Database Systems

Session 2 – Main Theme
Relational Data Model
& Relational Database Constraints

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Presentation material partially based on textbook slides
Fundamentals of Database Systems (7th Edition)
by Ramez Elmasri and Shamkant Navathe

Agenda

1. Session Overview
2. Relational Data Model & Database Constraints
3. Summary and Conclusion

Session Agenda

- Session Overview
- Relational Data Model & Database Constraints
- Summary & Conclusion

What is the Course About?

- Course description and syllabus:
  - » http://www.nyu.edu/classes/jcf/CSCI-GA.2433-001
  - » http://cs.nyu.edu/courses/fall22/CSCI-GA.2433-001/
- Textbooks:
  - » ***Fundamentals of Database Systems (7th Edition)***

Ramez Elmasri and Shamkant Navathe
Pearson
ISBN-10: 0133970779, ISBN-13: 978-0133970777 7th Edition (06/18/15)

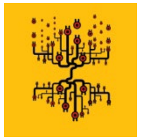
Icons / Metaphors

Information

Common Realization

Knowledge/Competency Pattern

Governance



Alignment

Solution Approach

Agenda

1 **Session Overview**

2 **Relational Data Model & Database Constraints**

3 **Summary and Conclusion**

Agenda

- The need for database management systems
- Brief overview of the relational model
- Querying relational database directly and through views
- Need for good logical design
- Need for good physical design
- Recovery
- Concurrency
- Layers of database management systems
- Independence between/among layers
- Various roles of designers, users, and maintainers

Two Main Functions Of Databases

- A very large fraction of computer use is devoted to business processing of data using databases
  - Think about what Amazon has to do to manage its operations
- Two main uses of databases
  - ***OLTP*** (Online Transaction Processing)

    The database is used is for entering, modifying, and querying data

    Correctness, at least for entering and modifying data must be assured

    Example: Amazon charges customer's credit card for the price of the book that a customer ordered
  - ***OLAP*** (Online Analytical Processing)

    The database is used for business intelligence, including data mining

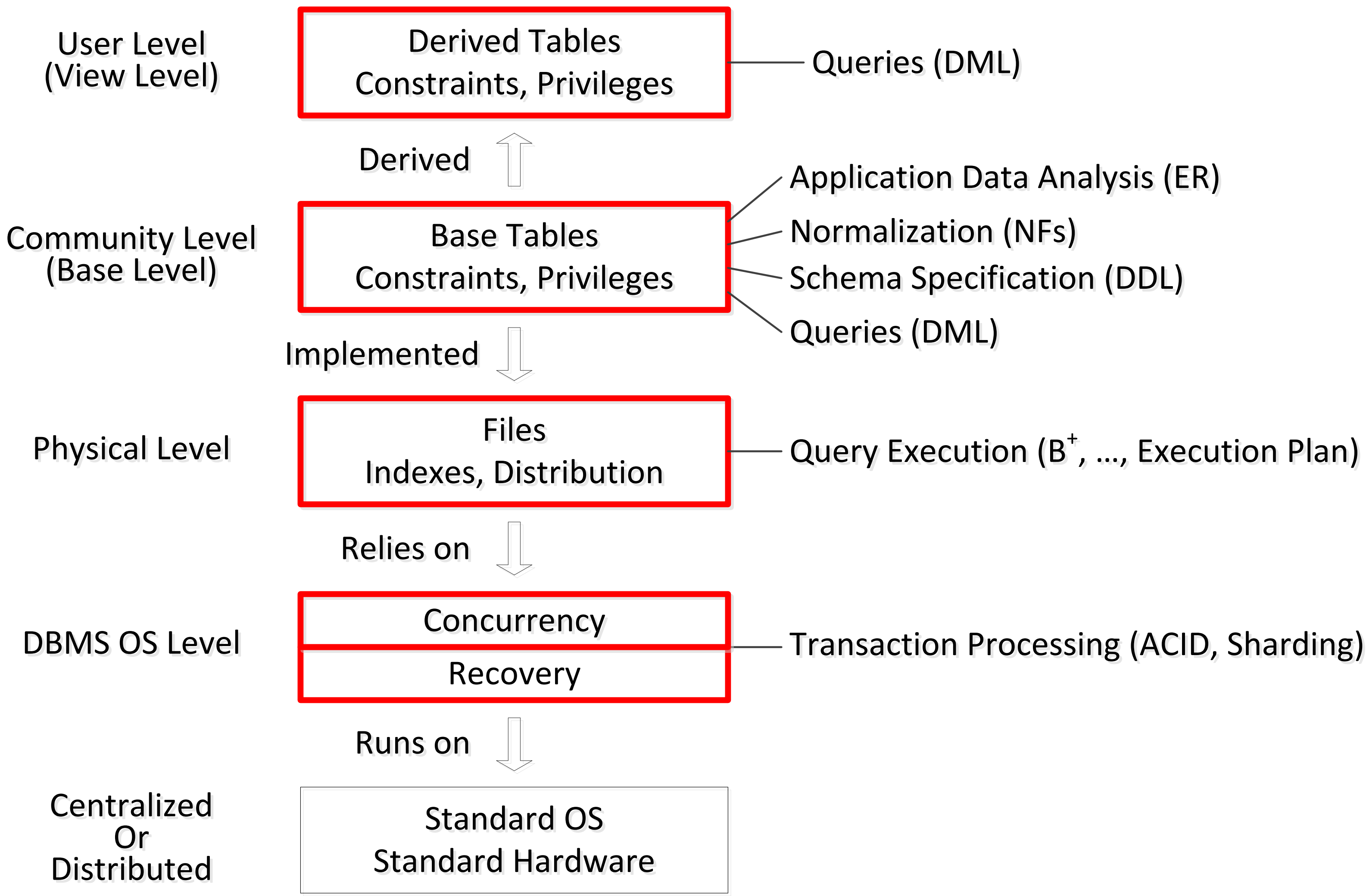
    The results do not have to be "completely correct," as this may be too inefficient to guarantee, but complex queries have to be answered (relatively) fast

    Example: Amazon wants to know how many books that cost less than $10 each were sold in New Jersey during December 2009

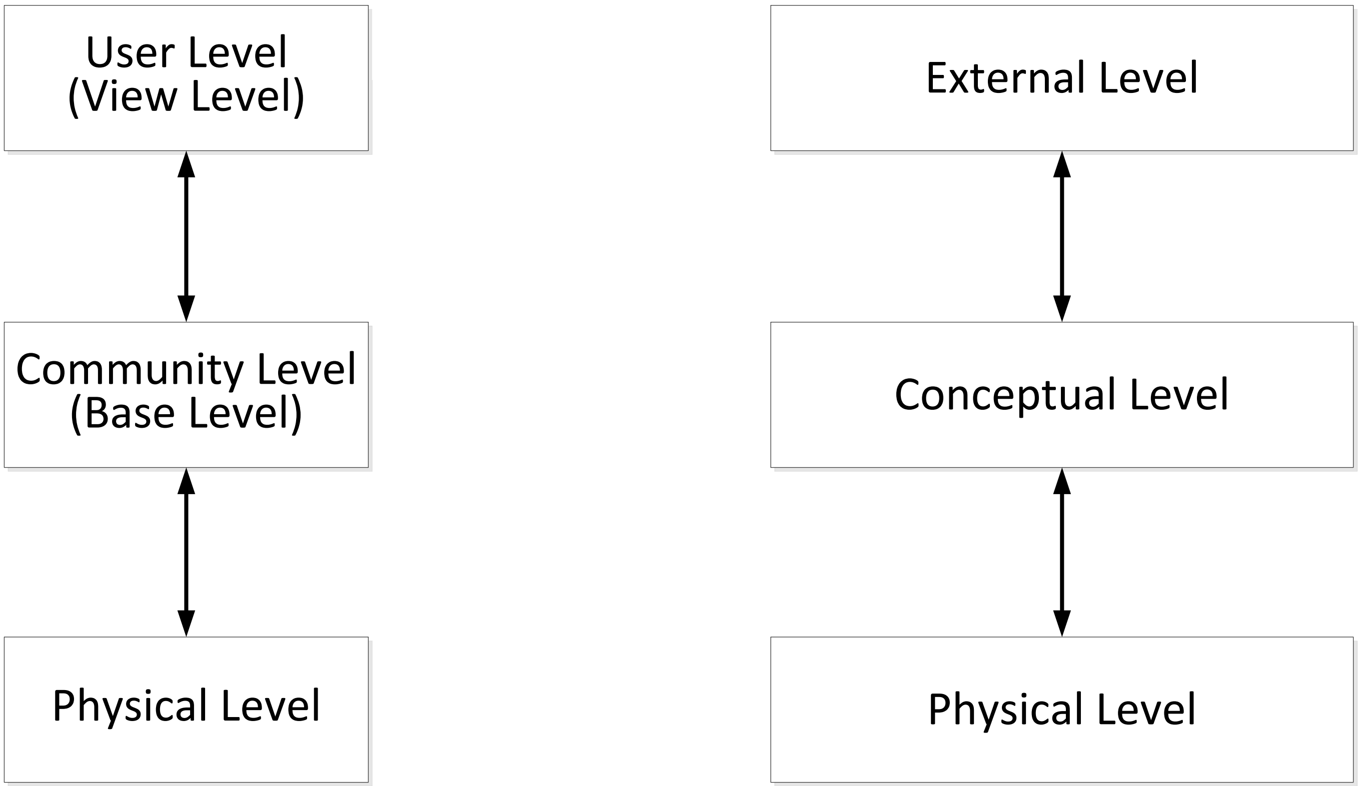
Managing The Data Of An Enterprise

- We may consider some enterprise (organization) and the totality of the information it maintains.
- We think about managing this information, focusing on OLTP
- Ideally, the information should be stored in a (logically) single (possibly physically distributed) database system
- We start with a very simple example to introduce some concepts and issues to address
- We look at only a very small part of information of the type that an enterprise may need to keep
- We need some way of describing sample data
- We will think, in this unit, of the database as ***a set of tables***, each stored as a ***file on a disk***

Levels of RDBMS Functionality



Three-Tier RDBMS Architecture Levels



Terminologies for the top 3 layers/levels/tiers

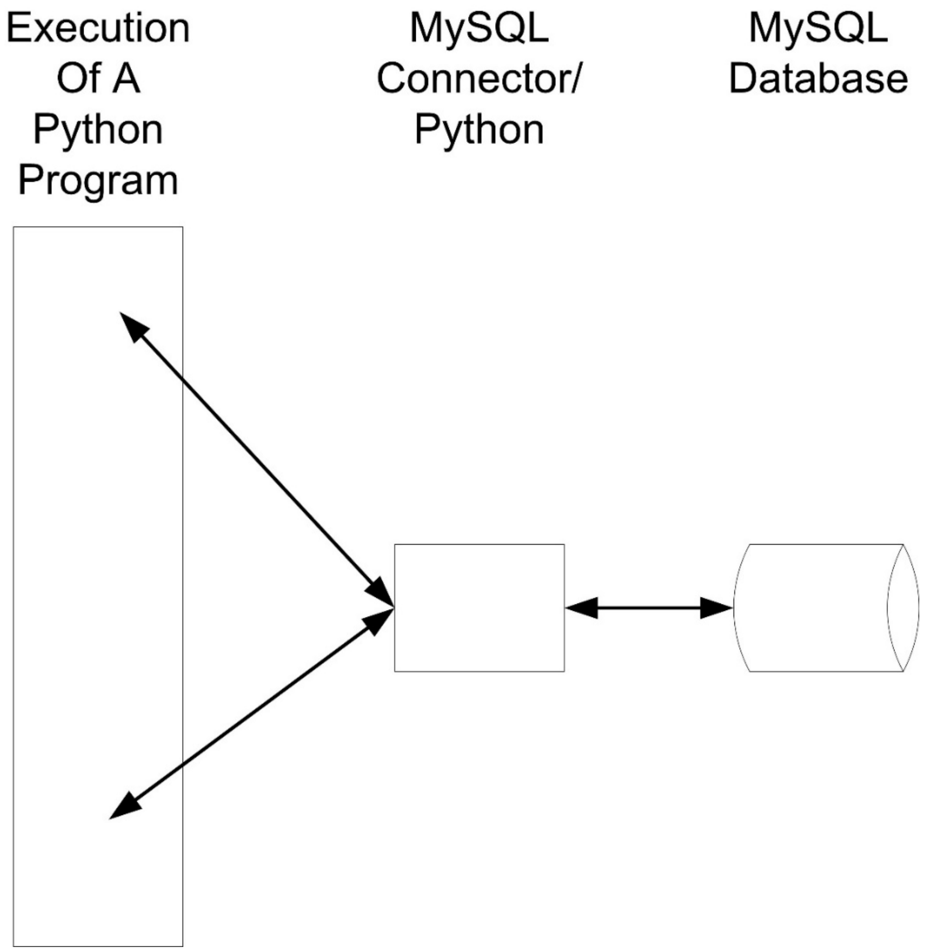
Sample RDBMS Discussion Topics Workflow

Business Requirements	Talk to customers (Unit 2)
↓ Conceptual Design	Specify using annotated EER diagrams (Unit 2)
↓ Logical Design	Specify a relational database schema (Units 3, 6 and 7)
↓ Physical Design (1)	Specify a relational database for a given DBMS (Unit 6)
↓ Physical Design (2)	Specify files, indexes, distribution, etc. (Units 8 and 12)
↓ Choose DBOS Options	Specify recovery and concurrency options. (Units 9 and 10)
↓ Queries (CRUD)	Specify create, read, update, delete queries. (Units 4, 5, and 11)
↓ Optimize and Fine-Tune	Goal self-explanatory (We do not cover this)

Database As A Component Of A Larger System

- Scenario
  - » You swipe your card at an ATM machine and a program (rather than a RDBMS) reads it
  - » You punch in your PIN, and the program reads it
  - » The program interacts with a relational database (e.g., MySQL) to see if the PIN matches (we assume it does)
  - » . . .
  - » You want to withdraw money; the program formulates a request to the relational database to update your account
  - » . . .
- You need an interface between the program (e.g., Python program) and the RDBMS (e.g., MySQL)
  - » MySQL understands what relations are and how to manipulate them but does not “understand” the outside world
  - » Python does not understand relations but “understands” the outside world
- You are using have an instance of a client/server architecture that leverages a Python program and the MySQL RDBMS

Interactions Between Program and RDBMS



More on this topic later …

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- The need for database management systems
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- Relational model
  - First commercial implementations available in early 1980s
  - Has been implemented in a large number of commercial system
- Hierarchical and network models
  - Preceded the relational model

Relational Model Concepts

- The relational Model of Data is based on the concept of a *Relation*
  - » The strength of the relational approach to data management comes from the formal foundation provided by the theory of relations
- While we review the essentials of the *formal relational model* here, there is a practical *standard model* based on SQL, which will be covered later in class as a language
- <u>Note:</u> There are several important differences between the *formal* model and the *practical* model, as we shall see

Relational Model Concepts (continued)

- A Relation is a mathematical concept based on the ideas of sets
- The model was first proposed by Dr. E.F. Codd of IBM Research in 1970 in the following paper:
  - "A Relational Model for Large Shared Data Banks," Communications of the ACM, June 1970
- The above paper caused a major revolution in the field of database management and earned Dr. Codd the coveted ACM Turing Award

Informal Definitions

- Informally, a **relation** looks like a **table** of values.
- A relation typically contains a **set of rows**.
- The data elements in each **row** represent certain facts that correspond to a real-world **entity** or **relationship**
  - » In the formal model, rows are called **tuples**
- Each **column** has a column header that gives an indication of the meaning of the data items in that column
  - » In the formal model, the column header is called an **attribute name** (or just **attribute**)

Relational Model Concepts (cont'd.)

Relation Name

Attributes

STUDENT

Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Benjamin Bayer	305-61-2435	373-1616	2918 Bluebonnet Lane	NULL	19	3.21
Chung-cha Kim	381-62-1245	375-4409	125 Kirby Road	NULL	18	2.89
Dick Davidson	422-11-2320	NULL	3452 Elgin Road	749-1253	25	3.53
Rohan Panchal	489-22-1100	376-9821	265 Lark Lane	749-6492	28	3.93
Barbara Benson	533-69-1238	839-8461	7384 Fontana Lane	NULL	19	3.25

Tuples

Figure 5.1
The attributes and tuples of a relation STUDENT.

- Key of a Relation:
  - » Each row has a value of a data item (or set of items) that uniquely identifies that row in the table
    - Called the *key*
  - » In the STUDENT table, SSN is the key
  - » Sometimes row-ids or sequential numbers are assigned as keys to identify the rows in a table
    - Called *artificial key* or *surrogate key*

Formal Definitions - Schema

- The **Schema** (or description) of a Relation:
  - Denoted by R(A1, A2, ...An)
  - R is the **name** of the relation
  - The **attributes** of the relation are A1, A2, ..., An
- Example:

  CUSTOMER (Cust-id, Cust-name, Address, Phone#)
  - CUSTOMER is the relation name
  - Defined over the four attributes: Cust-id, Cust-name, Address, Phone#
- Each attribute has a **domain** or a set of valid values.
  - For example, the domain of Cust-id is 6 digit numbers.

Formal Definitions - Tuple

- A **tuple** is an ordered set of values (enclosed in angled brackets ‘< … >’)
- Each value is derived from an appropriate *domain*.
- A row in the CUSTOMER relation is a 4-tuple and would consist of four values, for example:
  - » <632895, "John Smith", "101 Main St. Atlanta, GA 30332", "(404) 894-2000">
  - » This is called a 4-tuple as it has 4 values
  - » A tuple (row) in the CUSTOMER relation.
- A relation is a **set** of such tuples (rows)

Formal Definitions - Domain

- A **domain** has a logical definition:
  - » Example: “USA_phone_numbers” are the set of 10 digit phone numbers valid in the U.S.
- A domain also has a data-type or a format defined for it.
  - » The USA_phone_numbers may have a format: (ddd)ddd-dddd where each d is a decimal digit.
  - » Dates have various formats such as year, month, date formatted as yyyy-mm-dd, or as dd mm,yyyy etc.

- The attribute name designates the role played by a domain in a relation:
  - » Used to interpret the meaning of the data elements corresponding to that attribute
  - » Example: The domain Date may be used to define two attributes named “Invoice-date” and “Payment-date” with different meanings

Formal Definitions - State

- The **relation state** is a subset of the Cartesian product of the domains of its attributes
  - each domain contains the set of all possible values the attribute can take.
- Example: attribute Cust-name is defined over the domain of character strings of maximum length 25
  - dom(Cust-name) is varchar(25)
- The role these strings play in the CUSTOMER relation is that of the *name of a customer*.

Meaning of a Relation

- Interpretation (meaning) of a relation
  - Assertion
    - Each tuple in the relation is a fact or a particular instance of the assertion
  - Predicate
    - Values in each tuple interpreted as values that satisfy predicate

Relational Model Notation

- Relation schema R of degree n
  - Denoted by $R(A_1, A_2, ..., A_n)$
- Uppercase letters Q, R, S
  - Denote relation names
- Lowercase letters q, r, s
  - Denote relation states
- Letters t, u, v
  - Denote tuples

Formal Definitions - Summary

- Formally,
  - » Given R(A1, A2, ..., An)
  - » $r(R) \subset dom(A1) \times dom(A2) \times \ldots \times dom(An)$
- R(A1, A2, …, An) is the **schema** of the relation
- R is the **name** of the relation
- A1, A2, …, An are the **attributes** of the relation
- r(R): a specific **state** (or "value" or “population”) of relation R – this is a *set of tuples* (rows)
  - » r(R) = {t1, t2, …, tn} where each ti is an n-tuple
  - » ti = <v1, v2, …, vn> where each vj *element-of* dom(Aj)

Formal Definitions - Example

- Let R(A1, A2) be a relation schema:
  - » Let dom(A1) = {0,1}
  - » Let dom(A2) = {a,b,c}
- Then: dom(A1) X dom(A2) is all possible combinations:

  {<0,a> , <0,b> , <0,c>, <1,a>, <1,b>, <1,c> }

- The relation state r(R) $\subset$ dom(A1) X dom(A2)
- For example: r(R) could be {<0,a> , <0,b> , <1,c> }
  - » this is one possible state (or “population” or “extension”) r of the relation R, defined over A1 and A2.
  - » It has three 2-tuples: <0,a> , <0,b> , <1,c>

Definition Summary

Informal Terms		Formal Terms
Table		Relation
Column Header		Attribute
All possible Column Values		Domain
Row		Tuple
Table Definition		Schema of a Relation
Populated Table		State of the Relation

Example – A Relation STUDENT

Relation Name

Attributes

STUDENT

Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Benjamin Bayer	305-61-2435	373-1616	2918 Bluebonnet Lane	NULL	19	3.21
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Tuples

Figure 5.1
The attributes and tuples of a relation STUDENT.

Characteristics of Relations

- Ordering of tuples in a relation r(R):
  - » The tuples are *not considered to be ordered*, even though they appear to be in the tabular form.
- Ordering of attributes in a relation schema R (and of values within each tuple):
  - » We will consider the attributes in R(A1, A2, ..., An) and the values in t=<v1, v2, ..., vn> to be ordered .
    - (However, a more general alternative definition of relation does not require this ordering. It includes both the name and the value for each of the attributes).
    - Example: t= { <name, “John” >, <SSN, 123456789> }
    - This representation may be called as “self-describing”.

Same State as Previous Figure but Different Order of Tuples

Figure 5.2
The relation STUDENT from Figure 5.1 with a different order of tuples.

STUDENT

Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Dick Davidson	422-11-2320	NULL	3452 Elgin Road	749-1253	25	3.53
Barbara Benson	533-69-1238	839-8461	7384 Fontana Lane	NULL	19	3.25
Rohan Panchal	489-22-1100	376-9821	265 Lark Lane	749-6492	28	3.93
Chung-cha Kim	381-62-1245	375-4409	125 Kirby Road	NULL	18	2.89
Benjamin Bayer	305-61-2435	373-1616	2918 Bluebonnet Lane	NULL	19	3.21

Characteristics of Relations (continued)

- Values in a tuple:
  - » All values are considered atomic (indivisible).
  - » Each value in a tuple must be from the domain of the attribute for that column
    - If tuple t = <v1, v2, …, vn> is a tuple (row) in the relation state r of R(A1, A2, …, An)
    - Then each *vi* must be a value from *dom(Ai)*
  - » A special **null** value is used to represent values that are unknown or not available or inapplicable in certain tuples.

Characteristics of Relations (continued)

- Notation:
  - » We refer to **component values** of a tuple t by:
    - t[Ai] or t.Ai
    - This is the value vi of attribute Ai for tuple t
  - » Similarly, t[Au, Av, ..., Aw] refers to the subtuple of t containing the values of attributes Au, Av, ..., Aw, respectively in t

Characteristics of Relations (continued)

- Values and NULLs in tuples
  - Each value in a tuple is atomic
  - Flat relational model
    - Composite and multivalued attributes not allowed
    - First normal form assumption
  - Multivalued attributes
    - Must be represented by separate relations
  - Composite attributes
    - Represented only by simple component attributes in basic relational model

Characteristics of Relations (continued)

- NULL values
  - Represent the values of attributes that may be unknown or may not apply to a tuple
  - Meanings for NULL values
    - *Value unknown*
    - *Value exists but is not available*
    - *Attribute does not apply to this tuple (also known as value undefined)*

A Sample Relational Database

SSN	City	DOB
101	Boston	3498
106	London	2987
121	Portland	2367
132	Miami	3678

Name	SSN	DOB	Grade	Salary
A	121	2367	2	80
A	132	3678	3	70
B	101	3498	4	70
C	106	2987	2	80

SSN	Book	Date
132	Plants	8976
121	Animals	9003

SSN	Illness	Date
101	Cold	3498
121	Flu	2987

- Of course, the values do not pretend to be real, they were chosen to be short, so can be easily fitted on the slide
- The database talks about employees, books they have checked out from the library (and when), and various illnesses they have had (and when)

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Some Typical Queries

- Some typical queries
  - Give Name of every employee born before 3500
  - Give Name and City for every employee who took out a Book after 9000
  - Prepare a recall notice to for every employee who had a flu to come for a checkup
- ***Note that some queries involve a single table, and some involve several tables***
- We would like to have a convenient language, as close as possible to a natural language, to express these queries, and similar ones, thinking of tables, not of lower-level structures (files)
- Some languages
  - ***SQL*** (used to be called Structured Query Language): every relational database supports some "close to standard" version
  - ***QBE*** (Query By Example); underlying, e.g., Microsoft Access's GUI

Two Queries in SQL

- Imagine that the tables are have names (as they of course do in SQL)
  - » Table1: with columns SSN, City, DOB
  - » Table2: with columns Name, SSN, DOB, Grade, Salary
  - » Table3: with columns SSN, Book, Date
  - » Table4: with columns SSN, Illness, date
- Give Name of every employee born before 3500

```
SELECT Name
FROM Table2
WHERE DOB < 3500;
```

- Give Name and City for every employee who took out a Book after 9000

```
SELECT Name, City
FROM Table2, Table 1
WHERE Table2.SSN = Table1.SSN;
```

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The Need For Good Design

- It is important also to think carefully about the correct (or just good!) choice of which tables to use and what should be their structure
- This we should do in order to have good logical design, not worrying (yet) about efficient storage in files
- Our initial design suffers (for pedagogical reasons) from various problems, which we will see next

Redundancy

- A data item appears more than once ***unnecessarily***
  - » Assuming that each SSN has only one DOB, DOB appears twice unnecessarily (in two different tables)

    There is a danger that this will be inconsistent
  - » Even more dangerous would have been multiple storage of employee’s City

    If the employee moves, the City must be changed everywhere it appears
- Note, however, that from an efficiency point of view, it might be useful to replicate information, to speed up access
  - » In our example, if frequently we want to correlate DOB with Grade and also DOB with City, it may be good to have it in both tables, and not insist on a “clean” design
- Note that ***it was necessary*** for SSN to appear in two different tables, as otherwise we could not “assemble” information about employees

Relational Model Constraints

Constraints determine which values are permissible and which are not in the database.

They are of three main types:

1. **Inherent or Implicit Constraints**: These are based on the data model itself. (E.g., relational model does not allow a list as a value for any attribute)
2. **Schema-based or Explicit Constraints**: They are expressed in the schema by using the facilities provided by the model. (E.g., max. cardinality ratio constraint in the ER model)
3. **Application based or semantic constraints**: These are beyond the expressive power of the model and must be specified and enforced by the application programs.

Relational Integrity Constraints

- Constraints are **conditions** that must hold on **all** valid relation states.
- There are three *main types* of (explicit schema-based) constraints that can be expressed in the relational model:
  - **Key** constraints
  - **Entity integrity** constraints
  - **Referential integrity** constraints
- Another schema-based constraint is the **domain** constraint
  - Every value in a tuple must be from the *domain of its attribute* (or it could be **null**, if allowed for that attribute)

Key Constraints

- **Superkey** of R:
  - » Is a set of attributes SK of R with the following condition:
    - No two tuples in any valid relation state r(R) will have the same value for SK
    - That is, for any distinct tuples t1 and t2 in r(R), t1[SK] $\neq$ t2[SK]
    - This condition must hold in *any valid state* r(R)
- **Key** of R:
  - » A "minimal" superkey
  - » That is, a key is a superkey K such that removal of any attribute from K results in a set of attributes that is not a superkey (does not possess the superkey uniqueness property)
- A Key is a Superkey but not vice versa

Key Constraints (continued)

- Example: Consider the CAR relation schema:
  - CAR(State, Reg#, SerialNo, Make, Model, Year)
  - CAR has two keys:
    - Key1 = {State, Reg#}
    - Key2 = {SerialNo}
  - Both are also superkeys of CAR
  - {SerialNo, Make} is a superkey but *not* a key.
- In general:
  - Any *key* is a *superkey* (but not vice versa)
  - Any set of attributes that *includes a key* is a *superkey*
  - A *minimal* superkey is also a key

Key Constraints (continued)

- If a relation has several **candidate keys**, one is chosen arbitrarily to be the **primary key**.
  - » The primary key attributes are <u>underlined</u>.
- Example: Consider the CAR relation schema:
  - » CAR(State, Reg#, <u>SerialNo</u>, Make, Model, Year)
  - » We chose SerialNo as the primary key
- The primary key value is used to *uniquely identify* each tuple in a relation
  - » Provides the tuple identity
- Also used to *reference* the tuple from another tuple
  - » General rule: Choose as primary key the smallest of the candidate keys (in terms of size)
  - » Not always applicable – choice is sometimes subjective

CAR Table with Two Candidate Keys

CAR

License_number	Engine_serial_number	Make	Model	Year
Texas ABC-739	A69352	Ford	Mustang	02
Florida TVP-347	B43696	Oldsmobile	Cutlass	05
New York MPO-22	X83554	Oldsmobile	Delta	01
California 432-TFY	C43742	Mercedes	190-D	99
California RSK-629	Y82935	Toyota	Camry	04
Texas RSK-629	U028365	Jaguar	XJS	04

Figure 5.4
The CAR relation, with two candidate keys: License_number and Engine_serial_number.

- **Relational Database Schema:**
  - » A set S of relation schemas that belong to the same database.
  - » S is the name of the whole **database schema**
  - » S = {R1, R2, ..., Rn} and a set IC of integrity constraints.
  - » R1, R2, …, Rn are the names of the individual **relation schemas** within the database S
- Following slide shows a COMPANY database schema with 6 relation schemas

COMPANY Database Schema

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship

Figure 5.5
Schema diagram for the COMPANY relational database schema.

Relational Database State

- A **relational database state** DB of S is a set of relation states DB = $\{r_1, r_2, ..., r_m\}$ such that each r_i is a state of R_i and such that the r_i relation states satisfy the integrity constraints specified in IC.
- A relational database *state* is sometimes called a relational database *snapshot* or *instance*.
- We will not use the term *instance* since it also applies to single tuples.
- A database state that does not meet the constraints is an invalid state

Populated Database State

- Each *relation* will have many tuples in its current relation state
- The *relational database state* is a union of all the individual relation states
- Whenever the database is changed, a new state arises
- Basic operations for changing the database:
  - INSERT a new tuple in a relation
  - DELETE an existing tuple from a relation
  - MODIFY an attribute of an existing tuple
- Next slide shows an example state for the COMPANY database schema shown in Fig. 5.5.

Populated Database State for COMPANY Database Schema

Figure 5.6
One possible database state for the COMPANY relational database schema.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPARTMENT

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

DEPT_LOCATIONS

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

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship
333445555	Alice	F	1986-04-05	Daughter
333445555	Theodore	M	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	M	1942-02-28	Spouse
123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

- **Entity Integrity:**
  - The *primary key attributes* PK of each relation schema R in S cannot have null values in any tuple of r(R).
    - This is because primary key values are used to *identify* the individual tuples.
    - $t[PK] \neq$ null for any tuple t in r(R)
    - If PK has several attributes, null is not allowed in any of these attributes
  - Note: Other attributes of R may be constrained to disallow null values, even though they are not members of the primary key.

Referential Integrity

- A constraint involving **two** relations
  - The previous constraints involve a single relation.
- Used to specify a **relationship** among tuples in two relations:
  - The **referencing relation** and the **referenced relation.**

Referential Integrity (continued)

- Tuples in the **referencing relation** R1 have attributes FK (called **foreign key** attributes) that reference the primary key attributes PK of the **referenced relation** R2.
  - » A tuple t1 in R1 is said to **reference** a tuple t2 in R2 if t1[FK] = t2[PK].
- A referential integrity constraint can be displayed in a relational database schema as a directed arc from R1.FK to R2.

Referential Integrity (or Foreign Key) Constraint

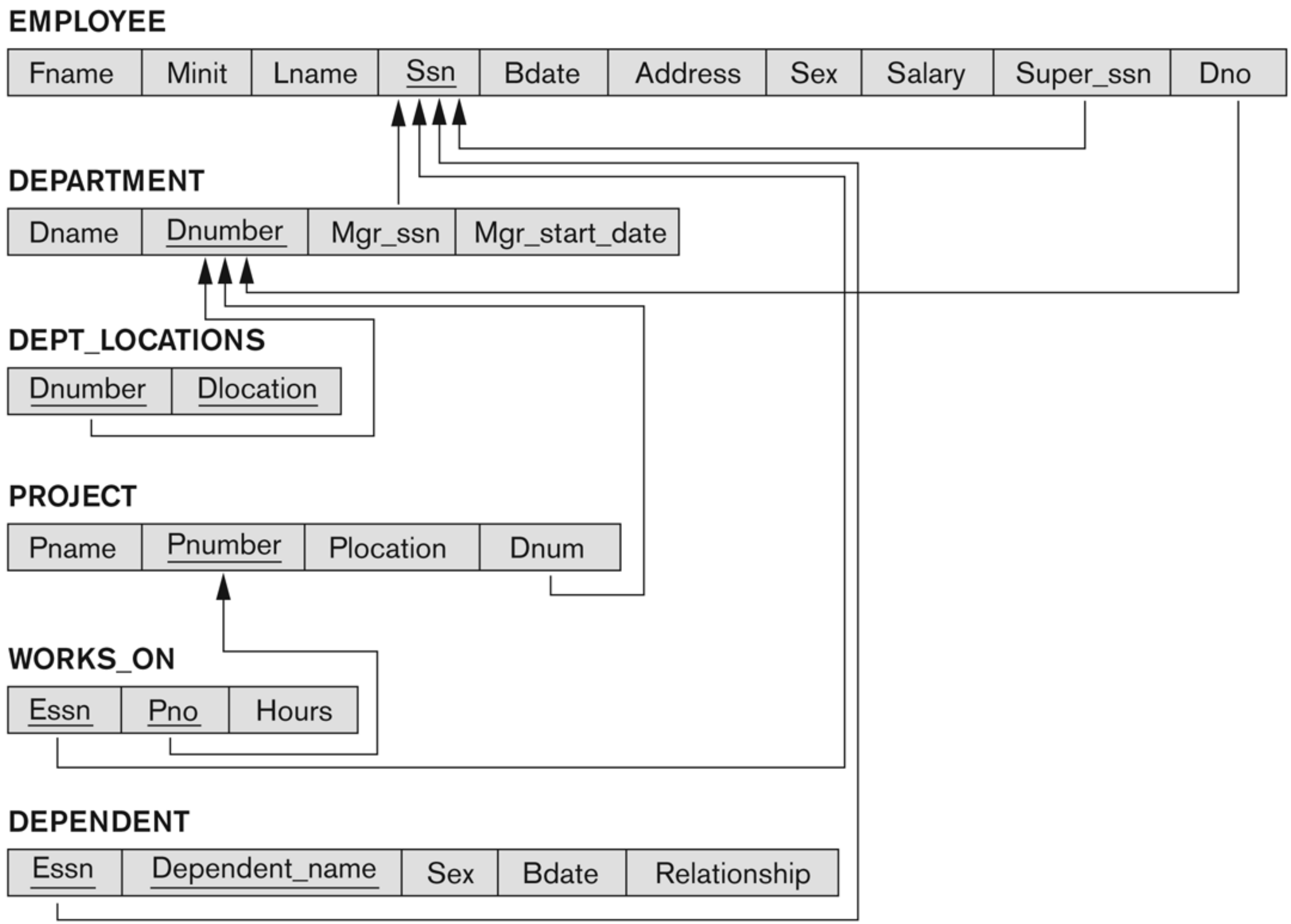
- Statement of the constraint
  - » The value in the foreign key column (or columns) FK of the the **referencing relation** R1 can be **either**:
    - (1) a value of an existing primary key value of a corresponding primary key PK in the **referenced relation** R2, <u>or</u>
    - (2) a **null**.
- In case (2), the FK in R1 should **not** be a part of its own primary key.

Displaying a Relational Database Schema and its Constraints

- Each relation schema can be displayed as a row of attribute names
- The name of the relation is written above the attribute names
- The primary key attribute (or attributes) will be underlined
- A foreign key (referential integrity) constraints is displayed as a directed arc (arrow) from the foreign key attributes to the referenced table
  - Can also point the the primary key of the referenced relation for clarity
- Next slide shows the COMPANY **relational schema diagram with referential integrity constraints**

Referential Integrity Constraints for COMPANY Database

Figure 5.7
Referential integrity constraints displayed on the COMPANY relational database schema.



Other Types of Constraints

- Semantic Integrity Constraints:
  - » based on application semantics and cannot be expressed by the model per se
  - » Example: “the max. no. of hours per employee for all projects he or she works on is 56 hrs per week”
- A **constraint specification** language may have to be used to express these
- SQL-99 allows **CREATE TRIGGER** and **CREATE ASSERTION** to express some of these semantic constraints
- Keys, Permissibility of Null values, Candidate Keys (Unique in SQL), Foreign Keys, Referential Integrity etc. are expressed by the **CREATE TABLE** statement in SQL.

Other Types of Constraints (continued)

- Functional dependency constraint
  - Establishes a functional relationship among two sets of attributes *X* and *Y*
  - Value of *X* determines a unique value of *Y*
- State constraints
  - Define the constraints that a valid state of the database must satisfy
- Transition constraints
  - Define to deal with state changes in the database

Storage Of Constraints (aka., "Business Rules")

- Assume that it is the policy of our enterprise that the value of Salary is determined only by the value of Grade; this is an example of a ***business rule***
  - Thus the fact that the Grade = 2 implies Salary = 80 is written twice in the database
  - This is another type of redundancy, which is less obvious at first
- There are additional problems with this design.
  - We are unable to store the salary structure for a Grade that does not currently exist for any employee.
  - For example, we cannot store that Grade = 1 implies Salary = 90
  - For example, if employee with SSN = 132 leaves, we forget which Salary should be paid to employee with Grade = 3
  - We could perhaps invent a fake employee with such a Grade and such a Salary, but this brings up additional problems, e.g.,

    What is the SSN of such a fake employee?
- Note that our constraints specify a pay scale, which is independent of a particular employee

Handling Storage Of Constraints

- The problem can be solved by replacing

Name	SSN	DOB	Grade	Salary
A	121	2367	2	80
A	132	3678	3	70
B	101	3498	4	70
C	106	2987	2	80

with two tables

Name	SSN	DOB	Grade
A	121	2367	2
A	132	3678	3
B	101	3498	4
C	106	2987	2

Grade	Salary
2	80
3	70
4	70

Handling Storage Of Constraints

- And now we can store information more naturally
  - We can specify that Grade 3 implies Salary 70, even after the only employee with this Grade, i.e., employee with SSN 132 left the enterprise
  - We can specify that Grade 1 (a new Grade just established) implies Salary 90, even before any employee with this grade is higher

Name	SSN	DOB	Grade
A	121	2367	2
B	101	3498	4
C	106	2987	2

Grade	Salary
1	90
2	80
3	70
4	70

Clean Design Versus Efficiency

- However, if the correlation between an employee and salary is needed frequently, e.g., for producing payroll, it may be inefficient to recompute this correlation repeatedly.
- So, returning to our original instance of the database, perhaps we should have (despite some redundancy) both the original table and the table associating salaries with grades

Name	SSN	DOB	Grade	Salary
A	121	2367	2	80
A	132	3678	3	70
B	101	3498	4	70
C	106	2987	2	80

Grade	Salary
2	80
3	70
4	70

Sample Database State

Figure 3.6
One possible database state for the COMPANY relational database schema.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPARTMENT

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

DEPT_LOCATIONS

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

Sample Database State (cont'd)

Figure 3.6
One possible database state for the COMPANY relational database schema.

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

PROJECT

Pname	Pnumber	Plocation	Dnum
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123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

Sample Referential Integrity Constraints

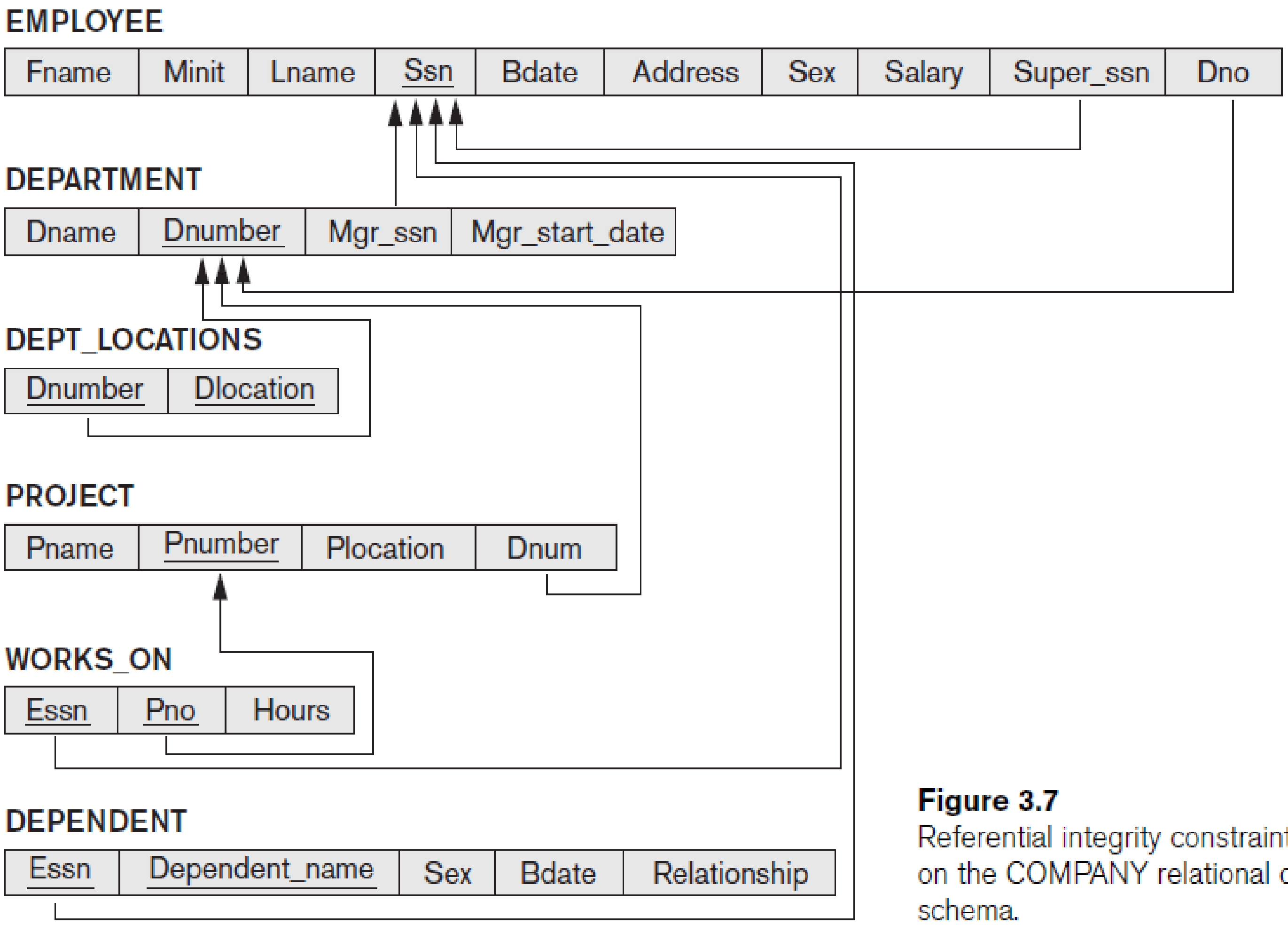

Figure 3.7
Referential integrity constraints displayed on the COMPANY relational database schema.

One More Problem

- What if it becomes illegal to use social security numbers for anything other than payroll related matters?
- We will have an incredible mess and enormous amount of work to restructure the database, unless we have designed the application appropriately to begin with
- Of course, we did not know that it would become illegal to use social security numbers and it was convenient to do so, so that's what we used
- So how to be able to anticipate potential problems?
- NYU had to spend considerable effort to switch from social security numbers to University ID's
- We will discuss how to "anticipate" such problems, so such switching is painless

Update Operations on Relations

- INSERT a tuple.
- DELETE a tuple.
- MODIFY a tuple.
- Integrity constraints should not be violated by the update operations.
- Several update operations may have to be grouped together.
- Updates may **propagate** to cause other updates automatically. This may be necessary to maintain integrity constraints.

Update Operations on Relations (continued)

- In case of integrity violation, several actions can be taken:
  - Cancel the operation that causes the violation (RESTRICT or REJECT option)
  - Perform the operation but inform the user of the violation
  - Trigger additional updates so the violation is corrected (CASCADE option, SET NULL option)
  - Execute a user-specified error-correction routine

Possible Violations for Insert Operation

- INSERT may violate any of the constraints:
  - Domain constraint:
    - if one of the attribute values provided for the new tuple is not of the specified attribute domain
  - Key constraint:
    - if the value of a key attribute in the new tuple already exists in another tuple in the relation
  - Referential integrity:
    - if a foreign key value in the new tuple references a primary key value that does not exist in the referenced relation
  - Entity integrity:
    - if the primary key value is null in the new tuple

Possible Violations for Delete Operation

- DELETE may violate only referential integrity:
  - » If the primary key value of the tuple being deleted is referenced from other tuples in the database
    - Can be remedied by several actions: RESTRICT, CASCADE, SET NULL (see Chapter 6 for more details)
      - – RESTRICT option: reject the deletion
      - – CASCADE option: propagate the new primary key value into the foreign keys of the referencing tuples
      - – SET NULL option: set the foreign keys of the referencing tuples to NULL
  - » One of the above options must be specified during database design for each foreign key constraint

Possible Violations for Update Operation

- UPDATE may violate domain constraint and NOT NULL constraint on an attribute being modified
- Any of the other constraints may also be violated, depending on the attribute being updated:
  - » Updating the primary key (PK):
    - Similar to a DELETE followed by an INSERT
    - Need to specify similar options to DELETE
  - » Updating a foreign key (FK):
    - May violate referential integrity
  - » Updating an ordinary attribute (neither PK nor FK):
    - Can only violate domain constraints

Different Users Need Different Data

- It may be our goal to create a design that best reflects the inherent properties of the data.
  - » But, various user groups may need to look at the data assuming different structure (organization) of the data
- For privacy/security reasons we may want to give different users different access privileges to the database
  - » The payroll department can see salaries but cannot see diseases.
  - » The health department can see diseases but cannot see salaries.
- Users may prefer to look at different aspects of the information.
  - » The payroll department may prefer to see the salary in a different currency
  - » The health department may prefer to see Age instead of, or in addition to DOB

Views

- A possible solution: give each user (class of users) privileges to look at a ***view***, that is, a small derived database
- The health department may think that there is a table:

Name	SSN	City	DOB	Age	Illness	Date
A	121	Portland	2367	47	Flu	2987
B	101	Boston	3498	25	Cold	3498

- The database should provide such a view, which is computed from the existing tables (and the current date), without the user knowing other (prohibited for this user) information
- We need to leave flexibility for unanticipated queries.
  - Some people may later be given the right and want to ask the query: "How are salaries and diseases correlated?"

Manipulating Data Through Views

- The ideal goal is for the users to both query and modify the database through views
- Unfortunately, sometimes it impossible or difficult to do so
  - » If the user wants to change the age of an employee, how should the change be reflected in the date of birth?

    There is no unique way of doing it
  - » How to change the sum of salaries, if some view contains this information?

    We want to give a total raise of 5% (increase sum of salaries by 5%), so how to reflect this in individual salaries?

    Some employees may get more than 5% and some may get less than 5%

Agenda

- The need for database management systems
- Brief overview of the relational model
- Querying relational database directly and through views
- Need for good logical design
- Need for good physical design
- Recovery
- Concurrency
- Layers of database management systems
- Independence between/among layers
- Various roles of designers, users, and maintainers

Physical Design

- The database system must be organized so that it is able to process queries efficiently
- To do this:
  - *Files must be organized appropriately*
  - *Indices may be employed*
- For example, if we frequently want to find the grade for various SSN, perhaps the file should be hashed on this value, allowing direct access
- But, if we want to print the salaries of all the employees born in 2783, maybe the file should be sorted by DOB
- Physical design of databases deals with such issues (including how to distribute information among various sites), which are also closely related to the optimization of query processing

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Recovery

- The database must be resilient even though the system is prone to faults.
- Assume one more table, describing employees' accounts in the credit union

SSN	Savings	Checking
101	40	30
106	40	20
121	0	80
132	10	0

- We want to give each employee a bonus of 10 in the savings account.
  - To do that, a transaction (execution of a user program) will sequentially change the values of Savings

Example Of A Problem

- The file describing the table is stored on a disk, values are read into RAM, modified and written out
- If X is a local variable then we have a trace of the desired execution (in shorthand):

.	
X := Savings[101]	read from disk
X := X + 10	process in RAM
Savings[101] := X	write to disk
.	

- What if the system crashes in the middle, say power goes out
- We do not know which of the values have been changed, so what to do to recover (get back a correct state)?
- Various techniques exist for managing the execution, so that reliable execution is possible

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Concurrency

- There may also be problems because of the concurrent execution of several transactions in a time sharing system
- Assume that we are running a transaction, T1 (an “reporting” transaction), that should compute and print for each employee the sum of Savings and Checking:

SSN	Balance
101	70
106	60
121	80
132	10

- Concurrently SSN = 121 wants to move 40 from Checking to Savings, using transaction T2 (a “moving” transaction)
- In a time-sharing system we could have an incorrect execution.
- We will write “CH” for Checking and “SA” for Savings

The Transaction Concept

- Transaction
  - Executing program
  - Includes some database operations
  - Must leave the database in a valid or consistent state
- Online transaction processing (OLTP) systems
  - Execute transactions at rates that reach several hundred per second

Execution Trace Of Two Transactions

T1	T2
.	
X1 := SA[121] (X1 = 0)	
	Y1 := CH[121] (Y1 = 80)
	Y1 := Y1 − 40 (Y1 = 40)
	CH[121] := Y1
X2 := CH[121] (X2 = 40)	
X1 := X1 + X2 (X1 = 40)	
PRINT X1 (X1 = 40)	
	Y2 := SA[121] (Y2 = 0)
	Y2 := Y2 + 40 (Y2 = 40)
	SA[121] := Y2
.	

- We get 40, an incorrect value of Balance for SSN = 121
- Standard operating system constructs do not help here, but concurrency control mechanisms that solve the problem exist in databases (but not in Microsoft Access)

Some Concurrency Aspects

- In the previous examples, we could allow the two transactions to interleave in this way, with the user of the “reporting” transaction being told that correct results are not guaranteed
- The user may get only approximate result, which perhaps is sufficient if we are producing “statistical” reports
- But the database will remain consistent (correct) and the “moving” transaction can execute
- But if instead of the “reporting” transaction which only read the database, we have a “multiplying” transaction that updates all the values in the database by multiplying them by 2, then the database could be corrupted, and the interleaving cannot be permitted

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The Layers/Levels Of The Ideal Database

- It is customary to think of the database as made of several layers or levels, which are not completely standardized
- Different levels have different roles
- We will think of 4 levels:

» **External** (User)	Various user views
» **Conceptual** (Community)	Description of the enterprise
» **Internal** (Physical)	Files, access methods, indices, distribution
» **Database O.S.**	Recovery and concurrency

- The database, does not run on a bare machine
- The Database O.S. (DBOS) runs on top of the O.S., such as Windows or Linux

The Conceptual Level

- The conceptual level is most fundamental as it describes the total information and its structure/meaning
  - to the extent we understand the information and know how to express our understanding
- It is also generally used for manipulating the database, that is querying and modifying it
- The tools we have:
  - ***Data Definition Language*** (DDL), for description
  - ***Data Manipulation Language*** (DML), for querying and modifying
- Tables in our example (their structure, not the specific values which change in time) were a kind of DDL
  - They form a schema, a description of the structure.
- Of course, this level changes as the needs of the enterprise change

The External Level

- The external level is seen by various users.
- Each view (subschema) is like a small conceptual level.
- It can also change in time.
- A particular view may be modified, deleted, or added even if the conceptual level does not change
  - For example, it may become illegal for some user to see some information

The Internal Level

- The internal level deals with file organization/storage management
- It changes in time too
  - New storage devices are brought
  - Files may have indices created because some queries have become more frequent
  - The data may be geographically distributed

The Data Base Operating System Level

- The data base operating system level deals with concurrency and recovery
- The data base operating system can change too
- The vendor of the data base may discover better methods to handle recovery/concurrency

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Independence Among Levels

- A very important goal is (Data-) independence between/among levels
- We must make sure that changes in one level disturb as little as possible the other levels (propagate as little as possible)

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Who Does What?

- The vendor sends:
  - The database operating system
  - Tools to create and manipulate the three top levels: external, conceptual, and internal
- The database administrator (DBA) and his/her staff discuss with the users what information the database should contain and its structure
  - A common model (language for describing reality) is needed for them to communicate

    Entity-relationship model is frequently used
- The DBA and the users design the conceptual and the external levels

Design And Management Of The System

- During the actual design the database administrator uses a specific data model and a specific DDL (a completely precise way of describing the data)
  - Now, it is usually relational
  - Previously hierarchical and network models were popular
  - In the future, perhaps object-oriented (some in use)
- The database administrator and the users write programs in DML to access and manipulate the database
- The database administrator maintains the internal level changing it depending on changing applications and equipment
- The database administrator makes backups, arranges for recovery, etc
- The above description is idealized

Challenges

- We have seen just the tip of the iceberg of what needs to happen for database systems to function as required
- We need
  - Natural semantics
  - Convenient syntax
  - Efficiency
  - 100% reliability
- Enormous effort has been spent since mid 70s to achieve this

Agenda

1. Session Overview
2. Relational Data Model & Database Constraints
3. Summary and Conclusion

Summary

- Presented Relational Model Concepts
  - Definitions
  - Characteristics of relations
- Discussed Relational Model Constraints and Relational Database Schemas
  - Domain constraints
  - Key constraints
  - Entity integrity
  - Referential integrity
- Described the Relational Update Operations and Dealing with Constraint Violations

Exercise

(Taken from Exercise 5.15)

Consider the following relations for a database that keeps track of student enrollment in courses and the books adopted for each course:

STUDENT(<u>SSN</u>, Name, Major, Bdate)

COURSE(<u>Course#</u>, Cname, Dept)

ENROLL(<u>SSN</u>, <u>Course#</u>, <u>Quarter</u>, Grade)

BOOK_ADOPTION(<u>Course#</u>, <u>Quarter</u>, Book_ISBN)

TEXT(<u>Book_ISBN</u>, Book_Title, Publisher, Author)

Draw a relational schema diagram specifying the foreign keys for this schema.

Assignments & Readings

- Readings

  - » Slides and Handouts posted on the course web site
  - » Textbook: Chapter 5

- Assignment #2
  - » Textbook exercises: 1.9, 1.12, 2.14, 2.15, 5.16, 5.18, 5.20

- Project Framework Setup
  - » TBD

Next Session: - Data Modeling Using ER Model
- Relational Design via ER/EER to Relational Mapping

Any Questions?