

# ***DBMS: Relational Model and SQL***

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# Data Models

- **Data Model:**

- A set of concepts to describe the ***structure*** of a database, the ***operations*** for manipulating these structures, and certain ***constraints*** that the database should obey.

- **Data Model Structure and Constraints:**

- Constructs are used to define the database structure
- Constructs typically include ***elements*** (and their ***data types***) as well as groups of elements (e.g. ***entity, record, table***), and ***relationships*** among such groups
- Constraints specify some restrictions on valid data; these constraints must be enforced at all times

## Data Model Operations:

These operations are used for specifying database *retrievals* and *updates* by referring to the constructs of the data model.

Operations on the data model may include ***basic model operations*** (e.g. generic insert, delete, update) and ***user-defined operations*** (e.g. compute\_student\_gpa, update\_inventory)

# Categories of Data Models

- **Conceptual (high-level, semantic) data models:**
  - Provide concepts that are close to the way many users perceive data.
    - (Also called *entity-based* or *object-based* data models.)
- **Physical (low-level, internal) data models:**
  - Provide concepts that describe details of how data is stored in the computer. These are usually specified in an ad-hoc manner through DBMS design and administration manuals
- **Implementation (representational) data models:**
  - Provide concepts that fall between the above two, used by many commercial DBMS implementations (e.g. relational data models used in many commercial systems).
- **Self-Describing Data Models:**
  - Combine the description of data with the data values. Examples include XML, key-value stores and some NOSQL systems.

# Schemas versus Instances

- Database Schema:
  - The ***description*** of a database.
  - Includes descriptions of the database structure, data types, and the constraints on the database.
- Schema Diagram:
  - An ***illustrative*** display of (most aspects of) a database schema.
- Schema Construct:
  - A ***component*** of the schema or an object within the schema, e.g., STUDENT, COURSE.
- Database State:
  - The actual data stored in a database at a ***particular moment in time***. This includes the collection of all the data in the database.
  - Also called database instance (or occurrence or snapshot).
    - The term *instance* is also applied to individual database components, e.g. *record instance*, *table instance*, *entity instance*

# Database Schema vs. Database State

- Database State:
  - Refers to the ***content*** of a database at a moment in time.
- Initial Database State:
  - Refers to the database state when it is initially loaded into the system.
- Valid State:
  - A state that satisfies the structure and constraints of the database.
- Distinction
  - The ***database schema*** changes very infrequently.
  - The ***database state*** changes every time the database is updated.
- **Schema** is also called **intension**.
- **State** is also called **extension**.

# Example of a Database Schema

## STUDENT

Name	Student_number	Class	Major
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## COURSE

Course_name	Course_number	Credit_hours	Department
-------------	---------------	--------------	------------

## PREREQUISITE

Course_number	Prerequisite_number
---------------	---------------------

## SECTION

Section_identifier	Course_number	Semester	Year	Instructor
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## GRADE\_REPORT

Student_number	Section_identifier	Grade
----------------	--------------------	-------

**Figure 2.1**

Schema diagram for the database in Figure 1.2.

# Example of a database state

## COURSE

Course_name	Course_number	Credit_hours	Department
Intro to Computer Science	CS1310	4	CS
Data Structures	CS3320	4	CS
Discrete Mathematics	MATH2410	3	MATH
Database	CS3380	3	CS

## SECTION

Section_identifier	Course_number	Semester	Year	Instructor
85	MATH2410	Fall	04	King
92	CS1310	Fall	04	Anderson
102	CS3320	Spring	05	Knuth
112	MATH2410	Fall	05	Chang
119	CS1310	Fall	05	Anderson
135	CS3380	Fall	05	Stone

## GRADE\_REPORT

Student_number	Section_identifier	Grade
17	112	B
17	119	C
8	85	A
8	92	A
8	102	B
8	135	A

## PREREQUISITE

Course_number	Prerequisite_number
CS3380	CS3320
CS3380	MATH2410
CS3320	CS1310

**Figure 1.2**

A database that stores student and course information.

# Three-Schema Architecture

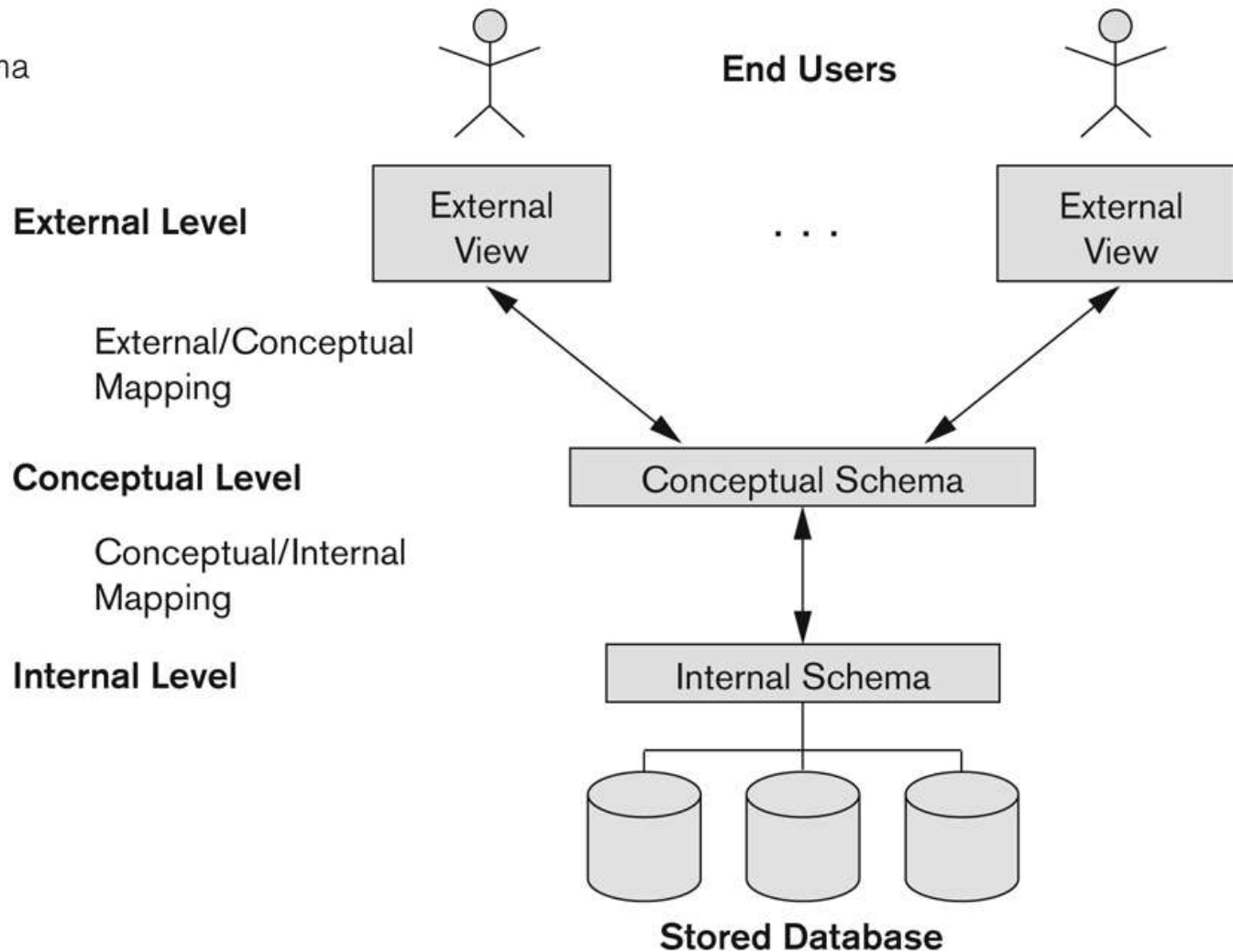
- Proposed to support DBMS characteristics of:
  - **Program-data independence.**
  - Support of **multiple views** of the data.
- Not explicitly used in commercial DBMS products, but has been useful in explaining database system organization
- Defines DBMS schemas at **three** levels:
  - **Internal schema** at the internal level to describe physical storage structures and access paths (e.g indexes).
    - Typically uses a **physical** data model.
  - **Conceptual schema** at the conceptual level to describe the structure and constraints for the whole database for a community of users.
    - Uses a **conceptual** or an **implementation** data model.
  - **External schemas** at the external level to describe the various user views.
    - Usually uses the same data model as the conceptual schema



# The three-schema architecture

**Figure 2.2**

The three-schema architecture.



# Three-Schema Architecture

- Mappings among schema levels are needed to transform requests and data.
  - Programs refer to an external schema, and are mapped by the DBMS to the internal schema for execution.
  - Data extracted from the internal DBMS level is reformatted to match the user's external view (e.g. formatting the results of an SQL query for display in a Web page)

# Data Independence

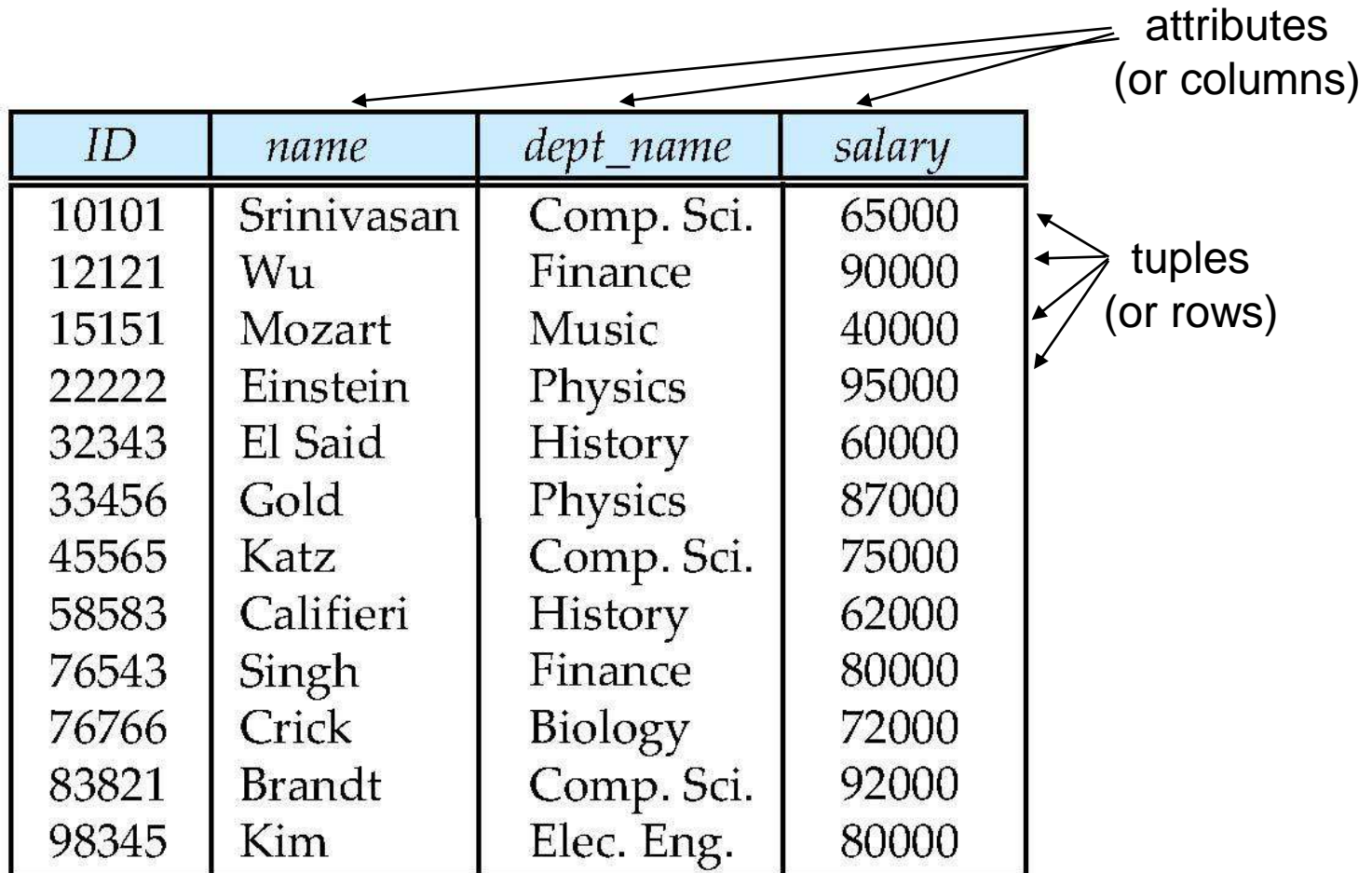
- **Logical Data Independence:**

- The capacity to change the conceptual schema without having to change the external schemas and their associated application programs.

- **Physical Data Independence:**

- The capacity to change the internal schema without having to change the conceptual schema.
  - For example, the internal schema may be changed when certain file structures are reorganized or new indexes are created to improve database performance
- When a schema at a lower level is changed, only the **mappings** between this schema and higher-level schemas need to be changed in a DBMS that fully supports data independence.
  - The higher-level schemas themselves are **unchanged**.
    - Hence, the application programs need not be changed since they refer to the external schemas.

# Example of a Relation



The diagram shows a table representing a relation. The table has four columns: *ID*, *name*, *dept\_name*, and *salary*. The first row of data is highlighted. Annotations with arrows point to the columns, labeled 'attributes (or columns)', and to the rows, labeled 'tuples (or rows)'.

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
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

# Attribute Types

- The set of allowed values for each attribute is called the **domain** of the attribute
- Attribute values are (normally) required to be **atomic**; that is, indivisible
- 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

# Relation Schema and Instance

- $A_1, A_2, \dots, A_n$  are *attributes*
- $R = (A_1, A_2, \dots, A_n)$  is a *relation schema*

Example:

*instructor* = (*ID*, *name*, *dept\_name*, *salary*)

- Formally, given sets  $D_1, D_2, \dots, D_n$  a **relation**  $r$  is a subset of

$$D_1 \times D_2 \times \dots \times D_n$$

Thus, a relation is a set of  $n$ -tuples  $(a_1, a_2, \dots, a_n)$  where each  $a_i \in D_i$

- The current values (**relation instance**) of a relation are specified by a table
- An element  $t$  of  $r$  is a *tuple*, represented by a *row* in a table

# Relations are Unordered

- Order of tuples is irrelevant (tuples may be stored in an arbitrary order)
- Example: *instructor* relation with unordered tuples

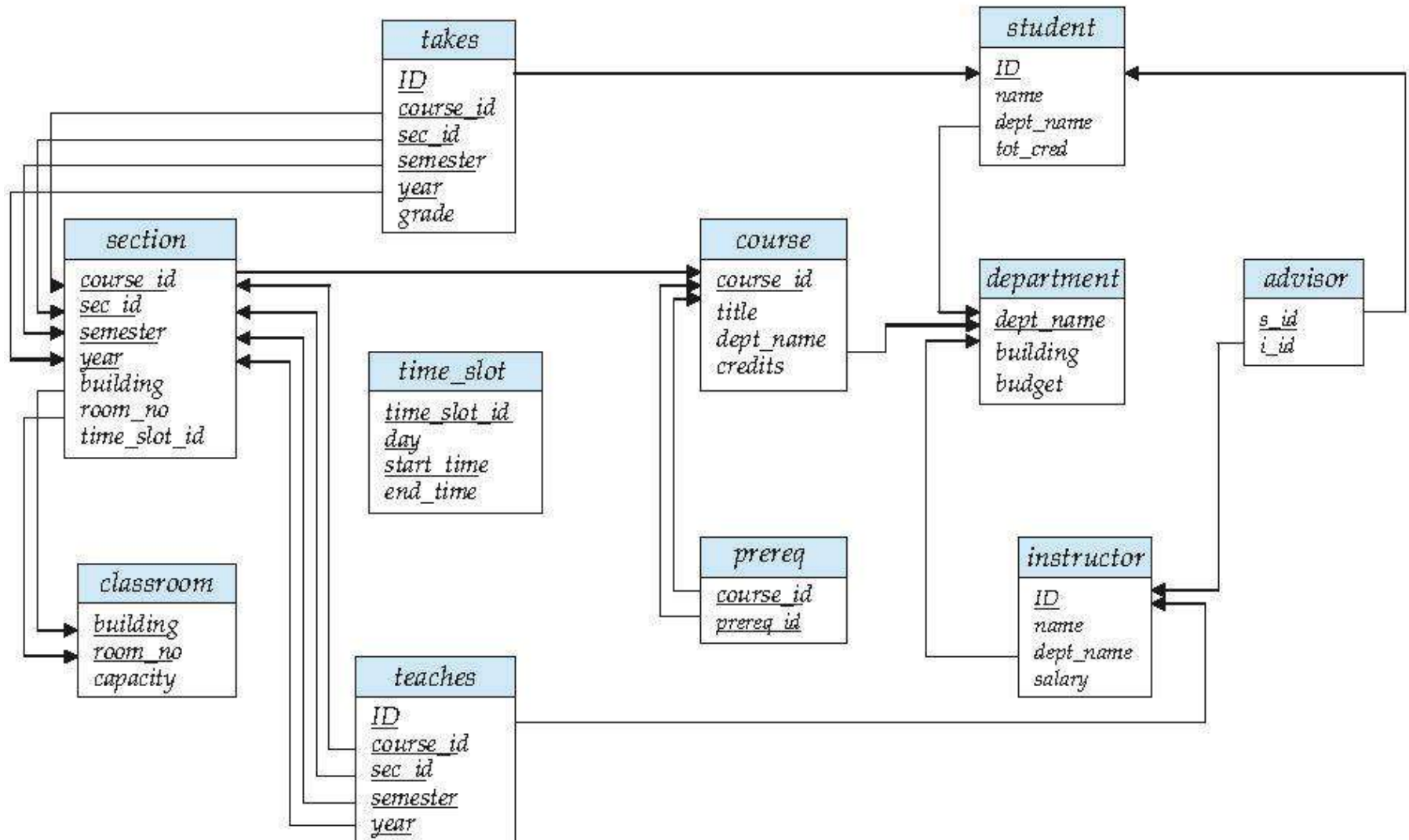
<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
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83821	Brandt	Comp. Sci.	92000
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# Keys

- 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?
- **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*



# Schema Diagram for University Database



# Relational Query Languages

- Procedural vs .non-procedural, or declarative
- “Pure” languages:
  - Relational algebra
  - Tuple relational calculus
  - Domain relational calculus
- The above 3 pure languages are equivalent in computing power
- We will concentrate in this chapter on relational algebra
  - Not turning-machine equivalent
  - consists of 6 basic operations

# Select Operation – selection of rows (tuples)

□ Relation r

A	B	C	D
$\alpha$	$\alpha$	1	7
$\alpha$	$\beta$	5	7
$\beta$	$\beta$	12	3
$\beta$	$\beta$	23	10

■  $\sigma_{A=B \wedge D > 5}(r)$

A	B	C	D
$\alpha$	$\alpha$	1	7
$\beta$	$\beta$	23	10

## Project Operation – selection of columns (Attributes)

- Relation  $r$ :

$A$	$B$	$C$
$\alpha$	10	1
$\alpha$	20	1
$\beta$	30	1
$\beta$	40	2

- $\Pi_{A,C}(r)$

$A$	$C$
$\alpha$	1
$\alpha$	1
$\beta$	1
$\beta$	2

 $=$ 

$A$	$C$
$\alpha$	1
$\beta$	1
$\beta$	2

# Union of two relations

- Relations  $r, s$ :

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1

$r$

$A$	$B$
$\alpha$	2
$\beta$	3

$s$

□  $r \cup s$ :

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1
$\beta$	3

# Set difference of two relations

- Relations  $r, s$ :

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1

$r$

$A$	$B$
$\alpha$	2
$\beta$	3

$s$

□  $r - s$ :

$A$	$B$
$\alpha$	1
$\beta$	1

# Set intersection of two relations

- Relation  $r, s$ :

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1

$r$

$A$	$B$
$\alpha$	2
$\beta$	3

$s$

- $r \cap s$

$A$	$B$
$\alpha$	2

Note:  $r \cap s = r - (r - s)$

# joining two relations -- Cartesian-product

□ Relations  $r, s$ :

$A$	$B$
$\alpha$	1
$\beta$	2

$r$

$C$	$D$	$E$
$\alpha$	10	a
$\beta$	10	a
$\beta$	20	b
$\gamma$	10	b

$s$

□  $r \times s$ :

$A$	$B$	$C$	$D$	$E$
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b



# Cartesian-product – naming issue

□ Relations  $r, s$ :

$A$	$B$
$\alpha$	1
$\beta$	2

$r$

$B$	$D$	$E$
$\alpha$	10	a
$\beta$	10	a
$\beta$	20	b
$\gamma$	10	b

$s$

□  $r \times s$ :

$A$	$r.B$	$s.B$	$D$	$E$
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

# Renaming a Table

- Allows us to refer to a relation, (say  $E$ ) by more than one name.

$$\rho_x(E)$$

returns the expression  $E$  under the name  $X$

- Relations  $r$

$A$	$B$
$\alpha$	1
$\beta$	2

$r$

- $r \times \rho_s(r)$

$r.A$	$r.B$	$s.A$	$s.B$
$\alpha$	1	$\alpha$	1
$\alpha$	1	$\beta$	2
$\beta$	2	$\alpha$	1
$\beta$	2	$\beta$	2

# Composition of Operations

- Can build expressions using multiple operations
- Example:  $\sigma_{A=C}(r \times s)$

- $r \times s$

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

- $\sigma_{A=C}(r \times s)$

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b

# Joining two relations – Natural Join

- Let  $r$  and  $s$  be relations on schemas  $R$  and  $S$  respectively.

Then, the “natural join” of relations  $R$  and  $S$  is a relation on schema  $R \cup S$  obtained as follows:

- Consider each pair of tuples  $t_r$  from  $r$  and  $t_s$  from  $s$ .
- If  $t_r$  and  $t_s$  have the same value on each of the attributes in  $R \cap S$ , add a tuple  $t$  to the result, where
  - $t$  has the same value as  $t_r$  on  $r$
  - $t$  has the same value as  $t_s$  on  $s$

# Natural Join Example

- Relations  $r, s$ :

A	B	C	D
$\alpha$	1	$\alpha$	a
$\beta$	2	$\gamma$	a
$\gamma$	4	$\beta$	b
$\alpha$	1	$\gamma$	a
$\delta$	2	$\beta$	b

$r$

B	D	E
1	a	$\alpha$
3	a	$\beta$
1	a	$\gamma$
2	b	$\delta$
3	b	$\epsilon$

$s$

□ Natural Join

□  $r \bowtie s$

A	B	C	D	E
$\alpha$	1	$\alpha$	a	$\alpha$
$\alpha$	1	$\alpha$	a	$\gamma$
$\alpha$	1	$\gamma$	a	$\alpha$
$\alpha$	1	$\gamma$	a	$\gamma$
$\delta$	2	$\beta$	b	$\delta$

$$\Pi_{A, r.B, C, r.D, E}(\sigma_{r.B=s.B \wedge r.D=s.D}(r \times s))$$

# Notes about Relational Languages

- Each Query input is a table (or set of tables)
- Each query output is a table.
- All data in the output table appears in one of the input tables
- Relational Algebra is not Turing complete
- Can we compute:
  - SUM
  - AVG
  - MAX
  - MIN

# Summary of Relational Algebra Operators

Symbol (Name)	Example of Use
$\sigma$ (Selection)	$\sigma \text{ salary} \geq 85000$ ( <i>instructor</i> )  Return rows of the input relation that satisfy the predicate.
$\Pi$ (Projection)	$\Pi ID, salary$ ( <i>instructor</i> )  Output specified attributes from all rows of the input relation. Remove duplicate tuples from the output.
$\times$ (Cartesian Product)	$instructor \times department$  Output pairs of rows from the two input relations that have the same value on all attributes that have the same name.
$\cup$ (Union)	$\Pi name (instructor) \cup \Pi name (student)$  Output the union of tuples from the <i>two</i> input relations.
$-$ (Set Difference)	$\Pi name (instructor) - \Pi name (student)$  Output the set difference of tuples from the two input relations.
$\bowtie$ (Natural Join)	$instructor \bowtie department$  Output pairs of rows from the two input relations that have the same value on all attributes that have the same name.

# DBMS Languages

- Data Definition Language (DDL)
- Data Manipulation Language (DML)
  - High-Level or Non-procedural Languages: These include the relational language SQL
    - May be used in a standalone way or may be embedded in a programming language
  - Low Level or Procedural Languages:
    - These must be embedded in a programming language



# DBMS Interfaces

- Stand-alone query language interfaces
  - Example: Entering SQL queries at the DBMS interactive SQL interface (e.g. SQL\*Plus in ORACLE)
- Programmer interfaces for embedding DML in programming languages
- User-friendly interfaces
  - Menu-based, forms-based, graphics-based, etc.
- Mobile Interfaces: interfaces allowing users to perform transactions using mobile apps

# DBMS Programming Language Interfaces

- Programmer interfaces for embedding DML in a programming languages:
  - **Embedded Approach:** e.g. embedded SQL (for C, C++, etc.), SQLJ (for Java)
  - **Procedure Call Approach:** e.g. JDBC for Java, ODBC (Open Database Connectivity) for other programming languages as API's (application programming interfaces)
  - **Database Programming Language Approach:** e.g. ORACLE has PL/SQL, a programming language based on SQL; language incorporates SQL and its data types as integral components
  - **Scripting Languages:** PHP (client-side scripting) and Python (server-side scripting) are used to write database programs.

# User-Friendly DBMS Interfaces

- Menu-based (Web-based), popular for browsing on the web
- Forms-based, designed for naïve users used to filling in entries on a form
- Graphics-based
  - Point and Click, Drag and Drop, etc.
  - Specifying a query on a schema diagram
- Natural language: requests in written English
- Combinations of the above:
  - For example, both menus and forms used extensively in Web database interfaces

# Other DBMS Interfaces

- Natural language: free text as a query
- Speech : Input query and Output response
- Web Browser with keyword search
- Parametric interfaces, e.g., bank tellers using function keys.
- Interfaces for the DBA:
  - Creating user accounts, granting authorizations
  - Setting system parameters
  - Changing schemas or access paths

# Database System Utilities

- To perform certain functions such as:
  - Loading data stored in files into a database. Includes data conversion tools.
  - Backing up the database periodically on tape.
  - Reorganizing database file structures.
  - Performance monitoring utilities.
  - Report generation utilities.
  - Other functions, such as sorting, user monitoring, data compression, etc.

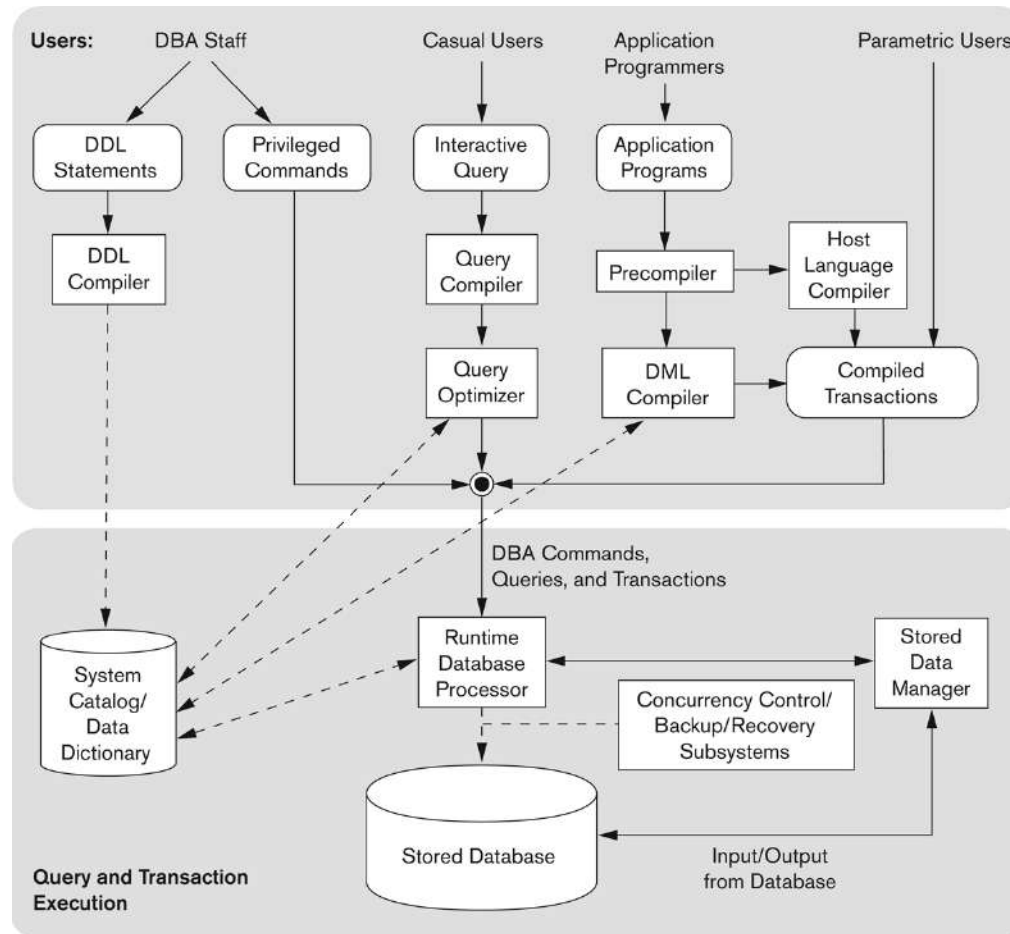
# Other Tools

- Data dictionary / repository:
  - Used to store schema descriptions and other information such as design decisions, application program descriptions, user information, usage standards, etc.
  - **Active data dictionary** is accessed by DBMS software and users/DBA.
  - **Passive data dictionary** is accessed by users/DBA only.

# Other Tools

- Application Development Environments and CASE (computer-aided software engineering) tools:
- Examples:
  - PowerBuilder (Sybase)
  - JBuilder (Borland)
  - JDeveloper 10G (Oracle)

# Typical DBMS Component Modules



**Figure 2.3**

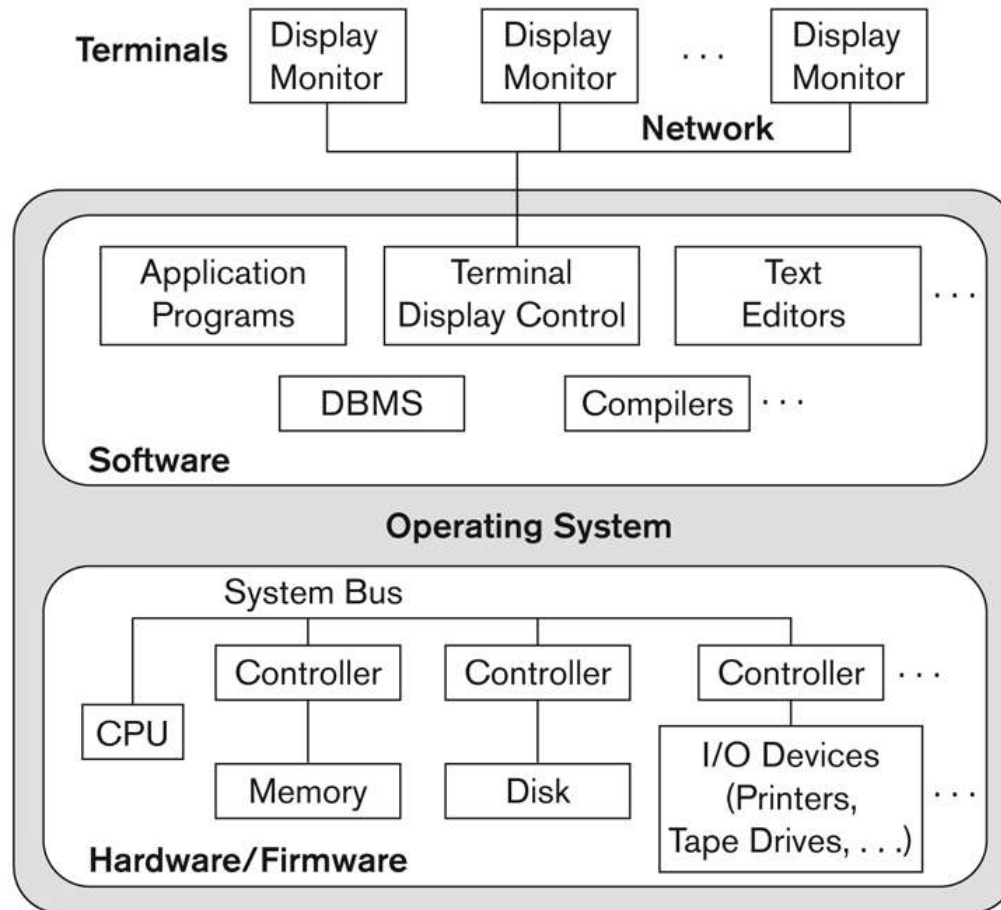
Component modules of a DBMS and their interactions.



# Centralized and Client-Server DBMS Architectures

- Centralized DBMS:
  - Combines everything into single system including- DBMS software, hardware, application programs, and user interface processing software.
  - User can still connect through a remote terminal – however, all processing is done at centralized site.

# A Physical Centralized Architecture



**Figure 2.4**  
A physical centralized architecture.

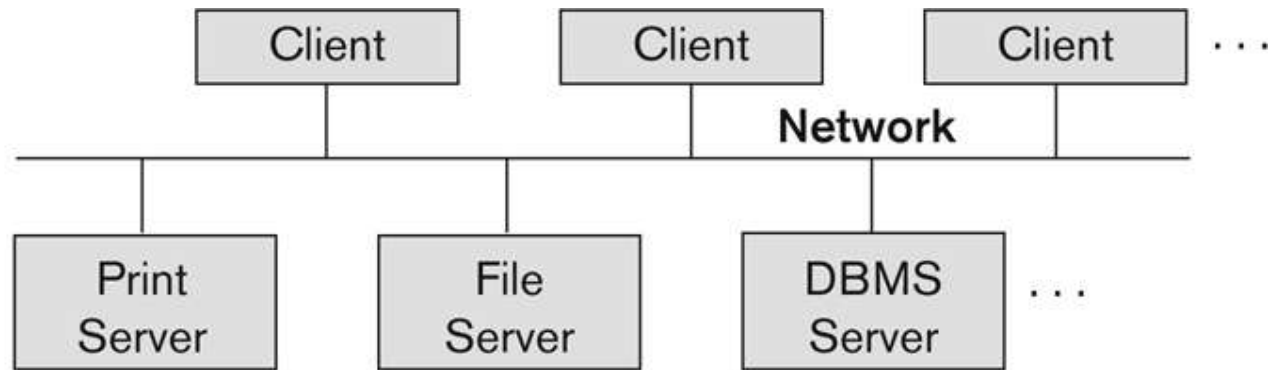
# Basic 2-tier Client-Server Architectures

- Specialized Servers with Specialized functions
  - Print server
  - File server
  - DBMS server
  - Web server
  - Email server
- Clients can access the specialized servers as needed

# Logical two-tier client server architecture

**Figure 2.5**

Logical two-tier  
client/server  
architecture.



# Clients

- Provide appropriate interfaces through a client software module to access and utilize the various server resources.
- Clients may be diskless machines or PCs or Workstations with disks with only the client software installed.
- Connected to the servers via some form of a network.
  - (LAN: local area network, wireless network, etc.)

# DBMS Server

- Provides database query and transaction services to the clients
- Relational DBMS servers are often called SQL servers, query servers, or transaction servers
- Applications running on clients utilize an Application Program Interface (**API**) to access server databases via standard interface such as:
  - ODBC: Open Database Connectivity standard
  - JDBC: for Java programming access

# Two Tier Client-Server Architecture

- Client and server must install appropriate client module and server module software for ODBC or JDBC
- A client program may connect to several DBMSs, sometimes called the data sources.
- In general, data sources can be files or other non-DBMS software that manages data.

# Three Tier Client-Server Architecture

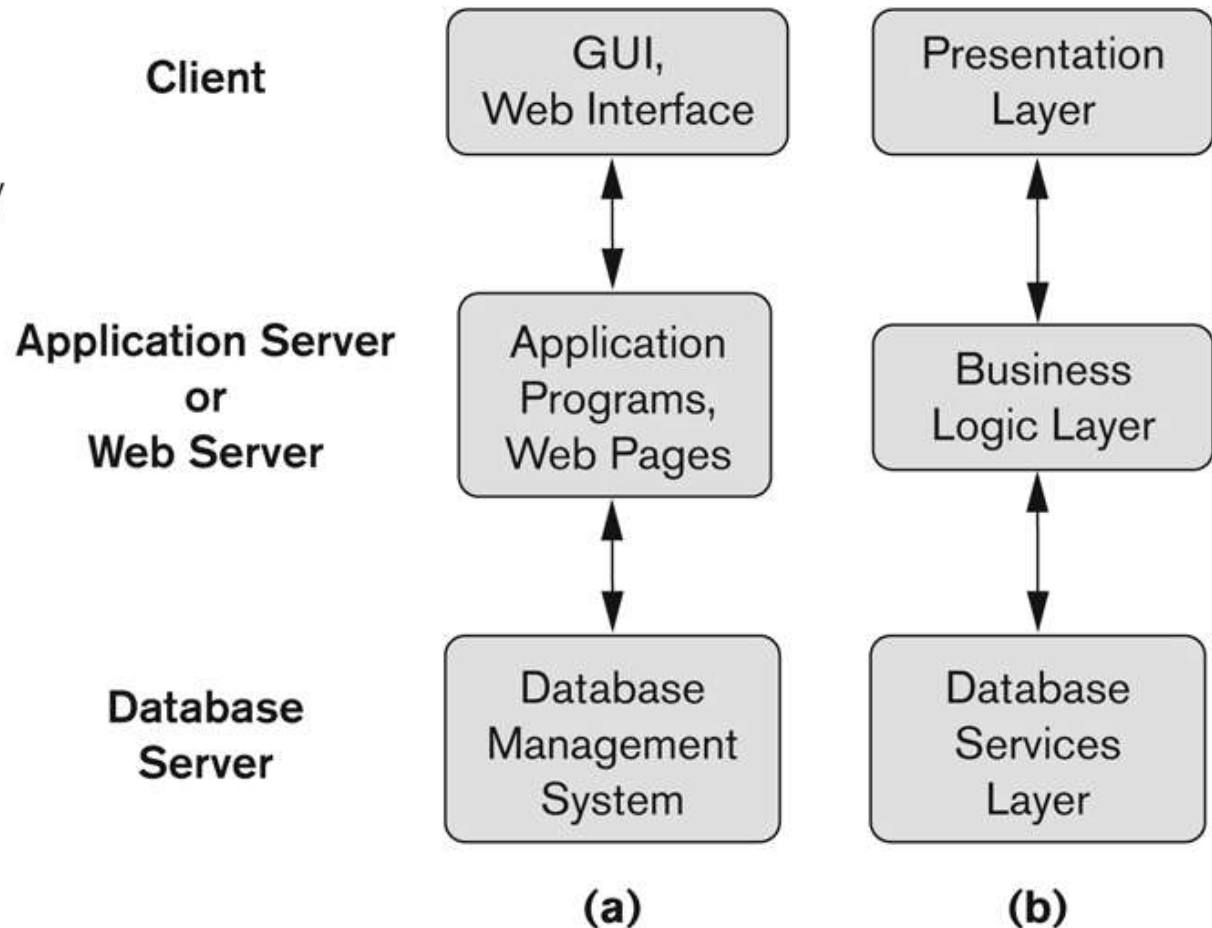
- Common for Web applications
- Intermediate Layer called Application Server or Web Server:
  - Stores the web connectivity software and the business logic part of the application used to access the corresponding data from the database server
  - Acts like a conduit for sending partially processed data between the database server and the client.
- Three-tier Architecture Can Enhance Security:
  - Database server only accessible via middle tier
  - Clients cannot directly access database server
  - Clients contain user interfaces and Web browsers
  - The client is typically a PC or a mobile device connected to the Web



# Three-tier client-server architecture

**Figure 2.7**

Logical three-tier client/server architecture, with a couple of commonly used nomenclatures.



# Classification of DBMSs

- Based on the data model used
  - Legacy: Network, Hierarchical.
  - Currently Used: Relational, Object-oriented, Object-relational
  - Recent Technologies: Key-value storage systems, NOSQL systems: document based, column-based, graph-based and key-value based. Native XML DBMSs.
- Other classifications
  - Single-user (typically used with personal computers) vs. multi-user (most DBMSs).
  - Centralized (uses a single computer with one database) vs. distributed (multiple computers, multiple DBs)

# Variations of Distributed DBMSs (DDBMSs)

- Homogeneous DDBMS
- Heterogeneous DDBMS
- Federated or Multidatabase Systems
  - Participating Databases are loosely coupled with high degree of autonomy.
- Distributed Database Systems have now come to be known as client-server based database systems because:
  - They do not support a totally distributed environment, but rather a set of database servers supporting a set of clients.

# Cost considerations for DBMSs

- Cost Range: from free open-source systems to configurations costing millions of dollars
- Examples of free relational DBMSs: MySQL, PostgreSQL, others
- Commercial DBMS offer additional specialized modules, e.g. time-series module, spatial data module, document module, XML module
  - These offer additional specialized functionality when purchased separately
  - Sometimes called cartridges (e.g., in Oracle) or blades
- Different licensing options: site license, maximum number of concurrent users (seat license), single user, etc.

# Other Considerations

- Type of access paths within database system
  - E.g.- inverted indexing based (ADABAS is one such system). Fully indexed databases provide access by any keyword (used in search engines)
- General Purpose vs. Special Purpose
  - E.g.- Airline Reservation systems or many others-reservation systems for hotel/car etc. Are special purpose OLTP (Online Transaction Processing Systems)

# Domain Types in SQL

- **char(*n*)**. Fixed length character string, with user-specified length *n*.
- **varchar(*n*)**. Variable length character strings, with user-specified maximum length *n*.
- **int**. Integer (a finite subset of the integers that is machine-dependent).
- **smallint**. Small integer (a machine-dependent subset of the integer domain type).
- **numeric(*p*,*d*)**. Fixed point number, with user-specified precision of *p* digits, with *d* digits to the right of decimal point. (ex., **numeric(3,1)**, allows 44.5 to be stored exactly, but not 444.5 or 0.32)
- **real, double precision**. Floating point and double-precision floating point numbers, with machine-dependent precision.
- **float(*n*)**. Floating point number, with user-specified precision of at least *n* digits.

# Create Table Construct

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

```
create table  $r$  ( $A_1 D_1, A_2 D_2, \dots, A_n D_n,$   
                (integrity-constraint1),  
                ...,  
                (integrity-constraintk))
```

- $r$  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  $A_i$
- Example:

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

# Integrity Constraints in Create Table

- **not null**
- **primary key** ( $A_1, \dots, A_n$ )
- **foreign key** ( $A_m, \dots, A_n$ ) **references**  $r$

*Example:*

```
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);
```

**primary key** declaration on an attribute automatically ensures **not null**



# And a Few More Relation Definitions

- **create table** *student* (  
    *ID*                **varchar**(5),  
    *name*            **varchar**(20) not null,  
    *dept\_name*       **varchar**(20),  
    *tot\_cred*        **numeric**(3,0),  
    **primary key** (*ID*),  
    **foreign key** (*dept\_name*) **references** *department*);
- **create table** *takes* (  
    *ID*                **varchar**(5),  
    *course\_id*       **varchar**(8),  
    *sec\_id*           **varchar**(8),  
    *semester*        **varchar**(6),  
    *year*             **numeric**(4,0),  
    *grade*            **varchar**(2),  
    **primary key** (*ID*, *course\_id*, *sec\_id*, *semester*, *year*) ,  
    **foreign key** (*ID*) **references** *student*,  
    **foreign key** (*course\_id*, *sec\_id*, *semester*, *year*) **references**  
    *section*);
  - Note: *sec\_id* can be dropped from primary key above, to ensure a student cannot be registered for two sections of the same course in the same semester

## And more still

- **create table** *course* (  
    *course\_id*      **varchar**(8),  
    *title*          **varchar**(50),  
    *dept\_name*     **varchar**(20),  
    *credits*        **numeric**(2,0),  
    **primary key** (*course\_id*),  
    **foreign key** (*dept\_name*) **references** *department*);

# Updates to tables

- **Insert**

- **insert into** *instructor* **values** ('10211', 'Smith', 'Biology', 66000);

- **Delete**

- Remove all tuples from the *student* relation
    - **delete from** *student*

- **Drop Table**

- **drop table** *r*

- **Alter**

- **alter table** *r* **add** *A D*
    - where *A* is the name of the attribute to be added to relation *r* and *D* is the domain of *A*.
    - All exiting tuples in the relation are assigned *null* as the value for the new attribute.
  - **alter table** *r* **drop** *A*
    - where *A* is the name of an attribute of relation *r*
    - Dropping of attributes not supported by many databases.

# Basic Query Structure

- A typical SQL query has the form:

**select**  $A_1, A_2, \dots, A_n$   
**from**  $r_1, r_2, \dots, r_m$   
**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.

# The select Clause

- 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 (i.e., you may use upper- or lower-case letters.)
  - E.g., *Name*  $\equiv$  *NAME*  $\equiv$  *name*
  - Some people use upper case wherever we use bold font.

# The select Clause (Cont.)

- SQL allows duplicates in relations as well as in query results.
- To force the elimination of duplicates, insert the keyword **distinct** after select.
- Find the department names of all instructors, and remove duplicates

```
select distinct dept_name  
from instructor
```

- The keyword **all** specifies that duplicates should not be removed.

```
select all dept_name  
from instructor
```

# The select Clause (Cont.)

- An asterisk in the select clause denotes “all attributes”

**select \***  
**from** *instructor*

- An attribute can be a literal with no **from** clause

**select** '437'

- Results is a table with one column and a single row with value “437”
- Can give the column a name using:

**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”

# The select Clause (Cont.)

- 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 “*salary/12*” using the **as** clause:

```
select ID, name, salary/12 as monthly_salary
```



# The where Clause

- The **where** clause specifies conditions that the result must satisfy
  - Corresponds to the selection predicate of the relational algebra.
- To find all instructors in Comp. Sci. dept

```
select name  
from instructor  
where dept_name = 'Comp. Sci.'
```

- Comparison results can be combined using the logical connectives **and**, **or**, and **not**
  - To find all instructors in Comp. Sci. dept with salary > 80000

```
select name  
from instructor  
where dept_name = 'Comp. Sci.' and salary > 80000
```

- Comparisons can be applied to results of arithmetic expressions.

# The from Clause

- The **from** clause lists the relations involved in the query
  - Corresponds to the Cartesian product operation of the relational algebra.

- Find the Cartesian product *instructor X teaches*

**select \***  
**from** *instructor, teaches*

- generates every possible instructor – teaches pair, with all attributes from both relations.
- For common attributes (e.g., *ID*), the attributes in the resulting table are renamed using the relation name (e.g., *instructor.ID*)
- Cartesian product not very useful directly, but useful combined with where-clause condition (selection operation in relational algebra).

# Cartesian Product

*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

*teaches*

ID	course_id	sec_id	semester	year
10101	CS-101	1	Fall	2009
10101	CS-315	1	Spring	2010
10101	CS-347	1	Fall	2009
12121	FIN-201	1	Spring	2010
15151	MU-199	1	Spring	2010
22222	PHY-101	1	Fall	2009

Inst.ID	name	dept_name	salary	teaches.ID	course_id	sec_id	semester	year
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	12121	FIN-201	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	15151	MU-199	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
12121	Wu	Finance	90000	10101	CS-101	1	Fall	2009
12121	Wu	Finance	90000	10101	CS-315	1	Spring	2010
12121	Wu	Finance	90000	10101	CS-347	1	Fall	2009
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2010
12121	Wu	Finance	90000	15151	MU-199	1	Spring	2010
12121	Wu	Finance	90000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

# Examples

- Find the names of all instructors who have taught some course and the 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'*

# The Rename Operation

- The SQL allows renaming relations and attributes using the **as** clause:

*old-name as new-name*

- 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*  $\equiv$  *instructor T*

# Self Join Example

- Relation *emp-super*

<i>person</i>	<i>supervisor</i>
Bob	Alice
Mary	Susan
Alice	David
David	Mary

- Find the supervisor of “Bob”
- Find the supervisor of the supervisor of “Bob”
- Find ALL the supervisors (direct and indirect) of “Bob”

# String Operations

- SQL includes a string-matching operator for comparisons on character strings. The operator **like** uses patterns that are described using two special characters:
  - percent ( % ). The % character matches any substring.
  - underscore ( \_ ). The \_ character matches any character.
- Find the names of all instructors whose name includes the substring “dar”.

```
select name  
from instructor  
where name like '%dar%'
```

- Match the string “100%”

```
like '100 \%' escape '\'
```

in that above we use backslash (\) as the escape character.

# String Operations (Cont.)

- Patterns are case sensitive.
- Pattern matching examples:
  - 'Intro%' matches any string beginning with "Intro".
  - '%Comp%' matches any string containing "Comp" as a substring.
  - '\_\_\_' matches any string of exactly three characters.
  - '\_\_\_%' matches any string of at least three characters.
- SQL supports a variety of string operations such as
  - concatenation (using "||")
  - converting from upper to lower case (and vice versa)
  - finding string length, extracting substrings, etc.



# Ordering the Display of Tuples

- List in alphabetic order the names of all instructors

```
select distinct name  
from instructor  
order by name
```

- We may specify **desc** for descending order or **asc** for ascending order, for each attribute; ascending order is the default.
  - Example: **order by** *name* **desc**
- Can sort on multiple attributes
  - Example: **order by** *dept\_name*, *name*

# Where Clause Predicates

- SQL includes a **between** comparison operator
- Example: Find the names of all instructors with salary between \$90,000 and \$100,000 (that is,  $\geq$  \$90,000 and  $\leq$  \$100,000)
  - **select** *name*  
**from** *instructor*  
**where** *salary* **between** 90000 **and** 100000
- Tuple comparison
  - **select** *name, course\_id*  
**from** *instructor, teaches*  
**where** (*instructor.ID, dept\_name*) = (*teaches.ID, 'Biology'*);

# Duplicates

- In relations with duplicates, SQL can define how many copies of tuples appear in the result.
- **Multiset** versions of some of the relational algebra operators – given multiset relations  $r_1$  and  $r_2$ :
  1.  $\sigma_{\theta}(r_1)$ : If there are  $c_1$  copies of tuple  $t_1$  in  $r_1$ , and  $t_1$  satisfies selections  $\sigma_{\theta}$ , then there are  $c_1$  copies of  $t_1$  in  $\sigma_{\theta}(r_1)$ .
  2.  $\Pi_A(r)$ : For each copy of tuple  $t_1$  in  $r_1$ , there is a copy of tuple  $\Pi_A(t_1)$  in  $\Pi_A(r_1)$  where  $\Pi_A(t_1)$  denotes the projection of the single tuple  $t_1$ .
  3.  $r_1 \times r_2$ : If there are  $c_1$  copies of tuple  $t_1$  in  $r_1$  and  $c_2$  copies of tuple  $t_2$  in  $r_2$ , there are  $c_1 \times c_2$  copies of the tuple  $t_1 \cdot t_2$  in  $r_1 \times r_2$ .

## Duplicates (Cont.)

- Example: Suppose multiset relations  $r_1 (A, B)$  and  $r_2 (C)$  are as follows:

$$r_1 = \{(1, a) (2, a)\} \quad r_2 = \{(2), (3), (3)\}$$

- Then  $\Pi_B(r_1)$  would be  $\{(a), (a)\}$ , while  $\Pi_B(r_1) \times r_2$  would be  $\{(a, 2), (a, 2), (a, 3), (a, 3), (a, 3), (a, 3)\}$
- SQL duplicate semantics:

**select**  $A_1, A_2, \dots, A_n$   
**from**  $r_1, r_2, \dots, r_m$   
**where**  $P$

is equivalent to the *multiset* version of the expression:

$$\Pi_{A_1, A_2, \dots, A_n} (\sigma_P (r_1 \times r_2 \times \dots \times r_m))$$

# Set Operations

- Find courses that ran in Fall 2009 or in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)  
union  
(select course_id from section where sem = 'Spring' and year = 2010)
```

- Find courses that ran in Fall 2009 and in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)  
intersect  
(select course_id from section where sem = 'Spring' and year = 2010)
```

- Find courses that ran in Fall 2009 but not in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)  
except  
(select course_id from section where sem = 'Spring' and year = 2010)
```

# Set Operations (Cont.)

- Find the salaries of all instructors that are less than the largest salary.
  - **select distinct** *T.salary*  
**from** *instructor as T, instructor as S*  
**where** *T.salary < S.salary*
- Find all the salaries of all instructors
  - **select distinct** *salary*  
**from** *instructor*
- Find the largest salary of all instructors.
  - **(select** “second query” )  
**except**  
**(select** “first query”)

# Set Operations (Cont.)

- Set operations **union**, **intersect**, and **except**
  - Each of the above operations automatically eliminates duplicates
- To retain all duplicates use the corresponding multiset versions **union all**, **intersect all** and **except all**.
- Suppose a tuple occurs  $m$  times in  $r$  and  $n$  times in  $s$ , then, it occurs:
  - $m + n$  times in  $r$  **union all**  $s$
  - $\min(m, n)$  times in  $r$  **intersect all**  $s$
  - $\max(0, m - n)$  times in  $r$  **except all**  $s$

# Null Values

- It is possible for tuples to have a null value, denoted by *null*, for some of their attributes
- *null* signifies an unknown value or that a value does not exist.
- The result of any arithmetic expression involving *null* is *null*
  - Example:  $5 + \text{null}$  returns null
- The predicate **is null** can be used to check for null values.
  - Example: Find all instructors whose salary is null.

```
select name  
from instructor  
where salary is null
```



# Null Values and Three Valued Logic

- Three values – *true, false, unknown*
- Any comparison with *null* returns *unknown*
  - Example:  $5 < null$  or  $null <> null$  or  $null = null$
- Three-valued logic using the value *unknown*:
  - OR:  $(unknown \text{ or } true) = true$ ,  
 $(unknown \text{ or } false) = unknown$   
 $(unknown \text{ or } unknown) = unknown$
  - AND:  $(true \text{ and } unknown) = unknown$ ,  
 $(false \text{ and } unknown) = false$ ,  
 $(unknown \text{ and } unknown) = unknown$
  - NOT:  $(\text{not } unknown) = unknown$
  - “*P* is **unknown**” evaluates to true if predicate *P* evaluates to *unknown*
- Result of **where** clause predicate is treated as *false* if it evaluates to *unknown*

# Aggregate Functions

- These functions operate on the multiset of values of a column of a relation, and return a value

**avg:** average value

**min:** minimum value

**max:** maximum value

**sum:** sum of values

**count:** number of values

# Aggregate Functions (Cont.)

- 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 2010 semester
  - **select count** (**distinct** *ID*)  
**from** *teaches*  
**where** *semester* = 'Spring' **and** *year* = 2010;
- Find the number of tuples in the *course* relation
  - **select count** (\*)  
**from** *course*;

# Aggregate Functions – Group By

- Find the average salary of instructors in each department
  - select** *dept\_name*, **avg** (*salary*) **as** *avg\_salary*  
**from** *instructor*  
**group by** *dept\_name*;

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
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

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

# Aggregation (Cont.)

- Attributes in **select** clause outside of aggregate functions must appear in **group by** list
  - */\* erroneous query \*/*  
**select** *dept\_name, ID, avg (salary)*  
**from** *instructor*  
**group by** *dept\_name;*

# Aggregate Functions – Having Clause

- Find the names and average salaries of all departments whose average salary is greater than 42000

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

Note: predicates in the **having** clause are applied after the formation of groups whereas predicates in the **where** clause are applied before forming groups

# Null Values and Aggregates

- Total all salaries

```
select sum (salary )  
from instructor
```

- Above statement ignores null amounts
- Result is *null* if there is no non-null amount
- All aggregate operations except **count(\*)** ignore tuples with null values on the aggregated attributes
- What if collection has only null values?
  - count returns 0
  - all other aggregates return null

# Nested Subqueries

- SQL provides a mechanism for the nesting of subqueries. A **subquery** is a **select-from-where** expression that is nested within another query.
- The nesting can be done in the following SQL query

```
select  $A_1, A_2, \dots, A_n$   
from  $r_1, r_2, \dots, r_m$   
where  $P$ 
```

as follows:

- $A_i$  can be replaced by a subquery that generates a single value.
- $r_i$  can be replaced by any valid subquery
- $P$  can be replaced with an expression of the form:

$B <\text{operation}> (\text{subquery})$

Where  $B$  is an attribute and  $<\text{operation}>$  to be defined later.



# Subqueries in the Where Clause

# Subqueries in the Where Clause

- A common use of subqueries is to perform tests:
  - For set membership
  - For set comparisons
  - For set cardinality.

# Set Membership

- Find courses offered in Fall 2009 and in Spring 2010

```
select distinct course_id  
from section  
where semester = 'Fall' and year= 2009 and  
       course_id in (select course_id  
                        from section  
                        where semester = 'Spring' and year= 2010);
```

- Find courses offered in Fall 2009 but not in Spring 2010

```
select distinct course_id  
from section  
where semester = 'Fall' and year= 2009 and  
       course_id not in (select course_id  
                            from section  
                            where semester = 'Spring' and year= 2010);
```

# Set Membership (Cont.)

- Find the total number of (distinct) students who have taken course sections taught by the instructor with *ID* 10101

```
select count (distinct ID)  
from takes  
where (course_id, sec_id, semester, year) in  
      (select course_id, sec_id, semester, year  
       from teaches  
       where teaches.ID= 10101);
```

- Note: Above query can be written in a much simpler manner.  
The formulation above is simply to illustrate SQL features.

# Set Comparison – “some” Clause

- Find names of instructors with salary greater than that of some (at least one) instructor in the Biology department.

```
select distinct T.name  
from instructor as T, instructor as S  
where T.salary > S.salary and S.dept name = 'Biology';
```

- Same query using > **some** clause

```
select name  
from instructor  
where salary > some (select salary  
                        from instructor  
                        where dept name = 'Biology');
```

# Definition of “some” Clause

- $F <\text{comp}> \text{some } r \Leftrightarrow \exists t \in r \text{ such that } (F <\text{comp}> t)$   
Where  $<\text{comp}>$  can be:  $<, \leq, >, =, \neq$

$$(5 < \text{some } \begin{array}{|c|} \hline 0 \\ \hline 5 \\ \hline 6 \\ \hline \end{array}) = \text{true}$$

(read: 5 < some tuple in the relation)

$$(5 < \text{some } \begin{array}{|c|} \hline 0 \\ \hline 5 \\ \hline \end{array}) = \text{false}$$

$$(5 = \text{some } \begin{array}{|c|} \hline 0 \\ \hline 5 \\ \hline \end{array}) = \text{true}$$

$$(5 \neq \text{some } \begin{array}{|c|} \hline 0 \\ \hline 5 \\ \hline \end{array}) = \text{true (since } 0 \neq 5)$$

$(= \text{some}) \equiv \text{in}$

However,  $(\neq \text{some}) \not\equiv \text{not in}$

# Set Comparison – “all” Clause

- Find the names of all instructors whose salary is greater than the salary of all instructors in the Biology department.

```
select name
from instructor
where salary > all (select salary
                      from instructor
                      where dept name = 'Biology');
```

# Definition of “all” Clause

- $F <\text{comp}> \mathbf{all} \ r \Leftrightarrow \forall t \in r \ (F <\text{comp}> t)$

$$(5 < \mathbf{all} \begin{array}{|c|} \hline 0 \\ \hline 5 \\ \hline 6 \\ \hline \end{array}) = \text{false}$$

$$(5 < \mathbf{all} \begin{array}{|c|} \hline 6 \\ \hline 10 \\ \hline \end{array}) = \text{true}$$

$$(5 = \mathbf{all} \begin{array}{|c|} \hline 4 \\ \hline 5 \\ \hline \end{array}) = \text{false}$$

$$(5 \neq \mathbf{all} \begin{array}{|c|} \hline 4 \\ \hline 6 \\ \hline \end{array}) = \text{true (since } 5 \neq 4 \text{ and } 5 \neq 6)$$

$(\neq \mathbf{all}) \equiv \mathbf{not\ in}$

However,  $(= \mathbf{all}) \not\equiv \mathbf{in}$



# Test for Empty Relations

- The **exists** construct returns the value **true** if the argument subquery is nonempty.
- **exists**  $r \Leftrightarrow r \neq \emptyset$
- **not exists**  $r \Leftrightarrow r = \emptyset$

# Use of “exists” Clause

- Yet another way of specifying the query “Find all courses taught in both the Fall 2009 semester and in the Spring 2010 semester”

```
select course_id
from section as S
where semester = 'Fall' and year = 2009 and
      exists (select *
              from section as T
              where semester = 'Spring' and year = 2010
                  and S.course_id = T.course_id);
```

- **Correlation name** – variable *S* in the outer query
- **Correlated subquery** – the inner query

# Use of “not exists” Clause

- Find all students who have taken all courses offered in the Biology department.

```
select distinct S.ID, S.name
from student as S
where not exists ( (select course_id
                    from course
                    where dept_name = 'Biology')
except
    (select T.course_id
     from takes as T
     where S.ID = T.ID));
```

- First nested query lists all courses offered in Biology
- Second nested query lists all courses a particular student took

□ Note that  $X - Y = \emptyset \Leftrightarrow X \subseteq Y$

□ *Note:* Cannot write this query using = **all** and its variants

# Test for Absence of Duplicate Tuples

- The **unique** construct tests whether a subquery has any duplicate tuples in its result.
- The **unique** construct evaluates to “true” if a given subquery contains no duplicates .
- Find all courses that were offered at most once in 2009

```
select T.course_id
from course as T
where unique (select R.course_id
                  from section as R
                  where T.course_id = R.course_id
                      and R.year = 2009);
```

# Subqueries in the Form Clause

# Subqueries in the Form Clause

- SQL allows a subquery expression to be used in the **from** clause
- Find the average instructors' salaries of those departments where the average salary is greater than \$42,000."

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

- Note that we do not need to use the **having** clause
- Another way to write above query

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

# With Clause

- The **with** clause provides a way of defining a temporary relation whose definition is available only to the query in which the **with** clause occurs.
- Find all departments with the maximum budget

```
with max_budget (value) as  
    (select max(budget)  
     from department)  
select department.name  
from department, max_budget  
where department.budget = max_budget.value;
```

# Complex Queries using With Clause

- Find all departments where the total salary is greater than the average of the total salary at all departments

```
with dept_total (dept_name, value) as  
    (select dept_name, sum(salary)  
     from instructor  
     group by dept_name),  
dept_total_avg(value) as  
    (select avg(value)  
     from dept_total)  
select dept_name  
from dept_total, dept_total_avg  
where dept_total.value > dept_total_avg.value;
```



# Subqueries in the Select Clause

# Scalar Subquery

- Scalar subquery is one which is used where a single value is expected
- List all departments along with the number of instructors in each department

```
select dept_name,  
      (select count(*)  
       from instructor  
       where department.dept_name = instructor.dept_name)  
      as num_instructors  
from department;
```

- Runtime error if subquery returns more than one result tuple

# Modification of the Database

- Deletion of tuples from a given relation.
- Insertion of new tuples into a given relation
- Updating of values in some tuples in a given relation

# Deletion

- Delete all instructors

**delete from** *instructor*

- Delete all instructors from the Finance department

**delete from** *instructor*  
**where** *dept\_name* = 'Finance';

- Delete all tuples in the *instructor* relation for those instructors associated with a department located in the Watson building.

**delete from** *instructor*  
**where** *dept name* in (**select** *dept name*  
**from** *department*  
**where** *building* = 'Watson');

# Deletion (Cont.)

- Delete all instructors whose salary is less than the average salary of instructors

```
delete from instructor  
where salary < (select avg (salary)  
                  from instructor);
```

- Problem: as we delete tuples from deposit, the average salary changes
- Solution used in SQL:
  1. First, compute **avg** (*salary*) and find all tuples to delete
  2. Next, delete all tuples found above (without recomputing **avg** or retesting the tuples)

# Insertion

- Add a new tuple to *course*

```
insert into course  
values ('CS-437', 'Database Systems', 'Comp. Sci.', 4);
```

- or equivalently

```
insert into course (course_id, title, dept_name, credits)  
values ('CS-437', 'Database Systems', 'Comp. Sci.', 4);
```

- Add a new tuple to *student* with *tot\_creds* set to null

```
insert into student  
values ('3003', 'Green', 'Finance', null);
```

## Insertion (Cont.)

- Add all instructors to the *student* relation with tot\_creds set to 0

```
insert into student  
    select ID, name, dept_name, 0  
from instructor
```

- The **select from where** statement is evaluated fully before any of its results are inserted into the relation.

Otherwise queries like

```
insert into table1 select * from table1  
would cause problem
```

# Updates

- Increase salaries of instructors whose salary is over \$100,000 by 3%, and all others by a 5%
  - Write two **update** statements:  
**update instructor**  
    **set** *salary* = *salary* \* 1.03  
    **where** *salary* > 100000;  
**update instructor**  
    **set** *salary* = *salary* \* 1.05  
    **where** *salary* <= 100000;
- The order is important
- Can be done better using the **case** statement (next slide)



# Case Statement for Conditional Updates

- Same query as before but with case statement

```
update instructor  
  set salary = case  
                                when salary <= 100000 then salary *  
1.05  
                                else salary * 1.03  
                                end
```

# Updates with Scalar Subqueries

- Recompute and update `tot_creds` value for all students

**update** *student S*

**set** *tot\_cred* = (**select** **sum**(*credits*)

**from** *takes, course*

**where** *takes.course\_id* = *course.course\_id* **and**

*S.ID* = *takes.ID* **and**

*takes.grade* <> 'F' **and**

*takes.grade* **is not null**);

- Sets *tot\_creds* to null for students who have not taken any course
- Instead of **sum**(*credits*), use:

**case**

**when** **sum**(*credits*) **is not null** **then** **sum**(*credits*)

**else** 0

**end**

# Joined Relations

- **Join operations** take two relations and return as a result another relation.
- A join operation is a Cartesian product which requires that tuples in the two relations match (under some condition). It also specifies the attributes that are present in the result of the join
- The join operations are typically used as subquery expressions in the **from** clause

# Join operations – Example

- Relation *course*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>
BIO-301	Genetics	Biology	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3

- Relation *prereq*

<i>course_id</i>	<i>prereq_id</i>
BIO-301	BIO-101
CS-190	CS-101
CS-347	CS-101

- Observe that

prereq information is missing for CS-315 and  
course information is missing for CS-437

# Outer Join

- An extension of the join operation that avoids loss of information.
- Computes the join and then adds tuples from one relation that does not match tuples in the other relation to the result of the join.
- Uses *null* values.

# Left Outer Join

□ *course* **natural left outer join** *prereq*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	<i>null</i>

# Right Outer Join

□ *course* **natural right outer join** *prereq*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-347	<i>null</i>	<i>null</i>	<i>null</i>	CS-101

# Joined Relations

- **Join operations** take two relations and return as a result another relation.
- These additional operations are typically used as subquery expressions in the **from** clause
- **Join condition** – defines which tuples in the two relations match, and what attributes are present in the result of the join.
- **Join type** – defines how tuples in each relation that do not match any tuple in the other relation (based on the join condition) are treated.

<i>Join types</i>	<i>Join Conditions</i>
<b>inner join</b> <b>left outer join</b> <b>right outer join</b> <b>full outer join</b>	<b>natural</b> <b>on</b> <predicate> <b>using</b> ( $A_1, A_1, \dots, A_n$ )



# Full Outer Join

□ *course* **natural full outer join** *prereq*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	<i>null</i>
CS-347	<i>null</i>	<i>null</i>	<i>null</i>	CS-101

# Joined Relations – Examples

- **course inner join prereq on**  
*course.course\_id = prereq.course\_id*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>	<i>course_id</i>
BIO-301	Genetics	Biology	4	BIO-101	BIO-301
CS-190	Game Design	Comp. Sci.	4	CS-101	CS-190

- What is the difference between the above, and a natural join?
- **course left outer join prereq on**  
*course.course\_id = prereq.course\_id*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>	<i>course_id</i>
BIO-301	Genetics	Biology	4	BIO-101	BIO-301
CS-190	Game Design	Comp. Sci.	4	CS-101	CS-190
CS-315	Robotics	Comp. Sci.	3	<i>null</i>	<i>null</i>

# Joined Relations – Examples

□ *course* **natural right outer join** *prereq*

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-347	<i>null</i>	<i>null</i>	<i>null</i>	CS-101

□ *course* **full outer join** *prereq* **using** (*course\_id*)

<i>course_id</i>	<i>title</i>	<i>dept_name</i>	<i>credits</i>	<i>prereq_id</i>
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	<i>null</i>
CS-347	<i>null</i>	<i>null</i>	<i>null</i>	CS-101

# Views

- In some cases, it is not desirable for all users to see the entire logical model (that is, all the actual relations stored in the database.)
- Consider a person who needs to know an instructors name and department, but not the salary. This person should see a relation described, in SQL, by

```
select ID, name, dept_name  
from instructor
```

- A **view** provides a mechanism to hide certain data from the view of certain users.
- Any relation that is not of the conceptual model but is made visible to a user as a “virtual relation” is called a **view**.

# View Definition

- A view is defined using the **create view** statement which has the form

**create view v as < query expression >**

where <query expression> is any legal SQL expression. The view name is represented by v.

- Once a view is defined, the view name can be used to refer to the virtual relation that the view generates.
- View definition is not the same as creating a new relation by evaluating the query expression
  - Rather, a view definition causes the saving of an expression; the expression is substituted into queries using the view.

# Example Views

- A view of instructors without their salary

**create view** *faculty* **as**

**select** *ID, name, dept\_name*  
**from** *instructor*

- Find all instructors in the Biology department

**select** *name*  
**from** *faculty*  
**where** *dept\_name* = 'Biology'

- Create a view of department salary totals

**create view** *departments\_total\_salary*(*dept\_name, total\_salary*) **as**  
**select** *dept\_name, sum (salary)*  
**from** *instructor*  
**group by** *dept\_name;*

# Views Defined Using Other Views

- **create view** *physics\_fall\_2009* **as**  
    **select** *course.course\_id, sec\_id, building, room\_number*  
    **from** *course, section*  
    **where** *course.course\_id = section.course\_id*  
          **and** *course.dept\_name = 'Physics'*  
          **and** *section.semester = 'Fall'*  
          **and** *section.year = '2009'*;
- **create view** *physics\_fall\_2009\_watson* **as**  
    **select** *course\_id, room\_number*  
    **from** *physics\_fall\_2009*  
    **where** *building = 'Watson'*;

# View Expansion

- Expand use of a view in a query/another view

```
create view physics_fall_2009_watson as  
(select course_id, room_number  
from (select course.course_id, building, room_number  
        from course, section  
        where course.course_id = section.course_id  
              and course.dept_name = 'Physics'  
              and section.semester = 'Fall'  
              and section.year = '2009')  
where building = 'Watson';
```



# Views Defined Using Other Views

- One view may be used in the expression defining another view
- A view relation  $v_1$  is said to *depend directly* on a view relation  $v_2$  if  $v_2$  is used in the expression defining  $v_1$
- A view relation  $v_1$  is said to *depend on* view relation  $v_2$  if either  $v_1$  depends directly to  $v_2$  or there is a path of dependencies from  $v_1$  to  $v_2$
- A view relation  $v$  is said to be *recursive* if it depends on itself.

# View Expansion

- A way to define the meaning of views defined in terms of other views.
- Let view  $v_1$  be defined by an expression  $e_1$  that may itself contain uses of view relations.
- View expansion of an expression repeats the following replacement step:

**repeat**

Find any view relation  $v_i$  in  $e_1$

Replace the view relation  $v_i$  by the expression defining  $v_i$

**until** no more view relations are present in  $e_1$

- As long as the view definitions are not recursive, this loop will terminate

# Update of a View

- Add a new tuple to *faculty* view which we defined earlier

**insert into *faculty* values ('30765', 'Green', 'Music');**

This insertion must be represented by the insertion of the tuple

('30765', 'Green', 'Music', null)

into the *instructor* relation

# Some Updates cannot be Translated Uniquely

- **create view** *instructor\_info* as  
    **select** *ID, name, building*  
    **from** *instructor, department*  
    **where** *instructor.dept\_name= department.dept\_name;*
- **insert into** *instructor\_info* **values** ('69987', 'White', 'Taylor');
  - which department, if multiple departments in Taylor?
  - what if no department is in Taylor?
- Most SQL implementations allow updates only on simple views
  - The **from** clause has only one database relation.
  - The **select** clause contains only attribute names of the relation, and does not have any expressions, aggregates, or **distinct** specification.
  - Any attribute not listed in the **select** clause can be set to null
  - The query does not have a **group** by or **having** clause.

# And Some Not at All

- **create view** *history\_instructors* **as**  
    **select** \*  
    **from** *instructor*  
    **where** *dept\_name*= 'History';
- What happens if we insert ('25566', 'Brown', 'Biology', 100000) into *history\_instructors*?

# Materialized Views

- **Materializing a view**: create a physical table containing all the tuples in the result of the query defining the view
- If relations used in the query are updated, the materialized view result becomes out of date
  - Need to **maintain** the view, by updating the view whenever the underlying relations are updated.

# Transactions

- Unit of work
- Atomic transaction
  - either fully executed or rolled back as if it never occurred
- Isolation from concurrent transactions
- Transactions begin implicitly
  - Ended by **commit work** or **rollback work**
- But default on most databases: each SQL statement commits automatically
  - Can turn off auto commit for a session (e.g. using API)
  - In SQL:1999, can use: **begin atomic .... end**
    - Not supported on most databases

# Integrity Constraints

- Integrity constraints guard against accidental damage to the database, by ensuring that authorized changes to the database do not result in a loss of data consistency.
  - A checking account must have a balance greater than \$10,000.00
  - A salary of a bank employee must be at least \$4.00 an hour
  - A customer must have a (non-null) phone number



# Integrity Constraints on a Single Relation

- **not null**
- **primary key**
- **unique**
- **check (P)**, where P is a predicate

# Not Null and Unique Constraints

- **not null**

- Declare *name* and *budget* to be **not null**

*name* **varchar(20) not null**

*budget* **numeric(12,2) not null**

- **unique** (  $A_1, A_2, \dots, A_m$  )

- The unique specification states that the attributes  $A_1, A_2, \dots, A_m$  form a candidate key.
  - Candidate keys are permitted to be null (in contrast to primary keys).

# The check clause

- **check** (P)

where P is a predicate

Example: ensure that semester is one of fall, winter, spring or summer:

```
create table section (  
    course_id varchar (8),  
    sec_id varchar (8),  
    semester varchar (6),  
    year numeric (4,0),  
    building varchar (15),  
    room_number varchar (7),  
    time slot id varchar (4),  
    primary key (course_id, sec_id, semester, year),  
    check (semester in ('Fall', 'Winter', 'Spring', 'Summer'))  
);
```

# Referential Integrity

- Ensures that a value that appears in one relation for a given set of attributes also appears for a certain set of attributes in another relation.
  - Example: If “Biology” is a department name appearing in one of the tuples in the *instructor* relation, then there exists a tuple in the *department* relation for “Biology”.
- Let A be a set of attributes. Let R and S be two relations that contain attributes A and where A is the primary key of S. A is said to be a **foreign key** of R if for any values of A appearing in R these values also appear in S.

# Cascading Actions in Referential Integrity

- **create table** *course* (  
    *course\_id* **char**(5) **primary key**,  
    *title* **varchar**(20),  
    *dept\_name* **varchar**(20) **references** *department*  
)
- **create table** *course* (  
    ...  
    *dept\_name* **varchar**(20),  
    **foreign key** (*dept\_name*) **references** *department*  
        **on delete cascade**  
        **on update cascade**,  
    ...  
)
- alternative actions to cascade: **set null, set default**

# Integrity Constraint Violation During Transactions

- E.g.

```
create table person (  
    ID char(10),  
    name char(40),  
    mother char(10),  
    father char(10),  
    primary key ID,  
    foreign key father references person,  
    foreign key mother references person)
```

- How to insert a tuple without causing constraint violation ?
  - insert father and mother of a person before inserting person
  - OR, set father and mother to null initially, update after inserting all persons (not possible if father and mother attributes declared to be **not null**)
  - OR defer constraint checking (next slide)

# Complex Check Clauses

- **check** (*time\_slot\_id* in (**select** *time\_slot\_id* **from** *time\_slot*))
  - why not use a foreign key here?
- Every section has at least one instructor teaching the section.
  - how to write this?
- Unfortunately: subquery in check clause not supported by pretty much any database
  - Alternative: triggers (later)
- **create assertion** <assertion-name> **check** <predicate>;
  - Also not supported by anyone

# Built-in Data Types in SQL

- **date**: Dates, containing a (4 digit) year, month and date
  - Example: **date** '2005-7-27'
- **time**: Time of day, in hours, minutes and seconds.
  - Example: **time** '09:00:30'      **time** '09:00:30.75'
- **timestamp**: date plus time of day
  - Example: **timestamp** '2005-7-27 09:00:30.75'
- **interval**: period of time
  - Example: interval '1' day
  - Subtracting a date/time/timestamp value from another gives an interval value
  - Interval values can be added to date/time/timestamp values



# Index Creation

- **create table** *student*  
(*ID* **varchar** (5),  
*name* **varchar** (20) **not null**,  
*dept\_name* **varchar** (20),  
*tot\_cred* **numeric** (3,0) **default** 0,  
**primary key** (*ID*))
- **create index** *studentID\_index* **on** *student*(*ID*)
- Indices are data structures used to speed up access to records with specified values for index attributes
  - e.g. **select** \*  
    **from** *student*  
    **where** *ID* = '12345'

can be executed by using the index to find the required record, without looking at all records of *student*

*More on indices in Chapter 11*

# User-Defined Types

- **create type** construct in SQL creates user-defined type

**create type** *Dollars* as numeric (12,2) final

- **create table** *department*  
(*dept\_name* **varchar** (20),  
*building* **varchar** (15),  
*budget* *Dollars*);

# Domains

- **create domain** construct in SQL-92 creates user-defined domain types

**create domain *person\_name* char(20) not null**

- Types and domains are similar. Domains can have constraints, such as **not null**, specified on them.
- **create domain *degree\_level* varchar(10)  
constraint *degree\_level\_test*  
check (value in ('Bachelors', 'Masters', 'Doctorate'));**

# Large-Object Types

- Large objects (photos, videos, CAD files, etc.) are stored as a *large object*:
  - **blob**: binary large object -- object is a large collection of uninterpreted binary data (whose interpretation is left to an application outside of the database system)
  - **clob**: character large object -- object is a large collection of character data
- When a query returns a large object, a pointer is returned rather than the large object itself.

# Authorization

Forms of authorization on parts of the database:

- **Read** - allows reading, but not modification of data.
- **Insert** - allows insertion of new data, but not modification of existing data.
- **Update** - allows modification, but not deletion of data.
- **Delete** - allows deletion of data.

Forms of authorization to modify the database schema

- **Index** - allows creation and deletion of indices.
- **Resources** - allows creation of new relations.
- **Alteration** - allows addition or deletion of attributes in a relation.
- **Drop** - allows deletion of relations.

# Authorization Specification in SQL

- The **grant** statement is used to confer authorization  
**grant** <privilege list>  
**on** <relation name or view name> **to** <user list>
- <user list> is:
  - a user-id
  - **public**, which allows all valid users the privilege granted
  - A role (more on this later)
- Granting a privilege on a view does not imply granting any privileges on the underlying relations.
- The grantor of the privilege must already hold the privilege on the specified item (or be the database administrator).

# Privileges in SQL

- **select**: allows read access to relation, or the ability to query using the view
  - Example: grant users  $U_1$ ,  $U_2$ , and  $U_3$  **select** authorization on the *instructor* relation:

**grant select on *instructor* to  $U_1$ ,  $U_2$ ,  $U_3$**

- **insert**: the ability to insert tuples
- **update**: the ability to update using the SQL update statement
- **delete**: the ability to delete tuples.
- **all privileges**: used as a short form for all the allowable privileges

# Revoking Authorization in SQL

- The **revoke** statement is used to revoke authorization.

**revoke** <privilege list>

**on** <relation name or view name> **from** <user list>

- Example:

**revoke select on** *branch* **from**  $U_1, U_2, U_3$

- <privilege-list> may be **all** to revoke all privileges the revokee may hold.
- If <revokee-list> includes **public**, all users lose the privilege except those granted it explicitly.
- If the same privilege was granted twice to the same user by different grantees, the user may retain the privilege after the revocation.
- All privileges that depend on the privilege being revoked are also revoked.



# Roles

- **create role** instructor;
- **grant** *instructor* **to** **Amit**;
- Privileges can be granted to roles:
  - **grant select on** *takes* **to** *instructor*;
- Roles can be granted to users, as well as to other roles
  - **create role** *teaching\_assistant*
  - **grant** *teaching\_assistant* **to** *instructor*;
    - *Instructor* inherits all privileges of *teaching\_assistant*
- Chain of roles
  - **create role** *dean*;
  - **grant** *instructor* **to** *dean*;
  - **grant** *dean* **to** Satoshi;

# Authorization on Views

- **create view** *geo\_instructor* **as**  
    (select \*  
    **from** *instructor*  
    **where** *dept\_name* = 'Geology');
- **grant select on** *geo\_instructor* **to** *geo\_staff*
- Suppose that a *geo\_staff* member issues
  - **select** \*  
    **from** *geo\_instructor*;
- What if
  - *geo\_staff* does not have permissions on *instructor*?
  - creator of view did not have some permissions on *instructor*?

# Other Authorization Features

- **references** privilege to create foreign key
  - **grant reference** (*dept\_name*) **on** *department* **to** Mariano;
  - why is this required?
- transfer of privileges
  - **grant select on** *department* **to** Amit **with grant option**;
  - **revoke select on** *department* **from** Amit, Satoshi **cascade**;
  - **revoke select on** *department* **from** Amit, Satoshi **restrict**;
- Etc. read Section 4.6 for more details we have omitted here.

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>tot_cred</i>
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

<i>ID</i>	<i>course_id</i>	<i>sec_id</i>	<i>semester</i>	<i>year</i>	<i>grade</i>
00128	CS-101	1	Fall	2009	A
00128	CS-347	1	Fall	2009	A-
12345	CS-101	1	Fall	2009	C
12345	CS-190	2	Spring	2009	A
12345	CS-315	1	Spring	2010	A
12345	CS-347	1	Fall	2009	A
19991	HIS-351	1	Spring	2010	B
23121	FIN-201	1	Spring	2010	C+
44553	PHY-101	1	Fall	2009	B-
45678	CS-101	1	Fall	2009	F
45678	CS-101	1	Spring	2010	B+
45678	CS-319	1	Spring	2010	B
54321	CS-101	1	Fall	2009	A-
54321	CS-190	2	Spring	2009	B+
55739	MU-199	1	Spring	2010	A-
76543	CS-101	1	Fall	2009	A
76543	CS-319	2	Spring	2010	A
76653	EE-181	1	Spring	2009	C
98765	CS-101	1	Fall	2009	C-
98765	CS-315	1	Spring	2010	B
98988	BIO-101	1	Summer	2009	A
98988	BIO-301	1	Summer	2010	<i>null</i>

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>tot_cred</i>	<i>course_id</i>	<i>sec_id</i>	<i>semester</i>	<i>year</i>	<i>grade</i>
00128	Zhang	Comp. Sci.	102	CS-101	1	Fall	2009	A
00128	Zhang	Comp. Sci.	102	CS-347	1	Fall	2009	A-
12345	Shankar	Comp. Sci.	32	CS-101	1	Fall	2009	C
12345	Shankar	Comp. Sci.	32	CS-190	2	Spring	2009	A
12345	Shankar	History	32	CS-315	1	Spring	2010	A
12345	Shankar	Finance	32	CS-347	1	Fall	2009	A
19991	Brandt	Music	80	HIS-351	1	Spring	2010	B
23121	Chavez	Physics	110	FIN-201	1	Spring	2010	C+
44553	Peltier	Physics	56	PHY-101	1	Fall	2009	B-
45678	Levy	Physics	46	CS-101	1	Fall	2009	F
45678	Levy	Physics	46	CS-101	1	Spring	2010	B+
45678	Levy	Physics	46	CS-319	1	Spring	2010	B
54321	Williams	Comp. Sci.	54	CS-101	1	Fall	2009	A-
54321	Williams	Comp. Sci.	54	CS-190	2	Spring	2009	B+
55739	Sanchez	Music	38	MU-199	1	Spring	2010	A-
76543	Brown	Comp. Sci.	58	CS-101	1	Fall	2009	A
76543	Brown	Comp. Sci.	58	CS-319	2	Spring	2010	A
76653	Aoi	Elec. Eng.	60	EE-181	1	Spring	2009	C
98765	Bourikas	Elec. Eng.	98	CS-101	1	Fall	2009	C-
98765	Bourikas	Elec. Eng.	98	CS-315	1	Spring	2010	B
98988	Tanaka	Biology	120	BIO-101	1	Summer	2009	A
98988	Tanaka	Biology	120	BIO-301	1	Summer	2010	<i>null</i>

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>tot_cred</i>	<i>course_id</i>	<i>sec_id</i>	<i>semester</i>	<i>year</i>	<i>grade</i>
00128	Zhang	Comp. Sci.	102	CS-101	1	Fall	2009	A
00128	Zhang	Comp. Sci.	102	CS-347	1	Fall	2009	A-
12345	Shankar	Comp. Sci.	32	CS-101	1	Fall	2009	C
12345	Shankar	Comp. Sci.	32	CS-190	2	Spring	2009	A
12345	Shankar	History	32	CS-315	1	Spring	2010	A
12345	Shankar	Finance	32	CS-347	1	Fall	2009	A
19991	Brandt	Music	80	HIS-351	1	Spring	2010	B
23121	Chavez	Physics	110	FIN-201	1	Spring	2010	C+
44553	Peltier	Physics	56	PHY-101	1	Fall	2009	B-
45678	Levy	Physics	46	CS-101	1	Fall	2009	F
45678	Levy	Physics	46	CS-101	1	Spring	2010	B+
45678	Levy	Physics	46	CS-319	1	Spring	2010	B
54321	Williams	Comp. Sci.	54	CS-101	1	Fall	2009	A-
54321	Williams	Comp. Sci.	54	CS-190	2	Spring	2009	B+
55739	Sanchez	Music	38	MU-199	1	Spring	2010	A-
70557	Snow	Physics	0	<i>null</i>	<i>null</i>	<i>null</i>	<i>null</i>	<i>null</i>
76543	Brown	Comp. Sci.	58	CS-101	1	Fall	2009	A
76543	Brown	Comp. Sci.	58	CS-319	2	Spring	2010	A
76653	Aoi	Elec. Eng.	60	EE-181	1	Spring	2009	C
98765	Bourikas	Elec. Eng.	98	CS-101	1	Fall	2009	C-
98765	Bourikas	Elec. Eng.	98	CS-315	1	Spring	2010	B
98988	Tanaka	Biology	120	BIO-101	1	Summer	2009	A
98988	Tanaka	Biology	120	BIO-301	1	Summer	2010	<i>null</i>



<i>ID</i>	<i>course_id</i>	<i>sec_id</i>	<i>semester</i>	<i>year</i>	<i>grade</i>	<i>name</i>	<i>dept_name</i>	<i>tot_cred</i>
00128	CS-101	1	Fall	2009	A	Zhang	Comp. Sci.	102
00128	CS-347	1	Fall	2009	A-	Zhang	Comp. Sci.	102
12345	CS-101	1	Fall	2009	C	Shankar	Comp. Sci.	32
12345	CS-190	2	Spring	2009	A	Shankar	Comp. Sci.	32
12345	CS-315	1	Spring	2010	A	Shankar	History	32
12345	CS-347	1	Fall	2009	A	Shankar	Finance	32
19991	HIS-351	1	Spring	2010	B	Brandt	Music	80
23121	FIN-201	1	Spring	2010	C+	Chavez	Physics	110
44553	PHY-101	1	Fall	2009	B-	Peltier	Physics	56
45678	CS-101	1	Fall	2009	F	Levy	Physics	46
45678	CS-101	1	Spring	2010	B+	Levy	Physics	46
45678	CS-319	1	Spring	2010	B	Levy	Physics	46
54321	CS-101	1	Fall	2009	A-	Williams	Comp. Sci.	54
54321	CS-190	2	Spring	2009	B+	Williams	Comp. Sci.	54
55739	MU-199	1	Spring	2010	A-	Sanchez	Music	38
70557	<i>null</i>	<i>null</i>	<i>null</i>	<i>null</i>	<i>null</i>	Snow	Physics	0
76543	CS-101	1	Fall	2009	A	Brown	Comp. Sci.	58
76543	CS-319	2	Spring	2010	A	Brown	Comp. Sci.	58
76653	EE-181	1	Spring	2009	C	Aoi	Elec. Eng.	60
98765	CS-101	1	Fall	2009	C-	Bourikas	Elec. Eng.	98
98765	CS-315	1	Spring	2010	B	Bourikas	Elec. Eng.	98
98988	BIO-101	1	Summer	2009	A	Tanaka	Biology	120
98988	BIO-301	1	Summer	2010	<i>null</i>	Tanaka	Biology	120



<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
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
69987	White	<i>null</i>	<i>null</i>

*instructor*

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

*department*

### *Join types*

**inner join**  
**left outer join**  
**right outer join**  
**full outer join**

### *Join conditions*

**natural**  
**on** <predicate>  
**using** ( $A_1, A_2, \dots, A_n$ )

