Object-Based Databases

Limitations of traditional Database system

- Databases are applied to wider range of applications like
  - CAD and
  - GIS
- Limitations to relational Databases complex data types not allowed
- Difficult to access database from programs written in Java, C++ etc.

Object-Based Databases

- Complex Data Types and Object Orientation
- Structured Data Types and Inheritance in SQL
- Table Inheritance
- Array and Multiset Types in SQL
- Object Identity and Reference Types in SQL
- Implementing O-R Features
- Persistent Programming Languages
- Comparison of Object-Oriented and Object-Relational Databases

Object-Relational Data Models

- Extend the relational data model by including object orientation and constructs to deal with added data types.
- Allow attributes of tuples to have complex types, including non-atomic values such as nested relations.
- Preserve relational foundations, in particular the declarative access to data, while extending modeling power.
- Upward compatibility with existing relational languages.

Object Relational DBMS(ORDBMS)

RDBMS Concept

- Secondary storage Management
- Schema Management
- Concurrency Control
- Transaction management
- Recovery
- Query Processing
- Access authorization and control, safety, security

OOPS Concept

- Complete Objects
- Object identities
- User-defined types (ADTs)
- Encapsulation
- Type/class hierarchy with inheritance
- Overloading, overriding, polymorphism

Reasons for having ORDBMSs over conventional RDBMs

- Storage requirements of newer applications
- Handling of data stored for newer applications
- Ability to define user define data types
- Reusability nature of objects
- Database extensibility

Complex Data Types

- Motivation:
  - Permit non-atomic domains (atomic ≡ indivisible)
  - Example of non-atomic domain: set of integers, strings,or set of tuples

  Eg. Address(street_address, city, state ,postal_code)
  - Allows more natural modeling for applications with complex data
- Natural definition:
  - allow relations whenever we allow atomic (scalar) values — relations within relations
  - 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
  - Object orientation
    - Including object identifiers and references
- Not fully implemented in any database system currently
  - 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** (a.k.a. **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*

select name.firstname, address.city from person

Structured Types (cont.)

- **User-defined row types for table creation**

  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 *person* **of** *PersonType*

- Alternative using **unnamed row types**.

```
create table person_r(
        name     row(firstname  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 *PersonType*
begin
    return *onDate* - **self**.*dateOfBirth*;
end

- We can now find the age of each customer:

select *name.lastname, ageOnDate* (**current_date**)
from *person*

create type *PersonType* **as** (
name Name,
address Address,
dateOfBirth **date**)
not final
method *ageOnDate* (*onDate* **date**)
returns interval year

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’]);

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**

Immediate supertype of new subtype

Suppose entity has type person and student then its most specific type is student and not person

Entity related to type like Teaching Assistant has both teacher and students as most specific types.

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*

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 us 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

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 (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

- 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

- Similar to how E-R features are mapped onto relation schemas
- Subtable implementation
  - Each table stores primary key and those attributes defined in that table

  or,
  - Each table stores both locally defined and inherited attributes

Persistent Programming Languages

- Languages extended with constructs to handle persistent data

  DB handling languages are persistent but host languages are not

  Types are different so conversion is required
- Programmer can manipulate persistent data directly
  - no need to fetch it into memory and store it back to disk (unlike embedded SQL)
- 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

Object Identity and Pointers

- Degrees of permanence of object identity
  - **Intraprocedure**: only during execution of a single procedure

  Eg. Local variables
  - **Intraprogram**: only during execution of a single program or query

  Eg. Global variables
  - **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(object data management group standard) C++
  - Java
    - Java Database Objects (JDO)

Object-Relational Mapping

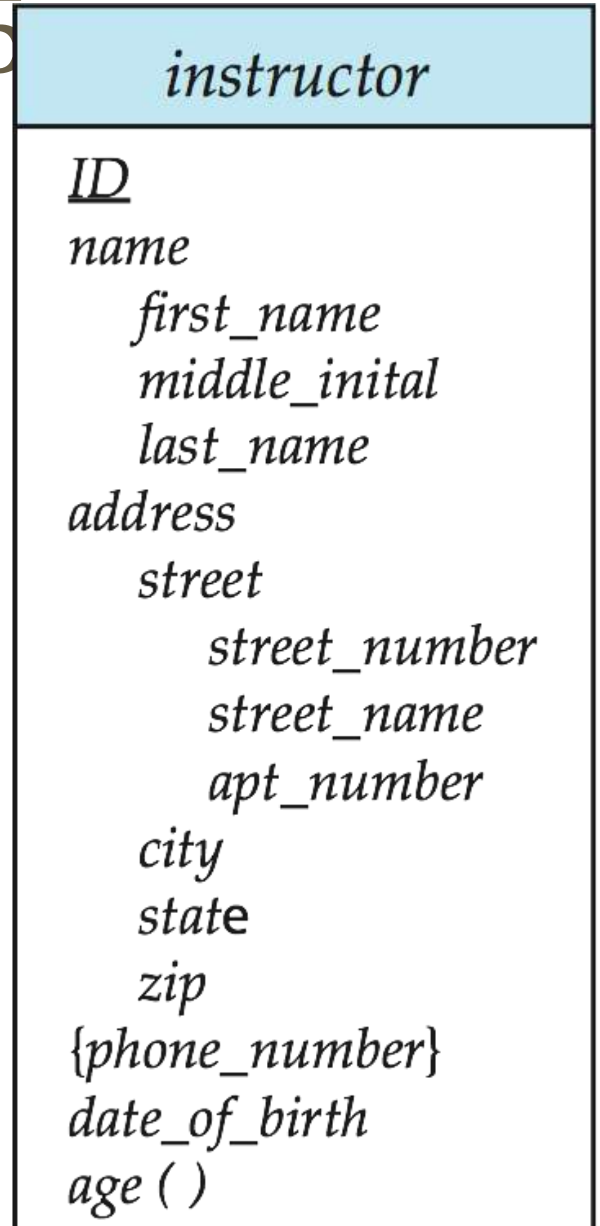
- **Object-Relational Mapping (ORM)** systems built on top of traditional relational databases
- Implementer provides a mapping from objects to relations
  - Objects are purely transient, no permanent object identity
- Objects can be retrived from database
  - System uses mapping to fetch relevant data 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.

End of Chapter 22

Figure 22.05


instructor
ID
name
first_name
middle_inital
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address
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date_of_birth
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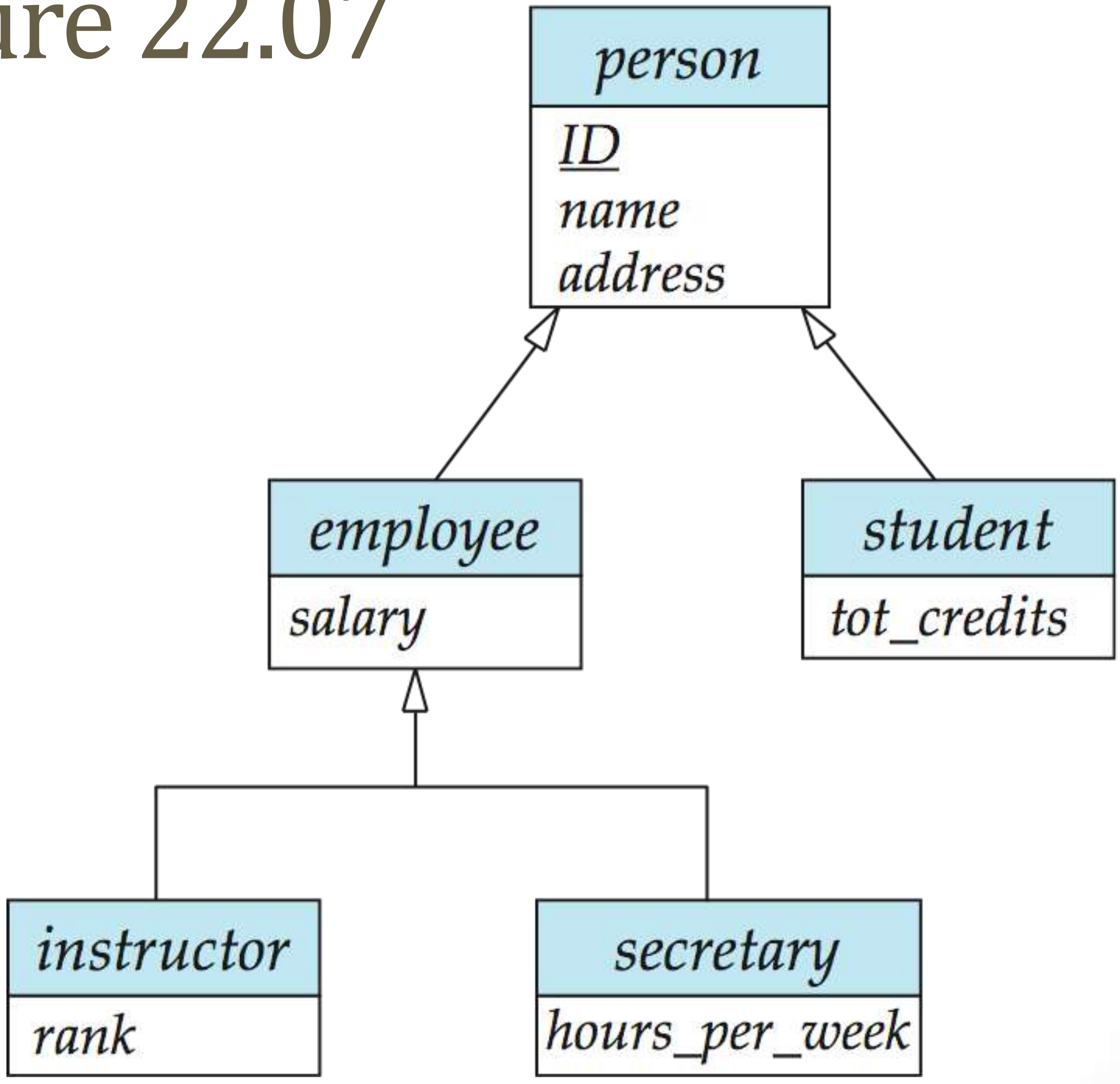
Figure 22.07


person
ID
name
address
employee
salary
student
tot_credits
instructor
rank
secretary
hours_per_week