Database Systems (CS 355 / CE 373)

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Acknowledgements

 Many slides have been borrowed from the official lecture slides accompanying the textbook:

Database System Concepts, (2019), Seventh Edition,

Avi Silberschatz, Henry F. Korth, S. Sudarshan

McGraw-Hill, ISBN 9780078022159

The original lecture slides are available at:

https://www.db-book.com/

 Some of the slides have been borrowed from the lectures by Dr. Immanuel Trummer (Cornell University). Available at: (<u>www.itrummer.org</u>)

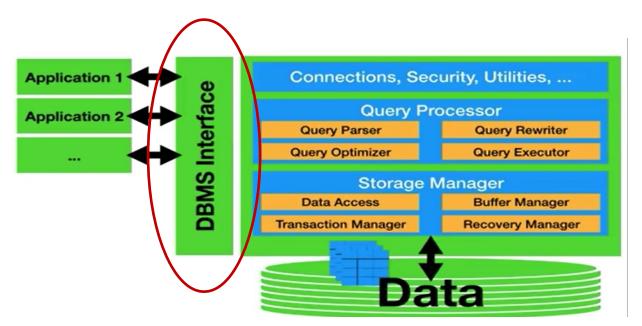
Outline: Week 7

SQL: Major Clauses in an SQL Query

SQL: Aggregate Functions

• SQL: Joins

DBMS-based Approach



Data Model

 A collection of conceptual tools for describing data, data relationships, data semantics, and consistency constraints.

The Relational Model

• The relational model uses <u>a collection of tables</u> to represent both data and the relationships among those data.

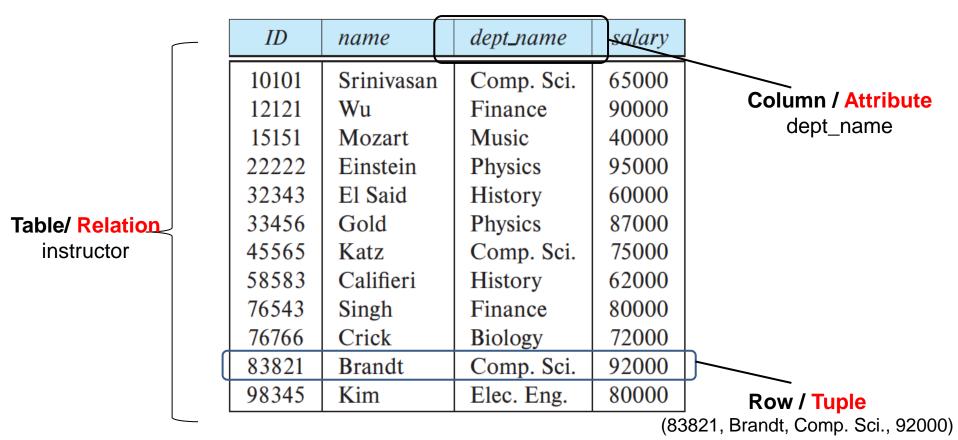


Figure 2.1 The instructor relation.

A Sample Relational Model

пате	dept_name	salary
Einstein	Physics	95000
Wu	Finance	90000
El Said	History	60000
Katz	Comp. Sci.	75000
Kim	Elec. Eng.	80000
Crick	Biology	72000
Srinivasan	Comp. Sci.	65000
Califieri	History	62000
Brandt	Comp. Sci.	92000
Mozart	Music	40000
Gold	Physics	87000
Singh	Finance	80000
	Einstein Wu El Said Katz Kim Crick Srinivasan Califieri Brandt Mozart Gold	Einstein Wu Finance El Said History Katz Comp. Sci. Kim Elec. Eng. Crick Biology Srinivasan Califieri Brandt Mozart Gold Physics

(a) The instructor table

dept_name	building	budget
Comp. Sci.	Taylor	100000
Biology	Watson	90000
Elec. Eng.	Taylor	85000
Music	Packard	80000
Finance	Painter	120000
History	Painter	50000
Physics	Watson	70000

(b) The department table

Utilizing Relational DBMS: Lifecycle

- Design relational schema
- (and Tell the DRMS about it)

] מפ

- Populate tables/relations
- Write queries to get information back from tables

} DML

Structured Query Language (SQL)

- The standard to access/retrieve/manipulate data in a relational database
- Examples of a Data Definition Language (DDL) Component

```
create table department
(dept_name char (20),
building char (15),
budget numeric (12,2));
```

Examples of a Data Manipulation Language (DML) Component

```
select instructor.name
from instructor
where instructor.dept_name = 'History';
```

SQL Queries: University Database (1/4)

ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The *instructor* relation.

ID	course_id	sec_id	semester	year
10101	CS-101	1	Fall	2017
10101	CS-315	1	Spring	2018
10101	CS-347	1	Fall	2017
12121	FIN-201	1	Spring	2018
15151	MU-199	1	Spring	2018
22222	PHY-101	1	Fall	2017
32343	HIS-351	1	Spring	2018
45565	CS-101	1	Spring	2018
45565	CS-319	1	Spring	2018
76766	BIO-101	1	Summer	2017
76766	BIO-301	1	Summer	2018
83821	CS-190	1	Spring	2017
83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

Figure 2.7 The teaches relation.

SQL Queries: University Database (2/4)

dept_name	building	budget
Biology	Watson	90000
Comp. Sci.	Taylor	100000
Elec. Eng.	Taylor	85000
Finance	Painter	120000
History	Painter	50000
Music	Packard	80000
Physics	Watson	70000

Figure 2.5 The department relation.

course_id	sec_id	semester	year	building	room_number	time_slot_id
BIO-101	1	Summer	2017	Painter	514	В
BIO-301	1	Summer	2018	Painter	514	A
CS-101	1	Fall	2017	Packard	101	Н
CS-101	1	Spring	2018	Packard	101	F
CS-190	1	Spring	2017	Taylor	3128	E
CS-190	2	Spring	2017	Taylor	3128	Α
CS-315	1	Spring	2018	Watson	120	D
CS-319	1	Spring	2018	Watson	100	В
CS-319	2	Spring	2018	Taylor	3128	C
CS-347	1	Fall	2017	Taylor	3128	A
EE-181	1	Spring	2017	Taylor	3128	C
FIN-201	1	Spring	2018	Packard	101	В
HIS-351	1	Spring	2018	Painter	514	C
MU-199	1	Spring	2018	Packard	101	D
PHY-101	1	Fall	2017	Watson	100	A

Figure 2.6 The section relation.

SQL Queries: University Database (3/4)

course_id	prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-319	CS-101
CS-347	CS-101
EE-181	PHY-101

Figure 2.3 The prereq relation.

course_id	title	dept_name	credits
BIO-101	Intro. to Biology	Biology	4
BIO-301	Genetics	Biology	4
BIO-399	Computational Biology	Biology	3
CS-101	Intro. to Computer Science	Comp. Sci.	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3
CS-319	Image Processing	Comp. Sci.	3
CS-347	Database System Concepts	Comp. Sci.	3
EE-181	Intro. to Digital Systems	Elec. Eng.	3
FIN-201	Investment Banking	Finance	3
HIS-351	World History	History	3
MU-199	Music Video Production	Music	3
PHY-101	Physical Principles	Physics	4

Figure 2.2 The course relation.

SQL Queries: University Database (4/4)

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	A
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

Figure 4.2 The takes relation.

Structured Query Language (SQL)

- The standard to access/retrieve/manipulate data in a relational database
- Examples of a Data Definition Language (DDL) Component

```
create_table department
(dept_name char (20),
building char (15),
budget numeric (12,2));
```

Examples of a Data Manipulation Language (DML) Component

```
select instructor.name
from instructor
where instructor.dept_name = 'History';
```

SQL: Data Manipulation

- Basic query structure
- Major clauses in an SQL query
- SELECT
 - TROW
 - WHERE
 - GROUP BY
 - HAVING

Remember: Order of Execution in SQL Queries

In general, the meaning of an SQL query can be understood as follows:

- Generate a Cartesian product of the relations listed in the from clause.
- Apply the predicates specified in the where clause on the result of Step 1.
- For each tuple in the result of Step 2, output the attributes (or results of expressions) specified in the select clause.

Remember: Updated Order of Execution in SQL Queries

The meaning of a query containing aggregation, **group by**, or **having** clauses is defined by the following sequence of operations:

- 1. As was the case for queries without aggregation, the **from** clause is first evaluated to get a relation.
- 2. If a where clause is present, the predicate in the where clause is applied on the result relation of the from clause.
- 3. Tuples satisfying the where predicate are then placed into groups by the group by clause if it is present. If the group by clause is absent, the entire set of tuples satisfying the where predicate is treated as being in one group.
- 4. The **having** clause, if it is present, is applied to each group; the groups that do not satisfy the **having** clause predicate are removed.
- 5. The <u>select</u> clause uses the remaining groups to generate tuples of the result of the query, applying the aggregate functions to get a single result tuple for each group.

Find the names of all instanctors in "Comp. Sci"?

Select From Where

SQL Queries: University Database (1/4)

			<i>_</i>		
	ID	name	dept_name	salary	
4	10101	Srinivasan	Comp. Sci.	65000	
	12121	Wu	Finance	90000	
	15151	Mozart	Music	40000	
ı	22222	Einstein	Physics	-95000 mll	1
	32343	El Said	History	60000	
I	33456	Gold	Physics	87000	
ġ	45565	Katz	Comp. Sci.	75000	
V	58583	Califieri	History	-62000 NWS	1
	76543	Singh	Finance	80000	
	76766	Crick	Biology	72000	
	83821	Brandt	Comp. Sci.	92000	
Y	98345	Kim	Elec. Eng.	80000	
-					

Figure 2.1 The *instructor* relation.

ID	course_id	sec_id	semester	year
10101	CS-101	1	Fall	2017
10101	CS-315	1	Spring	2018
10101	CS-347	1	Fall	2017
12121	FIN-201	1	Spring	2018
15151	MU-199	1	Spring	2018
22222	PHY-101	1	Fall	2017
32343	HIS-351	1	Spring	2018
45565	CS-101	1	Spring	2018
45565	CS-319	1	Spring	2018
76766	BIO-101	1	Summer	2017
76766	BIO-301	1	Summer	2018
83821	CS-190	1	Spring	2017
83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

3) SELECT 'D, name 1) FROM instantor 2) WHERE deft-name: 'Comp. Sci"

SELECT dytember

From Indianter

MERE Solary is not 17 hall

Aggregate Functions: Group By

Find the average salary of instructors in each department

1) FROM INSTRUCTOR Aggregate Functions: Group By 2) WHERE MY (Salay) > 42000

Find the average salary of instructors in each department



ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The *instructor* relation.

Aggregate Functions: Group By

• Find the average salary of instructors in each department

ID	name	dept_name	salary	
76766	Crick	Biology	72000	} —
45565	Katz	Comp. Sci.	75000	7
10101	Srinivasan	Comp. Sci.	65000	1 -
83821	Brandt	Comp. Sci.	92000	J
98345	Kim	Elec. Eng.	80000	} -
12121	Wu	Finance	90000	Ι [_
76543	Singh	Finance	80000	5
32343	El Said	History	60000	5 _
58583	Califieri	History	62000	5
15151	Mozart	Music	40000	3 -
33456	Gold	Physics	87000	1
22222	Einstein	Physics	95000) -



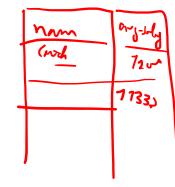
Aggregate Functions: Group By

• Find the average salary of instructors in each department

select dept_rame, avg (salary) as avg_salary , in from instructor group by dept_name;

ID	name	dept_name	salary
76766	Crick	Biology	72000
45565	Katz	Comp. Sci.	75000
10101	Srinivasan	Comp. Sci.	65000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
22222	Einstein	Physics	95000

dept_name	avg_salary
Biology	72000
Comp. Sci.	77333
Elec. Eng.	80000
Finance	85000
History	61000
Music	40000
Physics	91000



ı) F	RUM	ister	ds
<u> </u>	WHER	E	
31	GROUP	By	deft-num
	HAVI		•

ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The instructor relation.

```
from instructor
group by dept_name
HAVING avg(salar) > 42000
```

ID	name	dept_name	salary
76766	Crick	Biology	72000
45565	Katz	Comp. Sci.	75000
10101	Srinivasan	Comp. Sci.	65000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
22222	Einstein	Physics	95000

```
s) SELECT deft_nam, anglishly)

from instructor

group by dept_name

h) having avg (salary) > 42000;
```

ID	name	dept_name	salary
76766	Crick	Biology	72000
45565	Katz	Comp. Sci.	75000
10101	Srinivasan	Comp. Sci.	65000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
22222	Einstein	Physics	95000

```
select dept_name, avg (salary) as avg_salary
from instructor
group by dept_name
having avg (salary) > 42000;
```

dept_name	avg_salary
Biology	72000
Comp. Sci.	77333.33333333333
Elec. Eng.	80000
Finance	85000
History	61000
Physics	91000

```
select dept_name, avg (salary) as avg_salary
from instructor
group by dept_name
having avg (salary) > 42000;
6, Older by avg_salary
```

dept_	name	avg_salary
Biolo	gy	72000
Comp.	Sci.	77333.3333333333
Elec.	Eng.	80000
Finan	ce	85000
History		61000
Physi	cs	91000

SQL: Various Join Operations

- Inner Join
- Left Outer Join
- Right Outer Join
- Full Outer Join

Basic Operations of Relational Algebra: Join (⋈)

- The <u>join</u> operation allows us to combine a select operation and a cartesian product operation into a single operation.
 - Notation: Consider relations r(R) and s(S). Let θ be a predicate on attributes in the schema R \cup S. The join operation $r \bowtie_{\theta} s$ is defined as follows:

$$r \bowtie_{\theta} s = \sigma_{\theta} (r \times s)$$

• Thus $\sigma_{instructor.id = teaches.id}$ (instructor x teaches) can equivalently be written as:

instructor ⋈ _{Instructor.id = teaches.id} teaches.

ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The instructor relation.

ID	course_id	sec_id	semester	year
10101	CS-101	1	Fall	2017
10101	CS-315	1	Spring	2018
10101	CS-347	1	Fall	2017
12121	FIN-201	1	Spring	2018
15151	MU-199	1	Spring	2018
22222	PHY-101	1	Fall	2017
32343	HIS-351	1	Spring	2018
45565	CS-101	1	Spring	2018
45565	CS-319	1	Spring	2018
76766	BIO-101	1	Summer	2017
76766	BIO-301	1	Summer	2018
83821	CS-190	1	Spring	2017
83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

Figure 2.7 The teaches relation.

instructor.ID	name	dept_name	salary	teaches.ID	course_id	sec_id	semester	year
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2017
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2018
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2017
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2018
15151	Mozart	Music	40000	15151	MU-199	1	Spring	2018
22222	Einstein	Physics	95000	22222	PHY-101	1	Fall	2017
32343	El Said	History	60000	32343	HIS-351	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-101	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-319	1	Spring	2018
76766	Crick	Biology	72000	76766	BIO-101	1	Summer	2017
76766	Crick	Biology	72000	76766	BIO-301	1	Summer	2018
83821	Brandt	Comp. Sci.	92000	83821	CS-190	1	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-190	2	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-319	2	Spring	2018
98345	Kim	Elec. Eng.	80000	98345	EE-181	1	Spring	2017

More about Join Operation: Inner Join (⋈)

- The <u>join</u> operation allows us to combine a select operation and a cartesian product operation into a single operation.
 - Notation: Consider relations r(R) and s(S). Let θ be a predicate on attributes in the schema R \cup S. The join operation $r \bowtie_{\theta} s$ is defined as follows:

$$r \bowtie_{\theta} s = \sigma_{\theta} (r \times s)$$

- Thus $\sigma_{instructor.id} = teaches.id$ (instructor x teaches) can equivalently be written as: instructor \bowtie Instructor.id = teaches.id teaches.
- This is also known as <u>Inner Join.</u>

ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The instructor relation.

ID	course_id	sec_id	semester	year
10101	CS-101	1	Fall	2017
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12121	FIN-201	1	Spring	2018
15151	MU-199	1	Spring	2018
22222	PHY-101	1	Fall	2017
32343	HIS-351	1	Spring	2018
45565	CS-101	1	Spring	2018
45565	CS-319	1	Spring	2018
76766	BIO-101	1	Summer	2017
76766	BIO-301	1	Summer	2018
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83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

Figure 2.7 The teaches relation.

instructor.ID	name	dept_name	salary	teaches.ID	course_id	sec_id	semester	year
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2017
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2018
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2017
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2018
15151	Mozart	Music	40000	15151	MU-199	1	Spring	2018
22222	Einstein	Physics	95000	22222	PHY-101	1	Fall	2017
32343	El Said	History	60000	32343	HIS-351	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-101	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-319	1	Spring	2018
76766	Crick	Biology	72000	76766	BIO-101	1	Summer	2017
76766	Crick	Biology	72000	76766	BIO-301	1	Summer	2018
83821	Brandt	Comp. Sci.	92000	83821	CS-190	1	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-190	2	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-319	2	Spring	2018
98345	Kim	Elec. Eng.	80000	98345	EE-181	1	Spring	2017

SQL: Inner Join (\bowtie)

select *
from instructor, teaches
where instructor.ID=teaches.ID

select *

from instructor join teaches on instructor.ID=teaches.ID

select *

from instructor inner join teaches on instructor.ID=teaches.ID

ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Figure 2.1 The instructor relation.

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15151	MU-199	1	Spring	2018
22222	PHY-101	1	Fall	2017
32343	HIS-351	1	Spring	2018
45565	CS-101	1	Spring	2018
45565	CS-319	1	Spring	2018
76766	BIO-101	1	Summer	2017
76766	BIO-301	1	Summer	2018
83821	CS-190	1	Spring	2017
83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

Figure 2.7 The teaches relation.

instructor.ID	name	dept_name	salary	teaches.II	course_id	sec_id	semester	year
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2017
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2018
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2017
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2018
15151	Mozart	Music	40000	15151	MU-199	1	Spring	2018
22222	Einstein	Physics	95000	22222	PHY-101	1	Fall	2017
32343	El Said	History	60000	32343	HIS-351	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-101	1	Spring	2018
45565	Katz	Comp. Sci.	75000	45565	CS-319	1	Spring	2018
76766	Crick	Biology	72000	76766	BIO-101	1	Summer	2017
76766	Crick	Biology	72000	76766	BIO-301	1	Summer	2018
83821	Brandt	Comp. Sci.	92000	83821	CS-190	1	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-190	2	Spring	2017
83821	Brandt	Comp. Sci.	92000	83821	CS-319	2	Spring	2018
98345	Kim	Elec. Eng.	80000	98345	EE-181	1	Spring	2017

More about Join Operation: Natural Join (*)

- Suppose two relations R_1 and R_2 have a number of attributes that have the same name and the same domain.
- A **natural join** of R_1 and R_2 (denoted by *) includes only those tuples where the values of common attributes of R_1 and R_2 are the same.
- In this case, tuples with same values from R_2 need not be included.

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	A
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	В-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

00128 Zhang Comp. Sci. 102 CS-101 1 Fall 2017 A 00128 Zhang Comp. Sci. 102 CS-347 1 Fall 2017 A 12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B 45678 Levy								_	
00128 Zhang Comp. Sci. 102 CS-347 1 Fall 2017 A 12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Fall 2017 F	grade	year	semester	sec_id	course_id	tot_cred	dept_name	name	ID
12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Fall 2017 F	A	2017	Fall	1	CS-101	102	Comp. Sci.	Zhang	00128
12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B 45678 Levy Physics 46 CS-101 1 Fall 2017 F	A-	2017	Fall	1	CS-347	102	Comp. Sci.	Zhang	00128
12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F	C	2017	Fall	1	CS-101	32	Comp. Sci.	Shankar	12345
12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F	A	2017	Spring	2	CS-190	32	Comp. Sci.	Shankar	12345
19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C C C C C C C C C	A	2018	Spring	1	CS-315	32	Comp. Sci.	Shankar	12345
23121 Chavez Finance 110 FIN-201 1 Spring 2018 C 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F	A	2017	Fall	1	CS-347	32	Comp. Sci.	Shankar	12345
44553 Peltier Physics Physics 56 PHY-101 Pall 1 Fall Pall 2017 Pa	В	2018	Spring	1	HIS-351	80	History	Brandt	19991
45678 Levy Physics 46 CS-101 1 Fall 2017 F	C+	2018	Spring	1	FIN-201	110	Finance	Chavez	23121
	B-	2017	Fall	1	PHY-101	56	Physics	Peltier	44553
45678 Levy Physics 46 CS-101 1 Spring 2018 B-	F	2017	Fall	1	CS-101	46	Physics	Levy	45678
	B+	2018	Spring	1	CS-101	46	Physics	Levy	45678
45678 Levy Physics 46 CS-319 1 Spring 2018 B	В	2018	Spring	1	CS-319	46	Physics	Levy	45678
	A-	2017	Fall	1	CS-101	54	Comp. Sci.		54321
54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B	B+	2017	Spring	2	CS-190	54	Comp. Sci.	Williams	54321
55739 Sanchez Music 38 MU-199 1 Spring 2018 A	A-	2018	Spring	1	MU-199	38	Music	Sanchez	55739
76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A	A	2017	Fall	1	CS-101	58	Comp. Sci.	Brown	76543
76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A	A	2018	Spring	2	CS-319	58	Comp. Sci.	Brown	76543
76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C	C	2017	Spring	1	EE-181	60	Elec. Eng.	Aoi	76653
98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C	C-	2017	Fall	1	CS-101	98	Elec. Eng.	Bourikas	98765
98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B	В	2018	Spring	1	CS-315	98	Elec. Eng.	Bourikas	98765
98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	Α	2017	Summer	1	BIO-101	120	Biology	Tanaka	98988
98988 Tanaka Biology 120 BIO-301 1 Summer 2018 m	null	2018	Summer	1	BIO-301	120	Biology	Tanaka	98988

Figure 4.2 The takes relation.

Figure 4.3 The natural join of the student relation with the takes relation.

SQL: Natural Join (*)

select *
from student natural join takes

not supported by MS SQL Server (used in lab)

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120
54321 55739 70557 76543 76653 98765	Williams Sanchez Snow Brown Aoi Bourikas	Physics Comp. Sci. Music Physics Comp. Sci. Elec. Eng. Elec. Eng.	54 38 0 58 60 98

Figure 4.1 The student relation.

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	Α
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

ID name dept_name tot_cred course_id sec_id semester year grade 00128 Zhang Comp. Sci. 102 CS-101 1 Fall 2017 A 12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 46 CS-101 1 Fall 2017 F 45678			_						
00128 Zhang Comp. Sci. 102 CS-347 1 Fall 2017 A- 12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy	ID	name	dept_name	tot_cred	course_id	sec_id	semester	year	grade
12345 Shankar Comp. Sci. 32 CS-101 1 Fall 2017 C 12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A 12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy	00128	Zhang	Comp. Sci.	102	CS-101	1	Fall	2017	A
12345 Shankar Comp. Sci. 32 CS-190 2 Spring 2017 A	00128	Zhang	Comp. Sci.	102	CS-347	1	Fall	2017	A-
12345 Shankar Comp. Sci. 32 CS-315 1 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Fall 2017 A 45678 Levy Physic	12345	Shankar	Comp. Sci.	32	CS-101	1	Fall	2017	C
12345 Shankar Comp. Sci. 32 CS-347 1 Fall 2017 A 19991 Brandt History 80 HIS-351 1 Spring 2018 B 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-319 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Fall 2017 A- 54321 Williams Com	12345	Shankar	Comp. Sci.	32	CS-190	2	Spring	2017	Α
19991 Brandt Chavez History Finance 80 HIS-351 1 Spring 2018 B C+ 23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-319 1 Spring 2018 B 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B+ 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988	12345	Shankar	Comp. Sci.	32	CS-315	1	Spring	2018	Α
23121 Chavez Finance 110 FIN-201 1 Spring 2018 C+ 44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B+ 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown <t< td=""><td>12345</td><td>Shankar</td><td>Comp. Sci.</td><td>32</td><td>CS-347</td><td>1</td><td>Fall</td><td>2017</td><td>Α</td></t<>	12345	Shankar	Comp. Sci.	32	CS-347	1	Fall	2017	Α
44553 Peltier Physics 56 PHY-101 1 Fall 2017 B- 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-319 1 Spring 2018 B+ 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Bourikas <	19991	Brandt	History	80	HIS-351	1	Spring	2018	В
45678 Levy Physics 46 CS-101 1 Fall 2017 F 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Bourikas <td< td=""><td>23121</td><td>Chavez</td><td>Finance</td><td>110</td><td>FIN-201</td><td>1</td><td>Spring</td><td>2018</td><td>C+</td></td<>	23121	Chavez	Finance	110	FIN-201	1	Spring	2018	C+
45678 Levy Physics 46 CS-101 1 Spring 2018 B+ 45678 Levy Physics 46 CS-319 1 Spring 2018 B 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 55739 Sanchez Music 38 MU-199 1 Spring 2018 B- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76543 Aoi Elec. Eng. 60 EE-181 1 Spring 2018 A 76543 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka	44553	Peltier	Physics	56	PHY-101	1	Fall	2017	B-
45678 Levy Physics 46 CS-319 1 Spring 2018 B 54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B+ 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	45678	Levy	Physics	46	CS-101	1	Fall	2017	F
54321 Williams Comp. Sci. 54 CS-101 1 Fall 2017 A- 54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B+ 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	45678	Levy	Physics	46	CS-101	1	Spring	2018	B+
54321 Williams Comp. Sci. 54 CS-190 2 Spring 2017 B+ 55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	45678	Levy	Physics	46	CS-319	1	Spring	2018	В
55739 Sanchez Music 38 MU-199 1 Spring 2018 A- 76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	54321	Williams	Comp. Sci.	54	CS-101	1	Fall	2017	A-
76543 Brown Comp. Sci. 58 CS-101 1 Fall 2017 A 76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	54321	Williams	Comp. Sci.	54	CS-190	2	Spring	2017	B+
76543 Brown Comp. Sci. 58 CS-319 2 Spring 2018 A 76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	55739	Sanchez	Music	38	MU-199	1	Spring	2018	A-
76653 Aoi Elec. Eng. 60 EE-181 1 Spring 2017 C 98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C- 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	76543	Brown	Comp. Sci.	58	CS-101	1	Fall	2017	Α
98765 Bourikas Elec. Eng. 98 CS-101 1 Fall 2017 C-98765 98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	76543	Brown	Comp. Sci.	58	CS-319	2	Spring	2018	Α
98765 Bourikas Elec. Eng. 98 CS-315 1 Spring 2018 B 98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	76653	Aoi	Elec. Eng.	60	EE-181	1	Spring	2017	C
98988 Tanaka Biology 120 BIO-101 1 Summer 2017 A	98765	Bourikas	Elec. Eng.	98	CS-101	1	Fall	2017	C-
	98765	Bourikas	Elec. Eng.	98	CS-315	1	Spring	2018	В
98988 Tanaka Biology 120 BIO-301 1 Summer 2018 <i>null</i>	98988	Tanaka	Biology	120	BIO-101	1	Summer	2017	Α
	98988	Tanaka	Biology	120	BIO-301	1	Summer	2018	null

Figure 4.2 The takes relation.

Figure 4.3 The natural join of the student relation with the takes relation.

Why do we Need Outer Joins?

- Consider student and takes relations. If we combine their information through inner join or natural join, the output does not include students who have not taken any courses.
- We can address this issue through the use of outer joins.

 An outer join is used where the user wants to keep all the tuples in R, or all those in S, or all those in both relations in the result of the JOIN, regardless of whether or not they

have matching tuples in the other relation.

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55730	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

•	•				
ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	Α
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

name dept_name tot_cred course_id sec_id semester vear 102 CS-101 00128 Zhang Comp. Sci. Fall 2017 A 00128 Zhang Comp. Sci. 102 CS-347 Fall 2017 A-12345 Shankar 32 CS-101 Fall 2017 Comp. Sci. 12345 Shankar 32 CS-190 2017 Comp. Sci. Spring IA Comp. Sci. 32 12345 Shankar CS-315 Spring 2018 A 12345 Shankar Comp. Sci. 32 CS-347 Fall 2017 19991 Brandt History HIS-351 Spring 2018 B 23121 | Chavez 110 FIN-201 Spring 2018 C+ Finance 44553 PHY-101 Fall 2017 Peltier Physics 45678 Levv Physics CS-101 Fall 2017 F 2018 45678 Levy Physics CS-101 Spring CS-319 2018 B 45678 Levy Physics Spring 54321 Williams Comp. Sci. CS-101 Fall 2017 A-54321 Williams Comp. Sci. CS-190 Spring 2017 B+ 55739 Sanchez MU-199 Spring 2018 A-Music 2017 76543 CS-101 Fall Brown Comp. Sci. CS-319 2018 A 76543 Brown Spring Comp. Sci. 76653 Aoi Elec, Eng. EE-181 Spring 2017 1C I C-Elec. Eng. 2017 98765 Bourikas CS-101 Fall 98765 Bourikas CS-315 2018 B Elec. Eng. Spring 98988 Tanaka 120 BIO-101 Summer 2017 Biology 98988 Tanaka Biology 120 BIO-301 Summer 2018 null

Figure 4.2 The takes relation.

Figure 4.3 The natural join of the student relation with the takes relation.

More about Join Operation: Left Outer Join ()

• A **left outer join** operation keeps every tuple in the first, or left, relation R in $R \bowtie S$; if no matching tuple is found in S, then the attributes of S in the join result are filled or padded with NULL values.

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

	ID	course_id	sec_id	semester	year	grade
	00128	CS-101	1	Fall	2017	Α
	00128	CS-347	1	Fall	2017	A-
	12345	CS-101	1	Fall	2017	C
	12345	CS-190	2	Spring	2017	Α
	12345	CS-315	1	Spring	2018	Α
	12345	CS-347	1	Fall	2017	Α
	19991	HIS-351	1	Spring	2018	В
	23121	FIN-201	1	Spring	2018	C+
	44553	PHY-101	1	Fall	2017	B-
	45678	CS-101	1	Fall	2017	F
	45678	CS-101	1	Spring	2018	B+
	45678	CS-319	1	Spring	2018	В
_	54321	CS-101	1	Fall	2017	A-
١	54321	CS-190	2	Spring	2017	B+
5	55739	MU-199	1	Spring	2018	A-
/	76543	CS-101	1	Fall	2017	Α
l	76543	CS-319	2	Spring	2018	Α
	76653	EE-181	1	Spring	2017	C
	98765	CS-101	1	Fall	2017	C-
	98765	CS-315	1	Spring	2018	В
	98988	BIO-101	1	Summer	2017	Α
	98988	BIO-301	1	Summer	2018	null

Figure 4.2 The takes relation.

ı	ID	пате	dept_name	tot_cred	course_id	sec_id	semester	year	grade
	00128	Zhang	Comp. Sci.	102	CS-101	1	Fall	2017	Α
ı	00128	Zhang	Comp. Sci.	102	CS-347	1	Fall	2017	A-
ı	12345	Shankar	Comp. Sci.	32	CS-101	1	Fall	2017	C
ı	12345	Shankar	Comp. Sci.	32	CS-190	2	Spring	2017	Α
ı	12345	Shankar	Comp. Sci.	32	CS-315	1	Spring	2018	Α
ı	12345	Shankar	Comp. Sci.	32	CS-347	1	Fall	2017	Α
ı	19991	Brandt	History	80	HIS-351	1	Spring	2018	В
ı	23121	Chavez	Finance	110	FIN-201	1	Spring	2018	C+
ı	44553	Peltier	Physics	56	PHY-101	1	Fall	2017	B-
ı	45678	Levy	Physics	46	CS-101	1	Fall	2017	F
ı	45678	Levy	Physics	46	CS-101	1	Spring	2018	B+
ı	45678	Levy	Physics	46	CS-319	1	Spring	2018	В
ı	54321	Williams	Comp. Sci.	54	CS-101	1	Fall	2017	A-
ı	54321	Williams	Comp. Sci.	54	CS-190	2	Spring	2017	B+
	55739	Sanchez	Music	38	MU-199	1	Spring	2018	Α-
1	70557	Snow	Physics	U	null	null	null	null	null
1	76543	Brown	Comp. Sci.	58	CS-101	1	Fall	2017	Α
ı	76543	Brown	Comp. Sci.	58	CS-319	2	Spring	2018	Α
ı	76653	Aoi	Elec. Eng.	60	EE-181	1	Spring	2017	C
ı	98765	Bourikas	Elec. Eng.	98	CS-101	1	Fall	2017	C-
	98765	Bourikas	Elec. Eng.	98	CS-315	1	Spring	2018	В
	98988	Tanaka	Biology	120	BIO-101	1	Summer	2017	Α
	98988	Tanaka	Biology	120	BIO-301	1	Summer	2018	null
•									

Figure 4.4 Result of student natural left outer join takes.

SQL: Left Outer Join (⋈)

select *
from student left outer join takes on student.ID=takes.ID

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	Α
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

Figure 4.2 The takes relation.

ID	name	dept_name	tot_cred	course_id	sec_id	semester	year	grade
00128	Zhang	Comp. Sci.	102	CS-101	1	Fall	2017	A
00128	Zhang	Comp. Sci.	102	CS-347	1	Fall	2017	A-
12345	Shankar	Comp. Sci.	32	CS-101	1	Fall	2017	C
12345	Shankar	Comp. Sci.	32	CS-190	2	Spring	2017	Α
12345	Shankar	Comp. Sci.	32	CS-315	1	Spring	2018	Α
12345	Shankar	Comp. Sci.	32	CS-347	1	Fall	2017	Α
19991	Brandt	History	80	HIS-351	1	Spring	2018	В
23121	Chavez	Finance	110	FIN-201	1	Spring	2018	C+
44553	Peltier	Physics	56	PHY-101	1	Fall	2017	B-
45678	Levy	Physics	46	CS-101	1	Fall	2017	F
45678	Levy	Physics	46	CS-101	1	Spring	2018	B+
45678	Levy	Physics	46	CS-319	1	Spring	2018	В
54321	Williams	Comp. Sci.	54	CS-101	1	Fall	2017	A-
54321	Williams	Comp. Sci.	54	CS-190	2	Spring	2017	B+
55739	Sanchez	Music	38	MU-199	1	Spring	2018	A-
70557	Snow	Physics	0	null	null	null	null	null
76543	Brown	Comp. Sci.	58	CS-101	1	Fall	2017	Α
76543	Brown	Comp. Sci.	58	CS-319	2	Spring	2018	Α
76653	Aoi	Elec. Eng.	60	EE-181	1	Spring	2017	C
98765	Bourikas	Elec. Eng.	98	CS-101	1	Fall	2017	C-
98765	Bourikas	Elec. Eng.	98	CS-315	1	Spring	2018	В
98988	Tanaka	Biology	120	BIO-101	1	Summer	2017	Α
98988	Tanaka	Biology	120	BIO-301	1	Summer	2018	null

Figure 4.4 Result of student natural left outer join takes.

More about Join Operation: Right Outer Join (⋈)

• A similar operation **right outer join**, denoted by \bowtie , keeps every tuple in the second, or right, relation *S* in the result of $R \bowtie S$; if no matching tuple is found in *R*, then the attributes of R in the join result are filled or padded with NULL values.

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	Α
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55730	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	50
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

ID	course_id	sec_id	semester	year	grade	name	dept_name	tot_cred
00128	CS-101	1	Fall	2017	Α	Zhang	Comp. Sci.	102
00128	CS-347	1	Fall	2017	A-	Zhang	Comp. Sci.	102
12345	CS-101	1	Fall	2017	C	Shankar	Comp. Sci.	32
12345	CS-190	2	Spring	2017	Α	Shankar	Comp. Sci.	32
12345	CS-315	1	Spring	2018	Α	Shankar	Comp. Sci.	32
12345	CS-347	1	Fall	2017	Α	Shankar	Comp. Sci.	32
19991	HIS-351	1	Spring	2018	В	Brandt	History	80
23121	FIN-201	1	Spring	2018	C+	Chavez	Finance	110
44553	PHY-101	1	Fall	2017	B-	Peltier	Physics	56
45678	CS-101	1	Fall	2017	F	Levy	Physics	46
45678	CS-101	1	Spring	2018	B+	Levy	Physics	46
45678	CS-319	1	Spring	2018	В	Levy	Physics	46
54321	CS-101	1	Fall	2017	A-	Williams	Comp. Sci.	54
54321	CS-190	2	Spring	2017	B+	Williams	Comp. Sci.	54
55739	MU-199	-!	Spring	2018	A	Sanchez	Music	38
70557	null	null	null	null	null	Snow	Physics	0
76543	CS-101	1	Fall	2017	Α	Brown	Comp. Sci.	58
76543	CS-319	2	Spring	2018	Α	Brown	Comp. Sci.	58
76653	EE-181	1	Spring	2017	C	Aoi	Elec. Eng.	60
98765	CS-101	1	Fall	2017	C-	Bourikas	Elec. Eng.	98
98765	CS-315	1	Spring	2018	В	Bourikas	Elec. Eng.	98
98988	BIO-101	1	Summer	2017	Α	Tanaka	Biology	120
98988	BIO-301	1	Summer	2018	null	Tanaka	Biology	120

Figure 4.2 The takes relation.

Figure 4.5 The result of takes natural right outer join student.

More about Join Operation: Right Outer Join (⋈)

select *
from takes right outer join student on takes.ID=student.ID

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2017	Α
00128	CS-347	1	Fall	2017	A-
12345	CS-101	1	Fall	2017	C
12345	CS-190	2	Spring	2017	Α
12345	CS-315	1	Spring	2018	Α
12345	CS-347	1	Fall	2017	Α
19991	HIS-351	1	Spring	2018	В
23121	FIN-201	1	Spring	2018	C+
44553	PHY-101	1	Fall	2017	B-
45678	CS-101	1	Fall	2017	F
45678	CS-101	1	Spring	2018	B+
45678	CS-319	1	Spring	2018	В
54321	CS-101	1	Fall	2017	A-
54321	CS-190	2	Spring	2017	B+
55739	MU-199	1	Spring	2018	A-
76543	CS-101	1	Fall	2017	Α
76543	CS-319	2	Spring	2018	Α
76653	EE-181	1	Spring	2017	C
98765	CS-101	1	Fall	2017	C-
98765	CS-315	1	Spring	2018	В
98988	BIO-101	1	Summer	2017	Α
98988	BIO-301	1	Summer	2018	null

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

Figure 4.1 The student relation.

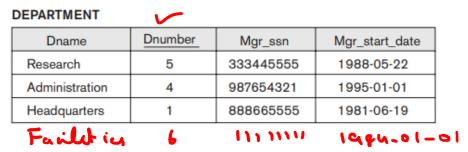
ID	course_id	sec_id	semester	year	grade	name	dept_name	tot_cred
	CS-101	1	Fall	2017	Α	Zhang	Comp. Sci.	102
00128	CS-347	1	Fall	2017	A-	Zhang	Comp. Sci.	102
12345	CS-101	1	Fall	2017	C	Shankar	Comp. Sci.	32
12345	CS-190	2	Spring	2017	Α	Shankar	Comp. Sci.	32
12345	CS-315	1	Spring	2018	Α	Shankar	Comp. Sci.	32
12345	CS-347	1	Fall	2017	Α	Shankar	Comp. Sci.	32
19991	HIS-351	1	Spring	2018	В	Brandt	History	80
23121	FIN-201	1	Spring	2018	C+	Chavez	Finance	110
44553	PHY-101	1	Fall	2017	B-	Peltier	Physics	56
45678	CS-101	1	Fall	2017	F	Levy	Physics	46
45678	CS-101	1	Spring	2018	B+	Levy	Physics	46
45678	CS-319	1	Spring	2018	В	Levy	Physics	46
54321	CS-101	1	Fall	2017	A-	Williams	Comp. Sci.	54
54321	CS-190	2	Spring	2017	B+	Williams	Comp. Sci.	54
55739	MU-199	1	Spring	2018	A-	Sanchez	Music	38
70557	null	null	null	null	null	Snow	Physics	0
76543	CS-101	1	Fall	2017	Α	Brown	Comp. Sci.	58
76543	CS-319	2	Spring	2018	Α	Brown	Comp. Sci.	58
76653	EE-181	1	Spring	2017	C	Aoi	Elec. Eng.	60
98765	CS-101	1	Fall	2017	C-	Bourikas	Elec. Eng.	98
98765	CS-315	1	Spring	2018	В	Bourikas	Elec. Eng.	98
98988	BIO-101	1	Summer	2017	Α	Tanaka	Biology	120
98988	BIO-301	1	Summer	2018	null	Tanaka	Biology	120

Figure 4.2 The takes relation.

Figure 4.5 The result of takes natural right outer join student.

More about Join Operation: Full Outer Join () ✓ ()

• Finally, a **full outer join** denoted by ⋈, keeps all tuples in both the left and the right relations when no matching tuples are found, padding them with NULL values as needed.



DEPT_LOCATIONS				
Dnumber	Dlocation			
1	Houston			
4	Stafford			
5	Bellaire			
5	Sugarland			
5	Houston			
7	Dallas			

DEDT LOCATIONS

Location
Houston
Stafford
Bellaire
Sugarland
Houston
null

More about Join Operation: Full Outer Join () ✓ ()

• Finally, a **full outer join** denoted by ⋈, keeps all tuples in both the left and the right relations when no matching tuples are found, padding them with NULL values as needed.

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

Failet in

1111111

1464-01-01

DEPT_LOCATIONS

<u>Drumber</u>	Dlocation	
1	Houston	
4	Stafford	
5	Bellaire	
5	Sugarland	
5	Houston	

DEPT_LOCS

DEFT_ECCS				<u> </u>
Dname	Dnumber	Mgr_ssn	Mgr_start_date	Location
Headquarters	1	888665555	1981-06-19	Houston
Administration	4	987654321	1995-01-01	Stafford
Research	5	333445555	1988-05-22	Bellaire
Research	5	333445555	1988-05-22	Sugarland
Research	5	333445555	1988-05-22	Houston

NULO

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More about Join Operation: Full Outer Join (≥<)

select *

from department full outer join dept_locations on department.Dnumber=dept_locations.Dnumber

DEPARTMENT

Dname	<u>Dnumber</u>	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

DEPT_LOCATIONS

Dnumber	Dlocation	
1	Houston	
4	Stafford	
5	Bellaire	
5	Sugarland	
5	Houston	

DEPT_LOCS

Dname	Dnumber	Mgr_ssn	Mgr_start_date	Location
Headquarters	1	888665555	1981-06-19	Houston
Administration	4	987654321	1995-01-01	Stafford
Research	5	333445555	1988-05-22	Bellaire
Research	5	333445555	1988-05-22	Sugarland
Research	5	333445555	1988-05-22	Houston