The Extended Entity Relationship Model and Object Model

By

Bishnu Gautam

New Summit College

ER Model (Revisited)

- Why ER model?
  - A very popular high-level conceptual data model
  - Facilitates database design by specifying schema that represent the overall logical structure of the DB
  - Entities and attributes: an attribute is a function which maps an entity set into a domain

    eg. Faculty (Name, Dept, SSN)

    domain for attribute Dept = {CS, EE, APMA, SYS}
  - A particular entity is described by a set of values:

    {(Name: John Doe), (Dept: CS), (SSN: 123-45-6789)}
  - Entity type plays a particular role in a relationship: usually implicit but must be specified if not distinct

    eg.Parents (Person, Person), War (Country, Country)

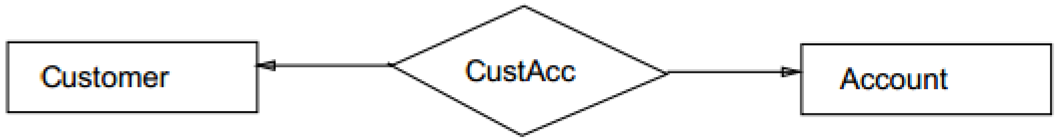
Mapping Cardinality

- Relationships
  - 1:1, 1:N, N:M are distinguished by a directed line
  - A directed line represents "at most one", not requiring there must be one corresponding entity for every entity
  - A description of all possible associations in the real-world that is being modeled
  - 1:1 relationship is rather rare in databases, while N:M relationships are quite common (hard to represent)
  - Naming relationships are sometimes tricky

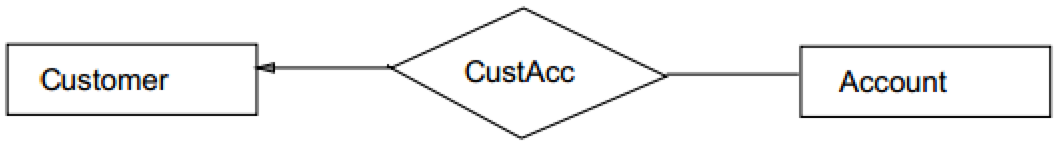
    eg. A relationship between Faculty and Students:

Should it be advisee or advisor?

Mapping Cardinality

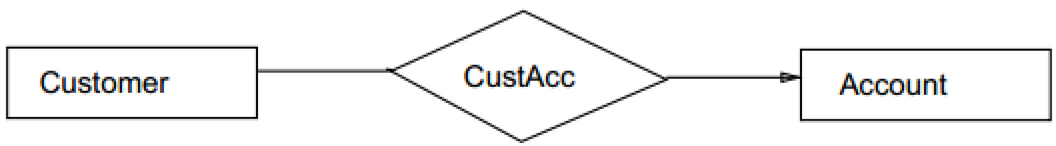


One-to-one relationship (one customer - one account)



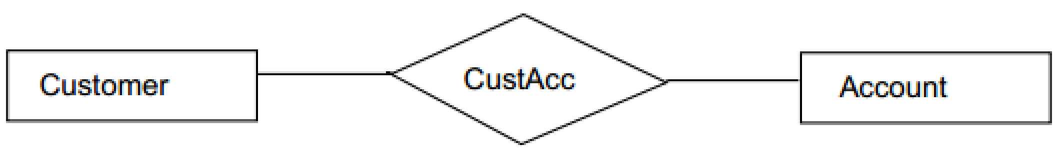
One-to-many from customer to account

A customer can have several accounts, but no account can be shared



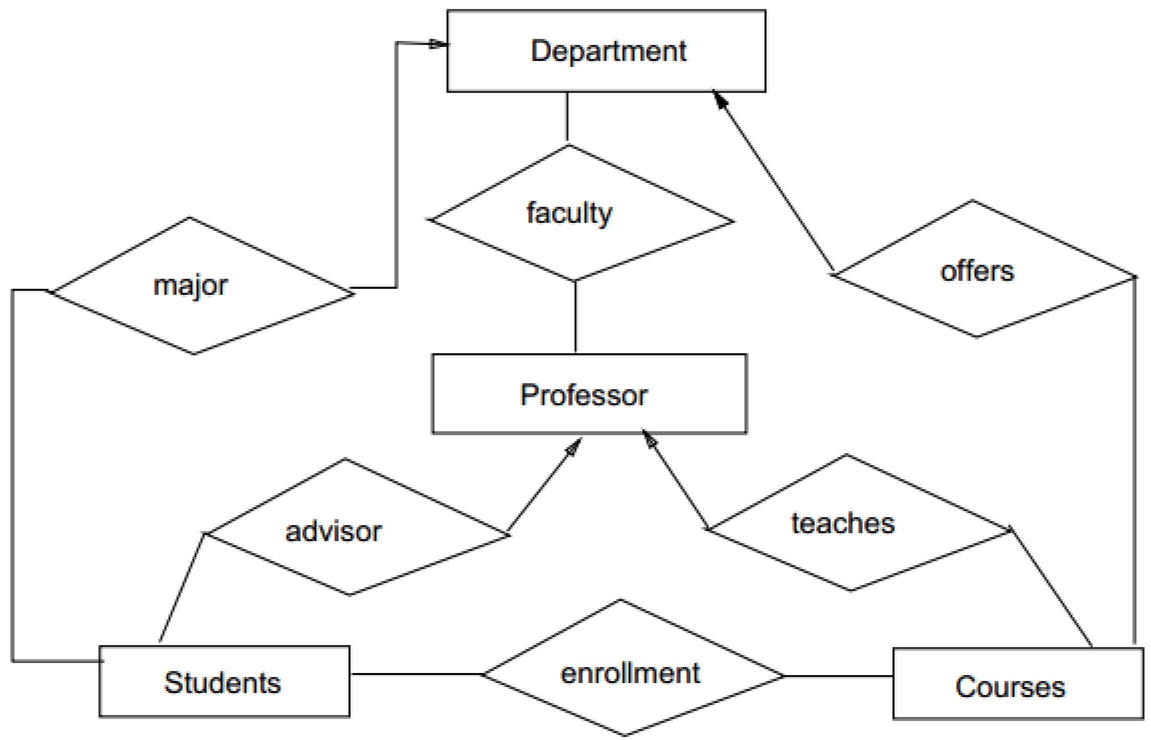
Many-to-one from customer to accountss

A customer can have only one account, but accounts can be shared



Many-to-many relationship

ER Diagram Design



An ER diagram represents several assertions about the real-world.
When attributes are added, more assertions are made.
How can we ensure that it is "faithful"?

- A database is judged correct if it captures ER diagram correctly.

- There is no way of verifying that ER diagram is logically correct.

Key Attributes

- Key and key attributes

  key: a unique value for an entity

  key attributes: a group of one or more attributes that uniquely identify an entity in the entity set

- Super key, candidate key, and primary key

  super key: a set of one or more attributes which allows to identify uniquely an entity in the entity set

  candidate key: minimal super key there can be many candidate keys

  eg. Employee (Name, Address, SSN, Salary, Project)

  (Name, Address) and (SSN) are candidate keys, but

  (Name, SSN) is not a candidate key

  primary key: a candidate key chosen by the DB designer denoted by underlining in ER diagram

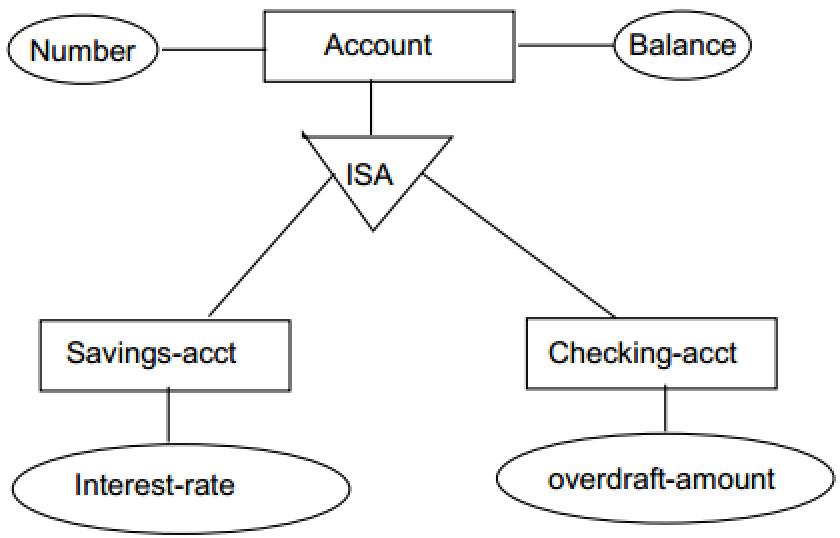
Weak Entity Types

- Weak entity type
  - Its existence depends on other entity (owner)
  - No key attributes of its own
  - Cannot be identified without an owner entity
  - Indicated in ER diagram by a double outlined boxes

    eg. Transaction (Txn#, Type, Date, Amount) is a weak entity with Account (Ac#, Balance) as its owner entity
- Partial key
  - A set of attributes that can uniquely identify weak entities related to the same owner entity eg. Txn# is a partial key in Transaction entity
- To use weak entity types or not?
  - Basically the designers choice.
  - Preferable if it has many attributes and participates in relationships besides its owner entity types.

Generalization

- Relationships among entity types
  - To emphasize the similarities among lower-level entity types and to hide their differences
  - Attributes of higher-level entity sets are inherited by lower-level entity sets



Transforming ISA into Relations

- Create a relation for the higher-level entity set, and for each lower-level entity set, create a relation with the primary key of the higher-level entity set

    Account (Number, Balance)

    Savings-acct (Number, Interest-rate)

    Checking-acct (Number, Overdraft-amount)

- Do not create for higher-level entity set. For each lower-level entity set, create a relation with all the attributes of the higher-level entity set

    Savings-acct (Number, Balance, Interest-rate)

    Checking-acct (Number, Balance, Overdraft-amount)

The second method is possible only when the generalization is

Disjoint: no entity belongs to more than 2 subclass

Complete: every member of superclass is a member of subclass

Complex Data Types

- Motivation:
  - Permit non-atomic domains (atomic ≡ indivisible)
  - Example of non-atomic domain: set of integers or set of tuples
  - Allows more intuitive modeling for applications with complex data
- Intuitive definition:
  - allow relations whenever we allow atomic (scalar) values
    - relations within relations
  - Retains mathematical foundation of relational model
  - Violates first normal form

Example of a Nested Relation

- Example: library information system
- Each book has
  - title,
  - a list (array) of authors,
  - Publisher, with subfields *name* and *branch*, and
  - a set of keywords
- Non-1NF relation *books*

title	*author_array*	*publisher*	*keyword_set*
		(*name*, *branch*)	
Compilers	[Smith, Jones]	(McGraw-Hill, NewYork)	{parsing, analysis}
Networks	[Jones, Frick]	(Oxford, London)	{Internet, Web}

4NF Decomposition of Nested Relation

- Suppose for simplicity that title uniquely identifies a book
  - In real world ISBN is a unique identifier
- Decompose *books* into 4NF using the schemas:
  - (*title, author, position*)
  - (*title, keyword*)
  - (*title, pub-name, pub-branch*)
- 4NF design requires users to include joins in their queries.

title	*author*	*position*
Compilers	Smith	1
Compilers	Jones	2
Networks	Jones	1
Networks	Frick	2

authors

title	*keyword*
Compilers	parsing
Compilers	analysis
Networks	Internet
Networks	Web

keywords

title	*pub_name*	*pub_branch*
Compilers	McGraw-Hill	New York
Networks	Oxford	London

books4

Complex Types and SQL

- Extensions introduced in SQL:1999 to support complex types:
  - Collection and large object types
    - Nested relations are an example of collection types
  - Structured types
    - Nested record structures like composite attributes
  - Inheritance
  - Other object orientation features
    - Including object identifiers and references
- Not fully implemented in all the database system
  - But some features are present in each of the major commercial database systems
    - Read the manual of your database system to see what it supports

Structured Types and Inheritance in SQL

- **Structured types** (**user-defined types**) can be declared and used in SQL

```
create type Name as
    (firstname      varchar(20),
     lastname       varchar(20))
     final

create type Address as
    (street     varchar(20),
     city       varchar(20),
     zipcode    varchar(20))
     not final
```

  – Note: **final** and **not final** indicate whether subtypes can be created

- Structured types can be used to create tables with composite attributes

```
create table person (
    name        Name,
    address     Address,
    dateOfBirth date)
```

- Dot notation used to reference components: ***name.firstname***

Structured Types (cont.)

- **User-defined row types**

  create type *PersonType* **as** (
  name Name,
  address Address,
  dateOfBirth **date**)
  not final

- Can then create a table whose rows are a user-defined type
  create table *customer* **of** *PersonType*

- Alternative using **unnamed row types**.

  create table *person_r*(
  name **row(**first*name* **varchar**(20),
  lastname **varchar**(20)),
  address **row(***street* **varchar**(20),
  city **varchar**(20),
  zipcode **varchar**(20)),
  dateOfBirth **date**)

Methods

- Can add a method declaration with a structured type.

  method *ageOnDate* (*onDate* **date**)

  returns interval year
- Method body is given separately.

```
create instance method ageOnDate (onDate date)
        returns interval year
        for CustomerType
begin
        return onDate - self.dateOfBirth;
end
```

- We can now find the age of each customer:

```
select name.lastname, ageOnDate (current_date)
from customer
```

Constructor Functions

- **Constructor functions** are used to create values of structured types
- E.g.
  create function *Name*(*firstname* **varchar**(20), *lastname* **varchar**(20))
  returns *Name*
  begin
  set self.*firstname = firstname;*
  set self.*lastname = lastname;*
  end
- To create a value of type *Name,* we use
  new *Name*('John', 'Smith')
- Normally used in insert statements
  insert into *Person* **values**
  (**new** *Name*('John', 'Smith),
  new *Address*('20 Main St', 'New York', '11001'),
  date '1960-8-22');

Type Inheritance

- Suppose that we have the following type definition for people:

```
create type Person
    (name varchar(20),
     address varchar(20))
```

- Using inheritance to define the student and teacher types

```
create type Student     under Person
  (degree       varchar(20),
   department   varchar(20))
create type Teacher     under Person
  (salary       integer,
   department   varchar(20))
```

- Subtypes can redefine methods by using **overriding method** in place of **method** in the method declaration

Multiple Type Inheritance

- SQL:1999 and SQL:2003 do not support multiple inheritance
- If our type system supports multiple inheritance, we can define a type for teaching assistant as follows:

  create type *Teaching Assistant*
  under *Student*, *Teacher*
- To avoid a conflict between the two occurrences of *department* we can rename them

  create type *Teaching Assistant*
  under
  Student **with** (*department* **as** *student_dept*),
  Teacher **with** (*department* **as** *teacher_dept*)
- Each value must have a **most-specific type**

Table Inheritance

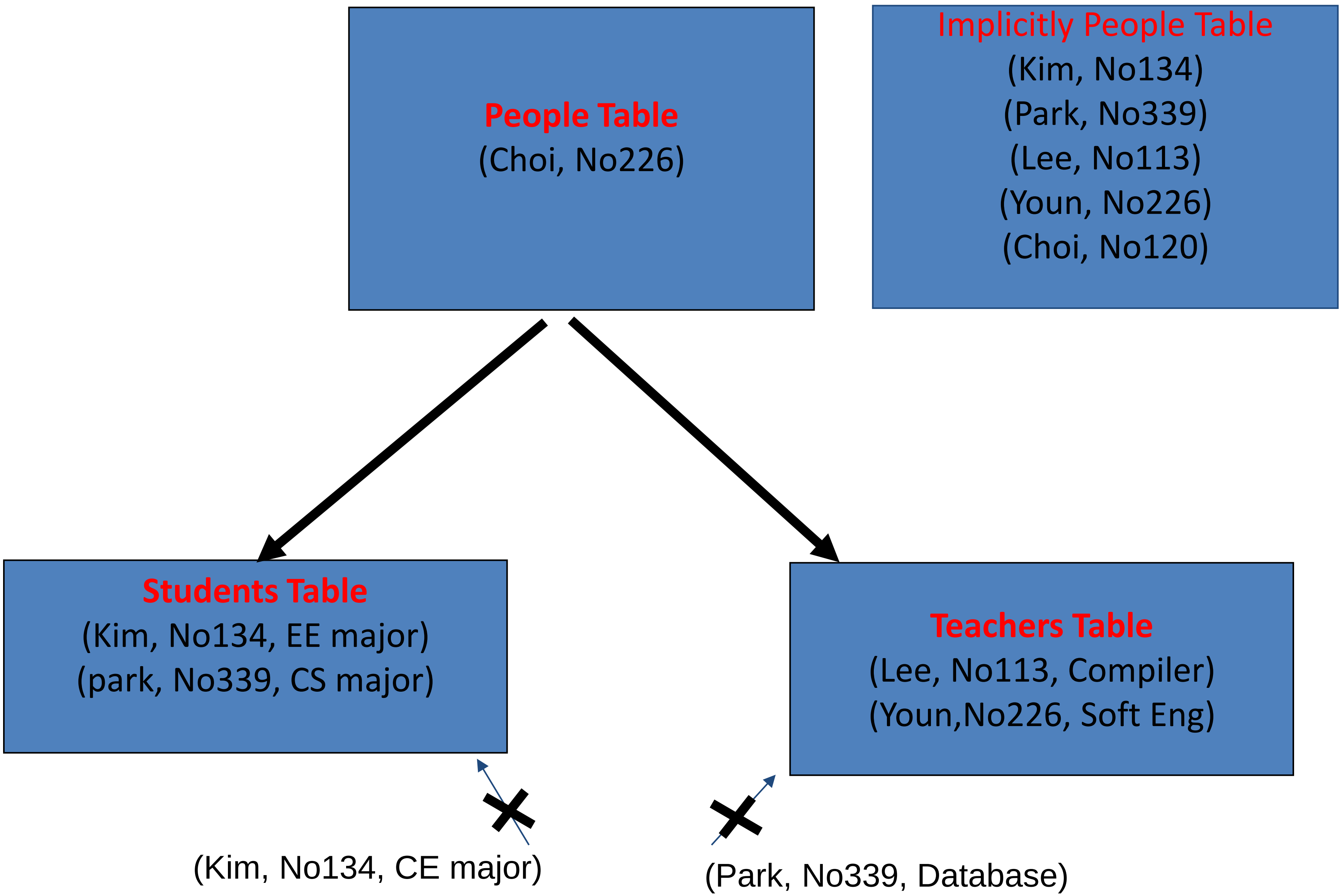
- Tables created from subtypes can further be specified as **subtables**
- E.g. **create table** *people* **of** *Person;*
  create table *students* **of** *Student* **under** *people;*
  create table *teachers* **of** *Teacher* **under** *people;*
- Tuples added to a subtable are automatically visible to queries on the supertable
  - E.g. query on *people* also sees *students* and *teacher*s.
  - Similarly updates/deletes on *people* also result in updates/deletes on subtables
  - To override this behaviour, use "**only** *people"* in query
- Conceptually, multiple inheritance is possible with tables
  - e.g. *teaching_assistants* under *students* and *teachers*
  - *But is not supported in SQL currently*
    - So we cannot create a person (tuple in *people*) who is both a student and a teacher

Consistency Requirements for Subtables

- Consistency requirements on subtables and supertables.
  - Each tuple of the supertable (e.g. *people)* can correspond to at most one tuple in each of the subtables (e.g. *students* and *teachers)*
  - Additional constraint in SQL:1999:

    All tuples corresponding to each other (that is, with the same values for inherited attributes) must be derived from one tuple (inserted into one table).
    - That is, each entity must have a most specific type
    - We cannot have a tuple in *people* corresponding to a tuple each in *students* and *teachers*

Subtable Consistency



Array and Multiset Types in SQL

- Example of array and multiset declaration:

```
create type Publisher as
  (name          varchar(20),
   branch        varchar(20));
create type Book as
  (title         varchar(20),
   author_array  varchar(20) array [10],
   pub_date      date,
   publisher     Publisher,
   keyword-set   varchar(20) multiset);
 create table books of Book;
```

Creation of Collection Values

- Array construction
  array [‘Silberschatz’,`Korth’,`Sudarshan’]

- Multisets
  multiset [‘computer’, ‘database’, ‘SQL’]

- To create a tuple of the type defined by the books relation:
  (‘Compilers’, **array**[`Smith’,`Jones’],
  new *Publisher* (`McGraw-Hill’,`New York’),
  multiset [`parsing’,`analysis’])

- To insert the preceding tuple into the relation books
  insert into *books*
  values
  (‘Compilers’, **array**[`Smith’,`Jones’],
  new *Publisher* (`McGraw-Hill’,`New York’),
  multiset [`parsing’,`analysis’]);

Querying Collection-Valued Attributes

- To find all books that have the word "database" as a keyword,

  select *title*
  from *books*
  where 'database' **in** (**unnest**(*keyword-set*))

- We can access individual elements of an array by using indices
  - E.g.: If we know that a particular book has three authors, we could write:

  select *author_array*[1], *author_array*[2], *author_array*[3]
  from *books*
  where *title* = `Database System Concepts'

- To get a relation containing pairs of the form "title, author_name" for each book and each author of the book

  select *B.title, A.author*
  from *books* **as** *B*, **unnest** (*B.author_array*) **as** *A* (*author*)

- To retain ordering information we add a **with ordinality** clause

  select *B.title, A.author, A.position*
  from *books* **as** *B*, **unnest** (*B.author_array*) **with ordinality as**
  A (*author, position*)

Unnesting

- The transformation of a nested relation into a form with fewer (or no) relation-valued attributes is called **unnesting**.
- E.g.

  select *title*, *A* **as** *author*, *publisher.name* **as** *pub_name*,
  publisher.branch **as** *pub_branch*, *K.keyword*
  from *books* **as** *B*, **unnest**(*B.author_array*) **as** *A* (*author*),
  unnest (*B.keyword_set*) **as** *K* (*keyword*)
- Result relation *flat_books*

title	*author*	*pub_name*	*pub_branch*	*keyword*
Compilers	Smith	McGraw-Hill	New York	parsing
Compilers	Jones	McGraw-Hill	New York	parsing
Compilers	Smith	McGraw-Hill	New York	analysis
Compilers	Jones	McGraw-Hill	New York	analysis
Networks	Jones	Oxford	London	Internet
Networks	Frick	Oxford	London	Internet
Networks	Jones	Oxford	London	Web
Networks	Frick	Oxford	London	Web

Querying Collection-Valued Attributes

- To find all books that have the word “database” as a keyword,

  select title
  from books
  where ‘database’ in (unnest(keyword-set))

- We can access individual elements of an array by using indices
  - E.g.: If we know that a particular book has three authors, we could write:

  select *author-array*[1], *author-array*[2], *author-array*[3]
  from *books*
  where *title* = `Database System Concepts’

- To get a relation containing pairs of the form “title, author-name” for each book and each author of the book

  select *B.title, A.author*

  from *books* **as** *B*, **unnest** (*B.author-array*) **as** *A* (*author*)

- To retain ordering information we add a **with ordinality** clause **select** *B.title, A.author, A.position*

  from *books* **as** *B*, **unnest** (*B.author-array*) **with ordinality as** *A* (*author, position*)

Nesting

- **Nesting** is the opposite of unnesting, creating a collection-valued attribute
- Nesting can be done in a manner similar to aggregation, but using the function **colect**() in place of an aggregation operation, to create a multiset
- To nest the *flat_books* relation on the attribute *keyword*:

select *title*, *author*, *Publisher* (*pub_name, pub_branch*) **as** *publisher*,
 collect (*keyword*) **as** *keyword_set*
from *flat_books*
groupby *title, author, publisher*

- To nest on both authors and keywords:

select *title*, **collect** (*author*) **as** *author_set*,
 Publisher (*pub_name, pub_branch*) **as** *publisher*,
 collect (*keyword*) **as** *keyword_set*
from *flat_books*
group by *title*, *publisher*

Nesting(Collect)

title	*author*	*pub-name*	*pub-branch*	*keyword*
Compilers	Smith	McGraw-Hill	New York	parsing
Compilers	Jones	McGraw-Hill	New York	parsing
Compilers	Smith	McGraw-Hill	New York	analysis
Compilers	Jones	McGraw-Hill	New York	analysis
Networks	Jones	Oxford	London	Internet
Networks	Frick	Oxford	London	Internet
Networks	Jones	Oxford	London	Web
Networks	Frick	Oxford	London	Web

title	*author-set*	*publisher*	*keyword-set*
		(*name*, *branch*)	
Compilers	{Smith, Jones}	(McGraw-Hill, New York)	{parsing, analysis}
Networks	{Jones, Frick}	(Oxford, London)	{Internet, Web}

** note: group by title, publisher

Nesting (Cont.)

- Another approach to creating nested relations is to use subqueries in the **select** clause, starting from the 4NF relation *books4*

select *title*,
        array (**select** *author*
                from *authors* **as** *A*
                where *A.title* = *B.title*
                        order by *A.position*) **as** *author_array*,
        Publisher (*pub-name*, *pub-branch*) **as** *publisher*,
        multiset (**select** *keyword*
                    from *keywords* **as** *K*
                    where *K.title* = *B.title*) **as** *keyword_set*
from *books4* **as** *B*

Object-Identity and Reference Types

- Define a type *Department* with a field *name* and a field *head* which is a reference to the type *Person,* with table *people* as scope:

  create type *Department* (
  name **varchar** (20),
  head **ref** (*Person*) **scope** *people*)

- We can then create a table *departments* as follows

  create table *departments* **of** *Department*

- We can omit the declaration **scope** people from the type declaration and instead make an addition to the **create table** statement:

  create table *departments* **of** *Department*
  (*head* **with options scope** *people*)

- Referenced table must have an attribute that stores the identifier, called the **self-referential attribute**

  create table *people* **of** *Person*
  ref is *person_id* **system generated;**

Initializing Reference-Typed Values

- To create a tuple with a reference value, we can first create the tuple with a null reference and then set the reference separately:

insert into *departments*
    values (`CS’, null)
update *departments*
    set *head* = (**select** *p.person_id*
        from *people* **as** *p*
        where *name* = `John’)
    where *name* = `CS’

User Generated Identifiers

- The type of the object-identifier must be specified as part of the type definition of the referenced table, and
- The table definition must specify that the reference is user generated

  create type *Person*
  (*name* **varchar**(20)
  address **varchar**(20))
  ref using varchar(20)
  create table *people* **of** *Person*
  ref is *person_id* **user generated**

- When creating a tuple, we must provide a unique value for the identifier:

  insert into *people* (*person_id, name, address*) **values**
  ('01284567', 'John', `23 Coyote Run')

- We can then use the identifier value when inserting a tuple into *departments*
  - Avoids need for a separate query to retrieve the identifier:

    insert into *departments*
    values(`CS', `02184567')

User Generated Identifiers (Cont.)

- Can use an existing primary key value as the identifier:

  create type *Person*
  (*name* **varchar** (20) **primary key**,
  address **varchar**(20))
  ref from (*name*)
  create table *people* **of** *Person*
  ref is *person_id* **derived**

- When inserting a tuple for *departments*, we can then use

  insert into *departments*
  values(`CS’,`John’)

Path Expressions

create type *Department* (
name **varchar** (20),
head **ref** (*Person*) **scope** *people*)

create type *Person*
(*name* **varchar**(20)
address **varchar**(20))
ref using **varchar**(20)

- Find the names and addresses of the heads of all departments:

  select *head* → *name*, *head* → *address*
  from *departments*

- An expression such as "head → name" is called a **path expression**

- Path expressions help avoid explicit joins
  - If department head were not a reference, a join of *departments* with *people* would be required to get at the address
  - Makes expressing the query much easier for the user

Implementing O-R Features in RDB

- If we want to keep existing RDBMS and utilize O-R advantages
  - Structured Type, Array, Multiset, Nested relations, Inheritance, Subtable
- Convert tables with O-R tables into Relational Tables
  - Similar to how E-R features are mapped onto relation schemas
  - Multivalued attribute vs Multi-Set valued attribute
  - Composite attribute vs Structured Type
  - ISA vs Table Inheritance
- Subtable implementation
  - Each table stores primary key and those attributes locally defined in that table or,
  - Each table stores both locally defined and inherited attributes

Persistent OO Programming Languages

- Languages extended with constructs to handle persistent data
- Programmer can manipulate persistent data directly
  - no need to fetch it into memory and store it back to disk (unlike embedded SQL)
- Supporting Persistent Objects inside Programming Language!
- Persistent objects:
  - **Persistence by class** - explicit declaration of persistence
  - **Persistence by creation** - special syntax to create persistent objects
  - **Persistence by marking** - make objects persistent after creation
  - **Persistence by reachability** - object is persistent if it is declared explicitly to be so or is reachable from a persistent object

Concerns in Persistent PL

- Object Identifiers
  - We need stronger version of in-memory pointers in Persistent PL
  - Degrees of permanence of object identity
    - Intraprocedure: only during execution of a single procedure
    - Intraprogram: only during execution of a single program or query
    - Interprogram: across program executions, but not if data-storage format on disk changes
    - Persistent: interprogram, plus persistent across data reorganizations
- How to represent class and its instances
- How to support Query
- How to support Transaction

Object Identity and Pointers

- Degrees of permanence of object identity
  - **Intraprocedure**: only during execution of a single procedure
  - **Intraprogram**: only during execution of a single program or query
  - **Interprogram**: across program executions, but not if data-storage format on disk changes
  - **Persistent**: interprogram, plus persistent across data reorganizations
- Persistent versions of C++ and Java have been implemented
  - C++
    - ODMG C++
    - ObjectStore
  - Java
    - Java Database Objects (JDO)

Persistent C++ Systems

- Extensions of C++ language to support persistent storage of objects
- Several proposals, ODMG standard proposed, but not much action of late
  - **persistent pointers**: e.g. d_Ref<T>
  - **creation of persistent objects**: e.g. new (db) T()
  - **Class extents**: access to all persistent objects of a particular class
  - **Relationships:** Represented by pointers stored in related objects
    - Issue: consistency of pointers
    - Solution: extension to type system to automatically maintain back-references
  - **Iterator interface**
  - **Transactions**
  - **Updates:** mark_modified() function to tell system that a persistent object that was fetched into memory has been updated
  - **Query language**

Persistent Java Systems

- Standard for adding persistence to Java : **Java Database Objects (JDO)**
  - Persistence by reachability
  - Byte code enhancement
    - Classes separately declared as persistent
    - Byte code modifier program modifies class byte code to support persistence
      - E.g. Fetch object on demand
      - Mark modified objects to be written back to database
  - Database mapping
    - Allows objects to be stored in a relational database
  - Class extents
  - Single reference type
    - no difference between in-memory pointer and persistent pointer
    - Implementation technique based on **hollow objects** (a.k.a. **pointer swizzling**)

Object-Relational Mapping

- **Object-Relational Mapping (ORM)** systems built on top of traditional relational databases
- Implementor provides a mapping from objects to relations
  - Objects are purely transient, no permanent object identity
- Objects can be retried from database
  - System uses mapping to fetch relevant data from relations and construct objects
  - Updated objects are stored back in database by generating corresponding update/insert/delete statements
- The **Hibernate** ORM system is widely used
  - described in Section 9.4.2
  - Provides API to start/end transactions, fetch objects, etc
  - Provides query language operating direcly on object model
    - queries translated to SQL
- Limitations: overheads, especially for bulk updates

Comparison of O-O and O-R Databases

- **Relational systems**
  - simple data types, powerful query languages, high protection.
- **Persistent-programming-language-based OODBs**
  - complex data types, integration with programming language, high performance.
- **Object-relational systems**
  - complex data types, powerful query languages, high protection.
- **Object-relational mapping systems**
  - complex data types integrated with programming language, but built as a layer on top of a relational database system
- Note: Many real systems blur these boundaries
  - E.g. persistent programming language built as a wrapper on a relational database offers first two benefits, but may have poor performance.