Section 2

Ch2. Introduction to the relational model

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Database System Concepts, 7th edition.

Prepared by:

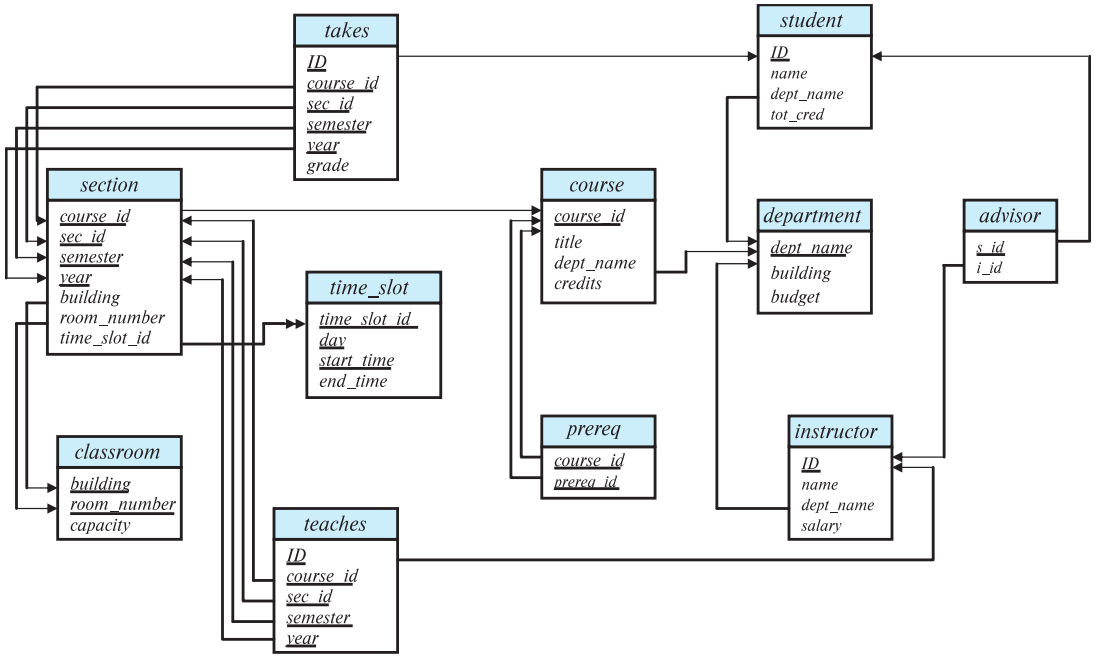
AbdElrahman Rabea, Eng.

Relational model

The relational data model is the foundation of Relational Database Management Systems (RDBMS).

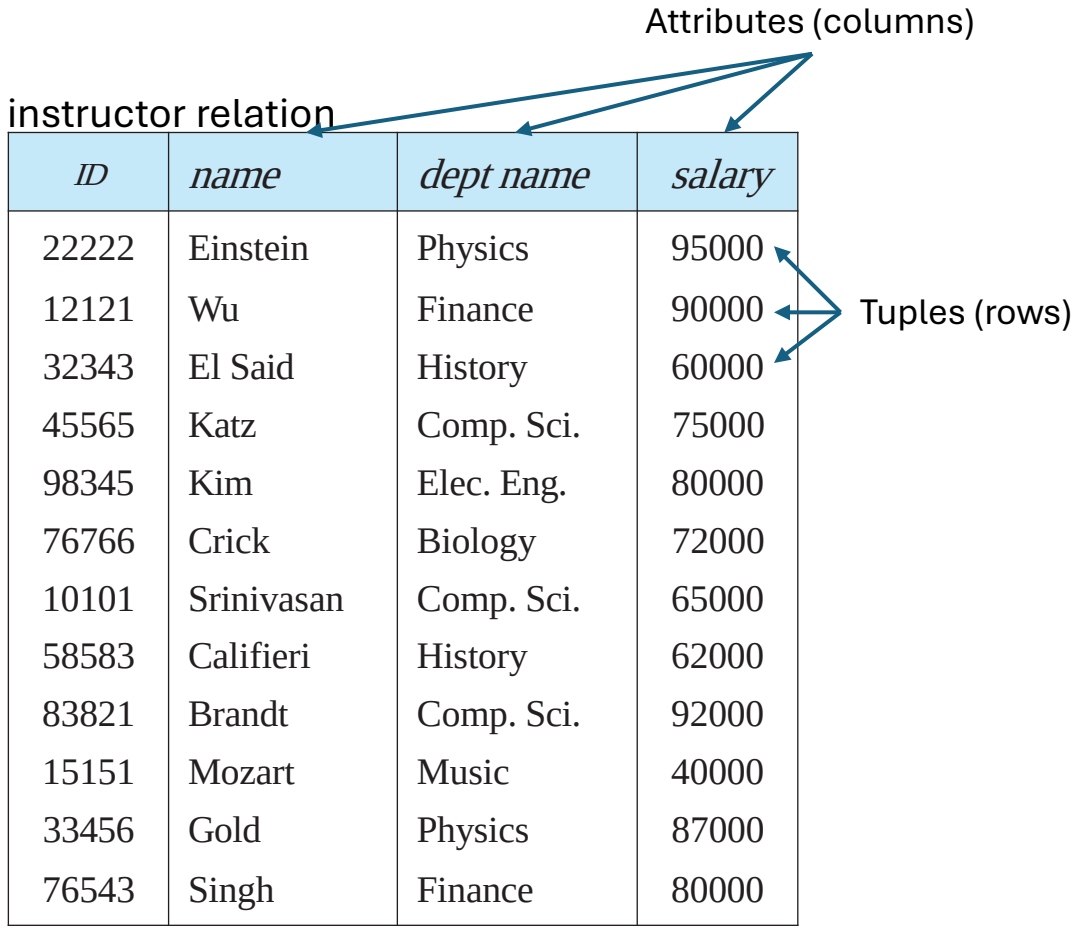
Key benefits:

- ✅ Widely Used & Standardized: relational model remains the primary data model for commercial data-processing applications.
- ✅ Simple & Structured – Data is described in clear table-based formats, making it easy to understand and manage.
- ✅ Data Integrity & Accuracy – Ensures consistency with constraints (Primary Key, Foreign Key, Unique) and eliminates redundancy.
- ✅ Efficient & Scalable – Optimized implementations support indexing, large datasets, and concurrent access.
- ✅ Flexible & Independent – Logical and physical storage are separate, allowing schema evolution without affecting applications.



Relational model structure

- A relational database consists of set of named relations (tables)
- Each relation has a set of named attributes (columns)
- Each tuple (row) has a value for each attribute
- Each attribute has a domain
- Domain is the set of allowed values for each attribute. Ex. dept-name
- The special value **null** is a member of every domain. Indicated that the value is “unknown”.
- The null value causes complications in the definition of many operations.



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

Database Schema vs instances

- Database schema -- is the logical structure of the database.
- Database instance -- is a snapshot of the data in the database at a given instant in time.
- Example:
  - schema: instructor (ID, name, dept_name, salary)

instance

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

Database Schema vs instances

Key: attribute whose value is unique in each tuple
Or set of attributes whose combined values are unique

Primary key: key that is unique and can't be null

Foreign-key constrainst:

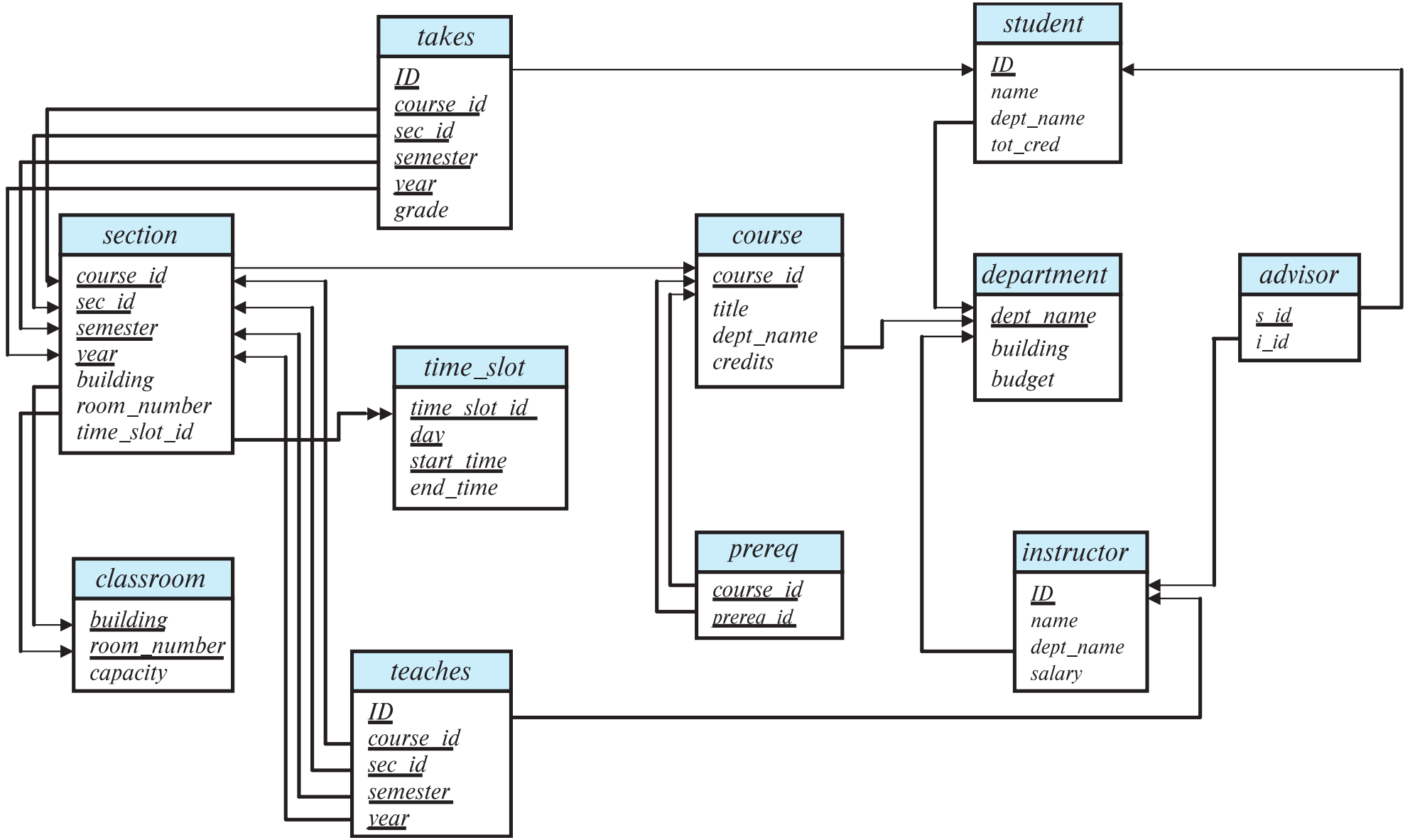
- **Foreign-key constraints** enforce consistency between relations in a database.
- The **dept_name** attribute in the instructor relation must correspond to an existing department in the department relation, that is No tuple in instructor should have a dept_name value that does not exist in department.
- Given a tuple **ta** from instructor, there must be a corresponding tuple **tb** in department with the same dept_name value.
- A **foreign-key constraint** from attribute(s) **A** in relation $\mathbf{r_1}$ to the primary key **B** in relation $\mathbf{r_2}$ ensures:
- The value of **A** in each tuple of $\mathbf{r_1}$ must match a value of **B** in some tuple of $\mathbf{r_2}$.
- The **foreign key (A)** belongs to $\mathbf{r_1}$ and references $\mathbf{r_2}$.
- $\mathbf{r_1}$ is called the **referencing relation**, while $\mathbf{r_2}$ is the **referenced relation**.

Classroom (*building*, *room number*, *capacity*)
department (*dept_name*, *building*, *budget*)
course (*course_id*, *title*, *dept name*, *credits*)
Instructor (*ID*, *name*, *dept name*, *salary*)
section (*course id*, *sec id*, *semester*, *year*, *building*, *room number*, *time slot id*)
teaches (*ID*, *course id*, *sec id*, *semester*, *year*)
student (*ID*, *name*, *dept name*, *tot cred*)
takes (*ID*, *course id*, *sec id*, *semester*, *year*, *grade*)
advisor (*s_ID*, *i_ID*)
time slot (*time slot id*, *day*, *start time*, *end time*)
prereq (*course id*, *prereq id*)

Schema of the university database.

Formal definition of keys as will as other types of keys will be discussed later

University Schema diagram



Query Languages

- Relational Algebra
  - The relational algebra consists of a set of operations that take one or two relations as input and produce a **new relation** as their result.
  - However the relational algebra operations form the basis for the widely used SQL query language, database systems do not allow users to write queries in relational algebra.
  - Select, project, rename, join
- SQL (next sections)

course(*course_id*, *title*, *dept name*, *credits*)
Instructor(*ID*, *name*, *dept name*, *salary*)
teaches(*ID*, *course id*, *sec id*, *semester*, *year*)
Simple schema to practice relational algabra

Relational Algebra (SIMPLE SCHEMA)

Instructor(*ID*, *name*, *dept_name*, *salary*)
teaches(*ID*, *course id*, *sec_id*, *semester*, *year*)
course(*course_id*, *title*, *dept_name*, *credits*)

instructor

ID	*name*	*dept name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
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76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

teaches

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

course

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

Relational Algebra

Simples query: relation name

Example: instructor

will return instructor instances

instructor

ID	*name*	*dept name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
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teaches

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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

Relational Algebra (select)

Select operation: selects tuples that satisfy a given predicate. σ

- select tuples of the instructor relation where the instructor is in the "Physics" department.

  $\sigma_{\text{dept name = "Physics"}}(\text{instructor})$

  =, ≠, <, ≤, >, ≥
  and (∧), or(∨) , not(¬)

- select tuples of the instructor relation where the instructor is in the "Physics" and salary > 9000

  $\sigma_{\text{dept name = "Physics"} \wedge \text{salary>90000}}(\text{instructor})$

- Select all departments whose name is the same as their building name

  $\sigma_{\textit{dept name = building}}(\textit{department})$

instructor

ID	*name*	*dept name*	*salary*
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15151	Mozart	Music	40000
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teaches

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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

Relational Algebra (project)

Project operation: to pick certain columns

- list all instructors' ID, name, and salary

$$\pi_{ID,\ name,\ salary}(instructor)$$

instructor

ID	*name*	*dept name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
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teaches

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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

Relational Algebra (Composition)

relational-algebra operations can be composed together into a **relational-algebra expression**

- Find the names of all instructors in the Physics department

$$\pi_{\text{name}} (\sigma_{\text{dept\_name} = \text{“Physics”}} (\text{instructor}))$$

Note: you can combine these operations because the output of every operation is a relation

instructor

ID	*name*	*dept name*	*salary*
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15151	Mozart	Music	40000
22222	Einstein	Physics	95000
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teaches

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MU-199	Music Video Production	Music	3
PHY-101	Physical Principles	Physics	4

Relational Algebra (Cartesian-product)

Cartesian-product: combine two relations

instructor × teaches

Output schema = (instructor.ID, name, dept name, salary, teaches.ID, course id, sec id, semester, year)

For n1 tuples in r1, n2 tuples in r2 => n1 * n2 tuples

instructor

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15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
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teaches

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PHY-101	Physical Principles	Physics	4

Relational Algebra (Join)

Cartesian product associates every instructor with every course that was taught, regardless of whether that instructor taught that course. (so we want to make some filtering on the output)

- Select ID and name of instructor corresponding with their course id.

$$\pi_{\text{instructor.ID, name, course\_id}}(\sigma_{instructor.ID = teaches.ID}(instructor \times teaches))$$

- The theta join operation allows us to combine a selection and a Cartesian product into a single operation.

$$r \bowtie_{\theta} s = \sigma_{\theta}(r \times s) \Rightarrow \text{instructor} \bowtie_{\text{instructor.ID = teaches.ID}} \text{teaches}$$

Different types of join operation will be introduced later

instructor

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
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76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

teaches

ID	*course id*	*sec id*	*semester*	*year*
10101	CS-101	1	Fall	2017
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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

Relational Algebra (Union operation)

- find the set of all courses taught in the Fall 2017 semester

$$\pi_{course\_id}(\sigma_{semester = \text{“Fall”} \wedge year=2017}(section))$$

section(*course id*, *sec id*, *semester*, *year*, *building*, *room number*, *time slot id*)

- set of all courses taught in the Spring 2018 semester

$$\pi_{course\_id}(\sigma_{semester = \text{“Spring”} \wedge year=2018}(section))$$

- all courses taught in the Fall 2017 semester, the Spring 2018 semester, or both.

$$\pi_{course\_id}(\sigma_{semester = \text{“Fall”} \wedge year=2017}(section)) \cup \pi_{course\_id}(\sigma_{semester = \text{“Spring”} \wedge year=2018}(section))$$

instructor

ID	*name*	*dept name*	*salary*
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teaches

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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

Relational Algebra (Set operation)

- we took the union of two sets, both of which consisted of course id values. In general, for a union operation to make sense:
  - We must ensure that the input relations to the union operation have the same number of attributes.
  - When the attributes have associated types, the types of the ith attributes of both input relations must be the same, for each i.
  - **(compatible relations)**

instructor

ID	*name*	*dept name*	*salary*
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teaches

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

course

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

Relational Algebra (intersection operation)

Intersection operation: allows us to find tuples that are in both the input relations. ($\cap$)

- Courses offered in both the Fall 2017 and Spring 2018 semesters

$$\pi_{course\_id}(\sigma_{semester = \text{“Fall”} \wedge year=2017}(section)) \cap \pi_{course\_id}(\sigma_{semester = \text{“Spring”} \wedge year=2018}(section))$$

As with the union operation, we must ensure that intersection is done between compatible relations

instructor

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

teaches

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

course

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

Relational Algebra (Difference)

Difference operation: allows us to find tuples that are in one relation but are not in another. (-)

- find all the courses taught in the Fall 2017 semester but not in Spring 2018 semester

$$\pi_{course\_id}(\sigma_{semester = \text{“Fall”} \wedge year=2017}(section)) - \pi_{course\_id}(\sigma_{semester = \text{“Spring”} \wedge year=2018}(section))$$

As with the union operation, we must ensure that difference is done between compatible relations

instructor

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

teaches

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
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83821	CS-190	1	Spring	2017
83821	CS-190	2	Spring	2017
83821	CS-319	2	Spring	2018
98345	EE-181	1	Spring	2017

course

course id	*title*	*dept name*	*credits*
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BIO-399	Computational Biology	Biology	3
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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

Rename operation

Difference operation: allows us to find tuples that are in one relation but are not in another.

- To rename table E and its attribute: $\rho_{x(A1,A2,\ldots,An)}(E)$ or $\rho_x(E)$ or $\rho_{A1,A2,\ldots,An}(E)$
- Benefits: 1. solves problems of set operations. 2. allows you to make complex queries.
- Find the ID and name of those instructors who earn more than the instructor whose ID is 12121

$$\pi_{i.ID,i.name}((\sigma_{i.salary > w.salary}(\rho_i(instructor) \times \sigma_{w.id=12121}(\rho_w(instructor)))))$$

instructor

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

teaches

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course

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CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3
CS-319	Image Processing	Comp. Sci.	3
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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