DSAA 5012
Advanced Database Management for Data Science

LECTURE 5
RELATIONAL ALGEBRA

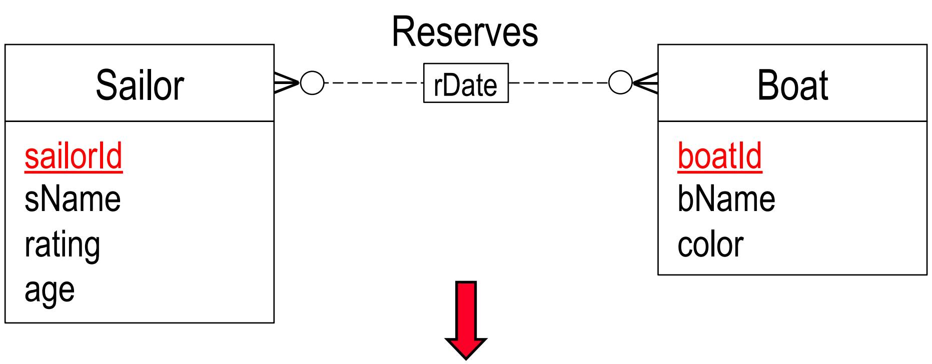
REVIEW: E-R SCHEMA REDUCTION

Sailor(sailorId, sName, rating, age)

Boat(boatId, bName, color)

Reserves(*sailorId, boatId, rDate*)

What is the E-R schema for this relational schema?



What about this schema?

Reserves(*sailorId, boatId*, rDate)

☞ **A sailor can reserve a given boat at most once!**

What do we get if we reduce Reserves?

☞ **rDate is not part of the key in the reduction!**

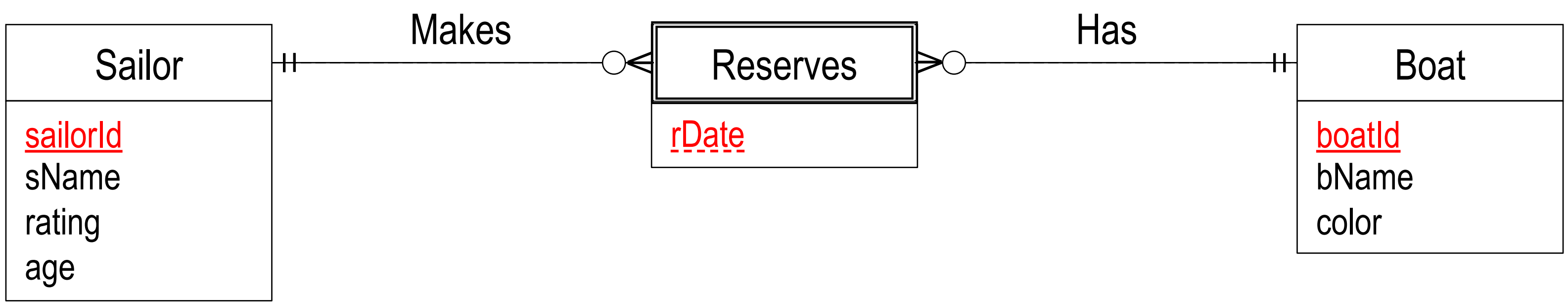
REVIEW: E-R SCHEMA REDUCTION

Sailor(sailorId, sName, rating, age)

Boat(boatId, bName, color)

Reserves(*sailorId, boatId,* rDate)

What about this schema?



What kind of entity is Reserves? ⇒ Weak entity.

On which entity is Reserves dependent? ⇒ Both Sailor and Boat!

Is rDate a discriminator for Reserves? ⇒ Yes

What should be the cardinality constraints for Makes? ⇒ 1:N

What should be the participation constraints for Makes? ⇒ Sailor - partial; Reserves - total

What should be the cardinality constraints for Has? ⇒ 1:N

What should be the participation constraints for Has? ⇒ Boat - partial; Reserves - total

RELATIONAL ALGEBRA: OUTLINE

Relational Algebra

Basic Operations

- Selection
- Projection
- Union
- Set difference
- Cartesian product

Additional Operations

- Intersection
- Join
- Assignment
- Rename

EXAMPLE RELATIONAL SCHEMA AND DATABASE

Sailor(sailorId, sName, rating, age)

Boat(boatId, bName, color)

Reserves(*sailorId, boatId*, rDate)

Attribute names in italics are foreign key attributes.

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

Reserves

sailorId	*boatId*	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

11 tuples

Boat

boatId	bName	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red
105	Serenity	Cyan

5 tuples

RELATIONAL QUERY LANGUAGES

- Two mathematical query languages form the basis for "real" relational query languages (e.g., SQL) and for implementation.

Our focus

Relational Algebra Procedural (*step-by-step*).
Need to describe how to compute a query result.

Relational Calculus Non-procedural (*declarative*).
Only need to describe what query result is wanted, not how to compute it.

☞ **Relational algebra is very useful for representing and optimizing query execution plans.**

Understanding relational algebra is the key to understanding SQL and how it is processed!

RELATIONAL ALGEBRA

- The relational algebra is an algebra whose
  - **operands** are either relations or variables that represent relations.
  - **operations** perform common, basic manipulations of relations.

☞ A relational algebra expression is evaluated from the inside-out.

Closure Property

- Relational algebra is closed with respect to the relational model.

☞ Each operation manipulates one or more relations and returns a relation as its result.

Due to the closure property, operations can be *composed*!

RELATIONAL ALGEBRA: OUTLINE

✓ Relational Algebra

➡ **Basic Operations**
- **Selection**
- **Projection**
- **Union**
- **Set difference**
- **Cartesian product**

Additional Operations
- Intersection
- Join
- Assignment
- Rename

RELATIONAL ALGEBRA: BASIC OPERATIONS

Operation	Symbol	Action
Selection	σ	Selects rows in a table that satisfy a predicate
Projection	π	Removes unwanted columns from a table
Union	$\cup$	Finds rows that belong to either table 1 or table 2
Set difference	$-$	Finds rows that are in table 1, but are not in table 2
Cartesian product	$\times$	Allows the rows in two tables to be combined

Additional operations *(not essential, but very useful)*:

Intersection	$\cap$	Finds tuples that appear in both table 1 and in table 2
Join	$\bowtie$	Cartesian product followed by a selection
Assignment	$\leftarrow$	Assigns a result to a temporary variable
Rename	ρ	Allows a table and/or its columns to be renamed

SELECTION: $\sigma_C(R)$

- Selects tuples (rows) that satisfy a *selection condition C*.
- The schema of the result is identical to the schema of the (only) input relation.
- A condition C has the form: **term** *op* **term** where
  - **term** is an attribute name or a constant
  - *op* is a comparison operator such as =, ≠, <, ≤, >, ≥.
- Conditions can be composed or negated using Boolean operators.

  $C_1 \wedge C_2$ where C_1 and C_2 are conditions and $\wedge$ means AND

  $C_1 \vee C_2$ where C_1 and C_2 are conditions and $\vee$ means OR

  $\neg C$ where $\neg$ means NOT

SELECTION: EXAMPLE

Query: Find tuples where the company is Boeing.

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

$\sigma_{company='Boeing'}(Plane)$ =

company	model
Boeing	B747
Boeing	B777

Query: Find tuples where the company is Boeing, or the model is A330.

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

$\sigma_{company='Boeing' \vee model='A330'}(Plane)$ = ?

company	model

PROJECTION: $\pi_L(R)$

- Keeps only the attributes (columns) in a *projection list* *L*.

  ☞ The schema of the result contains the same attributes as in the projection list L, with the same names that they had in the (only) input relation.

- The projection operator *eliminates duplicate tuples*. **Why?**

Query: Find the companies that make planes.

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

$\pi_{company}(Plane)$ =

company
Airbus
Boeing

COMPOSITION OF OPERATIONS

- Since relational algebra operations are closed, the result of one relational algebra operation can be the input for another relational algebra operation (i.e., operations can be composed).

☞ **The result of a relational algebra operation must be a relation.**

Query: Find only those models made by Boeing.

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

$\pi_{model}(\sigma_{company='Boeing'}(Plane))$ =

model
B747
B777

Is this a correct solution? $\sigma_{company='Boeing'}(\pi_{model}(Plane))$

SET OPERATIONS

- The set operations are:

  $\cup$ union

  $-$ set difference

  $\cap$ intersection (not basic; can be expressed using only set-difference, i.e., $r \cap s = r - (r - s)$)

- These operations take two input relations, which must be union-compatible, which means that
  - the relations have the same number of attributes.
  - corresponding attributes have the same type.

- The output is a single relation (without duplicates).

UNION: ∪

Query: Find tuples that appear in $Plane_1$, $Plane_2$ or both.

$Plane_1$

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

∪

$Plane_2$

company	model
Comac	C929
Comac	C939
Boeing	B747
Boeing	B777

=

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777
Comac	C929
Comac	C939

Appears only once in the result since set operations eliminate duplicates.

SET DIFFERENCE: −

Query: Find tuples that appear in $Plane_1$, but not in $Plane_2$.

$Plane_1$

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

−

$Plane_2$

company	model
Comac	C929
Comac	C939
Boeing	B747
Boeing	B777

=

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340

Removed from the result since they appear in both relations.

$Plane_2$

company	model
Comac	C929
Comac	C939
Boeing	B747
Boeing	B777

−

$Plane_1$

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

= ?

company	model

CARTESIAN PRODUCT: ×

- Cartesian product combines each row of one table with every row of another table.
- CanFly × Plane ⇒ **72 tuples**!!!
  (9 × 8)

CanFly

empNo	model
1001	B747
1001	B777
1001	A310
1002	A320
1002	A340
1002	B777
1002	C929
1003	A310
1003	C939

×

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777
Comac	C929
Comac	C939

=

empNo	model	company	model
1001	B747	Airbus	A310
1001	B747	Airbus	A320
1001	B747	Airbus	A330
1001	B747	Airbus	A340
1001	B747	Boeing	B747
1001	B747	Boeing	B777
1001	B747	Comac	C929
1001	B747	Comac	C939
1001	B777	Airbus	A310
1001	B777	Airbus	A320
1001	B777	Airbus	A330
1001	B777	Airbus	A340
1001	B777	Boeing	B747
1001	B777	Boeing	B777
1001	B777	Comac	C929
1001	B777	Comac	C939
1001	A310	Airbus	A310
1001	A310	Airbus	A320
⋮	⋮	⋮	⋮

RELATIONAL ALGEBRA

EXERCISES 1, 2

EXERCISE 1

Find the ids of sailors who have reserved boat 103.

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

Reserves

sailorId	*boatId*	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

11 tuples

Boat

boatId	bName	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red
105	Serenity	Cyan

5 tuples

EXERCISE 1

Find the <u>ids</u> of sailors who have reserved boat 103.

☞ **22, 31, 74**

1. Is this a solution?

$\sigma_{boatId=103}(\pi_{sailorId}Reserves)$ ✗

$\pi_{sailorId}Reserves$

sailorId
22
31
64
74

$\xrightarrow{\sigma_{boatId=103}}$ **?**

2. Is this a solution?

$\pi_{sailorId}(\sigma_{boatId=103}Reserves)$ ✓

$\sigma_{boatId=103}Reserves$

sailorId	boatId	rDate
22	103	08/10/17
31	103	06/11/17
74	103	08/09/17

$\xrightarrow{\pi_{sailorId}}$

sailorId
22
31
74

EXERCISE 2

Find the names of sailors who have reserved boat 103.

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

Reserves

sailorId	boatId	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

11 tuples

Boat

boatId	bName	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red
105	Serenity	Cyan

5 tuples

EXERCISE 2

Find the names of sailors who have reserved boat 103.

☞ **Dustin, Lubber, Horatio**

1. Is this a solution?

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId \wedge boatId=103}(Reserves \times Sailor))$$

2. Is this a solution?

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$$

Find the **names** of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 1

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId \wedge boatId=103}(Reserves \times Sailor))$$

☞ **Dustin, Lubber, Horatio**

Reserves

sailorId	boatId	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

11 tuples

X

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

=

How many tuples in the result? 11 x 11 = 121 tuples!

Find the **names** of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 1

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId \wedge boatId=103}(Reserves \times Sailor))$$

☞ **Dustin, Lubber, Horatio**

Reserves X Sailor						
Reserves.sailorId	boatId	rDate	Sailor.sailorId	sName	rating	age
22	101	10/10/17	22	Dustin	7	45
22	101	10/10/17	29	Brutus	1	33
22	101	10/10/17	31	Lubber	8	55
22	101	10/10/17	32	Andy	8	25
22	101	10/10/17	58	Rusty	10	35
22	101	10/10/17	64	Horatio	7	35
22	101	10/10/17	71	Zorba	10	16
22	101	10/10/17	74	Horatio	9	35
22	101	10/10/17	85	Art	3	25
22	101	10/10/17	95	Bob	3	63
22	101	10/10/17	99	Chris	10	30
22	102	10/10/17	22	Dustin	7	45
22	102	10/10/17	29	Brutus	1	33
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Find the **names** of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 1

$$\pi_{\text{sName}}(\sigma_{\text{Reserves.sailorId=Sailor.sailorId} \wedge \text{boatId=103}}(\text{Reserves} \times \text{Sailor}))$$

☞ **Dustin, Lubber, Horatio**

$\sigma_{\text{Reserves.sailorId=Sailor.sailorId} \wedge \text{boatId=103}}(\text{Reserves} \times \text{Sailor})$

Reserves.sailorId	boatId	rDate	Sailor.sailorId	sName	rating	age
22	103	08/10/17	22	Dustin	7	45
31	103	06/11/17	31	Lubber	8	55
74	103	08/09/17	74	Horatio	9	35

Apply π_{sName} to above result:

sName
Dustin
Lubber
Horatio

✓

Find the names of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 2

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$$

☞ **Dustin, Lubber, Horatio**

$\sigma_{boatId=103}Reserves$

sailorId	boatId	rDate
22	103	08/10/17
31	103	06/11/17
74	103	08/09/17

X

Sailor

sailorId	name	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

=

How many tuples in the result? 3 x 11 = 33 tuples!

Find the names of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 2

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$$

☞ **Dustin, Lubber, Horatio**

$(\sigma_{boatId=103}Reserves) \times Sailor$

Reserves.sailorId	boatId	rDate	Sailor.sailorId	sName	rating	age
22	103	08/10/17	22	Dustin	7	45
22	103	08/10/17	29	Brutus	1	33
22	103	08/10/17	31	Lubber	8	55
22	103	08/10/17	32	Andy	8	25
22	103	08/10/17	58	Rusty	10	35
22	103	08/10/17	64	Horatio	7	35
22	103	08/10/17	71	Zorba	10	16
22	103	08/10/17	74	Horatio	9	35
22	103	08/10/17	85	Art	3	25
22	103	08/10/17	95	Bob	3	63
22	103	08/10/17	99	Chris	10	30
31	103	06/11/17	22	Dustin	7	45
31	103	06/11/17	29	Brutus	1	33
31	103	06/11/17	31	Lubber	8	55
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Find the <u>names</u> of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 2

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$$

☞ **Dustin, Lubber, Horatio**

$\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor)$

Reserves.sailorId	boatId	rDate	Sailor.sailorId	sName	rating	age
22	103	08/10/17	22	Dustin	7	45
31	103	06/11/17	31	Lubber	8	55
74	103	08/09/17	74	Horatio	9	35

Apply π_{sName} to above result:

sName
Dustin
Lubber
Horatio

✓

EXERCISE 2

Find the names of sailors who have reserved boat 103.

☞ **Dustin, Lubber, Horatio**

1. Is this a solution? ✓

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId \wedge boatId=103}(Reserves \times Sailor))$$

Initial result:
121 tuples

2. Is this a solution? ✓

$$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$$

Initial result:
33 tuples

To be continued …

RELATIONAL ALGEBRA: OUTLINE

✓ Relational Algebra

✓ Basic Operations
- Selection
- Projection
- Union
- Set difference
- Rename
- Cartesian product

➡ **Additional Operations**
- **Intersection**
- **Join**
- **Assignment**

INTERSECTION: ∩

Query: Find tuples that appear in both $Plane_1$ and $Plane_2$.

$Plane_1$

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

∩

$Plane_2$

company	model
Comac	C929
Comac	C939
Boeing	B747
Boeing	B777

=

company	model
Boeing	B747
Boeing	B777

$Plane_2$

company	model
Comac	C929
Comac	C939
Boeing	B747
Boeing	B777

∩

$Plane_1$

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777

= ?

company	model

JOIN: ⋈

- Generating all possible tuple combinations of two relations is usually not meaningful.

  Example: For the relations CanFly and Plane, combining each CanFly and Plane tuple having a matching model value is more meaningful than CanFly × Plane.

- Join is a Cartesian product followed by a selection:

  $R_1 \bowtie_c R_2 = \sigma_c(R_1 \times R_2)$ *or* $R_1 \text{ JOIN}_c R_2 = \sigma_c(R_1 \times R_2)$

- Types of joins:

  natural join: Combines two relations on the equality of the attribute values with the same names.

  θ-join: Allows arbitrary conditions in the selection.

  equijoin: All conditions are equality.

☞ **Both equijoin and natural join project the result on only one of the join attributes.**

CanFly

empNo	model
1001	B747
1001	B777
1001	A310
1002	A320
1002	A340
1002	B777
1002	C929
1003	A310
1003	C939

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777
Comac	C929
Comac	C939

JOIN: NATURAL JOIN

CanFly $\bowtie_n$ Plane ⇔ CanFly $\bowtie$ Plane

CanFly JOIN$_n$ Plane ⇔ CanFly JOIN Plane

CanFly JOIN$_{model}$ Plane

CanFly JOIN$_{CanFly.model=Plane.model}$ Plane

n ⟹ look for attributes with common names in the two relations.

CanFly

empNo	model
1001	B747
1001	B777
1001	A310
1002	A320
1002	A340
1002	B777
1002	C929
1003	A310
1003	C939

$\bowtie_n$

Plane

company	model
Airbus	A310
Airbus	A320
Airbus	A330
Airbus	A340
Boeing	B747
Boeing	B777
Comac	C929
Comac	C939

=

empNo	model	company
1001	B747	Boeing
1001	B777	Boeing
1001	A310	Airbus
1002	A320	Airbus
1002	A340	Airbus
1002	B777	Boeing
1002	C929	Comac
1003	A310	Airbus
1003	C939	Comac

Cartesian product ⟹ 72 tuples; join ⟹ 9 tuples.

JOIN: θ-JOIN

- If we join this table with itself (*self-join*) using the condition:

  c = Flight1.destination=Flight2.origin $\wedge$ Flight1.arrivalTime<Flight2.deptartureTime

What should we get?

Flight1

flight#	origin	destination	departure Time	arrival Time
334	HKG	PVG	12:00	14:14
335	PVG	HKG	15:00	17:14
336	HKG	PVG	18:00	20:14
337	PVG	HKG	20:30	23:53
394	PEK	PVG	19:00	21:30
395	PVG	PEK	21:00	23:43

$\bowtie_c$

Flight2

flight#	origin	destination	departure Time	arrival Time
334	HKG	PVG	12:00	14:14
335	PVG	HKG	15:00	17:14
336	HKG	PVG	18:00	20:14
337	PVG	HKG	20:30	23:53
394	PEK	PVG	19:00	21:30
395	PVG	PEK	21:00	23:43

JOIN: θ-JOIN (cont'd)

$$Flight1 \bowtie_{Flight1.destination=Flight2.origin \wedge Flight1.arrivalTime<Flight2.departureTime} Flight2$$

Flight1. Flight#	Flight1. Origin	Flight1. Destination	Flight1. Departure Time	Flight1. Arrival Time	Flight2. Flight#	Flight2. Origin	Flight2. Destination	Flight2. Departure Time	Flight2. Arrival Time
334	HKG	PVG	12:00	14:14	335	PVG	HKG	15:00	17:14
335	PVG	HKG	15:00	17:14	336	HKG	PVG	18:00	20:14
336	HKG	PVG	18:00	20:14	337	PVG	HKG	20:30	23:53
334	HKG	PVG	12:00	14:14	337	PVG	HKG	20:30	23:53
336	HKG	PVG	18:00	20:14	395	PVG	PEK	21:00	23:43
334	HKG	PVG	12:00	14:14	395	PVG	PEK	21:00	23:43

What happens if we add the condition: … $\wedge$ Flight1.origin<>Flight2.destination?

RELATIONAL ALGEBRA

EXERCISES 2 (cont'd), 3

Find the <u>names</u> of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 3

$\pi_{sName}((\sigma_{boatId=103}Reserves)\ JOIN\ Sailor)$

☞ **Dustin, Lubber, Horatio**

$\sigma_{boatId=103}Reserves$

sailorId	boatId	rDate
22	103	08/10/17
31	103	06/11/17
74	103	08/09/17

JOIN

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

=

How many tuples in the result? 3 tuples!

Find the names of sailors who have reserved boat 103.

EXERCISE 2: SOLUTION 3

$$\pi_{sName}((\sigma_{boatId=103}Reserves) \text{ JOIN } Sailor)$$

☞ **Dustin, Lubber, Horatio**

$(\sigma_{boatId=103}Reserves)$ JOIN Sailor						
Reserves.sailorId	boatId	rDate	Sailor.sailorId	sName	rating	age
22	103	08/10/17	22	Dustin	7	45
31	103	06/11/17	31	Lubber	8	55
74	103	08/09/17	74	Horatio	9	35

Apply π_{sName} to above result:

sName
Dustin
Lubber
Horatio

✓

EXERCISE 2: SUMMARY

Find the names of sailors who have reserved boat 103.

☞ **All three queries get the correct answer, BUT ...**

1. Is this a solution? ✓

$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId \wedge boatId=103}(Reserves \times Sailor))$

Initial result: 121 tuples

2. Is this a solution? ✓

$\pi_{sName}(\sigma_{Reserves.sailorId=Sailor.sailorId}((\sigma_{boatId=103}Reserves) \times Sailor))$

Initial result: 33 tuples

3. Is this a solution? ✓

$\pi_{sName}((\sigma_{boatId=103}Reserves) \text{ JOIN } Sailor)$

Initial result: 3 tuples

Query Optimization

Relational DBMSs do such optimizations based on relational algebra.

EXERCISE 3

Find the names of sailors who have reserved a red boat.

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

11 tuples

Reserves

sailorId	*boatId*	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

11 tuples

Boat

boatId	bName	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red
105	Serenity	Cyan

5 tuples

EXERCISE 3: SOLUTION 1

Find the names of sailors who have reserved a red boat.

☞ **Dustin, Lubber, Horatio, Chris**

Is this a solution?

$\pi_{sName}((\sigma_{color='red'}Boat) \text{ JOIN } Reserves \text{ JOIN } Sailor)$

$\sigma_{color='red'}Boat$

boatId	bName	color
102	Interlake	red
104	Marine	red

JOIN

Reserves

sailorId	boatId	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

=

How many tuples in the result?

6 tuples!

How many columns in the result?

5 columns!

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SOLUTION 1

$\pi_{sName}((\sigma_{color='red'}Boat)$ JOIN Reserves JOIN Sailor)

☞ **Dustin, Lubber, Horatio, Chris**

($\sigma_{color='red'}$Boat) JOIN Reserves

bName	color	sailorId	boatId	rDate
Interlake	red	22	102	10/10/17
Marine	red	22	104	07/10/17
Interlake	red	31	102	10/11/17
Marine	red	31	104	12/11/17
Interlake	red	64	102	08/09/17
Marine	red	99	104	08/08/17

JOIN

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

=

How many tuples in the result?

6 tuples!

How many columns in the result?

8 columns!

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SOLUTION 1

$\pi_{sName}((\sigma_{color='red'}Boat)$ JOIN Reserves JOIN Sailor$)$

☞ **Dustin, Lubber, Horatio, Chris**

$(\sigma_{color='red'}Boat)$ JOIN Reserves JOIN Sailor

bName	color	sailorId	boatId	rDate	sName	rating	age
Interlake	red	22	102	10/10/17	Dustin	7	45
Marine	red	22	104	07/10/17	Dustin	7	45
Interlake	red	31	102	10/11/17	Lubber	8	55
Marine	red	31	104	12/11/17	Lubber	8	55
Interlake	red	64	102	08/09/17	Horatio	7	35
Marine	red	99	104	08/08/17	Chris	10	30

Apply π_{sName} to above result:

sName
Dustin
Lubber
Horatio
Chris

✓

EXERCISE 3: SOLUTION 2

Find the names of sailors who have reserved a red boat.

☞ **Dustin, Lubber, Horatio, Chris**

$$\pi_{sName}((\sigma_{color='red'}Boat) \text{ JOIN } Reserves \text{ JOIN } Sailor)$$

Can you give a more efficient solution in terms of result size?

$$\pi_{sName}((\pi_{boatId}(\sigma_{color='red'}Boat)) \text{ JOIN } Reserves \text{ JOIN } Sailor)$$

$\sigma_{color='red'}Boat$

boatId	bName	color
102	Interlake	red
104	Marine	red

After selecting red boats, first project onto boatId before doing the join since the name and color of the boat is not needed for the query. Thus, only the boatId is "carried" when evaluating the rest of the query.

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SOLUTION 2

$$\pi_{sName}((\pi_{boatId}(\sigma_{color='red'}Boat))\ \text{JOIN}\ Reserves\ \text{JOIN}\ Sailor)$$

☞ **Dustin, Lubber, Horatio, Chris**

$\pi_{boatId}(\sigma_{color='red'}Boat)$

boatId
102
104

JOIN

Reserves

sailorId	boatId	rDate
22	101	10/10/17
22	102	10/10/17
22	103	08/10/17
22	104	07/10/17
31	102	10/11/17
31	103	06/11/17
31	104	12/11/17
64	101	05/09/17
64	102	08/09/17
74	103	08/09/17
99	104	08/08/17

=

How many tuples in the result? 6 tuples!

How many columns in the result? 3 columns!

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SOLUTION 2

$\pi_{sName}((\pi_{boatId}(\sigma_{color='red'}Boat))$ JOIN $Reserves$ JOIN $Sailor)$

☞ **Dustin, Lubber, Horatio, Chris**

$(\pi_{boatId}(\sigma_{color='red'}Boat))$ JOIN Reserves

sailorId	boatId	rDate
22	102	10/10/17
22	104	07/10/17
31	102	10/11/17
31	104	12/11/17
64	102	08/09/17
99	104	08/08/17

JOIN

Sailor

sailorId	sName	rating	age
22	Dustin	7	45
29	Brutus	1	33
31	Lubber	8	55
32	Andy	8	25
58	Rusty	10	35
64	Horatio	7	35
71	Zorba	10	16
74	Horatio	9	35
85	Art	3	25
95	Bob	3	63
99	Chris	10	30

=

How many tuples in the result? 6 tuples!

How many columns in the result? 6 columns!

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SOLUTION 2

$\pi_{sName}((\pi_{boatId}(\sigma_{color='red'}Boat))$ JOIN Reserves JOIN Sailor)

☞ **Dustin, Lubber, Horatio, Chris**

($\sigma_{color='red'}$Boat) JOIN Reserves JOIN Sailor

sailorId	boatId	rDate	sName	rating	age
22	102	10/10/17	Dustin	7	45
22	104	07/10/17	Dustin	7	45
31	102	10/11/17	Lubber	8	55
31	104	12/11/17	Lubber	8	55
64	102	08/09/17	Horatio	7	35
99	104	08/08/17	Chris	10	30

Apply π_{sName} to above result:

sName
Dustin
Lubber
Horatio
Chris

✓

Find the names of sailors who have reserved a red boat.

EXERCISE 3: SUMMARY

Solution 1

$\pi_{sName}((\sigma_{color='red'}Boat)$ JOIN Reserves JOIN Sailor$)$

(6 tuples, 5 columns) + (6 tuples, 8 columns)

Solution 2

$\pi_{sName}((\pi_{boatId}(\sigma_{color='red'}Boat))$ JOIN Reserves JOIN Sailor$)$

(6 tuples, 3 columns) + (6 tuples, 6 columns)

☞ **Solution 2 is more efficient in terms of tuple size.**

Query Optimization

Relational DBMSs do such optimizations based on relational algebra.

OUTER JOIN

- An extension of the natural join operation that avoids loss of information.
- Computes the natural join and then adds tuples from one relation that do not have matching tuples in the other relation to the result of the join.
- Uses null values to fill in missing information.
  - Recall that null signifies that the value is unknown or does not exist.

☞ **All comparisons involving null are false.**

OUTER JOIN (cont'd)

Loan

loan Number	amount	branch Name
L-170	30000	Central
L-260	170000	Tsimshatsui
L-230	40000	Central

$\bowtie$

Borrower

client Name	loan Number
Pat Lee	L-170
Mary Kwan	L-230
Ted Hayes	L-155

=

loan Number	amount	branch Name	client Name
L-170	30000	Central	Pat Lee
L-230	40000	Central	Mary Kwan

- Natural join returns only the tuples that match on the join attributes (the "good tuples").
- The fact that
  - loan L-260 has no borrower is not explicit in the result.
  - customer Ted Hayes holds a non-existent loan L-155 with no amount and no branch is also not explicit.

LEFT OUTER JOIN: ⟕

Adds to the natural join all tuples in the left relation (Loan) that did not match with any tuple in the right relation (Borrower) and fills in null for the missing information.

Loan

loan Number	amount	branch Name
L-170	30000	Central
L-260	170000	Tsimshatsui
L-230	40000	Central

⟕

Borrower

client Name	loan Number
Pat Lee	L-170
Mary Kwan	L-230
Ted Hayes	L-155

=

loan Number	amount	branch Name	client Name
L-170	30000	Central	Pat Lee
L-230	40000	Central	Mary Kwan
L-260	170000	Tsimshatsui	null

☞ The result now shows that loan L-260 has no borrower.

RIGHT OUTER JOIN: ⟖

Adds to the natural join all tuples in the right relation (Borrower) that did not match with any tuple in the left relation (Loan) and fills in null for the missing information.

Loan

loan Number	amount	branch Name
L-170	30000	Central
L-260	170000	Tsimshatsui
L-230	40000	Central

⟖

Borrower

client Name	loan Number
Pat Lee	L-170
Mary Kwan	L-230
Ted Hayes	L-155

=

loan Number	amount	branch Name	client Name
L-170	30000	Central	Pat Lee
L-230	40000	Central	Mary Kwan
L-155	null	null	Ted Hayes

☞ The result now shows that loan L-155 has no amount and no branch.

FULL OUTER JOIN: $⟗$

Adds to the natural join all tuples in both relations that did not match with any tuples in the other relation and fills in null for missing information.

Loan

loan Number	amount	branch Name
L-170	30000	Central
L-260	170000	Tsimshatsui
L-230	40000	Central

$⟗$

Borrower

client Name	loan Number
Pat Lee	L-170
Mary Kwan	L-230
Ted Hayes	L-155

=

loan Number	amount	branch Name	client Name
L-170	30000	Central	Pat Lee
L-230	40000	Central	Mary Kwan
L-260	170000	Tsimshatsui	null
L-155	null	null	Ted Hayes

☞ The result now shows both that

- loan L-260 has no borrower.
- loan L-155 has no amount and no branch.

ASSIGNMENT: ←

- Works like assignment in programming languages.
- The relation variable assigned to can be used in subsequent expressions.
- Allows a query to be written as a sequential program consisting of a series of assignments followed by an expression whose value is the result of the query.
- Useful for expressing complex queries.

RENAMING: ρ

- Assigns a name to, or renames the attributes in, a relational-algebra expression.

$\rho_x(E)$	assigns name x to the result of *E*
$\rho_{x(A1,\ A2,\ \ldots,\ An)}(E)$	assigns name x to the result of *E* *and* renames the attributes of *E* as $A_1, A_2, \ldots, A_n$

☞ **Renaming is necessary when taking the Cartesian product of a table with itself.**

RELATIONAL ALGEBRA: SUMMARY

- Defines a set of algebraic operations that operate on relations and output relations as their result.

- The operations can be combined to express queries.

- The operations can be divided into:
  - basic operations.
  - additional operations that either
    - can be expressed in terms of the basic operations or
    - add further expressive power to the relational algebra.

COMP 3311: SYLLABUS

- ✓ Introduction
- ✓ Entity-Relationship (E-R) Model and Database Design
- ✓ Relational Algebra
- ➡ **Structured Query Language (SQL)**
- Relational Database Design
- Storage and File Structure
- Indexing
- Query Processing
- Query Optimization
- Transactions
- Concurrency Control
- Recovery System
- NoSQL Databases

RELATIONAL ALGEBRA
EXERCISES 4, 5, 6

Upload your completed exercise worksheet to Canvas by **11 p.m. of Feb 17th**