structured English Query Language

IBM releases commercial SQL-based DBMSs:
→ System/38 (1979), SQL/DS (1981), and DB2 (1983).

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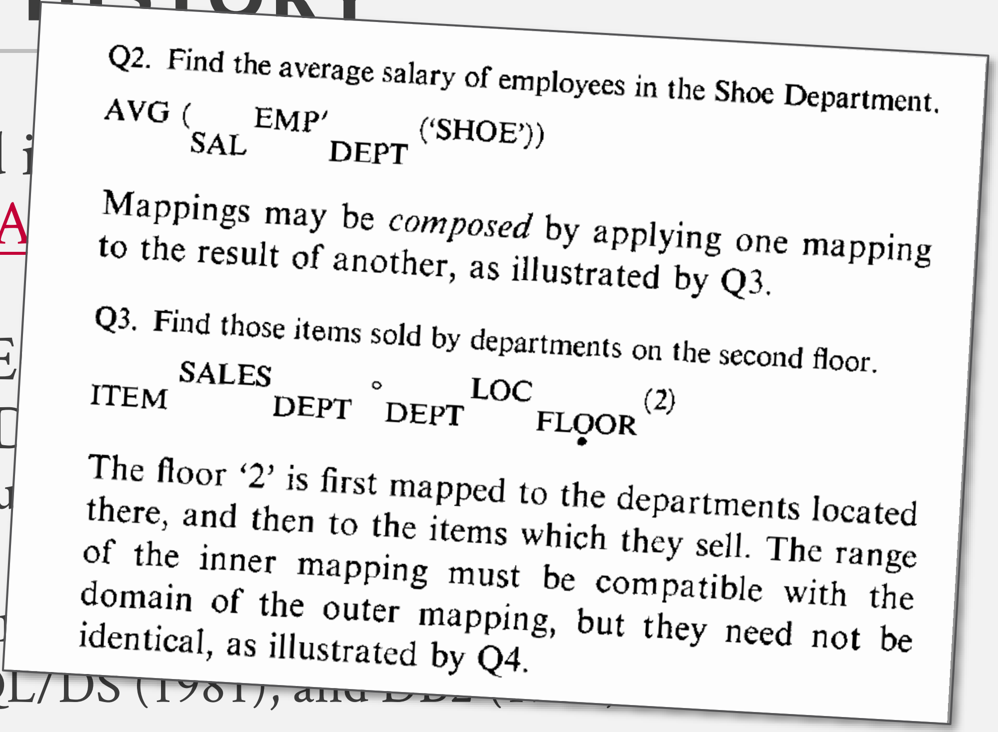
Q2. Find the average salary of employees in the Shoe Department.

AVG (SAL EMP' DEPT ('SHOE'))

Mappings may be *composed* by applying one mapping to the result of another, as illustrated by Q3.

Q3. Find those items sold by departments on the second floor.

ITEM SALES DEPT ∘ DEPT LOC FLOOR (2)

The floor '2' is first mapped to the departments located there, and then to the items which they sell. The range of the inner mapping must be compatible with the domain of the outer mapping, but they need not be identical, as illustrated by Q4.

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SQL HISTORY

ANSI Standard in 1986. ISO in 1987

→ Structured Query Language

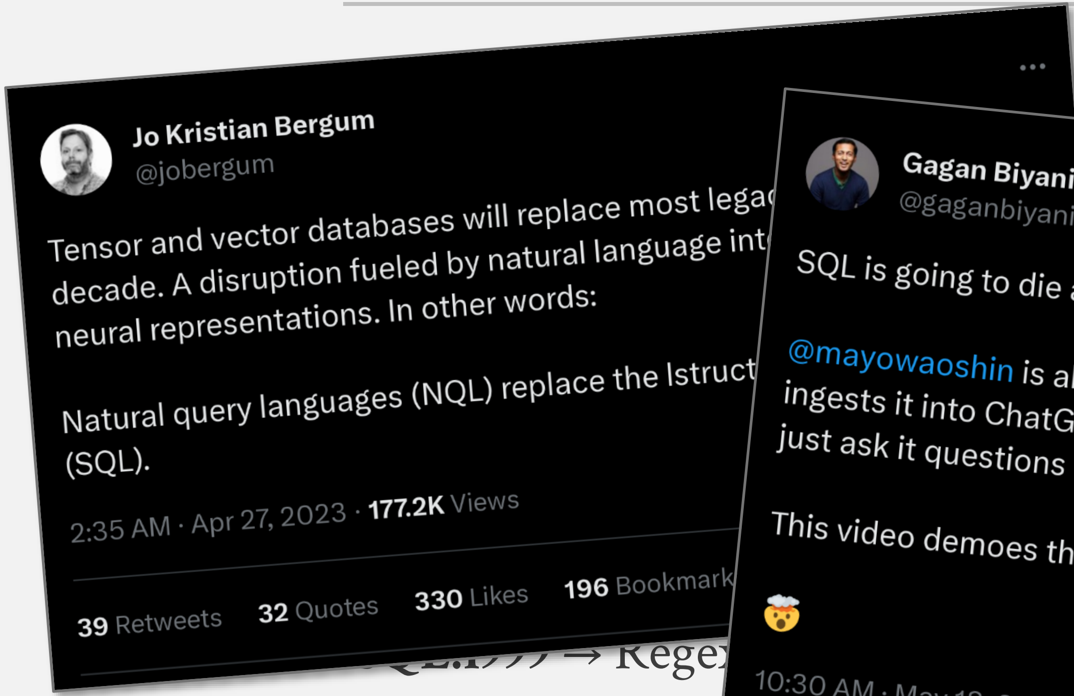
Current standard is **SQL:2023**

→ **SQL:2023** → Property Graph Queries, Muti-Dim. Arrays
→ **SQL:2016** → JSON, Polymorphic tables
→ **SQL:2011** → Temporal DBs, Pipelined DML
→ **SQL:2008** → Truncation, Fancy Sorting
→ **SQL:2003** → XML, Windows, Sequences, Auto-Gen IDs.
→ **SQL:1999** → Regex, Triggers, OO

The minimum language syntax a system needs to say that it supports SQL is **SQL-92**.

SQL HISTORY

1987


Jo Kristian Bergum
@jobergum

Tensor and vector databases will replace most legac
decade. A disruption fueled by natural language int
neural representations. In other words:

Natural query languages (NQL) replace the Istruct
(SQL).

2:35 AM · Apr 27, 2023 · 177.2K Views

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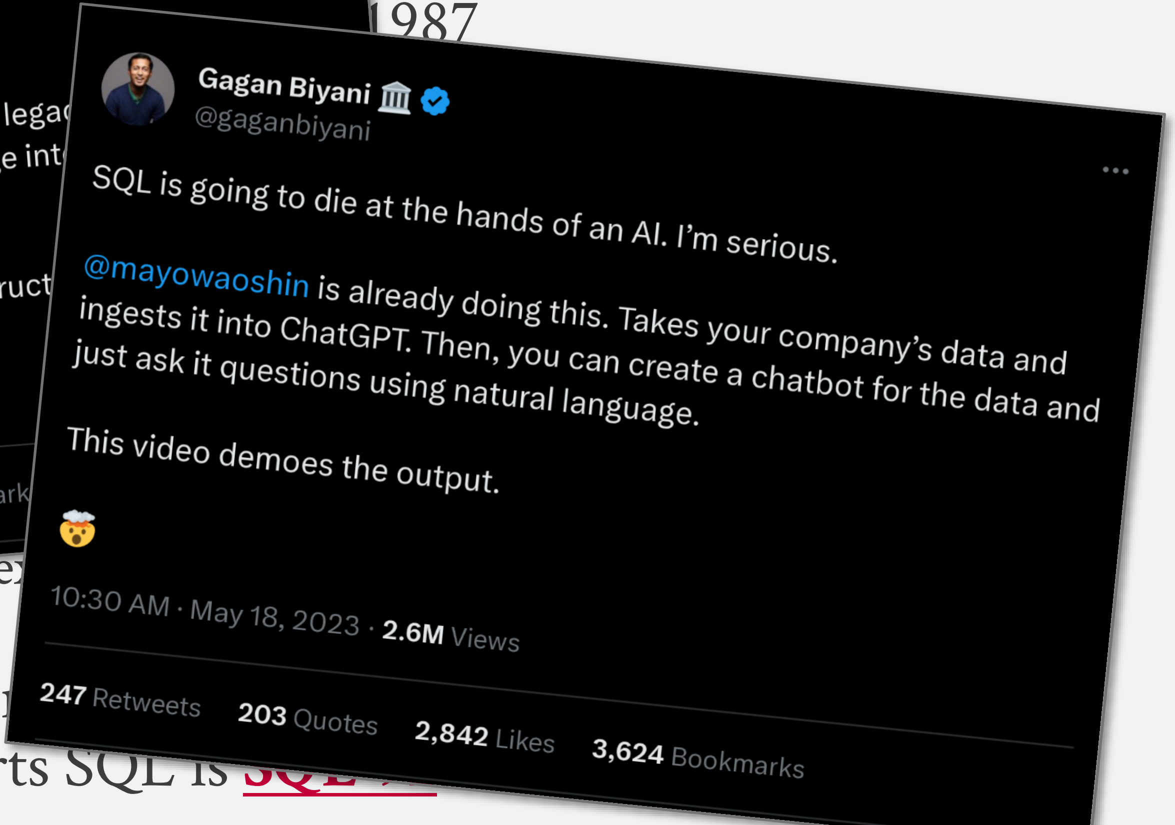
Gagan Biyani
@gaganbiyani

SQL is going to die at the hands of an AI. I'm serious.

@mayowaoshin is already doing this. Takes your company's data and ingests it into ChatGPT. Then, you can create a chatbot for the data and just ask it questions using natural language.

This video demoes the output.

🤯

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→ Regex

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NEWS | COMPUTING

The Rise of SQL ›It's become the second programming language everyone needs to know

BY RINA DIANE CABALLAR | 23 AUG 2022 | 3 MIN READ

ISTOCK

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TAGS
TOP PROGRAMMING LANGUAGES
SQL

SQL dominated the jobs ranking in *IEEE Spectrum*'s interactive rankings of the top programming languages this year. Normally, the top position is occupied by Python or other mainstays, such as C, C++, Java, and JavaScript, but the sheer number of times employers said they wanted developers with SQL skills, albeit in addition to a more general-purpose language, boosted it to No. 1.

So what's behind SQL's soar to the top? The ever-increasing use of databases, for one. SQL has become the primary query language for accessing and managing data stored in such databases—specifically relational databases, which represent data in table form with rows and columns. Databases serve as the foundation of many enterprise applications and are increasingly found in other places as well, for example taking the place of traditional file systems in smartphones.

"This ubiquity means that every software developer will have to interact with databases no matter the field, and SQL is the de facto standard for interacting with databases," says Andy Pavlo, a professor specializing in database management at the Carnegie Mellon University (CMU) School of Computer Science and a member of the CMU database group.

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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
Window Functions
Nested Queries
Lateral Joins
Common Table Expressions

EXAMPLE DATABASE

student(sid,name,login,gpa)

sid	name	login	age	gpa
53666	RZA	rza@cs	44	4.0
53688	Bieber	jbieber@cs	27	3.9
53655	Tupac	shakur@cs	25	3.5

course(cid,name)

cid	name
15-445	Database Systems
15-721	Advanced Database Systems
15-826	Data Mining
15-799	Special 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 (almost) 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'
```

AGGREGATES

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

```
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```

```
SELECT COUNT(*) AS cnt
```

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

AGGREGATES

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

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

```
SELECT COUNT(login) AS cnt
```

```
SELECT COUNT(*) AS cnt
```

```
SELECT COUNT(1) AS cnt
```

```
SELECT COUNT(1+1+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)
3.8	3

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 JOIN student AS s
    ON e.sid = s.sid
```

AVG(s.gpa)	e.cid
3.86	???

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 JOIN student AS s
    ON e.sid = s.sid
```

AVG(s.gpa)	e.cid
3.86	???

GROUP BY

Project tuples into subsets and calculate aggregates against each subset.

```
SELECT AVG(s.gpa), e.cid
  FROM enrolled AS e JOIN student AS s
    ON 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
```

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 JOIN student AS s
    ON 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(s.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
MSSQL	Sensitive	Single Only
Oracle	Sensitive	Single Only

```
WHERE UPPER(name) = UPPER('TuPaC')
```
SQL-92

```
WHERE name = "TuPaC"
```
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,1,5) AS abbrv_name
  FROM student WHERE sid = 53688
```

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

STRING OPERATIONS

SQL standard defines the **||** operator for concatenating two or more strings together.

SQL-92

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

MSSQL

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

MySQL

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

DATE/TIME OPERATIONS

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

Can be used in both 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.

SQL-92

```
SELECT DISTINCT cid INTO CourseIds
  FROM enrolled;
```

MySQL

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

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.

SQL-92

```
SELECT DISTINCT cid INTO CourseIds
  FROM
```

Postgres

```
SELECT DISTINCT cid
  INTO TEMPORARY CourseIds
  FROM enrolled;
```

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

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 integrity violations (e.g., invalid duplicates).

SQL-92

```
INSERT INTO CourseIds
(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
 WH
 OR
```

```
SELECT sid, grade FROM enrolled
 WHERE cid = '15-721'
 ORDER BY 2
```

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
 WH
 OR
```

```
SELECT sid, grade FROM enrolled
 WHERE cid = '15-721'
 ORDER BY 2
```

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

sid
53666
53650
53123
53334

OUTPUT CONTROL

FETCH {FIRST|NEXT} <count> ROWS
OFFSET <count> ROWS

→ Limit the # of tuples returned in output.
→ Can set an offset to return a "range"

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
FETCH FIRST 10 ROWS ONLY;
```

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
 ORDER BY gpa
OFFSET 10 ROWS
FETCH FIRST 10 ROWS WITH TIES;
```

OUTPUT CONTROL

FETCH {FIRST|NEXT} <count> ROWS
OFFSET <count> ROWS

→ Limit the # of tuples returned in output.
→ Can set an offset to return a "range"

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
FETCH FIRST 10 ROWS ONLY;
```

```
SELECT sid, name FROM student
 WHERE login LIKE '%@cs'
 ORDER BY gpa
OFFSET 10 ROWS
FETCH FIRST 10 ROWS WITH TIES;
```

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.

How to "slice" up data
Can also sort

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

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

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 second highest grade for each course.

Group tuples by cid
Then sort by grade

```
SELECT * FROM (
  SELECT *, RANK() OVER (PARTITION BY cid
            ORDER BY grade ASC) AS rank
    FROM enrolled) AS ranking
 WHERE ranking.rank = 2
```

NESTED QUERIES

Invoke a query inside of another query to compose more complex computations.

→ They are often difficult to optimize for the DBMS to optimize due to correlations.

→ 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 the sub-query.

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

IN→ Equivalent to '**=ANY()**' .

EXISTS→ At least one row is returned without comparing it to an attribute in outer query.

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

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;
```

This won't work in SQL-92. It runs in SQLite, but not Postgres or MySQL (v8 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 the highest enrolled 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 IN (
   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
 WHER
   SE
)
```

```
SELECT sid, name FROM student
 WHERE sid IN (
   SELECT sid FROM enrolled
    ORDER BY sid DESC FETCH FIRST 1 ROW ONLY
)
```

NESTED QUERIES

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

```
SELECT sid, name FROM student
 WHE
   SE
)
```

```
SELECT sid, name FROM student
 WHERE sid IN (
   SE
    (
)
```

```
SELECT student.sid, name
  FROM student
  JOIN (SELECT MAX(sid) AS sid
          FROM enrolled) AS max_e
    ON student.sid = max_e.sid;
```

NESTED QUERIES

Find all courses that have 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
15-799	Special 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 have no students enrolled in it.

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

NESTED QUERIES

Find all courses that have no students enrolled in it.

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

cid	name
15-799	Special Topics in Databases

LATERAL JOINS

The **LATERAL** operator allows a nested query to reference attributes in other nested queries that precede it.

→ You can think of it like a `for` loop that allows you to invoke another query for each tuple in a table.

```
SELECT * FROM
  (SELECT 1 AS x) AS t1,
  LATERAL (SELECT t1.x+1 AS y) AS t2;
```

t1.x	t2.y
1	2

LATERAL JOIN

Calculate the number of students enrolled in each course and the average GPA. Sort by enrollment count in descending order.

```
SELECT * FROM course AS c,
```

For each course:

- ***Compute the # of enrolled students***

For each course:

- ***Compute the average gpa of enrolled students***

LATERAL JOIN

Calculate the number of students enrolled in each course and the average GPA. Sort by enrollment count in descending order.

```
SELECT * FROM course AS c,
  LATERAL (SELECT COUNT(*) AS cnt FROM enrolled
             WHERE enrolled.cid = c.cid) AS t1,
  LATERAL (SELECT AVG(gpa) AS avg FROM student AS s
              JOIN enrolled AS e ON s.sid = e.sid
             WHERE e.cid = c.cid) AS t2;
```

LATERAL JOIN

Calculate the number of students enrolled in each course and the average GPA. Sort by enrollment count in descending order.

```
SELECT * FROM course AS c,
  LATERAL (SELECT COUNT(*) AS cnt FROM enrolled
            WHERE enrolled.cid = c.cid) AS t1,
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LATERAL JOIN

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LATERAL JOIN

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```

LATERAL JOIN

Calculate the number of students enrolled in each course and the average GPA. Sort by enrollment count in descending order.

```
SELECT * FROM course AS c,
  LATERAL (SELECT COUNT(*) A
           WHERE enrolled.cid = c.cid) AS t1,
  LATERAL (SELECT AVG(gpa) AS avg FROM student AS s
            JOIN enrolled AS e ON s.sid = e.sid
           WHERE e.cid = c.cid) AS t2;
```

cid	name	cnt	avg
15-445	Database Systems	2	3.75
15-721	Advanced Database Systems	2	3.95
15-826	Data Mining	1	3.9
15-799	Special Topics in Databases	0	null

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/alias output columns to names before the **AS** keyword.

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

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

COMMON TABLE EXPRESSIONS

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```
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```

Postgres

```
WITH cteName (colXXX, colXXX) AS (
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)
SELECT * 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
```

CONCLUSION

SQL is not a dead language.

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

HOMEWORK #1

Write SQL queries to perform basic data analysis.
→ Write the queries locally using SQLite + DuckDB.
→ Submit them to Gradescope
→ You can submit multiple times and use your best score.

Due: Sunday Sept 10th @ 11:59pm

https://15445.courses.cs.cmu.edu/fall2023/homework1

NEXT CLASS

Storage Management