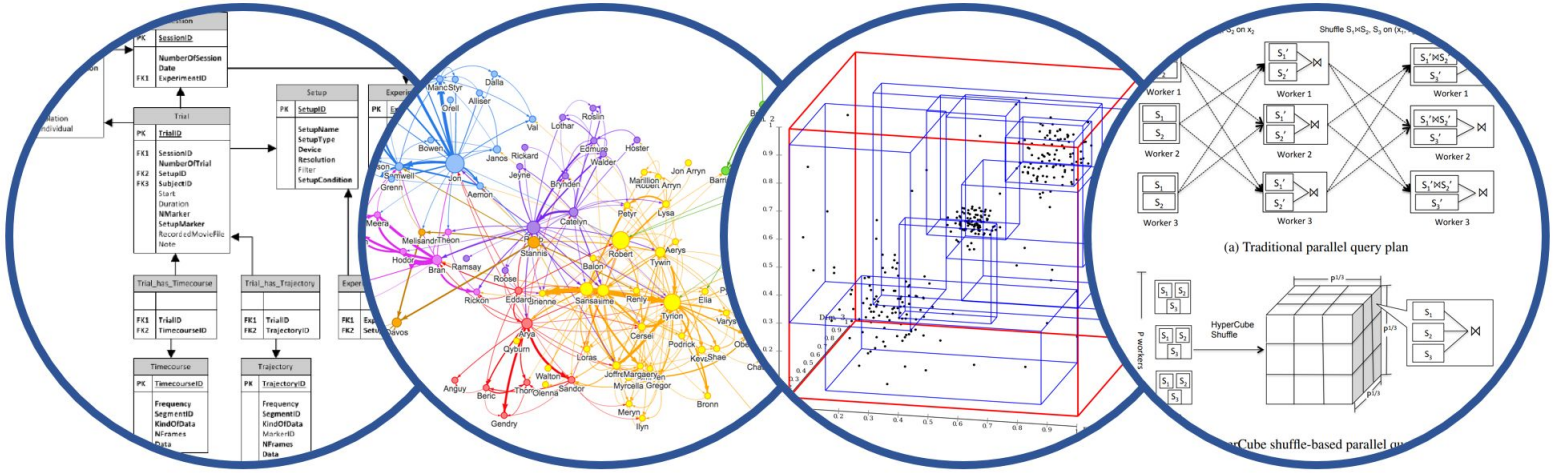

Introduction to Data Management

SQL Subqueries

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

Recap - RA Operators

- These are all the operators you will see in this class

$\bowtie$	Join	γ	Grouping & Aggregation	τ	Sort
$\times$	Cartesian Product	$\cup$	Union	δ	Duplicate Elimination
σ	Selection	$\cap$	Intersection		
π	Projection	$-$	Difference		

English to SQL to RA Example

```
CREATE TABLE Payroll (
  UserID INT PRIMARY KEY,
  Name   VARCHAR(100),
  Job    VARCHAR(100),
  Salary INT);
```

```
CREATE TABLE Regist (
  UserID INT REFERENCES Payroll,
  Car    VARCHAR(100));
```

Name all the TAs that drive multiple cars ordered by the number of cars they drive

```
SELECT DISTINCT P.Name
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID AND
       P.Job = 'TA'
 GROUP BY P.UserID, P.Name
HAVING COUNT(*) > 1
 ORDER BY COUNT(*)
```

English to SQL to RA Example

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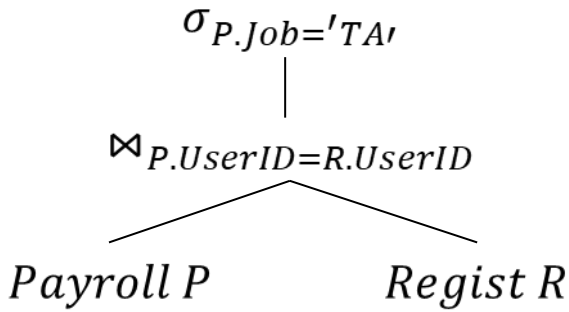

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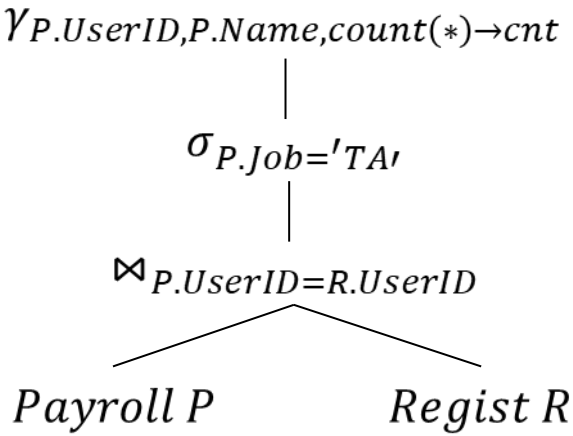

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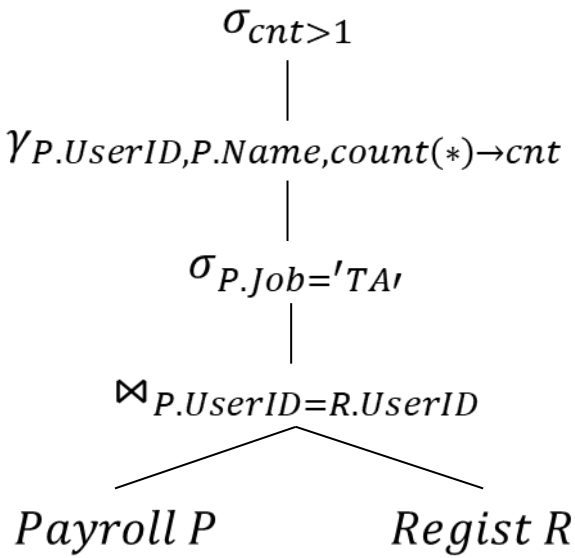

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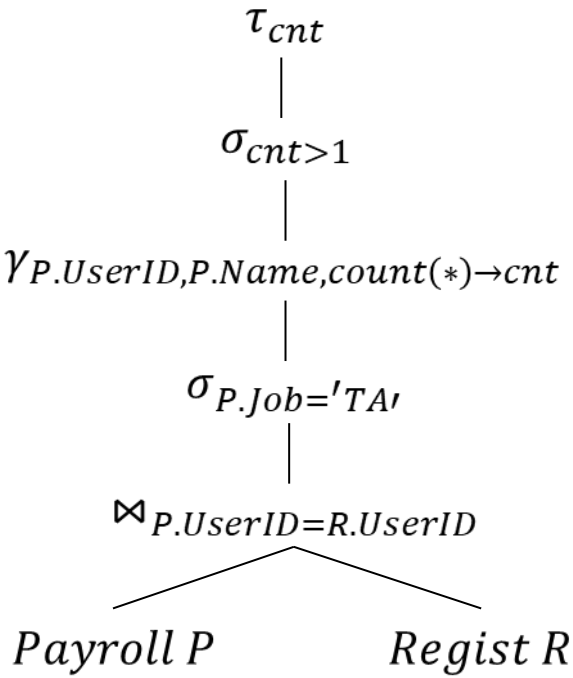

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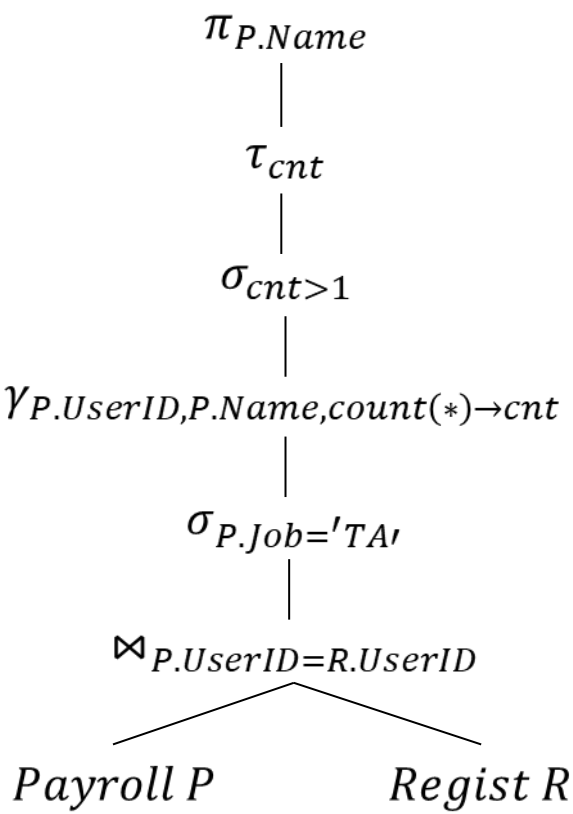

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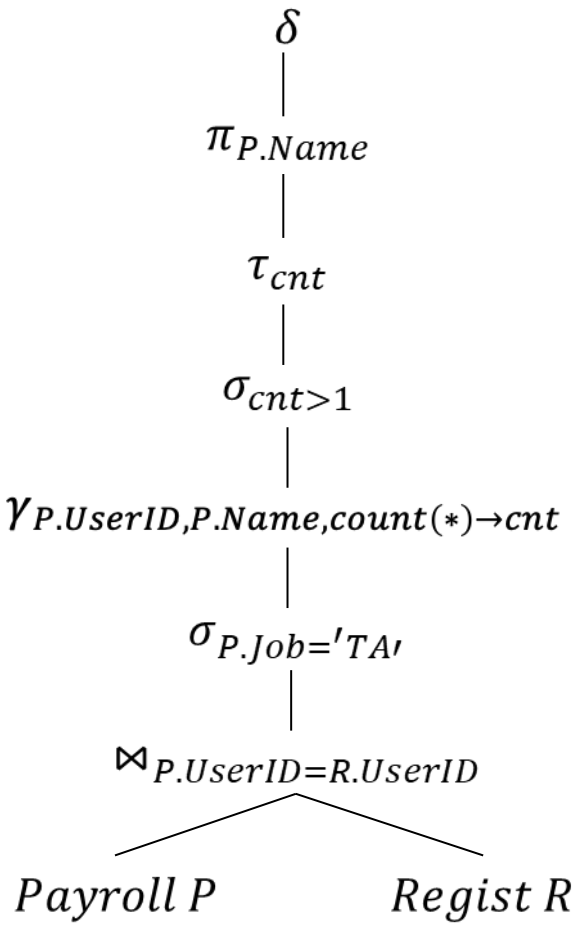

Summary of RA

- SQL = a declarative language where we say ***what*** data we want to retrieve

- RA = an algebra where we say ***how*** we want to retrieve the data

- RDMS translates SQL to RA then optimizes for performance

Announcements

- Make sure to format SQL queries in readable way
- Style suggestions in message board post: https://edstem.org/us/courses/50614/discussion/4144513
- Usually capitalization of SELECT, FROM, WHERE and indentation is most helpful

Example:

```
select m.id, m.name from movie m
where m.year > 1940 and m.year < 1950 and
m.rating > 4.5
```

```
SELECT m.id, m.name
FROM Movie m
WHERE  m.year > 1940 AND
           m.year < 1950 AND
           m.rating > 4.5
```

Recap – The Witnessing Problem

- A question pattern that asks for data associated with a maxima of some value
  - Observed how to do it with grouping
  - “Self join” on values you find the maxima for
  - GROUP BY to deduplicate one side of the join
  - HAVING to compare values with respective maxima

Goals for Today

- Conclude our unit on SQL queries
  - After today you'll have essentially all the building blocks of most all queries you can think of
- Use SQL queries to assist other SQL queries

Outline

- Witnessing via subquery
- Subquery mechanics
  - Set/bag operations
  - SELECT
  - FROM
  - WHERE/HAVING
- Decorrelation and unnesting along the way
- Notes about HW3

The Witnessing Problem Simplified

- Wanted to join respective maxima
  - GROUP BY technique was interesting
  - People have suggested that we can just compute the maxima first then join

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Return the person (or people) with the highest salary for each job type

The Witnessing Problem Simplified

- Wanted to join respective maxima
  - GROUP BY technique was interesting
  - People have suggested that we can just **compute the maxima first then join**

UserID	Name	Job	Salary	maxima
123	Jack	TA	50000	60000
345	Allison	TA	60000	60000
567	Magda	Prof	90000	100000
789	Dan	Prof	100000	100000

Return the person (or people) with the highest salary for each job type

The Witnessing Problem Simplified

MaxPay

Job	Salary
TA	60000
Prof	100000

```
WITH MaxPay AS
      (SELECT P1.Job AS Job,
              MAX(P1.Salary) AS Salary
         FROM Payroll AS P1
        GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

We can compute the same thing!

```
SELECT P1.Name, MAX(P2.Salary)
  FROM Payroll AS P1, Payroll AS P2
 WHERE P1.Job = P2.Job
 GROUP BY P2.Job, P1.Salary, P1.Name
HAVING P1.Salary = MAX(P2.Salary)
```

The Witnessing Problem Simplified

Useful intermediate result!

```
WITH MaxPay AS
      (SELECT P1.Job AS Job,
              MAX(P1.Salary) AS Salary
         FROM Payroll AS P1
        GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

The Witnessing Problem Simplified

```
WITH MaxPay AS
     (SELECT P1.Job AS Job,
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       GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

Payroll

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

MaxPay

Job	Salary
TA	60000
Prof	100000

The Witnessing Problem Simplified

```
WITH MaxPay AS
     (SELECT P1.Job AS Job,
             MAX(P1.Salary) AS
Salary
        FROM Payroll AS P1
      GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

Solving a subproblem can make your life easy

Payroll

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

MaxPay

Job	Salary
TA	60000
Prof	100000

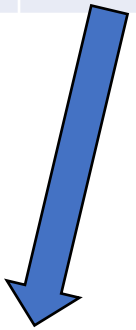
The Witnessing Problem Simplified

Payroll

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

MaxPay

Job	Salary
TA	60000
Prof	100000



UserID	Name	Job	Salary	MaxPay.Salary
123	Jack	TA	50000	60000
345	Allison	TA	60000	60000
567	Magda	Prof	90000	100000
789	Dan	Prof	100000	100000

The Punchline about Subqueries

- Subqueries can be interpreted as **single values** or as **whole relations**
  - A single value (a 1x1 relation) can be returned as part of a tuple
  - A relation can be:
    - Used as input for another query
    - Checked for containment of a value

Set Operations

- SQL mimics set theory in many ways, but with duplicates
  - Instead of sets, called bags = duplicates allowed
  - **UNION (ALL)** □ set union (bag union)
  - **INTERSECT** (ALL) □ set intersection (bag intersection)
  - **EXCEPT** (ALL) □ set difference (bag difference)
- SQL Server Management Studio 2017
  - INTERSECT ALL not supported
  - EXCEPT ALL not supported

Set Operations

- SQL set-like operators basically slap two queries together (not really a subquery…)

```
(SELECT * FROM T1)
UNION
(SELECT * FROM T2)
```

Subqueries in SELECT

- Must return a single value
- Uses:
  - Compute an associated value

Subqueries in SELECT

- Must return a single value
- Uses:
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```
SELECT P.Name, (SELECT AVG(P1.Salary)
                  FROM Payroll AS P1
                 WHERE P.Job = P1.Job)
  FROM Payroll AS P
```

Subqueries in SELECT

- Must return a single value
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```
SELECT P.Name, (SELECT AVG(P1.Salary)
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                WHERE P.Job = P1.Job)
FROM Payroll AS P
```

"Correlated" subquery!
Definition: A subquery that references an attribute from the outer query
(Payroll P is in the outer query, P1 is in the inner query)

Subqueries in SELECT

- Must return a single value
- Uses:
  - Compute an associated value

```
SELECT P.Name, (SELECT AVG(P1.Salary)
                  FROM Payroll AS P1
                 WHERE P.Job = P1.Job)
  FROM Payroll AS P
```

The Semantics of a correlated subquery are that the entire subquery is recomputed for each tuple in outer relation

Subqueries in SELECT

```
SELECT P.Name, (SELECT AVG(P1.Salary)
                  FROM Payroll AS P1
                 WHERE P.Job = P1.Job)
  FROM Payroll AS P
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
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Subqueries in SELECT

```
SELECT P.Name, (SELECT AVG(P1.Salary)
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Payroll P

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123	Jack	TA	50000
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567	Magda	Prof	90000
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Payroll P1

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
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Subqueries in SELECT

```
SELECT P.Name, (SELECT AVG(P1.Salary)
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Payroll P

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Subqueries in SELECT

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Payroll P

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55000

Payroll P1

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Subqueries in SELECT

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Payroll P

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Subqueries in SELECT

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55000

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Subqueries in SELECT

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Payroll P

UserID	Name	Job	Salary	
123	Jack	TA	50000	55000
345	Allison	TA	60000	55000
567	Magda	Prof	90000	95000
789	Dan	Prof	100000	

Payroll P1

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Subqueries in SELECT

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Payroll P

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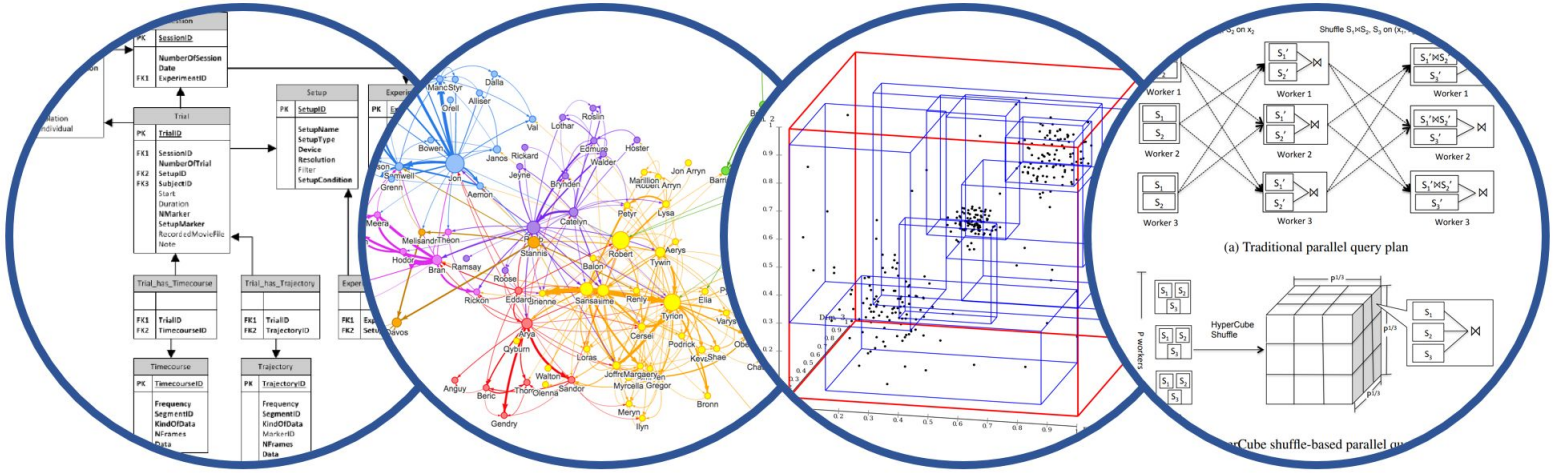

Introduction to Data Management

SQL Subqueries

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Recap - The Witnessing Problem Simplified

MaxPay

Job	Salary
TA	60000
Prof	100000

```
WITH MaxPay AS
      (SELECT P1.Job AS Job,
              MAX(P1.Salary) AS Salary
         FROM Payroll AS P1
        GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

We can compute the same thing!

```
SELECT P1.Name, MAX(P2.Salary)
  FROM Payroll AS P1, Payroll AS P2
 WHERE P1.Job = P2.Job
 GROUP BY P2.Job, P1.Salary, P1.Name
HAVING P1.Salary = MAX(P2.Salary)
```

Recap - Subqueries in SELECT

- Must return a single value
- Uses:
  - Compute an associated value

```
SELECT P.Name, (SELECT AVG(P1.Salary)
                FROM Payroll AS P1
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FROM Payroll AS P
```

"Correlated" subquery!
Definition: A subquery that references an attribute from the outer query
(Payroll P is in the outer query, P1 is in the inner query)

Recap - Subqueries in SELECT

For each person find the average salary of their job

```
SELECT P.Name, (SELECT AVG(P1.Salary)
                  FROM Payroll AS P1
                 WHERE P.Job = P1.Job)
  FROM Payroll AS P
```

Same (decorrelated and unnested)

```
SELECT P1.Name, AVG(P2.Salary)
  FROM Payroll AS P1, Payroll AS P2
 WHERE P1.Job = P2.Job
 GROUP BY P1.UserID, P1.Name
```

Subqueries in SELECT

For each person find the number of cars they drive

```
SELECT P.Name, (SELECT COUNT(R.Car)
                  FROM Regist AS R
                 WHERE P.UserID =
                       R.UserID)
  FROM Payroll AS P
```

Same?
Discuss!

```
SELECT P.Name, COUNT(R.Car)
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
 GROUP BY P.UserID, P.Name
```

Subqueries in SELECT

For each person find the number of cars they drive

```
SELECT P.Name, (SELECT COUNT(R.Car)
                  FROM Regist AS R
                 WHERE P.UserID =
                       R.UserID)
  FROM Payroll AS P
```

0-count case not covered!

```
SELECT P.Name, COUNT(R.Car)
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
 GROUP BY P.UserID, P.Name
```

Subqueries in SELECT

For each person find the number of cars they drive

```
SELECT P.Name, (SELECT COUNT(R.Car)
                FROM Regist AS R
                WHERE P.UserID =
                      R.UserID)
  FROM Payroll AS P
```

Name	Count
Jack	1
Allison	0
Magda	2
Dan	0

0-count

```
SELECT P.Name, COUNT(R.Car)
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
 GROUP BY P.UserID, P.Name
```

Name	Count
Jack	1
Magda	2

Subqueries in SELECT

For each person find the number of cars they drive

```
SELECT P.Name, (SELECT COUNT(R.Car)
                FROM Regist AS R
                WHERE P.UserID =
                      R.UserID)
  FROM Payroll AS P
```

Still possible to decorrelate and unnest

```
SELECT P.Name, COUNT(R.Car)
  FROM Payroll AS P LEFT OUTER JOIN
       Regist AS R ON P.UserID = R.UserID
 GROUP BY P.UserID, P.Name
```

Subqueries in FROM

- Equivalent to a WITH subquery
- Uses:
  - Solve subproblems that can be later joined/evaluated

```
WITH MaxPay AS
     (SELECT P1.Job AS Job,
             MAX(P1.Salary) AS Salary
        FROM Payroll AS P1
       GROUP BY P1.Job)
SELECT P.Name, P.Salary
  FROM Payroll AS P, MaxPay AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

Syntactic sugar

```
SELECT P.Name, P.Salary
  FROM Payroll AS P, (SELECT P1.Job AS Job,
                             MAX(P1.Salary) AS Salary
                        FROM Payroll AS P1
                       GROUP BY P1.Job) AS MP
 WHERE P.Job = MP.Job AND
       P.Salary = MP.Salary
```

Recap

- Usually best to avoid nested queries if trying for speed
- Be careful of semantics of nested queries
  - Correlated vs. decorrelated
- Think about edge cases
  - Zero matches
  - Null values

Review of Subqueries in SELECT/FROM

- SELECT
  - The subquery must return a **single value**
  - The subquery is **correlated** if it references a relation in the outer query.
    - Correlated subqueries run again for every tuple in the outer query

- FROM
  - Can write subquery in the style of:

```
FROM (<subquery>) AS alias
```

  - The normal semantics in the FROM clause apply! Be careful of **cross products** and don't forget join predicates.

Subqueries in WHERE/HAVING

- Uses:
  - ANY □ ∃
  - ALL □ ∀
  - (NOT) IN □ (∉) ∈
  - (NOT) EXISTS □ (∅ = …) ∅ ≠ …

Subqueries in WHERE/HAVING

- Uses:
  - ANY □ ∃
  - ALL □ ∀
  - (NOT) IN □ (∉) ∈
  - (NOT) EXISTS □ (∅ = …) ∅ ≠ …

Mathematical notation:
∃ "There exists"
∀ "For all"
∈ "Is contained in"
∅ "The empty set"

Subqueries in WHERE/HAVING

But first! Without subqueries:

Find the name and salary of people who **do** drive cars

Subqueries in WHERE/HAVING

UserID	Car
123	Charger
567	Civic
567	Pinto

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

But first! Without subqueries:

Find the name and salary of people who **do** drive cars

Subqueries in WHERE/HAVING

UserID	Car
123	Charger
567	Civic
567	Pinto

UserID	Name	Job	Salary
123	Jack	TA	50000
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567	Magda	Prof	90000
789	Dan	Prof	100000

But first! Without subqueries:

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
```

Subqueries in WHERE/HAVING

UserID	Car
123	Charger
567	Civic
567	Pinto

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

But first! Without subqueries:

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
```

Name	Salary
Jack	50000
Magda	90000
Magda	90000

Subqueries in WHERE/HAVING

UserID	Car
123	Charger
567	Civic
567	Pinto

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

But first! Without subqueries:

Find the name and salary of people who **do** drive cars

```
SELECT DISTINCT P.Name, P.Salary
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
```

Name	Salary
Jack	50000
Magda	90000

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub); $\emptyset \neq \{sub\}$

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub);
- SELECT …….. WHERE NOT EXISTS (sub);

$\emptyset = \{sub\}$

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT …….. WHERE NOT EXISTS (sub);

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Subqueries in WHERE/HAVING

- SELECT ……. WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT ……. WHERE NOT EXISTS (sub);

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

One single Boolean predicate that is `true` or `false`

For-Each Semantics

When in doubt, go back to for-each semantics, starting with FROM clause in outer query!

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

Output so far

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 123 = R.UserID)
```

Output so far

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 123 = R.UserID)
```

returns one tuple, so EXISTS (subquery) is true for the Jack tuple

Output so far

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 123 = R.UserID)
```

returns one tuple, so EXISTS (subquery) is true for the Jack tuple

Output so far

Name	Salary
Jack	60000

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 345 = R.UserID)
```

returns nothing, so EXISTS (subquery) is false for Allison

Output so far

Name	Salary
Jack	60000

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 567 = R.UserID)
```

returns two tuples, so EXISTS (subquery) is true for the Magda tuple

Output so far

Name	Salary
Jack	60000
Magda	90000

For-Each Semantics

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Payroll P

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000
789	Dan	Prof	100000

Regist R

UserID	Car
123	Charger
567	Civic
567	Pinto

```
(SELECT *
 FROM Regist AS R
 WHERE 789 = R.UserID)
```

returns nothing, so EXISTS (subquery) is false for Dan

Output so far

Name	Salary
Jack	60000
Magda	90000

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT …….. WHERE NOT EXISTS (sub);

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE EXISTS (SELECT *
                 FROM Regist AS R
                WHERE P.UserID = R.UserID)
```

Subqueries in WHERE/HAVING

- SELECT ..... WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT ..... WHERE NOT EXISTS (sub);

Find the name and salary of people who **do not** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE NOT EXISTS (SELECT *
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Subqueries in WHERE/HAVING

- SELECT ..... WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT ..... WHERE NOT EXISTS (sub);

Find the name and salary of people who **do not** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE NOT EXISTS (SELECT *
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Person P s.t.
∅ = {cars P drives}

Subqueries in WHERE/HAVING

Output

Name	Salary
Allison	60000
Dan	100000

Find the name and salary of people who **do not** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE NOT EXISTS (SELECT *
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Person P s.t.
∅ = {cars P drives}

Subqueries in WHERE/HAVING

NOT EXISTS (subquery) evaluates to **true** when subquery returns **no tuples**

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000

Exercise:

"Find the names of people who are the ONLY employee with their job in the Payroll table."

Subqueries in WHERE/HAVING

NOT EXISTS (subquery) evaluates to **true** when subquery returns **no tuples**

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000

Exercise:

"Find the names of people who are the ONLY employee with their job in the Payroll table."

May be easier if we re-write:

"Find the names of people where there does not exist another person with the same job."

Subqueries in WHERE/HAVING

NOT EXISTS (subquery) evaluates to **true** when subquery returns **no tuples**

UserID	Name	Job	Salary
123	Jack	TA	50000
345	Allison	TA	60000
567	Magda	Prof	90000

Exercise:

"Find the names of people who are the ONLY employee with their job in the Payroll table."

```
SELECT P.Name
  FROM Payroll AS P
 WHERE NOT EXISTS (SELECT *
                     FROM Payroll AS P1
                    WHERE P.Job = P1.Job AND
                          P.UserID != P1.UserID )
```

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub);
- SELECT …….. WHERE NOT EXISTS (sub);
- SELECT …….. WHERE attribute IN (sub); $e \in \{sub\}$
- SELECT …….. WHERE attribute NOT IN (sub); $e \notin \{sub\}$

Subqueries in WHERE/HAVING

attribute IN (subquery) evaluates to **true** when value of attribute matches some result in (subquery)

- SELECT ..... WHERE EXISTS (sub);
- SELECT ..... WHERE NOT EXISTS (sub);
- SELECT ..... WHERE attribute IN (sub); $e \in \{sub\}$
- SELECT ..... WHERE attribute NOT IN (sub); $e \notin \{sub\}$

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE P.UserID IN (SELECT UserID
                    FROM Regist)
```

Subqueries in WHERE/HAVING

attribute IN (subquery) evaluates to **true** when value of attribute matches some result in (subquery)

- SELECT ..... WHERE EXISTS (sub);
- SELECT ..... WHERE NOT EXISTS (sub);
- SELECT ..... WHERE attribute IN (sub); $e \in \{sub\}$
- SELECT ..... WHERE attribute NOT IN (sub); $e \notin \{sub\}$

Find the name and salary of people who **do** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE P.UserID IN (SELECT UserID
                    FROM Regist)
```

Decorrelated!

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub);
- SELECT …….. WHERE NOT EXISTS (sub);
- SELECT …….. WHERE attribute IN (sub); $e \in \{sub\}$
- SELECT …….. WHERE attribute NOT IN (sub); $e \notin \{sub\}$

Find the name and salary of people who **do not** drive cars

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE P.UserID NOT IN (SELECT UserID
                        FROM Regist)
```

Subqueries in WHERE/HAVING

Find the name and salary of people who do not drive cars

Our NOT EXISTS method:

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE NOT EXISTS (SELECT *
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Our NOT IN method:

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE P.UserID NOT IN (SELECT UserID
                          FROM Regist)
```

Decorrelated! Our EXISTS version was a correlated subquery

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub); $\emptyset \neq \{sub\}$
- SELECT …….. WHERE NOT EXISTS (sub); $\emptyset = \{sub\}$
- SELECT …….. WHERE attribute IN (sub); $e \in \{sub\}$
- SELECT …….. WHERE attribute NOT IN (sub); $e \notin \{sub\}$

Now, on to quantifier logic!

Subqueries in WHERE/HAVING

- SELECT …….. WHERE EXISTS (sub);
- SELECT …….. WHERE NOT EXISTS (sub);
- SELECT …….. WHERE attribute IN (sub);
- SELECT …….. WHERE attribute NOT IN (sub);
- SELECT …….. WHERE value > ANY (sub); $\exists e.v > e$
- SELECT …….. WHERE value > ALL (sub); $\forall e.v > e$

Subqueries in WHERE/HAVING

Find the name and salary of people who drive a car made before 2017

Subqueries in WHERE/HAVING

Find the name and salary of people who drive a car made before 2017

$$Person\ P\ s.t.$$
$$\exists c.\, year(c) < 2017$$

Subqueries in WHERE/HAVING

Find the name and salary of people who drive a car made before 2017

$$Person\ P\ s.t.$$
$$\exists c.\, year(c) < 2017$$

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE 2017 > ANY (SELECT R.Year
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Subqueries in WHERE/HAVING

Find the name and salary of people who drive a car made before 2017

$$Person\ P\ s.t.$$
$$\exists c.\, year(c) < 2017$$

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE 2017 > ANY (SELECT R.Year
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

True when 2017 > at least one of subquery

Subqueries in WHERE/HAVING

Find the name and salary of people who **only** drive cars made before 2017

$$Person\ P\ s.t.$$
$$\forall c.year(c) < 2017$$

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE 2017 > ALL (SELECT R.Year
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

Subqueries in WHERE/HAVING

Find the name and salary of people who **only** drive cars made before 2017

$$Person\ P\ s.t.$$
$$\forall c.year(c) < 2017$$

```
SELECT P.Name, P.Salary
  FROM Payroll AS P
 WHERE 2017 > ALL (SELECT R.Year
                     FROM Regist AS R
                    WHERE P.UserID = R.UserID)
```

True when 2017 > every single result of subquery

Subquery Takeaways

- Lots of different ways to get the same answer
  - You have an arsenal of tools now
- Side note: Depending on the DBMS/optimizer you may want to avoid subqueries when possible

Encoding Universal Quantifiers

- Could we ever encode a universal quantifier with a SELECT-FROM-WHERE query with no subqueries or aggregates?

- “Do I need to do something complex?”

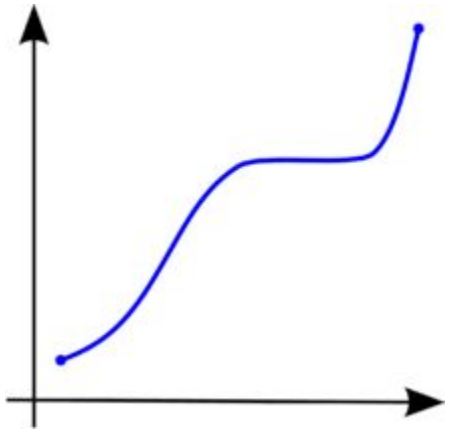
Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.



Monotonicity

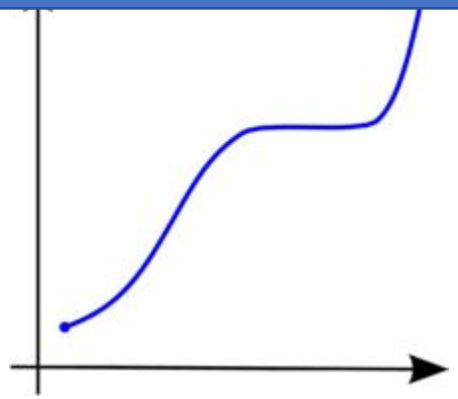
Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

In other words, adding more tuples to the input table never removes tuples from the output on the next query.



Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

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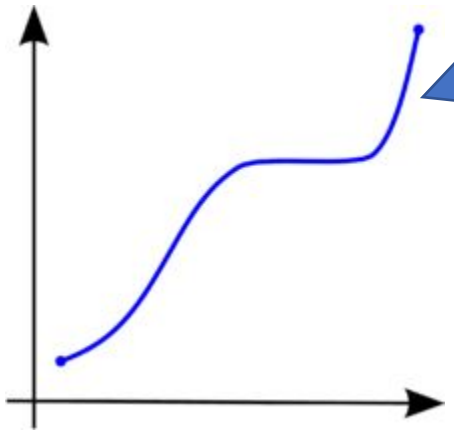

Monotone queries can be similar to monotonically increasing functions when considering cardinalities of results

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

```
SELECT P.Name, P.Car
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
```

Is this query monotone?

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

I can't add tuples to Payroll or Regist that would "remove" a previous result

```
SELECT P.Name, P.Car
  FROM Payroll AS P, Regist AS R
 WHERE P.UserID = R.UserID
```

Is this query monotone? Yes!

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

```
SELECT P.Name
  FROM Payroll AS P
 WHERE P.Salary >= ALL (SELECT Salary
                          FROM Payroll)
```

Is this query monotone?

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

I can add a tuple to Payroll that has a higher salary value than any other

```
SELECT P.Name
  FROM Payroll AS P
 WHERE P.Salary >= ALL (SELECT Salary
                          FROM Payroll)
```

Is this query monotone? No!

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

```
SELECT P.Job, COUNT(*)
  FROM Payroll AS P
GROUP BY P.Job
```

Is this query monotone?

Monotonicity

Monotone

A **Monotonic** query is one that obeys the following rule where I and J are data instances and q is a query:

$$I \subseteq J \rightarrow q(I) \subseteq q(J)$$

That is for any superset of I, the query over that superset must contain at least the query results of I.

Aggregates generally are sensitive to any new tuples

```
SELECT P.Job, COUNT(*)
  FROM Payroll AS P
 GROUP BY P.Job
```

Is this query monotone? No!

Monotone Queries

- Theorem: If Q is a SELECT-FROM-WHERE query that does not have subqueries, and no aggregates, then it is monotone.

Monotone Queries

- Theorem: If Q is a SELECT-FROM-WHERE query that does not have subqueries, and no aggregates, then it is monotone.

- Proof. We use the nested loop semantics: if we insert a tuple in a relation R_i, this will not remove any tuples from the answer

```
SELECT a1, a2, ..., ak
FROM   R1 AS x1, R2 AS x2, ..., Rn AS xn
WHERE  Conditions
```

```
for x1 in R1 do
  for x2 in R2 do
    ...
    for xn in Rn do
      if Conditions
        output
    (a1,...,ak)
```

Monotonicity

- Consequence: If a query is not monotonic, then we cannot write it as a SELECT-FROM-WHERE query without nested subqueries or aggregates.

- **Queries with universal quantifiers are not generally monotone**
- You have to do something "complex" if you need to code a universal quantifier

Takeaways

- SQL is able to mirror logic over sets more or less directly
- The internal interpretation of nested queries can be quite involved
  - But our DBMS is able to derive such interpretations automagically

Next Unit

- We are done with lectures on SQL queries!
- Up next:
  - Data modeling
  - Design theory
  - Database normalization