Advanced Data Management (CSCI 680/490)

Databases

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Python Features

- Iterators: for loops use to go through elements
  - `it = iter(d.values()); next(it)`
- Comprehensions: succinct computations over collections (map & filter)
  - `squares = [i**2 for i in range(10) if i % 3 != 1]`
- Exceptions: deal with errors when desired, allow aggregation
  - `try-except-else-finally`
- Object-Oriented Programming:
  - Class definitions (`__init__`, `self`)
  - Using object obj: `obj.field`, `obj.function()`

Databases & DBMSes

- Database:
  - Basically, just structured data/information stored on a computer
  - Very generic, doesn't specify specific way that data is stored
  - Can be single-file (or in-memory) or much more complex
- Database Management System (DBMS):
  - Software to manage databases
  - Instead of each program writing its own methods to manage data, abstract data management to the DBMS
  - Specify structure of the data (schema)
  - Provide query capabilities

Data Models

- The data model specifies:
  - what data can be stored (and sometimes how it is stored)
  - associations between different data values
  - what constraints can be enforced
  - how to access and manipulate the data
- Relational model
- Entity-Relationship data model (mainly for database design)
- Object-based data models (Object-oriented and Object-relational)
- Semistructured data model (XML)
- Network Model

[A. Silberschatz et al.]

Assignment 1

- Due Monday
- Using Python for data analysis on MoMA data
- Use basic python for now to work on language knowledge
- Use Anaconda or a hosted Python environment
- Turn `.ipynb` file in via Blackboard

Relational Model History

- Invented by Edgar F. Codd in early 1970s
- Focus was data independence
  - Previous data models required physical-level design and implementation
  - Changes to a database schema were very costly to applications that accessed the database
- IBM, Oracle were first implementers of relational model (1977)
  - Usage spread very rapidly through software industry
  - SQL was a particularly powerful innovation

[D. Pinkston]

Relations

- Relations are basically tables of data
  - Each row represents a **tuple** in the relation
- A relational database is an **unordered** set of relations
  - Each relation has a unique name in the database
- Each row in the table specifies a relationship between the values in that row
  - The account ID “A-307”, branch name “Seattle”, and balance “275” are all related to each other

acct_id	branch_name	balance
A-301	New York	350
A-307	Seattle	275
A-318	Los Angeles	550
…	…	…

[D. Pinkston]

Relations and Attributes

- Each relation has some number of **attributes**
  - Sometimes called "columns"
- Each attribute has a **domain**
  - Set of valid values for the attribute (+ `null`)
  - Values are usually **atomic**
- The `account` relation has 3 attributes
  - Domain of `balance` is the set of nonnegative integers
  - Domain of `branch_name` is the set of all valid branch names in the bank

acct_id	**branch_name**	**balance**
A-301	New York	350
A-307	Seattle	275
A-318	Los Angeles	550
…	…	…

[D. Pinkston]

Database Schema

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

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

[A. Silberschatz et al.]

Keys

- Let $K \subseteq R$
- K is a **superkey** of R if values for K are sufficient to identify a unique tuple of each possible relation $r(R)$
  - Example: `{ID}` and `{ID,name}` are both superkeys of `instructor`.
- Superkey K is a **candidate key** if K is **minimal**
  Example: `{ID}` is a candidate key for Instructor
- One of the candidate keys is selected to be the **primary key**.
  - Which one?

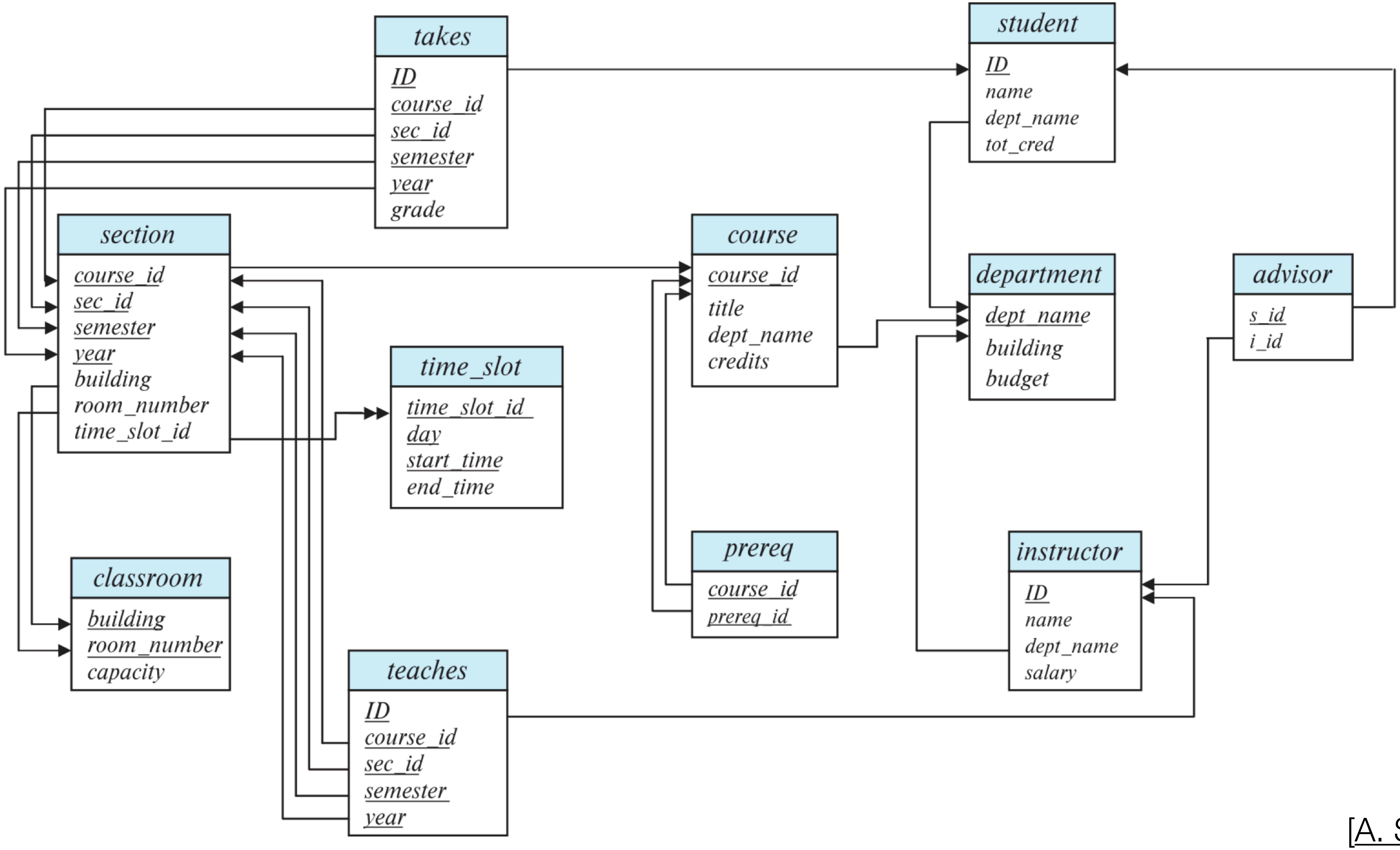
[A. Silberschatz et al.]

Foreign Key Constraints

- Foreign key constraint: Value in one relation **must appear** in another
  - *Referencing* relation
  - *Referenced* relation
  - Example: `dept_name` in `instructor` is a foreign key from `instructor` referencing `department`

[A. Silberschatz et al.]

Schema Diagram with Keys



[A. Silberschatz et al.]

Relational Query Languages

- Procedural versus non-procedural, or declarative
- “Pure” languages:
  - Relational algebra
  - Tuple relational calculus
  - Domain relational calculus
- The above 3 pure languages are **equivalent** in computing power
- Concentrate on relational algebra
  - Not Turing-machine equivalent
  - 6 basic operations

[A. Silberschatz et al.]

Relational Algebra

- Definition: A procedural language consisting of a set of operations that take one or two relations as input and produce a new relation as their result.
- Six basic operators
  - select: σ
  - project: $\prod$
  - union: $\cup$
  - set difference: –
  - Cartesian product: x
  - rename: ρ

[A. Silberschatz et al.]

Select Operation

- The select operation selects tuples that satisfy a given predicate.
- Notation: $\sigma_p(r)$
- p is called the selection predicate
- Example: select those tuples of the `instructor` relation where the instructor is in the "Physics" department.
  - Query: $\sigma_{dept\_name=\text{“Physics”}}(\texttt{instructor})$
  - Result:

ID	*name*	*dept_name*	*salary*
22222	Einstein	Physics	95000
33456	Gold	Physics	87000

[A. Silberschatz et al.]

Select Operation Comparisons

- We allow comparisons using $=, \neq, >, \geq, <, \leq$ in the selection predicate.
- We can combine several predicates into a larger predicate by using the connectives: ∧ (and), ∨ (or), ¬ (not)
- Example: Find the instructors in Physics with a salary greater than $90,000:
  - $\sigma_{\text{dept\_name}=\text{“Physics”} \wedge \text{salary} > 90{,}000}$ (`instructor`)
-
- The select predicate may include comparisons between two **attributes**.
  - Example: departments whose name is the same as their building name:
    - $\sigma_{\text{dept\_name}=\text{building}}$ (`department`)

[A. Silberschatz et al.]

Project Operation

- A unary operation that returns its argument relation, with certain attributes left out.
- Notation: $\prod_{A_1,A_2,A_3,\ldots,A_k} (\texttt{r})$
  where $A_1,A_2,A_3,\ldots,A_k$ are attribute names and `r` is a relation name.
- The result is defined as the relation of k columns obtained by erasing the columns that are not listed
- Duplicate rows removed from result, since relations are sets

[A. Silberschatz et al.]

Project Operation Example

ID	*name*	*salary*
10101	Srinivasan	65000
12121	Wu	90000
15151	Mozart	40000
22222	Einstein	95000
32343	El Said	60000
33456	Gold	87000
45565	Katz	75000
58583	Califieri	62000
76543	Singh	80000
76766	Crick	72000
83821	Brandt	92000
98345	Kim	80000

- Example: eliminate the `dept_name` attribute of instructor
- Query: $\prod_{\text{ID, name, salary}}$ (`instructor`)

[A. Silberschatz et al.]

Composition of Relational Operations

- The result of a relational-algebra operation is a **relation**
- … so relational-algebra operations can be **composed** together into a relational-algebra expression.
- Example: Find the names of all instructors in the Physics department.

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

- Instead of giving the name of a relation as the argument of the projection operation, we give an expression that evaluates to a relation.

[A. Silberschatz et al.]

Cartesian-Product Operation

- The **Cartesian-product** operation (denoted by X) allows us to combine information from any two relations.
- Example: the Cartesian product of the relations `instructor` and `teaches` is written as: `instructor` X `teaches`
- We construct a tuple of the result out of **each possible pair** of tuples: one from the instructor relation and one from the teaches relation
- Since the instructor ID appears in both relations we distinguish between these attribute by attaching to the attribute the name of the relation from which the attribute originally came.
  - `instructor.ID` and `teaches.ID`

[A. Silberschatz et al.]

The instructor X teaches table

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
10101	Srinivasan	Comp. Sci.	65000	12121	FIN-201	1	Spring	2018
10101	Srinivasan	Comp. Sci.	65000	15151	MU-199	1	Spring	2018
10101	Srinivasan	Comp. Sci.	65000	22222	PHY-101	1	Fall	2017
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
12121	Wu	Finance	90000	10101	CS-101	1	Fall	2017
12121	Wu	Finance	90000	10101	CS-315	1	Spring	2018
12121	Wu	Finance	90000	10101	CS-347	1	Fall	2017
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2018
12121	Wu	Finance	90000	15151	MU-199	1	Spring	2018
12121	Wu	Finance	90000	22222	PHY-101	1	Fall	2017
...	...	...	...	...	...	...	...	...

[A. Silberschatz et al.]

Join Operation

- The Cartesian-Product `instructor X teaches` associates every tuple of instructor with every tuple of teaches.
  - Most of the resulting rows have information about instructors who **did not** teach a particular course.
- To get only those tuples of `instructor X teaches` that pertain to instructors and the courses that they taught, we write:

$$\sigma_{\text{instructor.id = teaches.id}}(\texttt{instructor} \times \texttt{teaches})$$

  - We get only those tuples of `instructor X teaches` that pertain to instructors and the courses that they taught.

[A. Silberschatz et al.]

Join Operation (Cont.)

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

The table corresponding to $\sigma_{\text{instructor.id = teaches.id}}$ (`instructor` x `teaches`)

[A. Silberschatz et al.]

Join Operation

- The **join** operation allows us to combine a select operation and a Cartesian-Product operation into a single operation.
- Consider relations `r(R)` and `s(S)`
- Let θ be a predicate on attributes in the schema R ∪ S. The join operation is:

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

- Thus

$$\sigma_{\text{instructor.id = teaches.id}} (\texttt{instructor} \times \texttt{teaches})$$

- can equivalently be written as

$$\texttt{instructor} \bowtie_{\text{Instructor.id = teaches.id}} \texttt{teaches}$$

[A. Silberschatz et al.]

Union Operation

- The **union** operation allows us to combine two relations
- Notation: `r ∪ s`
- For `r ∪ s` to be valid.
  - `r`, `s` must have the same arity (same number of **attributes**)
  - The attribute domains must be **compatible** (example: 2nd column of `r` deals with the same type of values as does the 2nd column of `s`)

[A. Silberschatz et al.]

Union Example

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

  $\prod_{\text{course\_id}} (\sigma_{\text{semester="Fall"} \land \text{year=2017}} (\texttt{section})) \cup$
  $\prod_{\text{course\_id}} (\sigma_{\text{semester="Spring"} \land \text{year=2018}} (\texttt{section}))$

course_id
CS-101
CS-315
CS-319
CS-347
FIN-201
HIS-351
MU-199
PHY-101

[A. Silberschatz et al.]

Set-Intersection Operation

- The **set-intersection** operation allows us to find tuples that are in both the input relations.
- Notation: `r ∩ s`
- Same requirements as union:
  - `r`, `s` have the same arity
  - attributes of `r` and `s` are compatible
- Example: Find the set of all courses taught in both the Fall 2017 and the Spring 2018 semesters.
- $\prod_{\text{course\_id}} (\sigma_{\text{semester=“Fall”} \land \text{year=2017}} (\texttt{section})) \cap$

$\prod_{\text{course\_id}} (\sigma_{\text{semester=“Spring”} \land \text{year=2018}} (\texttt{section}))$

course_id
CS-101

[A. Silberschatz et al.]

Set Difference Operation

- The **set-difference** operation allows us to find tuples that are in one relation but are not in another.
- Notation `r` – `s`
- Same requirements as union and set-intersection: .
  - `r` and `s` must have the same arity
  - attribute domains of `r` and `s` must be compatible
- Example: Find all courses taught in the Fall 2017 semester, but **not** in the Spring 2018 semester

$$\prod_{\text{course\_id}} (\sigma_{\text{semester="Fall"} \land \text{year=2017}} (\texttt{section})) - \prod_{\text{course\_id}} (\sigma_{\text{semester="Spring"} \land \text{year=2018}} (\texttt{section}))$$

course_id
CS-347
PHY-101

[A. Silberschatz et al.]

Equivalent Queries

- There is more than one way to write a query in relational algebra.
- Example: Find information about courses taught by instructors in the Physics department with salary greater than 90,000
- Query 1: $\sigma_{\text{dept\_name="Physics"} \wedge \text{salary} > 90{,}000}$ ($\texttt{instructor}$)
- Query 2: $\sigma_{\text{dept\_name="Physics"}}$ ($\sigma_{\text{salary} > 90.000}$ ($\texttt{instructor}$))
- The two queries are **not identical**; they are, however, **equivalent** -- they give the same result on any database.

[A. Silberschatz et al.]

Equivalent Queries

- Example: Find information about courses taught by instructors in the Physics department
- Query 1:

$$\sigma_{\text{dept\_name=“Physics”}} (\texttt{instructor} \bowtie_{\text{instructor.ID = teaches.ID}} \texttt{teaches})$$

- Query 2

$$(\sigma_{\text{dept\_name=“Physics”}} (\texttt{instructor})) \bowtie_{\text{instructor.ID = teaches.ID}} \texttt{teaches}$$

- The **order** of joins is one focus of some of the work on query optimization

[A. Silberschatz et al.]

SQL

SQL History

- IBM Sequel language developed as part of System R project at the IBM San Jose Research Laboratory
- Renamed Structured Query Language (SQL)
- ANSI and ISO SQL: SQL-86, SQL-89, SQL-92, SQL:1999, SQL:2003
- Commercial systems offer most, if not all, SQL-92 features, plus varying feature sets from later standards and special proprietary features.
- Not all examples work on all systems

[A. Silberschatz et al.]

Components of SQL

- **Data Definition Language (DDL)**: the specification of information about relations, including schema, types, integrity constraints, indices, storage
- **Data Manipulation Language (DML)**: provides the ability to query information from the database and to insert tuples into, delete tuples from, and modify tuples in the database.
- **Integrity**: the DDL includes commands for specifying integrity constraints.
- **View definition**: The DDL includes commands for defining views.
- Also: **Transaction control**, **embedded and dynamic SQL**, **authorization**

[A. Silberschatz et al.]

Create Table

- An SQL relation is defined using the create table command:

  `create table r` $(A_1\ D_1,\ A_2\ D_2,\ \ldots,\ A_n\ D_n,\ (C_1),\ \ldots,\ (C_k))$

  - `r` is the **name** of the relation
  - each A_i is an **attribute name** in the schema of relation `r`
  - D_i is the **data type** of values in the domain of attribute A_i

C_i are integrity constraints

- Example:

```
create table instructor(
        ID              char(5),
        name            varchar(20),
        dept_name       varchar(20),
        salary          numeric(8,2));
```

[A. Silberschatz et al.]

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    salary      numeric(8,2));
```

[A. Silberschatz et al.]

Integrity Constraints in Create Table

- Types of integrity constraints
  - **primary key** $(A_1, \ldots, A_n)$
  - **foreign key** $(A_m, \ldots, A_n)$ **references** r
  - **not null**
- SQL prevents any update to the database that violates an integrity constraint
- **create table** instructor (

```
    ID              char(5),
    name            varchar(20) not null,
    dept_name       varchar(20),
    salary          numeric(8,2),
    primary key (ID),
    foreign key (dept_name) references department);
```

[A. Silberschatz et al.]

Updates to tables

- Insert: **`insert into`** `instructor` **`values`** `('10211', 'Smith', 'Biology', 66000);`
- Delete: **`delete from`** `student; -- remove all tuples from student`
- Drop Table: **`drop table`** `r`
- Alter: **`alter table`** `r` **`add`** *A D;* **`alter table`** `r` **`drop`** `A`
  - *A* is the name of the attribute to be added to relation `r`
  - *D* is the domain of *A*
  - All exiting tuples are assigned `null` for the new attribute's value
  - Dropping of attributes not widely supported

[A. Silberschatz et al.]

Basic Query Structure

- A typical SQL query has the form:

  `select` $A_1, A_2, \ldots, A_n$

  `from` $r_1, r_2, \ldots, r_m$

  `where` P

  - A_i represents an **attribute**
  - r_i represents a **relation**
  - P is a **predicate**.

- The result of an SQL query is a **relation**

[A. Silberschatz et al.]

Select

- The **select** clause lists the attributes desired in the result of a query
  - corresponds to the projection operation of the relational algebra
- Example: Find the names of all instructors
  - ```
    select name
    from instructor;
    ```
- Note: SQL names are **case insensitive**
  - `Name` and `NAME` and `name` are equivalent
  - Some people use upper case for language keywords (e.g. `SELECT`)

[A. Silberschatz et al.]
    ```

Select

- SQL allows **duplicates** in relations as well as in query results.
- To eliminate duplicates, put the keyword **`distinct`** after **`select`**.
- Example: Find the department names of all instructors (no duplicates)
  - ```
    select distinct dept_name
      from instructor;
    ```
- The keyword **`all`** specifies that duplicates should not be removed
  - ```
    select all dept_name
      from instructor;
    ```

dept_name
Comp. Sci.
Finance
Music
Physics
History
Physics
Comp. Sci.
History
Finance
Biology
Comp. Sci.
Elec. Eng.

[A. Silberschatz et al.]

Select

- An asterisk (*) in the select clause denotes “all attributes”
  - `select * from instructor;`
- An attribute can be a **literal** with no from clause (`select '437'`)
  - Result is a table with one column and a single row with value `'437'`
  - Can give the column a name using as: `select '437' as FOO`
- An attribute can be a literal with from clause:
  - `select 'A' from instructor`
  - Result is a table with one column and *N* rows (number of tuples in the instructors table), each row with value `“A”`

[A. Silberschatz et al.]

Select "Math"

- The select clause can contain **arithmetic expressions** involving the operation, `+`, `–`, `*`, and `/`, and operating on constants or attributes of tuples.
- The query

  ```
  select ID, name, salary/12 from instructor
  ```

  would return a relation that is the same as the `instructor` relation, except that the value of the attribute `salary` is divided by `12`.
- Can rename expressions using the **`as`** clause:
  - `select ID, name, salary/12 as monthly_salary`

[A. Silberschatz et al.]

Where

- The **where** clause specifies conditions that the result must satisfy
  - Confusingly corresponds to the **selection** predicate in relational algebra
- Example: Find all instructors in Comp. Sci. dept
  - ```
    select name
    from instructor
    where dept_name = 'Comp. Sci.'
    ```

[A. Silberschatz et al.]
    ```

Where

- The operands can be expressions with operators `<`, `<=`, `>`, `>=`, `=`, and **`<>`**
- SQL allows the use of the logical connectives `and`, `or`, and `not`
- Comparisons can be applied to results of arithmetic expressions
- Example: Find all instructors in Comp. Sci. with salary > 70000
  - ```
    select name
    from instructor
    where dept_name = 'Comp. Sci.' and salary > 70000
    ```

name
Katz
Brandt

[A. Silberschatz et al.]
    ```

From

- The **from** clause lists the relations involved in the query
  - Corresponds to the **Cartesian Product** operation in relational algebra
- Find the Cartesian product `instructor` X `teaches`
  - ```
    select *
    from instructor, teaches;
    ```
  - All possible `instructor` – `teaches` pairs, with all attributes from both
  - Shared attributes (e.g., `ID`) are renamed (e.g., `instructor.ID`)
- Not very useful directly but useful combined with where clauses.

[A. Silberschatz et al.]
    ```

From

- Find the names of all instructors who have taught some course and that course_id
  - ```
    select name, course_id
    from instructor, teaches
    where instructor.ID = teaches.ID
    ```
- Find the names of all instructors in the Art department who have taught some course and the course_id
  - ```
    select name, course_id
    from instructor, teaches
    where instructor.ID = teaches.ID
    and instructor.dept_name = 'Art'
    ```

name	*course_id*
Srinivasan	CS-101
Srinivasan	CS-315
Srinivasan	CS-347
Wu	FIN-201
Mozart	MU-199
Einstein	PHY-101
El Said	HIS-351
Katz	CS-101
Katz	CS-319
Crick	BIO-101
Crick	BIO-301
Brandt	CS-190
Brandt	CS-190
Brandt	CS-319
Kim	EE-181

[A. Silberschatz et al.]

The Rename Operation

- SQL allows renaming relations and attributes using the **as** clause:
  - *old-name* **as** *new-name*
- Example: Find the names of all instructors who have a higher salary than some instructor in 'Comp. Sci'.
  - ```
    select distinct T.name
    from instructor as T, instructor as S
    where T.salary > S.salary and S.dept_name = 'Comp. Sci.'
    ```
- Keyword as is optional and may be omitted
  - `instructor as T` is equivalent to `instructor T`

[A. Silberschatz et al.]
    ```

Set Operations

- Find courses that ran in Fall 2017 or in Spring 2018
- ```
  (select course_id from section where sem = 'Fall' and year = 2017)
    union
  (select course_id from section where sem = 'Spring' and year = 2018)
  ```
- Find courses that ran in Fall 2017 and in Spring 2018
- ```
  (select course_id from section where sem = 'Fall' and year = 2017)
    intersect
  (select course_id from section where sem = 'Spring' and year = 2018)
  ```
- Find courses that ran in Fall 2017 but not in Spring 2018
- ```
  (select course_id from section where sem = 'Fall' and year = 2017)
    except
  (select course_id from section where sem = 'Spring' and year = 2018)
  ```

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  ```

Aggregate Functions

- Find the average salary of instructors in the Computer Science department
  - ```
    select avg (salary)
    from instructor
    where dept_name = 'Comp. Sci.';
    ```
- Find the total number of instructors who teach a course in the Spring 2018 semester
  - ```
    select count(distinct ID)
    from teaches
    where semester = 'Spring' and year = 2018;
    ```
- Find the number of tuples in the course relation
  - ```
    select count(*)
    from course;
    ```

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    ```