Object-Oriented Databases

- Need for Complex Data Types
- The Object-Oriented Data Model
- Object-Oriented Languages
- Persistent Programming Languages
- Persistent C++ Systems

Need for Complex Data Types

- Traditional database applications in data processing had conceptually simple data types
  - ★ Relatively few data types, first normal form holds
- Complex data types have grown more important in recent years
  - ★ E.g. Addresses can be viewed as a
    - ➢ Single string, or
    - ➢ Separate attributes for each part, or
    - ➢ Composite attributes (which are not in first normal form)
  - ★ E.g. it is often convenient to store multivalued attributes as-is, without creating a separate relation to store the values in first normal form
- Applications
  - ★ computer-aided design, computer-aided software engineering
  - ★ multimedia and image databases, and document/hypertext databases.

Object-Oriented Data Model

- Loosely speaking, an **object** corresponds to an entity in the E-R model.
- The *object-oriented paradigm* is based on *encapsulating* code and data related to an object into single unit.
- The object-oriented data model is a logical data model (like the E-R model).
- Adaptation of the object-oriented programming paradigm (e.g., Smalltalk, C++) to database systems.

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Object Structure

- An object has associated with it:
  - A set of **variables** that contain the data for the object. The value of each variable is itself an object.
  - A set of **messages** to which the object responds; each message may have zero, one, or more *parameters.*
  - A set of **methods***,* each of which is a body of code to implement a message; a method returns a value as the *response* to the message
- The physical representation of data is visible only to the implementor of the object
- Messages and responses provide the only external interface to an object.
- The term message does not necessarily imply physical message passing. Messages can be implemented as procedure invocations.

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Messages and Methods

- Methods are programs written in general-purpose language with the following features
  - only variables in the object itself may be referenced directly
  - data in other objects are referenced only by sending *messages*.
- Methods can be read-only or update methods
  - Read-only methods do not change the value of the object
- Strictly speaking, every attribute of an entity must be represented by a variable and two methods, one to read and the other to update the attribute
  - e.g., the attribute *address* is represented by a variable *address* and two messages *get-address* and *set-address*.
  - For convenience, many object-oriented data models permit direct access to variables of other objects.

Object Classes

- Similar objects are grouped into a **class**; each such object is called an **instance** of its class
- All objects in a class have the same
  - Variables, with the same types
  - message interface
  - methods

  The may differ in the values assigned to variables
- Example: Group objects for people into a *person* class
- Classes are analogous to entity sets in the E-R model

Class Definition Example

```
class employee {
      /*Variables */
         string   name;
         string   address;
         date     start-date;
         int      salary;
      /* Messages */
         int      annual-salary();
         string   get-name();
         string   get-address();
         int      set-address(string new-address);
         int      employment-length();
};
```

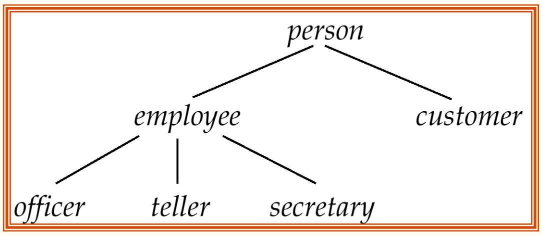
- Methods to read and set the other variables are also needed with strict encapsulation
- Methods are defined separately
  - E.g. **int** *employment-length*() { **return** *today*() – *start-date*;}
    int *set-address*(**string** *new-address*) { *address* = *new-address*;}

Inheritance

- E.g., class of bank customers is similar to class of bank employees, although there are differences
  - both share some variables and messages, e.g., *name* and *address.*
  - But there are variables and messages specific to each class e.g., *salary* for employees and *credit-rating* for customers.
- Every employee is a person; thus *employee* is a specialization of *person*
- *Similarly, customer* is a specialization of *person.*
- Create classes *person, employee* and *customer*
  - variables/messages applicable to all persons associated with class *person.*
  - variables/messages specific to employees associated with class *employee*; similarly for *customer*

Inheritance (Cont.)

- Place classes into a specialization/IS-A hierarchy
  - variables/messages belonging to class *person* are *inherited* by class *employee* as well as *customer*
- Result is a **class hierarchy**



Note analogy with ISA Hierarchy in the E-R model

Class Hierarchy Definition

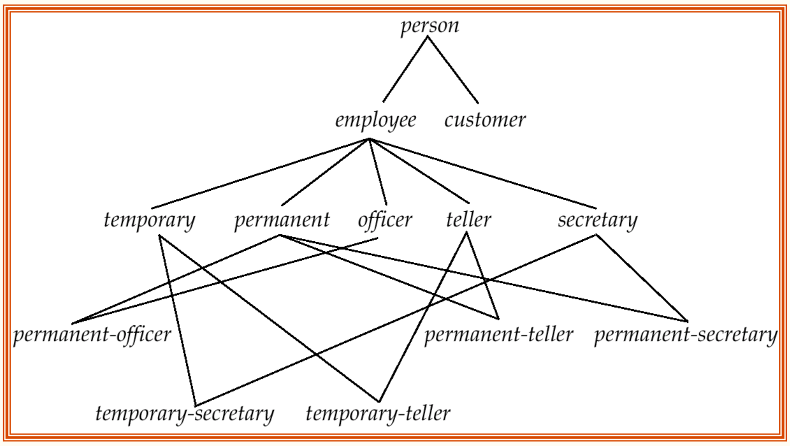
class *person*{
  string *name;*
  string *address:*
  };
class *customer* **isa** *person* {
  int *credit-rating;*
  };
class *employee* **isa** *person* {
  date *start-date;*
  int *salary;*
  };
class *officer* **isa** *employee* {
  int *office-number,*
  int *expense-account-number,*
  };

⋮

Class Hierarchy Example (Cont.)

- Full variable list for objects in the class *officer:*
  - *office-number, expense-account-number:* defined locally
  - *start-date, salary:* inherited from *employee*
  - *name, address:* inherited from *person*
- Methods inherited similar to variables.
- **Substitutability** — any method of a class, say *person,* can be invoked equally well with any object belonging to any subclass, such as subclass *officer* of *person.*
- **Class extent***:* set of all objects in the class. Two options:
  1. Class extent of *employee* includes all *officer, teller* and *secretary* objects.
  2. Class extent of *employee* includes only employee objects that are not in a subclass such as *officer, teller,* or *secretary*
     - This is the usual choice in OO systems
     - Can access extents of subclasses to find all objects of subtypes of employee

Example of Multiple Inheritance



Class DAG for banking example.

Multiple Inheritance

- With multiple inheritance a class may have more than one superclass.
  - The class/subclass relationship is represented by a **directed acyclic graph** (**DAG**)
  - Particularly useful when objects can be classified in more than one way, which are independent of each other
    - E.g. temporary/permanent is independent of Officer/secretary/teller
    - Create a subclass for each combination of subclasses
      - Need not create subclasses for combinations that are not possible in the database being modeled
- A class inherits variables and methods from all its superclasses
- There is potential for ambiguity when a variable/message N with the same name is inherited from two superclasses A and B
  - No problem if the variable/message is defined in a shared superclass
  - Otherwise, do one of the following
    - flag as an error,
    - rename variables (A.N and B.N)
    - choose one.

More Examples of Multiple Inheritance

- Conceptually, an object can belong to each of several subclasses
  - A *person* can play the roles of *student*, a *teacher* or *footballPlayer,* or any combination of the three
    - E.g., student teaching assistant who also play football
- Can use multiple inheritance to model "roles" of an object
  - That is, allow an object to take on any one or more of a set of types
- But many systems insist an object should have a **most-specific class**
  - That is, there must be one class that an object belongs to which is a subclass of all other classes that the object belongs to
  - Create subclasses such as *student-teacher* and *student-teacher-footballPlayer* for each combination
  - When many combinations are possible, creating subclasses for each combination can become cumbersome

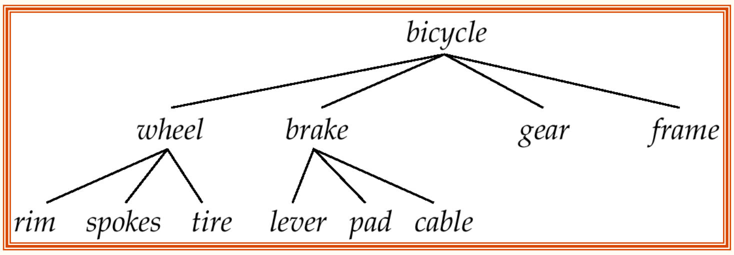
Object Identity

- An object retains its identity even if some or all of the values of variables or definitions of methods change over time.
- Object identity is a stronger notion of identity than in programming languages or data models not based on object orientation.
  - Value – data value; e.g. primary key value used in relational systems.
  - Name – supplied by user; used for variables in procedures.
  - Built-in – identity built into data model or programming language.
    - no user-supplied identifier is required.
    - Is the form of identity used in object-oriented systems.

Object Identifiers

- **Object identifiers** used to uniquely identify objects
  - Object identifiers are unique:
    - no two objects have the same identifier
    - each object has only one object identifier
  - E.g., the *spouse* field of a *person* object may be an identifier of another *person* object.
  - can be stored as a field of an object, to refer to another object.
  - Can be
    - system generated (created by database) or
    - external (such as social-security number)
  - System generated identifiers:
    - Are easier to use, but cannot be used across database systems
    - May be redundant if unique identifier already exists

Object Containment



- Each component in a design may contain other components
- Can be modeled as containment of objects. Objects containing; other objects are called **composite** objects.
- Multiple levels of containment create a **containment hierarchy**
  - links interpreted as **is-part-of,** not **is-a.**
- Allows data to be viewed at different granularities by different users.

Object-Oriented Languages

- Object-oriented concepts can be used in different ways
  - Object-orientation can be used as a design tool, and be encoded into, for example, a relational database
    - analogous to modeling data with E-R diagram and then converting to a set of relations)
  - The concepts of object orientation can be incorporated into a programming language that is used to manipulate the database.
    - **Object-relational systems** – add complex types and object-orientation to relational language.
    - **Persistent programming languages** – extend object-oriented programming language to deal with databases by adding concepts such as persistence and collections.

Persistent Programming Languages

- Persistent Programming languages allow objects to be created and stored in a database, and used directly from a programming language
  - ★ allow data to be manipulated directly from the programming language
    - ➢ No need to go through SQL.
  - ★ No need for explicit format (type) changes
    - ➢ format changes are carried out transparently by system
    - ➢ Without a persistent programming language, format changes becomes a burden on the programmer
      - – More code to be written
      - – More chance of bugs
  - ★ allow objects to be manipulated in-memory
    - ➢ no need to explicitly load from or store to the database
      - – Saved code, and saved overhead of loading/storing large amounts of data

Persistent Prog. Languages (Cont.)

- Drawbacks of persistent programming languages
  - ★ Due to power of most programming languages, it is easy to make programming errors that damage the database.
  - ★ Complexity of languages makes automatic high-level optimization more difficult.
  - ★ Do not support declarative querying as well as relational databases

Persistence of Objects

- Approaches to make transient objects persistent include establishing
  - Persistence by Class – declare all objects of a class to be persistent; simple but inflexible.
  - Persistence by Creation – extend the syntax for creating objects to specify that that an object is persistent.
  - Persistence by Marking – an object that is to persist beyond program execution is marked as persistent before program termination.
  - Persistence by Reachability - declare (root) persistent objects; objects are persistent if they are referred to (directly or indirectly) from a root object.
    - Easier for programmer, but more overhead for database system
    - Similar to garbage collection used e.g. in Java, which also performs reachability tests

Object Identity and Pointers

- A persistent object is assigned a persistent object identifier.
- Degrees of permanence of identity:
  - Intraprocedure – identity persists only during the executions of a single procedure
  - Intraprogram – identity persists only during execution of a single program or query.
  - Interprogram – identity persists from one program execution to another, but may change if the storage organization is changed
  - Persistent – identity persists throughout program executions and structural reorganizations of data; required for object-oriented systems.

Object Identity and Pointers (Cont.)

- In O-O languages such as C++, an object identifier is actually an in-memory pointer.
- Persistent pointer – persists beyond program execution
  - can be thought of as a pointer into the database
    - E.g. specify file identifier and offset into the file
  - Problems due to database reorganization have to be dealt with by keeping forwarding pointers

Storage and Access of Persistent Objects

How to find objects in the database:

- Name objects (as you would name files)
  - Cannot scale to large number of objects.
  - Typically given only to class extents and other collections of objects, but not objects.
- Expose object identifiers or persistent pointers to the objects
  - Can be stored externally.
  - All objects have object identifiers.
- Store collections of objects, and allow programs to iterate over the collections to find required objects
  - Model collections of objects as **collection types**
  - **Class extent** - the collection of all objects belonging to the class; usually maintained for all classes that can have persistent objects.

Persistent C++ Systems

- C++ language allows support for persistence to be added without changing the language
  - Declare a class called Persistent_Object with attributes and methods to support persistence
  - **Overloading** – ability to redefine standard function names and operators (i.e., +, –, the pointer deference operator –>) when applied to new types
  - **Template classes** help to build a type-safe type system supporting collections and persistent types.
- Providing persistence without extending the C++ language is
  - relatively easy to implement
  - but more difficult to use
- Persistent C++ systems that add features to the C++ language have been built, as also systems that avoid changing the language

ODMG C++ Object Definition Language

- The Object Database Management Group is an industry consortium aimed at standardizing object-oriented databases
  - in particular persistent programming languages
  - Includes standards for C++, Smalltalk and Java
  - ODMG-93
  - ODMG-2.0 and 3.0 (which is 2.0 plus extensions to Java)
    - Our description based on ODMG-2.0
- ODMG C++ standard avoids changes to the C++ language
  - provides functionality via template classes and class libraries

ODMG Types

- Template class d_Ref<class> used to specify references (persistent pointers)
- Template class d_Set<class> used to define sets of objects.
  - Methods include insert_element(e) and delete_element(e)
- Other collection classes such as d_Bag (set with duplicates allowed), d_List and d_Varray (variable length array) also provided.
- d_ version of many standard types provided, e.g. d_Long and d_string
  - Interpretation of these types is platform independent
  - Dynamically allocated data (e.g. for d_string) allocated in the database, not in main memory

ODMG C++ ODL: Example

```
class Branch  :  public d_Object {
  ....
}
class Person  :  public d_Object {
   public:
     d_String    name;      // should not use String!
     d_String    address;
};
class Account : public d_Object {
   private:
     d_Long       balance;
   public:
     d_Long       number;
     d_Set <d_Ref<Customer>> owners;
     int          find_balance();
     int          update_balance(int delta);
};
```

ODMG C++ ODL: Example (Cont.)

```
class Customer  :  public Person {
    public:
      d_Date             member_from;
      d_Long             customer_id;
      d_Ref<Branch> home_branch;
      d_Set <d_Ref<Account>> accounts; };
```


Implementing Relationships

- Relationships between classes implemented by references
- Special reference types enforces integrity by adding/removing inverse links.
  - Type d_Rel_Ref<Class, InvRef> is a reference to Class, where attribute InvRef of Class is the inverse reference.
  - Similarly, d_Rel_Set<Class, InvRef> is used for a set of references
- Assignment method (=) of class d_Rel_Ref is overloaded
  - Uses type definition to automatically find and update the inverse link
  - Frees programmer from task of updating inverse links
  - Eliminates possibility of inconsistent links
- Similarly, insert_element() and delete_element() methods of d_Rel_Set use type definition to find and update the inverse link automatically

Implementing Relationships

- E.g.

```
extern const char _owners[ ],   _accounts[ ];
class Account : public d.Object {
        ....
        d_Rel_Set <Customer, _accounts> owners;
}
  // .. Since strings can't be used in templates …
const char _owners= "owners";
const char _accounts= "accounts";
```


ODMG C++ Object Manipulation Language

- Uses persistent versions of C++ operators such as new(db)

  d_Ref<Account> account = new(bank_db, "Account") Account;

  - new allocates the object in the specified database, rather than in memory.
  - The second argument ("Account") gives typename used in the database.
- Dereference operator -> when applied on a d_Ref<Account> reference loads the referenced object in memory (if not already present) before continuing with usual C++ dereference.
- Constructor for a class – a special method to initialize objects when they are created; called automatically on new call.
- Class extents maintained automatically on object creation and deletion
  - Only for classes for which this feature has been specified
    - Specification via user interface, not C++
  - Automatic maintenance of class extents not supported in earlier versions of ODMG

ODMG C++OML: Database and Object Functions

- Class d_Database provides methods to
  - open a database: open(databasename)
  - give names to objects: set_object_name(object, name)
  - look up objects by name: lookup_object(name)
  - rename objects: rename_object(oldname, newname)
  - close a database (close());
- Class d_Object is inherited by all persistent classes.
  - provides methods to allocate and delete objects
  - method mark_modified() must be called *before* an object is updated.
    - Is automatically called when object is created

ODMG C++ OML: Example

```
int create_account_owner(String name, String Address){
    Database bank_db.obj;
    Database * bank_db= & bank_db.obj;
    bank_db =>open("Bank-DB");
    d.Transaction Trans;
    Trans.begin();

    d_Ref<Account> account = new(bank_db) Account;
    d_Ref<Customer> cust = new(bank_db) Customer;
    cust->name - name;
    cust->address = address;
    cust->accounts.insert_element(account);
    ... Code to initialize other fields

    Trans.commit();
}
```

ODMG C++ OML: Example (Cont.)

- Class extents maintained automatically in the database.
- To access a class extent:
  d_Extent<Customer> customerExtent(bank_db);
- Class d_Extent provides method
  d_Iterator<T> create_iterator()
  to create an iterator on the class extent
- Also provides select(pred) method to return iterator on objects that satisfy selection predicate pred.
- Iterators help step through objects in a collection or class extent.
- Collections (sets, lists etc.) also provide create_iterator() method.

ODMG C++ OML: Example of Iterators

```
int print_customers() {
    Database bank_db_obj;
    Database * bank_db = &bank_db_obj;
    bank_db->open ("Bank-DB");
    d_Transaction Trans; Trans.begin ();

    d_Extent<Customer> all_customers(bank_db);
    d_Iterator<d_Ref<Customer>> iter;
    iter = all_customers–>create_iterator();
    d_Ref <Customer> p;
    while{iter.next (p))
          print_cust (p);  // Function assumed to be defined elsewhere
    Trans.commit();
}
```

ODMG C++ Binding: Other Features

- Declarative query language OQL, looks like SQL
  - Form query as a string, and execute it to get a set of results (actually a bag, since duplicates may be present)

```
d_Set<d_Ref<Account>> result;
d_OQL_Query q1("select a
                from Customer c, c.accounts a
                where c.name= 'Jones'
                      and a.find_balance() > 100");
d_oql_execute(q1, result);
```

- Provides error handling mechanism based on C++ exceptions, through class d_Error
- Provides API for accessing the schema of a database.

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Making Pointer Persistence Transparent

- Drawback of the ODMG C++ approach:
  - Two types of pointers
  - Programmer has to ensure mark_modified() is called, else database can become corrupted
- ObjectStore approach
  - Uses *exactly* the same pointer type for in-memory and database objects
  - Persistence is transparent applications
    - Except when creating objects
  - Same functions can be used on in-memory and persistent objects since pointer types are the same
  - Implemented by a technique called pointer-swizzling which is described in Chapter 11.
  - No need to call mark_modified(), modification detected automatically.

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Persistent Java Systems

- ODMG-3.0 defines extensions to Java for persistence
  - Java does not support templates, so language extensions are required
- Model for persistence: persistence by reachability
  - Matches Java's garbage collection model
  - Garbage collection needed on the database also
  - Only one pointer type for transient and persistent pointers
- Class is made **persistence capable** by running a post-processor on object code generated by the Java compiler
  - Contrast with pre-processor used in C++
  - Post-processor adds mark_modified() automatically
- Defines collection types DSet, DBag, DList, etc.
- Uses Java iterators, no need for new iterator class

ODMG Java

- Transaction must start accessing database from one of the root object (looked up by name)
  - finds other objects by following pointers from the root objects
- Objects referred to from a fetched object are allocated space in memory, but not necessarily fetched
  - Fetching can be done lazily
  - An object with space allocated but not yet fetched is called a hollow object
  - When a hollow object is accessed, its data is fetched from disk.

Object-Relational Databases

- Nested Relations
- Complex Types and Object Orientation
- Querying with Complex Types
- Creation of Complex Values and Objects
- 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.

Nested Relations

- 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 set of authors,
  - ★ Publisher, and
  - ★ a set of keywords
- Non-1NF relation *books*

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

1NF Version of Nested Relation

- 1NF version of *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

flat-books

4NF Decomposition of Nested Relation

- Remove awkwardness of *flat-books* by assuming that the following multivalued dependencies hold:
  - *title* $\rightarrow\rightarrow$ *author*
  - *title* $\rightarrow\rightarrow$ *keyword*
  - *title* $\rightarrow\rightarrow$ *pub-name, pub-branch*
- Decompose *flat-doc* into 4NF using the schemas:
  - *(title, author)*
  - *(title, keyword)*
  - *(title, pub-name, pub-branch)*

4NF Decomposition of *flat–books*

title	*author*
Compilers	Smith
Compilers	Jones
Networks	Jones
Networks	Frick

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

Problems with 4NF Schema

- 4NF design requires users to include joins in their queries.
- 1NF relational view *flat-books* defined by join of 4NF relations:
  - eliminates the need for users to perform joins,
  - but loses the one-to-one correspondence between tuples and documents.
  - And has a large amount of redundancy
- Nested relations representation is much more natural here.

Complex Types and SQL:1999

- Extensions to SQL to support complex types include:
  - 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
- Our description is mainly based on the SQL:1999 standard
  - 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
  - We present some features that are not in SQL:1999
    - These are noted explicitly

Collection Types

- Set type (not in SQL:1999)

  create table *books* (

  .....

  keyword-set **setof**(**varchar**(20))

  ......

)
- Sets are an instance of collection types. Other instances include
  - Arrays (are supported in SQL:1999)
    - E.g. *author-array* **varchar**(20) **array**[10]
    - Can access elements of array in usual fashion:
      - *E.g. author-array*[1]
  - Multisets (not supported in SQL:1999)
    - I.e., unordered collections, where an element may occur multiple times
  - Nested relations are sets of tuples
    - SQL:1999 supports arrays of tuples

Large Object Types

- Large object types
  - **clob**: Character large objects

    book-review **clob**(10KB)
  - **blob**: binary large objects

    image **blob**(10MB)

    movie **blob** (2GB)
- JDBC/ODBC provide special methods to access large objects in small pieces
  - Similar to accessing operating system files
  - Application retrieves a **locator** for the large object and then manipulates the large object from the host language

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Structured and Collection Types

- Structured types can be declared and used in SQL

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 **setof**(**varchar**(20)))

  - Note: **setof** declaration of keyword-set is not supported by SQL:1999
  - Using an array to store authors lets us record the order of the authors
- Structured types can be used to create tables

  create table *books* **of** *Book*
  - Similar to the nested relation books, but with array of authors instead of set

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Structured and Collection Types (Cont.)

- Structured types allow composite attributes of E-R diagrams to be represented directly.
- Unnamed row types can also be used in SQL:1999 to define composite attributes
  - **E.g.** we can omit the declaration of type *Publisher* and instead use the following in declaring the type *Book*

    publisher **row** (*name* **varchar**(20),
    branch **varchar**(20))
- Similarly, collection types allow multivalued attributes of E-R diagrams to be represented directly.

Structured Types (Cont.)

- We can create tables without creating an intermediate type
  - For example, the table *books* could also be defined as follows:

```
create table books
   (title varchar(20),
    author-array varchar(20) array[10],
    pub-date date,
    publisher Publisher
   keyword-list setof(varchar(20)))
```

- Methods can be part of the type definition of a structured type:

```
create type Employee as (
    name varchar(20),
    salary integer)
 method giveraise (percent integer)
```

- We create the method body separately

```
create method giveraise (percent integer) for Employee
begin
    set self.salary = self.salary + (self.salary * percent) / 100;
end
```

Creation of Values of Complex Types

- Values of structured types are created using constructor functions
  - ★ E.g. *Publisher*('McGraw-Hill', 'New York')
  - ★ Note: a value is **not** an object
- SQL:1999 constructor functions
  - ★ E.g.
    create function *Publisher* (*n* **varchar**(20), *b* **varchar**(20))
    returns *Publisher*
    begin
      set *name*=*n*;
      set *branch*=*b*;
    end
  - ★ Every structured type has a default constructor with no arguments, others can be defined as required
- Values of **row** type can be constructed by listing values in parantheses
  - ★ E.g. given row type **row** (*name* **varchar**(20),
    branch **varchar**(20))
  - ★ We can assign (`McGraw-Hill', `New York') as a value of above type

Creation of Values of Complex Types

- Array construction
  array ['Silberschatz', `Korth', `Sudarshan']
- Set value attributes (not supported in SQL:1999)
  - ★ **set**(v1, v2, …, vn)
- To create a tuple of the *books* relation
  ('Compilers', **array**[`Smith', `Jones'],
  Publisher(`McGraw-Hill', `New York'),
  set(`parsing', `analysis'))
- To insert the preceding tuple into the relation *books*

  insert into *books*
  values
    (`Compilers', **array**[`Smith', `Jones'],
    Publisher('McGraw Hill', `New York'),
    set(`parsing', `analysis'))

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 Inheritance

- SQL:1999 does 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*)

Table Inheritance

- Table inheritance allows an object to have multiple types by allowing an entity to exist in more than one table at once.
- *E.g. people* table: **create table** *people* **of** *Person*
- We can then define the *students* and *teachers* tables as **subtables** of *people*

  create table *students* **of** *Student*
  under *people*
  create table *teachers* **of** *Teacher*
  under *people*

- Each tuple in a subtable (e.g. *students* and *teachers)* is implicitly present in its supertables (e.g. *people*)
- Multiple inheritance is possible with tables, just as it is possible with types.

  create table *teaching-assistants* **of** *Teaching Assistant*
  under *students, teachers*

  - Multiple inheritance not supported in SQL:1999

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Table Inheritance: Roles

- Table inheritance is useful for modeling **roles**
- permits a value to have multiple types, without having a **most-specific type** (unlike type inheritance).
  - e.g., an object can be in the *students* and *teachers subtables* simultaneously, without having to be in a subtable *student-teachers* that is under both *students* and *teachers*
  - object can gain/lose roles: corresponds to inserting/deleting object from a subtable
- **NOTE**: SQL:1999 requires values to have a most specific type
  - so above discussion is not applicable to SQL:1999

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Table Inheritance: Consistency Requirements

- 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*

Table Inheritance: Storage Alternatives

- Storage alternatives
  1. Store only local attributes and the primary key of the supertable in subtable
     - Inherited attributes derived by means of a join with the supertable
  2. Each table stores all inherited and locally defined attributes
     - Supertables implicitly contain (inherited attributes of) all tuples in their subtables
     - Access to all attributes of a tuple is faster: no join required
     - If entities must have most specific type, tuple is stored only in one table, where it was created
       - Otherwise, there could be redundancy

Reference Types

- Object-oriented languages provide the ability to create and refer to objects.
- In SQL:1999
  - References are to tuples, and
  - References must be scoped,
    - I.e., can only point to tuples in one specified table
- We will study how to define references first, and later see how to use references

Reference Declaration in SQL:1999

- E.g. 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*)

Initializing Reference Typed Values

- In Oracle, to create a tuple with a reference value, we can first create the tuple with a null reference and then set the reference separately by using the function **ref**(p) applied to a tuple variable
- E.g. to create a department with name CS and head being the person named John, we use

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

Initializing Reference Typed Values (Cont.)

- SQL:1999 does not support the **ref**() function, and instead requires a special attribute to be declared to store the object identifier
- The self-referential attribute is declared by adding a **ref is** clause to the create table statement:

  create table *people* **of** *Person*
  ref is *oid* **system generated**

  - ★ Here, *oid* is an attribute name, not a keyword.
- To get the reference to a tuple, the subquery shown earlier would use

            select *p.oid*
  instead of   **select ref**(*p*)

User Generated Identifiers

- SQL:1999 allows object identifiers to be user-generated
  - 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
  - E.g.

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

- When creating a tuple, we must provide a unique value for the identifier (assumed to be the first attribute):

insert into *people* **values**
(‘01284567’, ‘John’, `23 Coyote Run’)

User Generated Identifiers (Cont.)

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

E.g. **insert into** *departments*
values(`CS’, `02184567’)

- It is even possible to use an existing primary key value as the identifier, by including the **ref from** clause, and declaring the reference to be **derived**

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

Querying with Structured Types

- Find the title and the name of the publisher of each book.

  select *title*, *publisher.name*
  from *books*

Note the use of the dot notation to access fields of the composite attribute (structured type) *publisher*

Collection-Value Attributes

- Collection-valued attributes can be treated much like relations, using the keyword **unnest**
  - The *books* relation has array-valued attribute *author-array* and set-valued attribute *keyword-set*
- To find all books that have the word "database" as one of their keywords,

  select *title*
  from *books*
  where 'database' **in** (**unnest**(*keyword-set*))
  - Note: Above syntax is valid in SQL:1999, but the only collection type supported by SQL:1999 is the array type
- 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*
  from *books* **as** *B*, **unnest** (*B.author-array*) **as** *A*

Collection Valued Attributes (Cont.)

- 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'

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* **as** *keyword*

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

Nesting

- **Nesting** is the opposite of unnesting, creating a collection-valued attribute
- NOTE: SQL:1999 does not support nesting
- Nesting can be done in a manner similar to aggregation, but using the function set() in place of an aggregation operation, to create a set
- To nest the *flat-books* relation on the attribute *keyword*:

  select *title*, *author*, Publisher(*pub_name, pub_branch*) **as** *publisher*,
  set(*keyword*) **as** *keyword-list*
  from *flat-books*
  groupby *title, author, publisher*
- To nest on both authors and keywords:

  select *title*, **set**(*author*) **as** *author-list*,
  Publisher(*pub_name, pub_branch*) **as** *publisher*,
  set(*keyword*) **as** *keyword-list*
  from *flat-books*
  groupby *title*, *publisher*

Nesting (Cont.)

- Another approach to creating nested relations is to use subqueries in the select clause.

  select *title*,
      (**select** *author*
       from *flat-books* **as** *M*
       where *M.title=O.title*) **as** *author-set*,
      Publisher(*pub-name, pub-branch*) **as** *publisher*,
      (**select** *keyword*
       from *flat-books* **as** *N*
       where *N.title = O.title*) **as** *keyword-set*
  from *flat-books* **as** *O*

- Can use **orderby** clause in nested query to get an ordered collection
  - Can thus create arrays, unlike earlier approach

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Functions and Procedures

- SQL:1999 supports functions and procedures
  - Functions/procedures can be written in SQL itself, or in an external programming language
  - Functions are particularly useful with specialized data types such as images and geometric objects
    - E.g. functions to check if polygons overlap, or to compare images for similarity
  - Some databases support **table-valued functions**, which can return a relation as a result
- SQL:1999 also supports a rich set of imperative constructs, including
  - Loops, if-then-else, assignment
- Many databases have proprietary procedural extensions to SQL that differ from SQL:1999

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SQL Functions

- Define a function that, given a book title, returns the count of the number of authors (on the 4NF schema with relations *books4* and *authors*).

```
create function author-count(name varchar(20))
returns integer
begin
    declare a-count integer;
    select count(author) into a-count
    from authors
    where authors.title=name
    return a=count;
end
```

- Find the titles of all books that have more than one author.

```
select name
from books4
where author-count(title)> 1
```

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SQL Methods

- Methods can be viewed as functions associated with structured types
  - They have an implicit first parameter called **self** which is set to the structured-type value on which the method is invoked
  - The method code can refer to attributes of the structured-type value using the **self** variable
    - E.g. **self**.a

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SQL Functions and Procedures (cont.)

- The *author-count* function could instead be written as procedure:

  create procedure *author-count-proc* (**in** *title* **varchar(20)**,
  out *a-count* **integer)**
  begin
  select count(*author*) **into** *a-count*
  from *authors*
  where *authors.title = title*
  end
- Procedures can be invoked either from an SQL procedure or from embedded SQL, using the call statement.
  - E.g. from an SQL procedure

    declare *a-count* **integer**;
    call *author-count-proc*(`Database systems Concepts', *a-count*);
- SQL:1999 allows more than one function/procedure of the same name (called name **overloading**), as long as the number of arguments differ, or at least the types of the arguments differ

External Language Functions/Procedures

- SQL:1999 permits the use of functions and procedures written in other languages such as C or C++
- Declaring external language procedures and functions

  create procedure author-count-proc(**in** *title* **varchar**(20),
  out count **integer**)
  language C
  external name' /usr/avi/bin/author-count-proc'

  create function author-count(*title* **varchar**(20))
  returns integer
  language C
  external name '/usr/avi/bin/author-count'

External Language Routines (Cont.)

- Benefits of external language functions/procedures:
  - more efficient for many operations, and more expressive power
- Drawbacks
  - Code to implement function may need to be loaded into database system and executed in the database system's address space
    - risk of accidental corruption of database structures
    - security risk, allowing users access to unauthorized data
  - There are alternatives, which give good security at the cost of potentially worse performance
  - Direct execution in the database system's space is used when efficiency is more important than security

Security with External Language Routines

- To deal with security problems
  - Use **sandbox** techniques
    - that is use a safe language like Java, which cannot be used to access/damage other parts of the database code
  - Or, run external language functions/procedures in a separate process, with no access to the database process' memory
    - Parameters and results communicated via inter-process communication
- Both have performance overheads
- Many database systems support both above approaches as well as direct executing in database system address space

Procedural Constructs

- SQL:1999 supports a rich variety of procedural constructs
- Compound statement
  - is of the form **begin ... end**,
  - may contain multiple SQL statements between **begin** and **end**.
  - Local variables can be declared within a compound statements
- While and repeat statements

```
declare n integer default 0;
while n < 10 do
   set n = n+1
end while

repeat
   set n = n – 1
until n = 0
end repeat
```

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Procedural Constructs (Cont.)

- For loop
  - Permits iteration over all results of a query
  - E.g. find total of all balances at the Perryridge branch

```
declare n integer default 0;
for r as
     select balance from account
     where branch-name = 'Perryridge'
do
     set n = n + r.balance
end for
```

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Procedural Constructs (cont.)

- Conditional statements (if-then-else)
  E.g. To find sum of balances for each of three categories of accounts (with balance <1000, >=1000 and <5000, >= 5000)

  if *r.balance* < 1000
      then set *l* = *l* + *r.balance*
  elseif *r.balance* < 5000
      then set *m* = *m* + *r.balance*
  else set *h* = *h* + *r.balance*
  end if

- SQL:1999 also supports a **case** statement similar to C case statement
- Signaling of exception conditions, and declaring handlers for exceptions

  declare *out_of_stock* **condition**
  declare exit handler for *out_of_stock*
  begin
  …
  .. **signal** out-of-stock
  end

  - ★ The handler here is **exit** -- causes enclosing begin..end to be exited
  - ★ Other actions possible on exception

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Comparison of O-O and O-R Databases

- Summary of strengths of various database systems:
- **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.
- 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.

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Finding all employees of a manager

- Procedure to find all employees who work directly or indirectly for *mgr*
- Relation *manager*(*empname, mgrname*)specifies who directly works for whom
- Result is stored in *empl*(*name*)

```
create procedure findEmp(in mgr char(10))
begin
        create temporary table newemp(name char(10));
        create temporary table temp(name char(10));
        insert into newemp     -- store all direct employees of mgr in newemp
              select empname
              from manager
              where mgrname = mgr
```

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Finding all employees of a manager(cont.)

```
repeat
    insert into empl        -- add all new employees found to  empl
       select name
       from newemp;
    insert into temp        -- find all employees of people already found
       (select manager.empname
         from newemp, manager
         where newemp.empname = manager.mgrname;
       )
      except (              -- but remove those who were found earlier
         select empname
         from empl
      );
   delete from newemp;  -- replace contents of newemp by contents of temp
   insert into newemp
     select *
     from temp;
  delete from temp;
until not exists(select* from newemp)   -- stop when no new employees are found
end repeat;
end
```

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- Slides adapted from

Database System Concepts

Fourth Edition

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