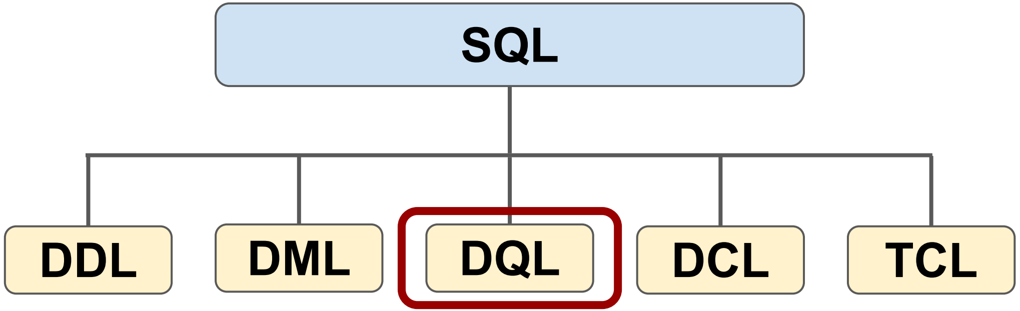
CS2102: Database Systems

Lecture 6 — SQL (Part 3)

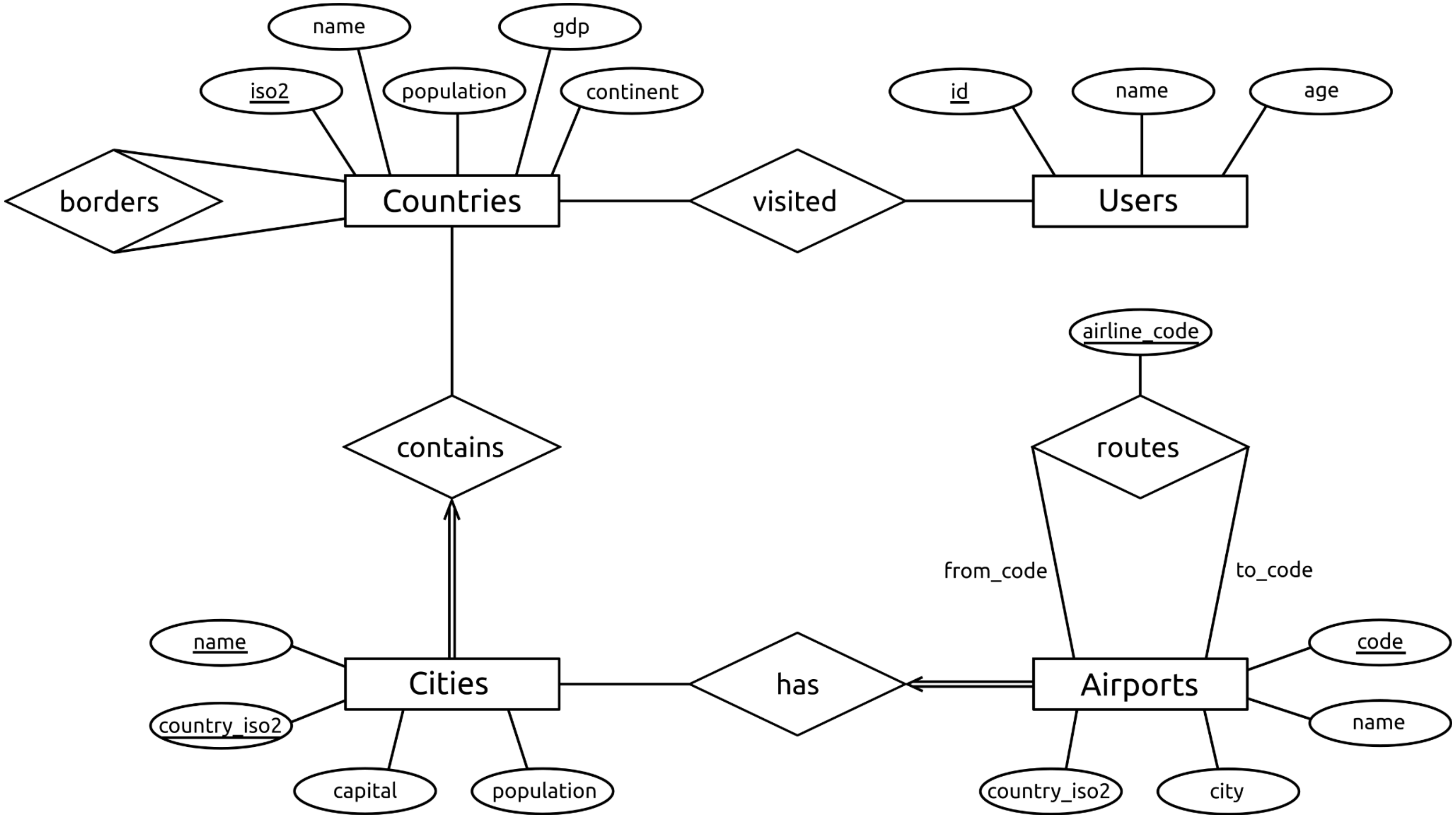
Quick Recap: Where We are Right Now

- Querying a database
  - Extracting information using SQL (DQL: data query language)
  - Anything with "**SELECT …**"



- Covered constructs
  - Basic queries: **SELECT** [**DISTINCT**] … **FROM** [**WHERE**]
  - Multirelational queries / join queries: (**INNER**) **JOIN**, **NATURAL JOIN**, **OUTER JOIN**, etc
  - Subquery expressions: (**NOT**) **IN**, **NOT** (**EXISTS**), **ANY/SOME**, **ALL**
  - Sorting & rank-based selection: **ORDER BY**, **LIMIT**, **OFFSET**

Example Database — ER Diagram



Example Database — Data Sample

Countries (225 tuples)

iso2	name	population	gdp	continent
SG	Singapore	5781728	488000000000	Asia
AU	Australia	22992654	1190000000000	Oceania
TH	Thailand	68200824	1160000000000	Asia
DE	Germany	80722792	3980000000000	Europe
CN	China	1373541278	21100000000000	Asia
...	...	...	...	...

Borders (699 tuples)

country1_iso2	country2_iso2
SG	*null*
AU	*null*
TH	KH
TH	LA
TH	MY
...	...

Airports (3,372 tuples)

code	name	city	country_iso2
SIN	Singapore Changi Airport	Singapore	SG
XSP	Seletar Airport	Singapore	SG
SYD	Sydney Int. Airport	Sydney	AU
MEL	Melbourne Int. Airport	Melbourne	AU
FRA	Frankfurt am Main Airport	Frankfurt	DE
...	...	...	...

Cities (24,567 tuples)

name	country_iso2	capital	population
Singapore	SG	primary	5745000
Kuala Lumpur	MY	primary	8285000
Nanyang	CN	*null*	12010000
Atlanta	US	admin	5449398
Washington	US	primary	5379184
...	...	...	...

Routes (47,076 tuples)

from_code	to_code	airline_code
ADD	BKK	SQ
ADL	SIN	SQ
AKL	SIN	SQ
AMS	SIN	SQ
BCN	GRU	SQ
...	....	...

Users (9 tuples)

user_id	name	age
101	Sarah	25
102	Judy	35
103	Max	52
104	Marie	36
105	Sam	30
...	....	...

Visited (585 tuples)

user_id	iso2
103	AU
103	US
103	SG
103	GB
104	GB
...	...

Overview

- **Common SQL constructs**
  - **Aggregation**
  - Grouping
  - Conditional Expressions

- Structuring Queries
  - Common Table Expressions
  - Views

- Extended concepts
  - Universal Quantification
  - Recursive Queries

- Summary

Aggregation

- Aggregate functions
  - Compute a single value from a set of tuples
  - Examples: **MIN**(), **MAX**(), **AVG**(), **COUNT**(), **SUM**()

Find find the lowest and highest population sizes among all countries, as well as the global population size (= sum over all countries).

```
SELECT MIN(population) AS lowest,
       MAX(population) AS highest,
       SUM(population) AS global
FROM countries;
```

lowest	highest	global
54	1373541278	7326984691

China

Aggregation — Interpretation of NULL values

...	A	...
...	3	...
null	*null*	null
...	42	...
...	0	...
...	3	...

- Let *R* be a non-empty relation with attribute *A*

	Query	Interpretation	Result	
1	**SELECT MIN**(A) **FROM** R;	Minimum non-null value in A	0	
2	**SELECT MAX**(A) **FROM** R;	Maximum non-null value in A	42	
3	**SELECT AVG**(A) **FROM** R;	Average of non-null values in A	12	
4	**SELECT SUM**(A) **FROM** R;	Sum of non-null values in A	48	
5	**SELECT COUNT**(A) **FROM** R;	Count of non-null values in A	4	
	SELECT COUNT(*) **FROM** R;	Count of rows in R	5	
6	**SELECT AVG**(**DISTINCT** A) **FROM** R;	Average of distinct non-null values in A	15	$\frac{45}{3}$
7	**SELECT SUM**(**DISTINCT** A) **FROM** R;	Sum of distinct non-null values in A	45	
8	**SELECT COUNT**(**DISTINCT** A) **FROM** R;	Count of distinct non-null values in A	3	

Aggregation — Interpretation of NULL values

- Let *R*, *S* be two relations with an attribute *A*
  - Let R be an empty relation
  - Let *S* be a non-empty relation with *n* tuples but only null values for *A*

Query	Result
SELECT MIN(A) **FROM** R;	null
SELECT MAX(A) **FROM** R;	null
SELECT AVG(A) **FROM** R;	null
SELECT SUM(A) **FROM** R;	null
SELECT COUNT(A) **FROM** R;	0
SELECT COUNT(*) **FROM** R;	0

Query	Result
SELECT MIN(A) **FROM** S;	null
SELECT MAX(A) **FROM** S;	null
SELECT AVG(A) **FROM** S;	null
SELECT SUM(A) **FROM** S;	null
SELECT COUNT(A) **FROM** S;	0
SELECT COUNT(*) **FROM** S;	***n***

Aggregation — More Examples

Find the first last city in the United States with respect to their lexicographic sorting.

```
SELECT MIN(name) AS lexi_first, MAX(name) AS lexi_last
FROM cities
WHERE country_iso2 = 'US';
```

lexi_first	lexi_last
Abbeville	Zuni Pueblo

Find the number countries with at least 10% of the population compared to the country with the largest population size.

```
SELECT COUNT(*) AS num_big_countries
FROM countries
WHERE population >= 0.1 * (SELECT MAX(population)
                           FROM countries);
```

China
1.3 B

Scalar subquery!

num_big_countries
9

Aggregate Functions — Signatures

- Data type of attribute/column of a table affects:
  - Applicability of aggregate functions
  - Return data type of aggregate functions

- Examples
  - **MIN**(), **MAX**() defined for all data types; return date type same as input data type
  - **SUM**() defined for all numeric data types; **SUM**(INTEGER)➝BIGINT, **SUM**(REAL)➝REAL, …
  - **COUNT**() defined for all data types; **COUNT**(...)➝BIGINT

Complete list for PostgreSQL: https://www.postgresql.org/docs/current/functions-aggregate.html

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Grouping — GROUP BY Clause

- Aggregation so far
  - Application of aggregate functions over <u>all</u> tuples of a relation
  - Result relation has only <u>one</u> tuple

➜ Grouping using **GROUP BY**
  - Logical partition of relation into groups based on values for specified attributes
  - In principle, always applied together with aggregation
    (**GROUP BY** without aggregation valid but typically not meaningful)
  - Application of aggregation functions over each group
  - One result tuple for each group

GROUP BY — Example

For each continent, find find the lowest and highest population sizes among all countries, as well as the overall population size for that continent.

Logical partition of "Countries" w.r.t. "continent"

iso2	name	population	gdp	continent
DZ	Algeria	40263711	609000000000	**Africa**
AO	Angola	25789024	189000000000	**Africa**
...	...	...	...	...
AF	Afghanistan	33332025	64080000000	**Asia**
BH	Bahrain	1378904	66370000000	**Asia**
...	...	...	...	...
AR	Argentina	43886748	879000000000	**South America**
BO	Bolivia	10969649	78660000000	**South America**
...	...	...	...	...
AI	Anguilla	16752	175400000	**North America**
BS	Bahamas	327316	9070000000	**North America**
...	...	...	...	...
...	...	...	...	**Europe**

```
SELECT continent,
       MIN(population) AS lowest,
       MAX(population) AS highest,
       SUM(population) AS overall
FROM countries
GROUP BY continent;
```

continent	lowest	highest	overall
Africa	93186	186053386	1194073093
Asia	392960	1373541278	4248430118
South America	2931	205823665	415117737
North America	5267	323995528	569827073
Europe	1000	142355415	861956872
Oceania	54	22992654	37579798

GROUP BY — Example

For each route, find the number of airlines that serve that route.

Logical partition of "Routes" w.r.t. "from_code" and "to_code"

from_code	to_code	airline_code
SIN	FRA	SQ
SIN	FRA	LH
SIN	FRA	US
PEK	SIN	CA
PEK	SIN	SQ
MNL	SIN	3K
MNL	SIN	5J
MNL	SIN	PR
MNL	SIN	SQ
MNL	SIN	TR
SIN	ADL	ET
SIN	ADL	SQ
SIN	ADL	VA
SIN	HEL	AY
...	...	...

```
SELECT from_code, to_code,
          COUNT(*) AS num_airlines
FROM routes
GROUP BY from_code, to_code;
```

from_code	to_code	num_airlines
SIN	FRA	3
PEK	SIN	2
MNL	SIN	5
SIN	ADL	3
SIN	HEL	1
MNL	KLO	6
ATL	JFK	10
KUL	BKK	9
...	...	...

GROUP BY Clause — Defining Groups

- Given "**GROUP BY** a_1, a_2, …, a_n", 2 tuples t and t' belong to the same group if

  "($t.a_1$ **IS NOT DISTINCT FROM** $t'.a_1$)" and
  "($t.a_2$ **IS NOT DISTINCT FROM** $t'.a_2$)" and
  … and
  "($t.a_n$ **IS DISTINCT FROM** $t'.a_n$)"
  NOT

  evaluates to "true"

- Example:
  - Table *R* with three attributes *A*, *B*, *C*

A	B	C
null	4	19
6	1	*null*
20	2	10
1	1	2
1	18	2
null	21	19
6	20	*null*

SELECT ...
FROM R
GROUP BY A, C;

this is not a result table

A	B	C
null	4	**19**
null	21	**19**
6	1	***null***
6	20	***null***
20	2	**10**
1	1	**2**
1	18	**2**

GROUP BY Clause — Restrictions to SELECT Clause

- If column A_i of table *R* appears in the **SELECT** clause, one of the following conditions must hold:
  - A_i appears in the **GROUP BY** clause
  - A_i appears as input of an aggregation function in the **SELECT** clause
  - The primary key ~~or a candidate key~~ of R appears in the **GROUP BY** clause

Valid in standard SQL but not supported by PostgreSQL.
In this module we follow PostgreSQL's tighter restriction

Example of an **invalid** query:

SELECT continent, gdp, **SUM**(population)
FROM countries
GROUP BY continent;

GROUP BY — Grouping over Primary Key

- Assume table "Countries" was created as shown on the right

```
CREATE TABLE Countries (
        iso2          CHAR(2) PRIMARY KEY,
        name          VARCHAR(255) UNIQUE,
        population    INTEGER,
        gdp           BIGINT,
        continent     VARCHAR(255)
);
```

225 { China 1.3B 1
Germany 90 M 1

This query is **valid**!

```
SELECT name, population, COUNT(*)
FROM countries
GROUP BY iso2;
```

pk

Quick Quiz: What is the "problem" with this query?

This query is **valid** SQL standard but **invalid** PostgreSQL!

```
SELECT name, population, COUNT(*)
FROM countries
GROUP BY name;
```

GROUP BY — Grouping over Primary Key

- Assume table "Countries" was created as shown on the right
  - No key constraints on "Cities"

```
CREATE TABLE Countries (
        iso2            CHAR(2) PRIMARY KEY,
        name            VARCHAR(255) UNIQUE,
        population      INTEGER,
        gdp             BIGINT,
        continent       VARCHAR(255)
);
```

This query is **valid**!

```
SELECT n.name, n.population, COUNT(*)
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.iso2;
```

This query is **invalid**!

```
SELECT n.name, c.name, COUNT(*)
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.iso2;
```

This query is **valid**!

SELECT n.name, n.population, **COUNT**(*)
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.iso2;

This query is **invalid**!

SELECT n.name, c.name, **COUNT**(*)
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.iso2;

GROUP BY

n.iso2	n.name	n.population	...	c.name	c.country_iso2	c.population	...
BS	Bahamas	327316	...	Nassau	BS	274400	...
BS	Bahamas	327316	..	Freeport City	BS	25383	...
BS	Bahamas	327316	...	Marsh Harbour	BS	6283	...
SG	Singapore	5781728	...	Singapore	SG	5745000	...
DJ	Djibouti	846687	...	Djibouti	DJ	562000	...
DJ	Djibouti	846687	...	Arta	DJ	null	...
DJ	Djibouti	846687	...	Ali Sabieh	DJ	37939	...
DJ	Djibouti	846687	...	Dikhil	DJ	35000	...
DJ	Djibouti	846687	...	Obock	DJ	21200	...
DJ	Djibouti	846687	...	Tadjourah	DJ	14820	...
AU	Australia	22992654	...	Sydney	AU	5312163	...
AU	Australia	22992654	...	Melbourne	AU	5078193	...
	...	...					...

HAVING Clause — Conditions over Groups

- **HAVING** conditions
  - Conditions check for each group defined by **GROUP BY** clause
  - **HAVING** clause cannot be used without a **GROUP** BY clause
  - Conditions typically involve aggregate functions

Find all routes that are served by more than 12 airlines.

```
SELECT from_code, to_code,
       COUNT(*) AS num_airlines
FROM routes
GROUP BY from_code, to_code
HAVING COUNT(*) > 12;
```

from_code	to_code	num_airlines
ORD	ATL	20
ATL	ORD	19
ORD	MSY	13
HKT	BKK	13

HAVING Clause — Conditions over Groups

*Find all countries that have at least one city with a population size large*r *than the average population size of all European countries*

```
SELECT n.name, n.continent
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.name, n.continent
HAVING MAX(c.population) > (SELECT AVG(population)
                            FROM countries
                            WHERE continent = 'Europe');
```

scalar subquery

name	continent
China	Asia
Mexico	North America
India	Asia
Egypt	Africa
Philippines	Asia
Russia	Europe
Thailand	Asia
Brazil	South America
South Korea	Asia
Indonesia	Asia
United States	North America

GROUP BY Clause — Restrictions to HAVING Clause

- If column A_i of table *R* appears in the **HAVING** clause, one of the following conditions must hold:
  - A_i appears in the **GROUP BY** clause
  - A_i appears as input of an aggregation function in the **HAVING** clause
  - The primary key ~~or a candidate key~~ of R appears in the **GROUP BY** clause

Asia , 1

Valid Queries

```
SELECT continent, COUNT(*)
FROM countries
GROUP BY continent
HAVING AVG(population) > 25000000;
```

```
SELECT continent, COUNT(*)
FROM countries
GROUP BY continent
HAVING continent = 'Asia';
```

```
SELECT continent, COUNT(*)
FROM countries
GROUP BY iso2
HAVING name = 'China';
```

Invalid Query

```
SELECT continent, COUNT(*)
FROM countries
GROUP BY continent
HAVING name = 'China';
```

Quick Quiz: What is the result of this query?

Conceptual Evaluation of Queries

FROM	Compute cross-product of all tables in FROM clause
WHERE	Filter tuples that evaluate to true on the WHERE condition(s)
GROUP BY	Partition table into groups w.r.t. to the grouping attribute(s)
HAVING	Filter groups that evaluate to true on the HAVING condition(s)
SELECT	Remove all attributes no specified in SELECT clause
ORDER BY	Sort tables based on specified attribute(s)
LIMIT/OFFSET	Filter tuples based on their order in the table

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CASE — Conditional Expressions

- CASE expression
  - Generic conditional expression
  - Similar to case or if/else statements in programming languages

- Two basic ways for formulating CASE expressions

CASE
  WHEN *condition*$_1$ **THEN** *result*$_1$
  WHEN *condition*$_2$ **THEN** *result*$_2$
  …
  WHEN *condition*$_n$ **THEN** *result*$_n$
  ELSE *result*$_0$
END

CASE *expression*
  WHEN *value*$_1$ **THEN** *result*$_1$
  WHEN *value*$_2$ **THEN** *result*$_2$
  …
  WHEN *value*$_n$ **THEN** *result*$_n$
  ELSE *result*$_0$
END

CASE — Conditional Expressions

Find the number of all cities regarding the classification (defined by a cities population size).

City Size	Urban Population (Million)
Super city	>10
Megacity	5–10
Large city	1–5
Medium city	0.5–1
Small city	<0.5

```
SELECT class, COUNT(*) AS city_count
FROM
    (SELECT name, CASE
        WHEN population > 10000000 THEN 'Super City'
        WHEN population > 5000000 THEN 'Mega City'
        WHEN population > 1000000 THEN 'Large City'
        WHEN population > 500000 THEN 'Medium City'
        ELSE 'Small City' END AS class
    FROM cities) t
GROUP BY class;
```

subquery

class	city_count
Medium City	556
Large City	563
Small City	23306
Mega City	104
Super City	38

CASE — Conditional Expressions

Find all countries and return the continent in Tamil.

```
SELECT name, CASE continent
        WHEN 'Africa' THEN 'ஆப்பிரிக்கா'
        WHEN 'Asia' THEN 'ஆசியா'
        WHEN 'Europe' THEN 'ஐரோப்பா'
        WHEN 'North America' THEN 'வட அமெரிக்கா'
        WHEN 'South America' THEN 'தென் அமெரிக்கா'
        WHEN 'Oceania' THEN 'ஓசியானியா'
        ELSE NULL END AS continent
FROM countries;
```

class	city_count
Afghanistan	ஆசியா
Albania	ஐரோப்பா
Algeria	ஆப்பிரிக்கா
Andorra	ஐரோப்பா
Angola	ஆப்பிரிக்கா
Antigua and Barbuda	வட அமெரிக்கா
Argentina	தென் அமெரிக்கா
...	...

COALESCE — Conditional Expressions for NULL Values

- COALESCE(value1, value2, value3, ...)
  - Returns the first non-NULL value in the list of input arguments
  - Returns NULL if all values in the list of input arguments are NULL
  - Example: **SELECT COALESCE**(*null*, *null*, 1, *null*, 2) ➜

val
1

1st non-null value

Find the number of cities for each city type;
consider cities with NULL for column "capital" as "other".

```
SELECT capital, COUNT(*) AS city_count
FROM
        (SELECT COALESCE(capital, 'other') AS capital
         FROM cities) t
GROUP BY capital;
```

c1 'admin' → 'admin'
c2 'minor' → 'minor'
c3 null → 'other'

capital	city_count
primary	202
other	17147
admin	3531
minor	3687

NULLIF — Conditional Expressions for NULL Values

- **NULLIF**(*$value_1$*, *$value_2$*)
  - Returns NULL if $value_1 = value_2$; otherwise returns $value_1$
  - Examples:

SELECT NULLIF(1, 1) **AS** val; ➜

val
null

SELECT NULLIF(1, 2) **AS** val; ➜

val
1

  - Common use case: convert "special" values (zero, empty string) to NULL values

Find the minimum and average GDP across all countries (unknown GDP values are represented by 0)

```
SELECT MIN(gdp) AS min_gdp,
       ROUND(AVG(gdp)) AS avg_gdp
FROM countries;
```

min_gdp	avg_gdp
0	529798224844

```
SELECT MIN(NULLIF(gdp, 0)) AS min_gdp,
       ROUND(AVG(NULLIF(gdp, 0))) AS avg_gdp
FROM countries;
```

min_gdp	avg_gdp
1500000	549329956636

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Common Table Expressions (CTEs)

country	city	airport
Iceland	Hofn	Hornafjörður Airport
Malta	Pembroke	Pembroke Airport
Malta	Victoria	Victoria Airport

- Motivation
  - SQL can quickly become complex and unreadable
  - CTEs allow to structure SQL queries to improve readability

➜ Common Table Expression CTE

- Temporary named query
- One or more CTEs a can be used with in an SQL statement

Example from last lecture:
Find all airports in European countries without a land border which cannot be reached by plane given the existing routes in the database.

```
SELECT t1.country, t1.city, t1.airport
FROM
   (SELECT n.name AS country, c.name AS city,
                 a.name AS airport, a.code
    FROM borders b, countries n, cities c, airports a
    WHERE  b.country1_iso2 = n.iso2
         AND n.iso2 = c.country_iso2
         AND c.name = a.city
         AND b.country2_iso2 IS NULL
         AND n.continent = 'Europe') t1
LEFT OUTER JOIN
   routes r
ON t1.code = r.to_code
WHERE r.to_code IS NULL;
```

Common Table Expressions (CTEs)

country	city	airport
Iceland	Hofn	Hornafjörður Airport
Malta	Pembroke	Pembroke Airport
Malta	Victoria	Victoria Airport

- Same examples using a CTE

CTE name

CTE body

```
WITH AirportsInIsolatedEuropeanCountries AS
     (SELECT n.name AS country, c.name AS city,
                 a.name AS airport, a.code
      FROM borders b, countries n, cities c, airports a
      WHERE  b.country1_iso2 = n.iso2
      AND n.iso2 = c.country_iso2
      AND c.name = a.city
      AND b.country2_iso2 IS NULL
      AND n.continent = 'Europe')
SELECT i.country, i.city, i.airport
FROM AirportsInIsolatedEuropeanCountries i LEFT OUTER JOIN routes r
   ON i.code = r.to_code
WHERE r.to_code IS NULL;
```

CTE usage

Common Table Expressions (CTEs)

- General syntax
  - Each C_i is the name of a temporary table defined by query Q_i
  - Each C_i can reference any other C_j that has been declared before C_i
  - SQL statement S can reference any possible subset of all C_i

```
WITH
      C1 AS (Q1),
      C2 AS (Q2),
      …,
      Cn AS (Qn)
SQL statement S;
```

can reference $C_1, C_2, \ldots, C_n$

can reference C_1 but not C_n

- Note
  - The goal of using CTEs is <u>not</u> to write less code
  - CTEs help to improve readability, debugging, maintenance

Common Table Expressions (CTEs)

country	city	airport
Iceland	Hofn	Hornafjörður Airport
Malta	Pembroke	Pembroke Airport
Malta	Victoria	Victoria Airport

- Extended example
  - Multiples CTEs
  - CTE referencing previously declared CTE
  - CTEs are not required to be referenced

```
WITH IsolatedEuropeanCountries AS (
        SELECT n.iso2, n.name AS country
        FROM borders b, countries n
        WHERE  b.country1_iso2 = n.iso2
            AND b.country2_iso2 IS NULL
            AND n.continent = 'Europe'),
    AirportsInIsolatedEuropeanCountries AS (
        SELECT n.country, c.name AS city, a.code, a.name AS airport
        FROM IsolatedEuropeanCountries n, cities c, airports a
        WHERE n.iso2 = c.country_iso2
            AND c.name = a.city),
    UnusedJustForFun AS (
        SELECT COUNT(*)
        FROM IsolatedEuropeanCountries)
SELECT i.country, i.city, i.airport
FROM AirportsInIsolatedEuropeanCountries i LEFT OUTER JOIN routes r
    ON i.code = r.to_code
WHERE r.to_code IS NULL;
```

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Views — Virtual Relations

id	name	salary

everyone

manager / HR

- Common observations when querying databases
  (beyond the case of increasing complexity of SQL queries)
  - Often only parts of a table (rows/columns) are of interest
  - Often not all parts of a table (rows/columns) should be accessible to all users
  - Often the same queries or subqueries are regularly and frequently used

➜ View

- Permanently named query (= virtual relation)
- Can be used like normal tables
  (with some restrictions; discussed later)
- The query is stored not the query result

```
CREATE VIEW <name> AS
    SELECT ...
    FROM ...
    ...
```

Views — Example

Assumption: Finding all European countries without a land border is a very frequent query.

*Find all airports in **European countries without a land border** which cannot be reached by plane given the existing routes in the database.*

```
CREATE VIEW IsolatedEuropeanCountries AS
        SELECT n.iso2, n.name AS country
        FROM borders b, countries n
        WHERE b.country1_iso2 = n.iso2
            AND b.country2_iso2 IS NULL
            AND n.continent = 'Europe';
```

```
WITH AirportsInIsolatedEuropeanCountries AS (
        SELECT n.country, c.name AS city, a.code, a.name AS airport
        FROM IsolatedEuropeanCountries n, cities c, airports a
        WHERE n.iso2 = c.country_iso2
            AND c.name = a.city)
SELECT i.country, i.city, i.airport
FROM AirportsInIsolatedEuropeanCountries i LEFT OUTER JOIN routes r
    ON i.code = r.to_code
WHERE r.to_code IS NULL;
```

country	city	airport
Iceland	Hofn	Hornafjörður Airport
Malta	Pembroke	Pembroke Airport
Malta	Victoria	Victoria Airport

Views — Example

```
CREATE VIEW CountryUrbanizationStats AS
SELECT
    n.iso2, n.name, n.population AS overall_population, SUM(c.population) AS city_population,
    SUM(c.population) / CAST(n.population AS NUMERIC) AS urbanization_rate
FROM cities c, countries n
WHERE c.country_iso2 = n.iso2
GROUP BY n.iso2;
```

Quick Quiz: Why do we need this?

Find all countries with a urbanization rate below 10%.

```
SELECT name, urbanization_rate
FROM CountryUrbanizationStats
WHERE urbanization_rate < 0.1
ORDER BY urbanization_rate ASC;
```

looks like table

INSERT INTO cus VALUES(...) ??? Fail

name	urbanization_rate
Grenada	0.039
Micronesia	0.059
Ethiopia	0.070
Burundi	0.081
Uganda	0.099

Views — Usability

- No restriction when used in SQL queries (**SELECT** statements)
  - But what about **INSERT**, **UPDATE**, **DELETE** statements?

➜ Updatable View — requirements

- Only one entry in **FROM** clause (table or updatable view)
- No **WITH**, **DISTINCT**, **GROUP BY**, **HAVING**, **LIMIT**, or **OFFSET**
- No **UNION**, **INTERSECT** or **EXCEPT**
- No aggregate functions
- etc. (incl. no constraint violations)

CREATE VIEW u2 AS
SELECT user_id, age
FROM users;

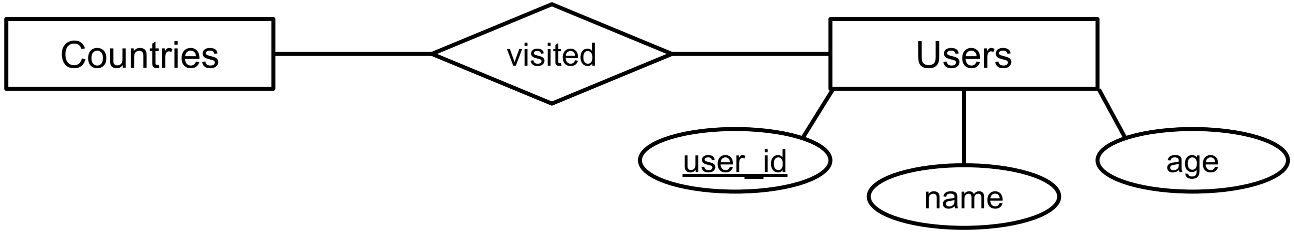
For more details: https://www.postgresql.org/docs/current/sql-createview.html

Overview

- Common SQL constructs
  - Aggregation
  - Grouping
  - Conditional Expressions
- Structuring Queries
  - Common Table Expressions
  - Views
- **Extended concepts**
  - **Universal Quantification**
  - Recursive Queries
- Summary

Universal Quantification

- Small extension to existing example DB



- Query with universal quantification
  - *"Find the names of all users that have visited all countries."*

Visited

user_id	iso2
101	SG
101	DE
103	SG
103	CN
103	FR
...	...

Users

user_id	name	age
101	Sarah	25
102	Judy	35
103	Max	52
...	...	...

➜ Problem: SQL directly supports only existential quantification (**EXISTS**)

not related to ALL

Universal Quantification

- "Transformation" of query using logical equivalences
  - *"user who visited all countries"* ➜ *"there does <u>not exists</u> a country the user has <u>not</u> visited"*

- Useful subquery
  - *All countries a user with user_id = x has not visited*

```
SELECT n.iso2
FROM countries n
WHERE NOT EXISTS (SELECT 1
                  FROM visited v
                  WHERE v.iso2 = n.iso2
                    AND v.user_id = x);
```

TRUE only for countries that do not have a match in "Visited" for all tuples where the user_id = x

Universal Quantification

"Find the names of all users that have visited <u>all</u> countries."

```
SELECT user_id, name
FROM users u
WHERE NOT EXISTS (SELECT n.iso2
                  FROM countries n
                  WHERE NOT EXISTS (SELECT 1
                                    FROM visited v
                                    WHERE v.iso2 = n.iso2
                                    AND v.user_id = u.user_id)
                 );
```

user_id	name
103	Max
107	Emma

➜ While not overly common, SQL queries requiring universal quantification can get "ugly".

Universal Quantification

- Alternative interpretation
  - *"user who visited all countries"* ➜ *"the number of tuples in "Visited" for that user must match the total number of countries"*

"Find the names of all users that have visited all countries."

```
SELECT u.user_id, u.name
FROM users u, visited v
WHERE u.user_id = v.user_id
GROUP BY u.user_id
HAVING COUNT(*) = (SELECT COUNT(*) FROM countries);
```

225

user_id	name
103	Max
107	Emma

Overview

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Recursive Queries

```
CREATE TABLE connections AS
  SELECT DISTINCT(from_code, to_code)
  FROM routes;
```

- Small extension to existing example DB
  - Create table "Connections" as shown
  - Eliminates duplicate routes served by multiple airlines

- Interesting queries
  - *"Find all airports that can be reached from SIN non-stop."*

```
SELECT to_code
FROM connections
WHERE from_code = 'SIN';
```

103 tuples

to_code
PEK
BKK
FRA
KUA
...

  - *"Find all airports that can be reached from SIN with 1/2/3/… stops."* ➜ ???

Recursive Queries

*Find all airports that can be reached from SIN with **1** stop.*

927 tuples

```
SELECT DISTINCT(c2.to_code) AS to_code
FROM
   connections c1,
   connections c2
WHERE c1.to_code = c2.from_code
    AND c1.from_code = 'SIN';
```

to_code
DUB
PEK
SIN
MME
...

*Find all airports that can be reached from SIN with **2** stop.*

1,725 tuples

```
SELECT DISTINCT(c3.to_code) AS to_code
FROM
   connections c1,
   connections c2,
   connections c3
WHERE c1.to_code = c2.from_code
    AND c2.to_code = c3.from_code
    AND c1.from_code = 'SIN';
```

to_code
DUB
PEK
SIN
MME
...

Recursive Queries

- Observation: *X* stops requires query with *X* joins
  - Requires to write a separate query for each X

➜ Recursive Queries using CTEs

Non-recursive term;
can not reference "cte_name"!

Recursive term
referencing "cte_name"

WITH RECURSIVE cte_name AS (
    Q_1
    UNION [**ALL**]
    Q_2(cte_name)
)
SELECT * **FROM** cte_name;

Recursive Queries

*Find all airports that can be reached from SIN with **0..2** stops.*
(limitation to max. 2 stops purely for performance reasons)

non-recursive

recursive

```
WITH RECURSIVE flight_path AS (
    SELECT from_code, to_code, 0 AS stops
    FROM connections
    WHERE from_code = 'SIN'
  UNION ALL
    SELECT c.from_code, c.to_code, p.stops+1
    FROM flight_path p, connections c
    WHERE p.to_code = c.from_code
    AND p.stops <= 2
)
SELECT DISTINCT to_code, stops
FROM flight_path
ORDER BY stops ASC;
```

to_code	stops
PEK	0
BKK	0
FRA	0
...	...
KUA	0
DUB	1
PEK	1
SIN	1
...	...
MME	1
AMS	2
BKK	2
PER	2
...	....
ZYL	2

103 tuples

927 tuples

1,725 tuples

*Find all airports that can be reached from SIN with **0..2** stops, including the exact paths.*

(limitation to max. 2 stops purely for performance reasons)

```
WITH RECURSIVE flight_path (airport_codes, stops, is_visited) AS (
        SELECT
                ARRAY[from_code, to_code],
                0 AS stops,
                from_code = to_code
        FROM connections
        WHERE from_code = 'SIN'
        UNION ALL
        SELECT
                (airport_codes || to_code)::char(3)[],
                p.stops + 1,
                c.to_code = ANY(p.airport_codes)
        FROM
                connections c,
                flight_path p
        WHERE p.airport_codes[ARRAY_LENGTH(airport_codes, 1)] = c.from_code
            AND NOT p.is_visited
            AND p.stops < 2
)
SELECT DISTINCT airport_codes, stops
FROM flight_path
ORDER BY stops;
```

airport_codes	stops	
{SIN, PEK}	0	103 tuples
{SIN, BKK}	0	
{SIN, FRA}	0	
...	...	
{SIN, KUA}	0	
{SIN, BKK, PEK}	1	5,351 tuples
{SIN, FRA, PEK}	1	
{SIN, DOH, PEK}	1	
...	...	
{SIN, MFM, DMK}	1	
{SIN, ADL, HKG, PEK}	2	281,522 tuples
{SIN, ADL, KUL, PEK}	2	
{SIN, ADL, SYD, PEK}	2	
...	....	
{SIN, TPE, FRA, CSS}	2	

Dealing with the Limitations of (Basic) SQL

- Other types of queries poorly or not support by basic SQL
  - *"Sorted by GDP, are there somewhere in the ranking 5 Asian countries listed in a row."*
  - Queries/tasks common for time series: moving average, sliding window, etc.

- Common approaches
  - Keep or move logic into the application
  - Use features that make SQL turing-complete
    (e.g. using SQL/PSM — Persistent Stored Modules)
  - Some a different data model / DBMS
    (e.g., a graph database for recursive queries, or time series databases)

➜ Covered in next lectures

Summary

- Covered: SQL (DQL)
  - Most common vocabulary for writing queries
  - Basic means to "organize" complex queries (CTEs, Views)

- Limitations of SQL (more general: Relational Model)
  - Universal quantification
  - Recursive queries
  - Sequential data
  - Graph data
  - ...

RDBMS & SQL not the solution for everything