CMPT 354: Database System I

Lecture 4. SQL Advanced

Announcements!

- A1 is due today
- A2 is released (due in 2 weeks)

Outline

- **Joins**
  - Inner Join
  - Outer Join
- **Aggregation Queries**
  - Simple Aggregations
  - Group By
  - Having
- **Discussion**

Joins: Recap

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

```
SELECT name, course
FROM   Student, Enroll
WHERE  name = stdName
```

name	gpa
Mary	354
Tom	354
Tom	454

Two equivalent ways to write joins

```
SELECT name, course
FROM   Student, Enroll
WHERE  name = stdName
```

=

```
SELECT name, course
FROM   Student JOIN Enroll ON
       name = stdName
```

Join Types

```
SELECT name, course
FROM   Student INNER JOIN Enroll ON
       name = stdName
```

```
SELECT name, course
FROM   Student FULL OUTER JOIN Enroll ON
       name = stdName
```

```
SELECT name
FROM   Student LEFT OUTER JOIN Enroll ON
       name = stdName
```

```
SELECT name
FROM   Student RIGHT OUTER JOIN Enroll ON
       name = stdName
```

Join Types

```
SELECT name, course
FROM   Student       JOIN Enroll ON
       name = stdName
```

```
SELECT name, course
FROM   Student FULL       JOIN Enroll ON
       name = stdName
```

```
SELECT name
FROM   Student LEFT       JOIN Enroll ON
       name = stdName
```

```
SELECT name
FROM   Student RIGHT       JOIN Enroll ON
       name = stdName
```

Left Join

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

```
SELECT name, course
FROM   Student LEFT JOIN Enroll ON
       name = stdName
```

We want to include all students no matter whether they enroll a course or not. How?

```
SELECT name, course
FROM   Student LEFT JOIN Enroll ON
       name = stdName
```

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

Output

name	course
Mary	354
Tom	354
Tom	454
Jack	NULL

```
SELECT name, course
FROM   Student RIGHT JOIN Enroll ON
       name = stdName
```

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

Output

name	course
Mary	354
Tom	354
Tom	454
NULL	354

```
SELECT name, course
FROM   Enroll FULL JOIN Student ON
       name = stdName
```

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Output

name	course
Mary	354
Tom	354
Tom	454
Jack	NULL
NULL	354

Outer Join

```
TableA (LEFT/RIGHT/FULL) JOIN TableB
```

- Left outer join:
    - Include tuples from tableA even if no match
- Right outer join:
    - Include tuples from tableB even if no match
- Full outer join:
    - Include tuples from both even if no match

Exercise - 1

```
SELECT name, course
FROM   Student LEFT JOIN Enroll ON
       name = stdName AND course = 354
```

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

name	course
Mary	354
Tom	354
Jack	NULL

(A)

name	course
Mary	354
Tom	354

(B)

Exercise - 2

```
SELECT name, course
FROM   Student LEFT JOIN Enroll ON
       name = stdName
WHERE  course = 354
```

Student

name	gpa
Mary	3.8
Tom	3.6
Jack	3.7

Enroll

stdName	course
Mary	354
Tom	354
Tom	454
Bob	354

name	course
Mary	354
Tom	354
Jack	NULL

(A)

name	course
Mary	354
Tom	354

(B)

Outline

- **Joins**
  - Inner Join
  - Outer Join
- **Aggregation Queries**
  - Simple Aggregations
  - Group By
  - Having
- **Discussion**

Simple Aggregation

```
SELECT agg(column)
FROM   <table name>
WHERE  <conditions>
```

```
agg = COUNT, SUM, AVG, MAX, MIN, etc.
```

Except count, all aggregations apply to a single attribute

Examples

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	3
Mary	F	4
Tom	M	4

`SELECT COUNT(*) FROM Student`	5
`SELECT SUM(gpa) FROM Student`	17
`SELECT AVG(gpa) FROM Student`	3.4
`SELECT MIN(gpa) FROM Student`	3
`SELECT MAX(gpa) FROM Student`	4

Examples

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	3
Mary	F	4
Tom	M	4

```
SELECT COUNT(DISTINCT gpa) FROM Student
```

2

```
SELECT SUM(DISTINCT gpa) FROM Student
```

7

```
SELECT AVG(gpa) FROM Student
WHERE gender = ‘F’
```

3.5

The need for Group By

- How to get AVG(gpa) for each gender?

```
SELECT AVG(gpa) FROM Student WHERE gender = ‘M’
```

```
SELECT AVG(gpa) FROM Student WHERE gender = ‘F’
```

- How to get AVG(gpa) for each age?

```
SELECT AVG(gpa) FROM Student WHERE age = 18
```

```
SELECT AVG(gpa) FROM Student WHERE age = 19
```

```
SELECT AVG(gpa) FROM Student WHERE age = 20
```

⋮

Grouping and Aggregation

```
SELECT agg(column)
FROM   <table name>
WHERE  <conditions>
GROUP BY <columns>
```

- How to get AVG(gpa) for each gender?

```
SELECT AVG(gpa) FROM Student GROUP BY gender
```

- How to get AVG(gpa) for each age?

```
SELECT AVG(gpa) FROM Student GROUP BY age
```

Grouping and Aggregation

- How is the following query processed?

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 2.5
GROUP BY gender
```

- Semantics of the query
  1. Compute the FROM and WHERE clauses
  2. Group by the attributes in the GROUP BY
  3. Compute the SELECT clause: grouped attributes and aggregates

1. Compute the FROM and WHERE clauses

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 2.5
GROUP BY gender
```

name	gender	gpa
Bob	M	2
Mike	M	3
Alice	F	3
Mary	F	4
Tom	M	3

name	gender	gpa
Mike	M	3
Alice	F	3
Mary	F	4
Tom	M	3

2. Group by the attributes in the GROUP BY

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 2.5
GROUP BY gender
```

name	gender	gpa
Mike	M	3
Alice	F	3
Mary	F	4
Tom	M	3

gender	name	gpa
M	Mike	3
	Tom	3
F	Alice	3
	Mary	4

3. Compute the SELECT clause: grouped attributes and aggregates

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 2.5
GROUP BY gender
```

gender	name	gpa
M	Mike	3
	Tom	3
F	Alice	3
	Mary	4

gender	AVG(gpa)
M	3
F	3.5

Exercise: Empty Group

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

gender	AVG(gpa)
F	4

(A)

VS

gender	AVG(gpa)
F	4
M	NULL

(B)

Exercise: Empty Group

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

↓

name	gender	gpa
Alice	F	4
Mary	F	4

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

Exercise: Empty Group

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

name	gender	gpa
Alice	F	4
Mary	F	4

gender	name	gpa
F	Alice	4
	Mary	4

Exercise: Empty Group

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```
SELECT gender, AVG(gpa)
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

name	gender	gpa
Alice	F	4
Mary	F	4

gender	name	gpa
F	Alice	4
	Mary	4

gender	AVG(gpa)
F	4

Exercise: Invalid Selection

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```sql
SELECT gender, AVG(gpa), name
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

gender	AVG(gpa)	name
F	4	Alice

(A)

VS

gender	AVG(gpa)	name
F	4	Mary

(B)

Exercise: Invalid Selection

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

name	gender	gpa
Alice	F	4
Mary	F	4

```
SELECT gender, AVG(gpa), name
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

Exercise: Invalid Selection

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```
SELECT gender, AVG(gpa), name
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

name	gender	gpa
Alice	F	4
Mary	F	4

gender	name	gpa
F	Alice	4
	Mary	4

Exercise: Invalid Selection

Everything in SELECT must be either a GROUP-BY attribute, or an aggregate

```
SELECT gender, AVG(gpa), name
FROM Student
WHERE gpa > 3.5
GROUP BY gender
```

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

name	gender	gpa
Alice	F	4
Mary	F	4

gender	name	gpa
F	Alice	4
	Mary	4

gender	AVG(gpa)	name
F	4	???

HAVING Clause

- Specify which groups you are interested in

```
SELECT agg(column)
FROM   <table name>
WHERE  <conditions>
GROUP BY <columns>
HAVING <columns>
```

HAVING Clause

- Same query as before, except that we require each group has more than 10 students

```
SELECT AVG(gpa), gender
FROM Student
WHERE gpa > 2.5
GROUP BY gender
HAVING COUNT(*) > 10
```

HAVING clause contains conditions on aggregates.

Order of Evaluation

SELECT S
FROM $R_1,…,R_n$
WHERE C_1
GROUP BY $a_1,…,a_k$
HAVING C_2

- Create the cross product of the tables in the **FROM** clause
- Remove rows not meeting the **WHERE** condition
- Divide records into groups by the **GROUP BY** clause
- Remove groups not meeting the **HAVING** clause
- Create one row for each group and remove columns not in the **SELECT** clause

Exercise

StudentInfo

name	gender	gpa
Bob	M	3
Mike	M	3
Alice	F	4
Mary	F	4
Tom	M	3

```
SELECT gender, AVG(gpa)
FROM StudentInfo
WHERE gpa > 2.5
GROUP BY gender
HAVING COUNT(*) > 2
```

```
SELECT gender, AVG(gpa)
FROM StudentInfo
WHERE gpa > 2.5
GROUP BY gender
HAVING SUM(gpa) < 9
```

gender	AVG(gpa)
M	3

(A)

gender	AVG(gpa)
F	4

(B)

gender	AVG(gpa)
M	3
F	4

(C)

Imagine you are a data scientist at a Bank

Computer Science vs. Data Science

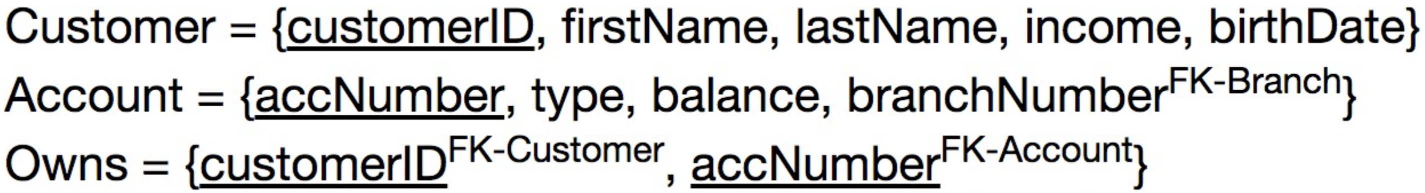
What	When	Who	Goal
Computer Science	1950-	Software Engineer	Write software to make computers work

Plan → Design → Develop → Test → Deploy → Maintain

What	When	Who	Goal
Data Science	2010-	Data Scientist	Extract insights from data to answer questions

Collect → Clean → Integrate → Analyze → Visualize → Communicate

Discussion



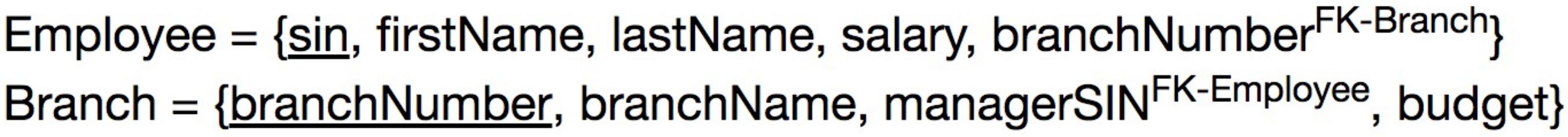
Customer = {$\underline{\text{customerID}}$, firstName, lastName, income, birthDate}

Account = {$\underline{\text{accNumber}}$, type, balance, branchNumber$^{\text{FK-Branch}}$}

Owns = {$\underline{\text{customerID}}^{\text{FK-Customer}}$, $\underline{\text{accNumber}}^{\text{FK-Account}}$}

Q1. Who is the richest customer?
Q2. Which customers have ONLY one account?

Discussion



Employee = {sin, firstName, lastName, salary, branchNumber$^{\text{FK-Branch}}$}

Branch = {branchNumber, branchName, managerSIN$^{\text{FK-Employee}}$, budget}

Q3. How many employees does each branch have?

Q4. Which branch has a higher pay?

Outline

- **Joins**
  - Inner Join
  - Outer Join
  - Self Join
- **Aggregation Queries**
  - Simple Aggregations
  - Group By
  - Having
- **Subqueries**
  - In the FROM clause
  - In the WHERE clause

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Subqueries

- A subquery is a SQL query nested inside a larger query
- Such inner-outer queries are called nested queries

```
SELECT C.customerID, C.birthDate, C.income
FROM Customer C
WHERE C.customerID IN
     (
         SELECT O.customerID
         FROM Account A, Owns A
         WHERE A.accNumber = O.accNumber
              AND A.branchName = 'Lonsdale’
     )
```

Outer Query

Inner Query

Subqueries

- Subqueries may appear in
  - A **FROM** clause,
  - A **WHERE** clause, and
  - A **HAVING** clause

```
SELECT <columns>
FROM   <table name>
WHERE  <conditions>
GROUP BY <columns>
HAVING <columns>
```

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Subqueries in FROM

- Sometimes we need to compute an intermediate table only to use it later in a SELECT-FROM-WHERE
- Who is the richest customer?

```
SELECT firstName, lastName, MAX(sumBalance)
FROM (SELECT firstName, lastName, sum(balance) AS sumBalance
          FROM Customer C, Account A, Owns O
          WHERE C.customerID = O.customerID
                    AND O.accNumber = A.accNumber
          GROUP BY C.customerID )
```

Customer = {$\underline{\text{customerID}}$, firstName, lastName, income, birthDate}

Account = {$\underline{\text{accNumber}}$, type, balance, branchName}

Owns = {$\underline{\text{customerID}}^{\text{FK-Customer}}$, $\underline{\text{accNumber}}^{\text{FK-Account}}$}

Subqueries in FROM

- Sometimes we need to compute an intermediate table only to use it later in a SELECT-FROM-WHERE
- Which customers have a total balance equal to 0?

```
SELECT firstName, lastName, sumBalance
FROM (SELECT firstName, lastName, sum(balance) AS sumBalance
          FROM Customer C, Account A, Owns O
          WHERE C.customerID = O.customerID
                    AND O.accNumber = A.accNumber
          GROUP BY C.customerID) AS T
WHERE T. sumBalance = 0
```

Customer = {customerID, firstName, lastName, income, birthDate}

Account = {accNumber, type, balance, branchName}

Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Subqueries in FROM

- Sometimes we need to compute an intermediate table only to use it later in a SELECT-FROM-WHERE
- Which customers have a total balance equal to 0?

```
SELECT firstName, lastName, sum(balance) AS sumBalance
FROM Customer C, Account A, Owns O
WHERE C.customerID = O.customerID AND O.accNumber = A.accNumber
GROUP BY C.customerID
HAVING sumBalance = 0
```

Rule of thumb: avoid nested queries when possible

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{FK\text{-}Customer}$, accNumber$^{FK\text{-}Account}$}

Subqueries in WHERE

- Subqueries return a single constant
  - >, <, =, <>, >=, <=
- Find the customerIDs of customers whose income is larger than avg(income)

```
SELECT C1.customerID
FROM Customer C1
WHERE C1.income > (SELECT avg(C2.income)
                   FROM Customer C2)
```

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Subqueries in WHERE

- Subqueries return a relation
  - IN
  - NOT IN
  - EXISTS
  - NOT EXISTS
  - ANY
  - ALL

Customer = {$\underline{\text{customerID}}$, firstName, lastName, income, birthDate}

Account = {$\underline{\text{accNumber}}$, type, balance, branchName}

Owns = {$\underline{\text{customerID}}^{\text{FK-Customer}}$, $\underline{\text{accNumber}}^{\text{FK-Account}}$}

Accounts IN Burnaby

- Find the customerIDs of customers with an account at the Burnaby branch

```
SELECT C.customerID
FROM Customer C
WHERE C.customerID IN (SELECT O.customerID
                       FROM Account A, Owns O
                        WHERE A.accNumber = O.accNumber
                           AND A.branchName = ’Burnaby’)
```

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Accounts NOT IN Burnaby

- Find the customerIDs of customers who do *not* have an account at the Burnaby branch

```
SELECT C.customerID
FROM Customer C
WHERE C.customerID NOT IN (SELECT O.customerID
                           FROM Account A, Owns O
                           WHERE A.accNumber = O.accNumber
                              AND A.branchName = ’Burnaby’)
```

Uncorrelated Queries

- The query shown previously contains an *uncorrelated*, or *independent*, sub-query
    - The sub-query does not contain references to attributes of the outer query

- An independent sub-query can be evaluated before evaluation of the outer query
    - And needs to be evaluated only once
        - The sub-query result can be checked for each row of the outer query
    - The cost is the cost for performing the sub-query (once) and the cost of scanning the outer relation

Customer = {$\underline{\text{customerID}}$, firstName, lastName, income, birthDate}

Account = {$\underline{\text{accNumber}}$, type, balance, branchName}

Owns = {$\underline{\text{customerID}}^{\text{FK-Customer}}$, $\underline{\text{accNumber}}^{\text{FK-Account}}$}

EXISTing BurnabyAccounts

- Find the customerIDs of customers with an account at the Burnaby branch

```
SELECT C.customerID
FROM Customer C
WHERE EXISTS ( SELECT *
               FROM Account A, Owns O
               WHERE C.customerID = O.customerID
                     AND A.accNumber = O.accNumber
                     AND A.branchName = ’Burnaby’)
```

EXISTS and NOT EXISTS test whether the associated sub-query is non-empty or empty

Correlated Queries

- The previous query contained a *correlated* sub-query
  - With references to attributes of the outer query
    - … WHERE C.customerID = O.customerID …
  - It is evaluated once *for each row* in the outer query
    - i.e. for each row in the Customer table
- Correlated queries are often inefficient

Customer = {customerID, firstName, lastName, income, birthDate}
Account = {accNumber, type, balance, branchName}
Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

EXISTing BurnabyAccounts

- Find the customerIDs of customers with an account at the Burnaby branch

```
SELECT DISTINCT C.customerID
FROM Customer C, Account A, Owns O
WHERE C.customerID = A.accNumber
    AND A.accNumber = O.customerID
   AND A.branchName = ’Burnaby’
```

Customer = {customerID, firstName, lastName, income, birthDate}

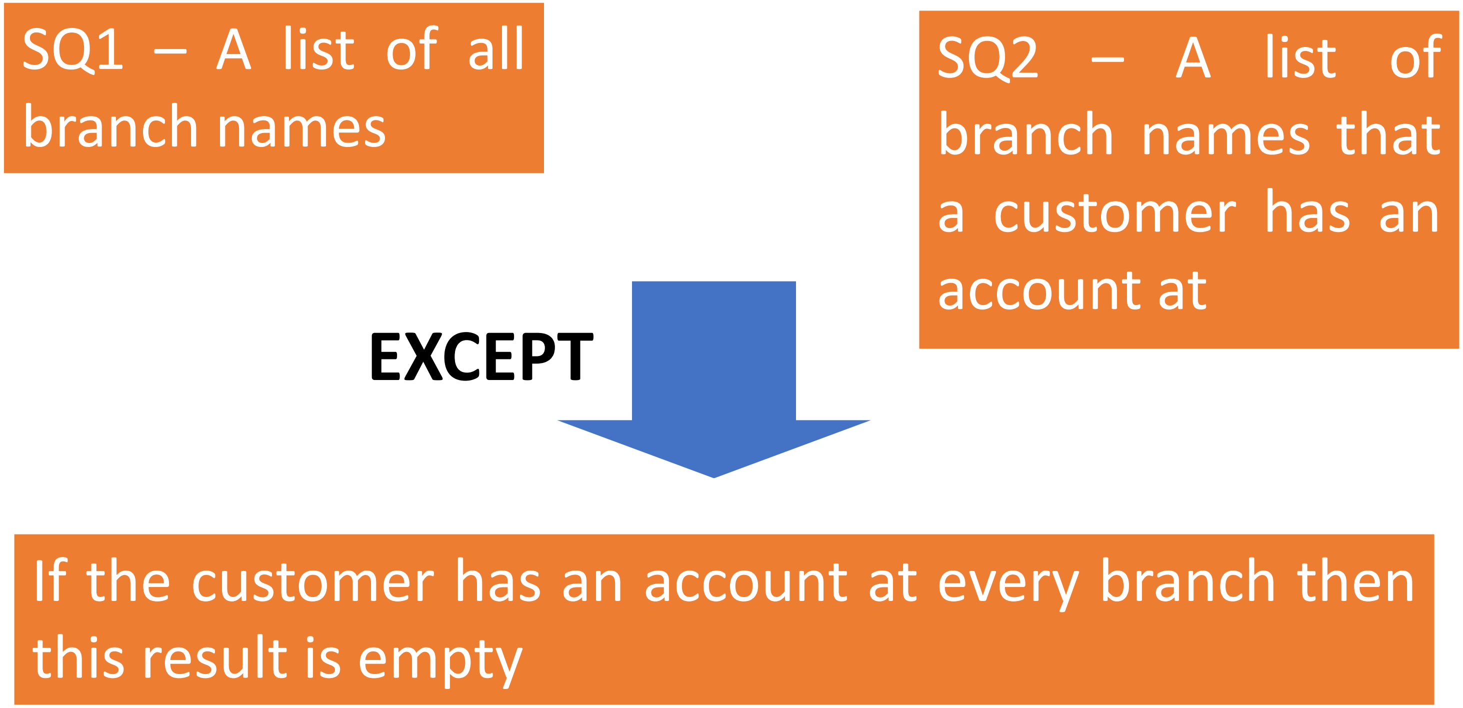
Account = {accNumber, type, balance, branchName}

Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

Branch = {branchNumber, branchName, managerSIN$^{\text{FK-Employee}}$, budget}

Have an account in all branches

- Find the customerIDs of customers who have an account in all branches



SQ1 – A list of all branch names

SQ2 – A list of branch names that a customer has an account at

EXCEPT

If the customer has an account at every branch then this result is empty

Have an account in all branches

- Putting it all together we have

```
SELECT C.customerID
FROM Customer C
WHERE NOT EXISTS ( (SELECT B.branchName
                    FROM Branch B)
                       EXCEPT
                   (SELECT A.branchName
                    FROM Account A, Owns O
                    WHERE O.customerID = C.customerID
                       AND O.accNumber = A.accNumber))
```

Customer = {customerID, firstName, lastName, income, birthDate}

Account = {accNumber, type, balance, branchName}

Owns = {customerID$^{\text{FK-Customer}}$, accNumber$^{\text{FK-Account}}$}

ANYone Richer Than Bruce

- Find the customerIDs of customers who earn more than *some* customer called Bruce

```
SELECT C.customerID
FROM Customer C
WHERE C.income > ANY
          (SELECT Bruce.income
           FROM Customer Bruce
           WHERE Bruce.firstName = 'Bruce')
```

Customers in the result table must have incomes greater than at least one of the rows in the sub-query result

Customer = {$\underline{\text{customerID}}$, firstName, lastName, income, birthDate}

Account = {$\underline{\text{accNumber}}$, type, balance, branchName}

Owns = {$\underline{\text{customerID}}^{\text{FK-Customer}}$, $\underline{\text{accNumber}}^{\text{FK-Account}}$}

Richer Than ALL the Bruces

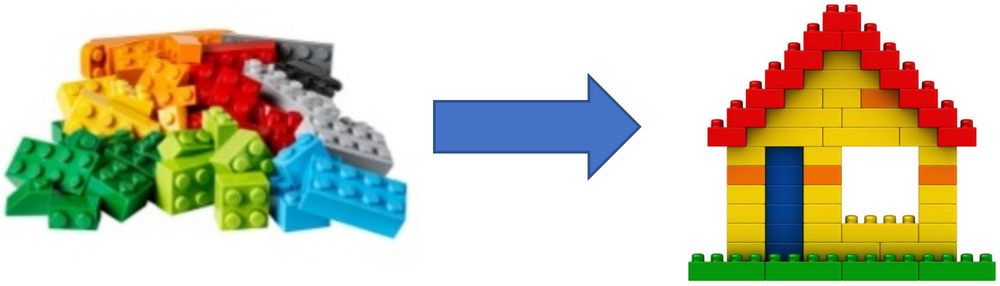
- Find the customerIDs of customers who earn more than *all* customer called Bruce

```
SELECT C.customerID
FROM Customer C
WHERE C.income > ALL
          (SELECT Bruce.income
           FROM Customer Bruce
           WHERE Bruce.firstName = 'Bruce')
```

If there were no customers called Bruce this query would return all customers

Summary

- Selection
- Projection
- Set Operators (UNION, INTERSECT, EXCEPT)
- Joins (INNER, OUTER)
- Aggregation
- Group By
- Having
- Order By
- Distinct
- Subqueries



SQL operators can be composed just like building LEGO buildings

Acknowledge

- Some lecture slides were copied from or inspired by the following course materials
  - “W4111: Introduction to databases” by Eugene Wu at Columbia University
  - “CSE344: Introduction to Data Management” by Dan Suciu at University of Washington
  - “CMPT354: Database System I” by John Edgar at Simon Fraser University
  - “CS186: Introduction to Database Systems” by Joe Hellerstein at UC Berkeley
  - “CS145: Introduction to Databases” by Peter Bailis at Stanford
  - “CS 348: Introduction to Database Management” by Grant Weddell at University of Waterloo