Carnegie Mellon University

# 02 Intermediate SQL

Intro to Database Systems
15-445/15-645
Fall 2020

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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.

→ High-end systems have a sophisticated **query optimizer** that can rewrite queries and search for optimal execution strategies.

# SQL HISTORY

IBM's first query language was called "SQUARE".

Originally developed in 1974 as "SEQUEL" for IBM System R prototype DBMS.

→ Structured English Query Language

→ Adopted by Oracle in the 1970s.

IBM releases commercial SQL-based DBMSs:

→ System/38 (1979), SQL/DS (1981), and DB2 (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** → 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**.

# 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 | 26 | 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 (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'
```

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  FROM student WHERE login LIKE '%@cs'
```

```
SELECT COUNT(*) 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
  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) |
|---|---|
| 3.8 | 3 |

# 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) |
| --- |
| 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, 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 |

| 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, 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
   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 |
| 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,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 says to use || operator to concatenate 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 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.

SQL-92

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

MySQL

```
CREATE TABLE CourseIds (
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 1
```

# 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 1
```

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

# 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 1
```

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

| sid |
|---|
| 53666 |
| 53650 |
| 53123 |
| 53334 |

# 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 1
```

```
SELECT sid FROM enrolled
 WHERE cid = '15-721'
 ORDER BY grade DESC, 1 ASC
```

# 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.

# 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.

# 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'
 )
```

```
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;
```

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 is the
   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 IN (
   SELECT MAX(sid) FROM enrolled
)
```

| sid | name |
|---|---|
| 53688 | Bieber |

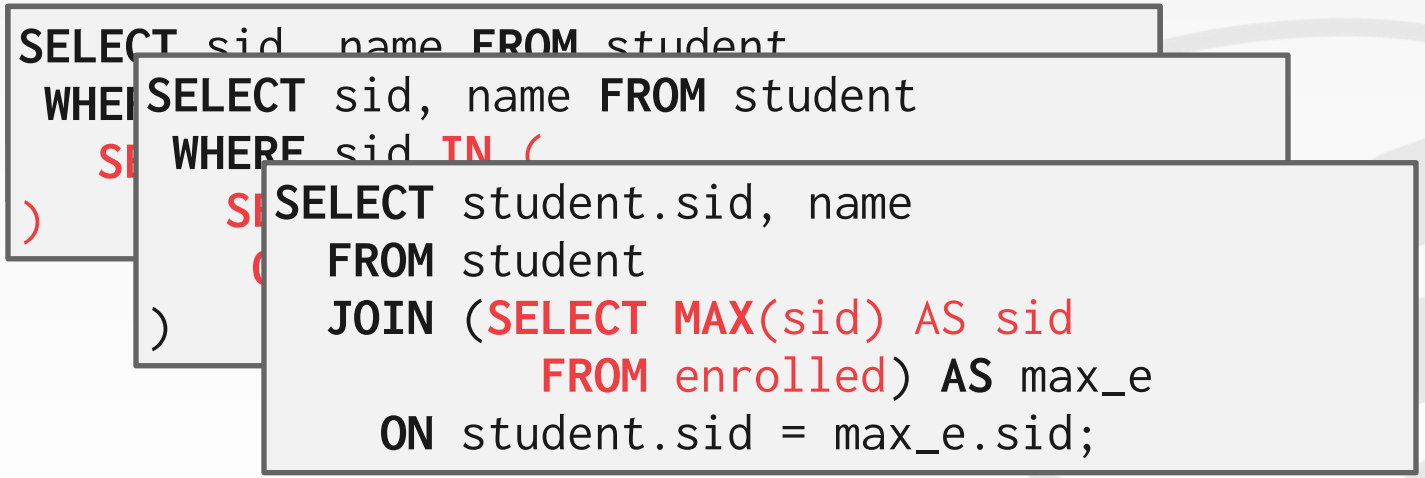
# NESTED QUERIES

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

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

# NESTED QUERIES

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



# 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
)
```

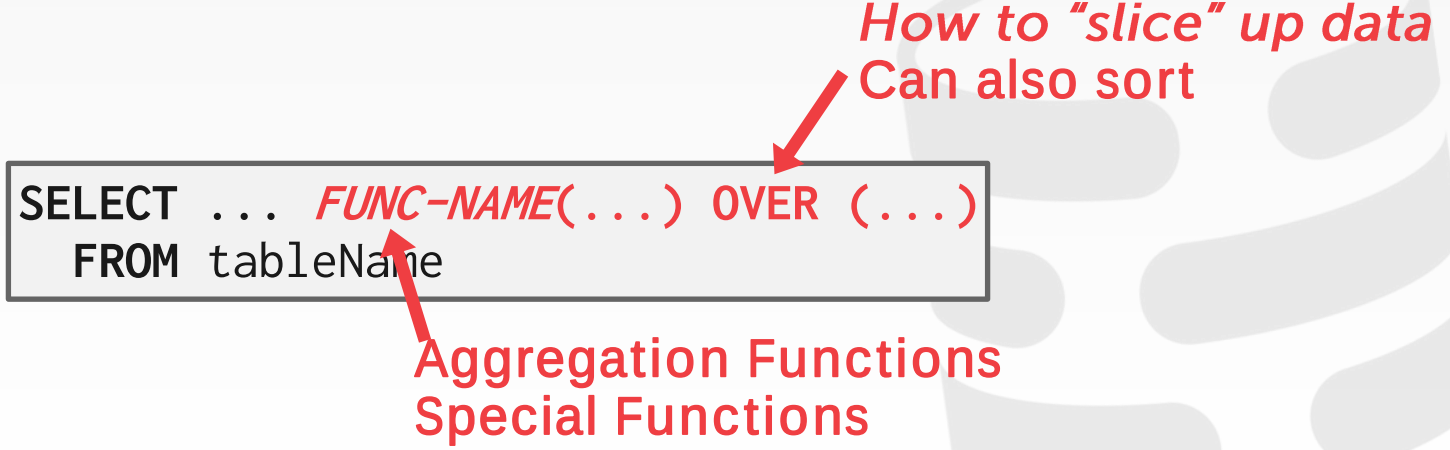


| cid | name |
|---|---|
| 15-823 | Advanced Topics in Databases |

# 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.



# 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
```

# 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
```

# 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

You can bind 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

You can bind 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

You can bind 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 * FROM cteName
```

# COMMON TABLE EXPRESSIONS

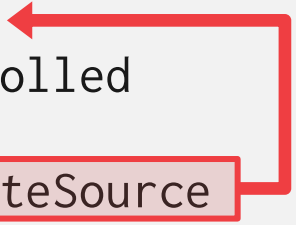
*Find student record with the highest id that is enrolled in at least one course.*

```
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
   (SELECT counter + 1 FROM cteSource
     WHERE counter < 10)
)
SELECT * FROM cteSource
```

**Demo: CTEs!**

# 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 on MusicBrainz data from SFO.

→ Write the queries locally using SQLite.
→ Submit them to Gradescope
→ You can submit multiple times and use your best score.

**Due: Sunday Sept 13th @ 11:59pm**

https://15445.courses.cs.cmu.edu/fall2020/homework1

# NEXT CLASS

Storage Management