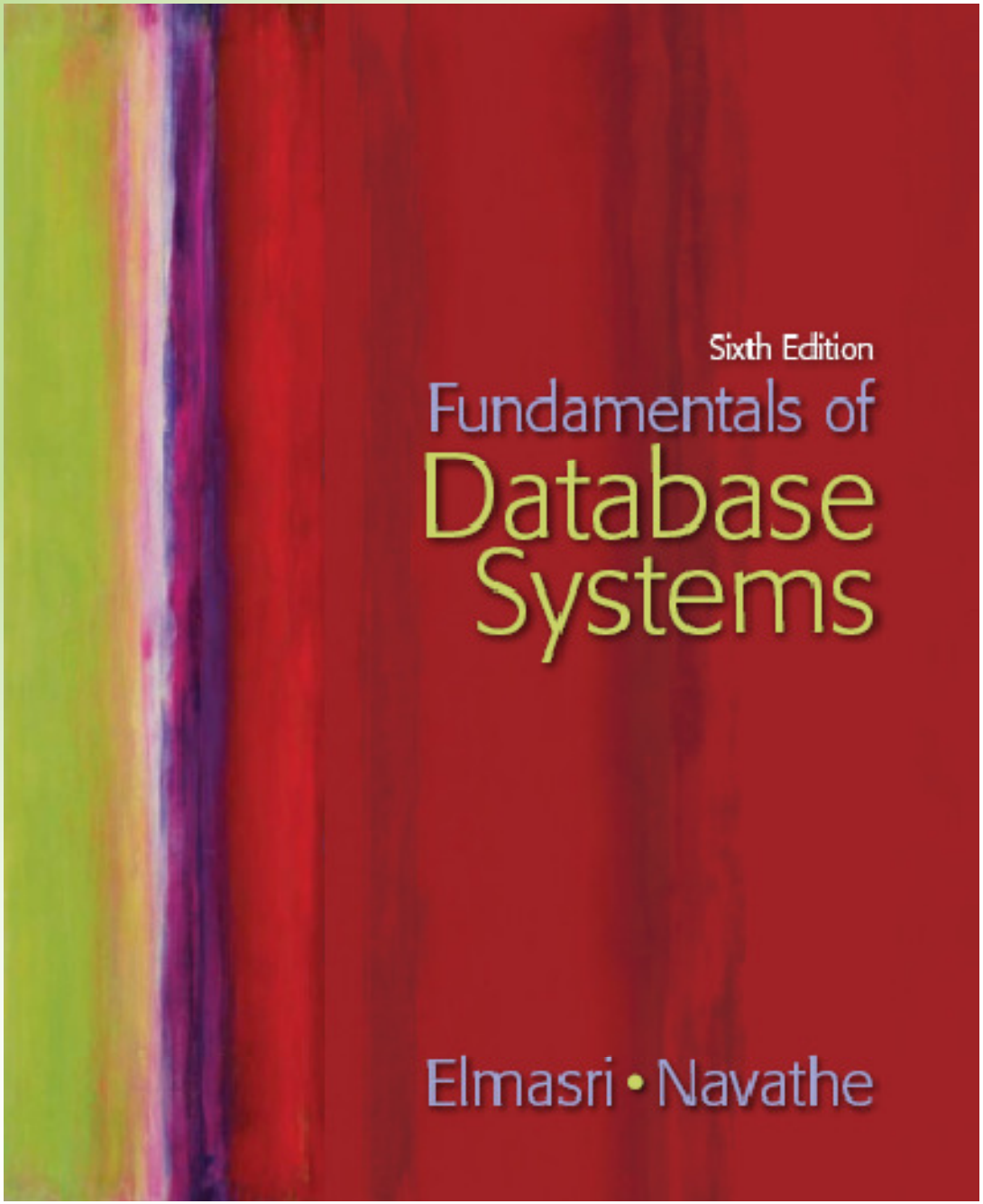
Chapter 11

Object and Object-Relational Databases



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Chapter 11 Outline

- Overview of Object Database Concepts
- Object-Relational Features: Object Database Extensions to SQL
- The ODMG Object Model and the Object Definition Language ODL
- Object Database Conceptual Design
- The Object Query Language OQL
- Overview of the C++ Language Binding in the ODMG Standard

Object and Object-Relational Databases

- **Object databases (ODB)**
  - **Object data management systems (ODMS)**
  - Meet some of the needs of more complex applications
  - Specify:
    - Structure of complex objects
    - Operations that can be applied to these objects

Overview of Object Database Concepts

- Introduction to object-oriented concepts and features
  - Origins in OO programming languages
  - Object has two components:
    - State (value) and behavior (operations)
  - Instance variables
    - Hold values that define internal state of object
  - Operation is defined in two parts:
    - Signature or interface and implementation

Overview of Object Database Concepts (cont'd.)

- Inheritance
  - Permits specification of new types or classes that inherit much of their structure and/or operations from previously defined types or classes
- Operator overloading
  - Operation's ability to be applied to different types of objects
  - Operation name may refer to several distinct implementations

Object Identity, and Objects versus Literals

- Unique identity
  - Implemented via a unique, system-generated object identifier (OID)
  - **Immutable**
- Most OO database systems allow for the representation of both objects and literals (or values)

Complex Type Structures for Objects and Literals

- Structure of arbitrary complexity
  - Contain all necessary information that describes object or literal
- Nesting **type constructors**
  - Construct complex type from other types
- Most basic constructors:
  - **Atom**
  - **Struct (or tuple)**
  - **Collection**

Complex Type Structures for Objects and Literals (cont'd.)

- Collection types:
  - **Set**
  - **Bag**
  - **List**
  - **Array**
  - **Dictionary**
- **Object definition language (ODL)**
  - Used to define object types for a particular database application

Figure 11.1
Specifying the object types EMPLOYEE, DATE, and DEPARTMENT using type constructors.

```
define type EMPLOYEE
    tuple (  Fname:       string;
             Minit:       char;
             Lname:       string;
             Ssn:         string;
             Birth_date:  DATE;
             Address:     string;
             Sex:         char;
             Salary:      float;
             Supervisor:  EMPLOYEE;
             Dept:        DEPARTMENT;

define type DATE
    tuple (  Year:        integer;
             Month:       integer;
             Day:         integer;  );

define type DEPARTMENT
    tuple (  Dname:       string;
             Dnumber:     integer;
             Mgr:         tuple (  Manager:     EMPLOYEE;
                                   Start_date:  DATE;  );
             Locations:   set(string);
             Employees:   set(EMPLOYEE);
             Projects:    set(PROJECT);  );
```

Encapsulation of Operations and Persistence of Objects

- Encapsulation
  - Related to abstract data types and information hiding in programming languages
  - Define **behavior** of a type of object based on operations that can be externally applied
  - External users only aware of interface of the operations
  - Divide structure of object into visible and hidden attributes

Object Behavior/Operations

- See figure 11.2

Encapsulation of Operations

- **Object constructor**
  - Used to create a new object
- **Destructor** operation
  - Used to destroy (delete) an object
- **Modifier** operations
  - Modify the states (values) of various attributes of an object
- **Retrieve** information about the object
- Dot notation used to apply operations to object

Persistence of Objects

- **Transient objects**
  - Exist in executing program
  - Disappear once program terminates
- **Persistent objects**
  - Stored in database and persist after program termination
  - **Naming mechanism**
  - **Reachability**

Type Hierarchies and Inheritance

- Inheritance
  - Definition of new types based on other predefined types
  - Leads to **type** (or **class**) **hierarchy**
- Type: **type name** and list of visible (public) **functions**
  - Format:
    - `TYPE_NAME: function, function, ..., function`

Type Hierarchies and Inheritance (cont'd.)

- **Subtype**
  - Useful when creating a new type that is similar but not identical to an already defined type
  - Example:
    - `EMPLOYEE subtype-of PERSON: Salary, Hire_date, Seniority`
    - `STUDENT subtype-of PERSON: Major, Gpa`

Type Hierarchies and Inheritance (cont'd.)

- **Extent**
  - Store collection of persistent objects for each type or subtype
  - Extents are subsets of the extent of class OBJECT
- **Persistent collection**
  - Stored permanently in the database
- **Transient collection**
  - Exists temporarily during the execution of a program

Other Object-Oriented Concepts

- **Polymorphism** of operations
  - Also known as **operator overloading**
  - Allows same operator name or symbol to be bound to two or more different implementations
  - Depending on type of objects to which operator is applied
- **Multiple inheritance**
  - Subtype inherits functions (attributes and methods) of more than one supertype

Other Object-Oriented Concepts (cont'd.)

- **Selective inheritance**
  - Subtype inherits only some of the functions of a supertype

Summary of Object Database Concepts

- Object identity
- Type constructor
- Encapsulation of operations
- Programming language compatibility
- Type hierarchies and inheritance
- Extents
- Polymorphism and operator overloading

Object-Relational Features: Object Database Extensions to SQL

- **Type constructors**
  - Specify complex objects
- Mechanism for specifying **object identity**
- **Encapsulation of operations**
  - Provided through user-defined types (UDTs)
- **Inheritance** mechanisms
  - Provided using keyword `UNDER`

User-Defined Types and Complex Structures for Objects

- **UDT** syntax:
  - `CREATE TYPE TYPE_NAME AS (<component declarations>);`
- `ROW TYPE`
  - Directly create a structured attribute using the keyword **`ROW`**

```
phone_no ROW (
        area_code char (3),
        prefix_no char (3),
        number    char (4),
),
```

User-Defined Types and Complex Structures for Objects (cont'd.)

- Array type
  - Reference elements using [ ]
- **`CARDINALITY`** function
  - Return the current number of elements in an array

Object Identifiers Using Reference Types

- **Reference type**
  - Create unique system-generated object identifiers
  - Examples:
    - `REF IS SYSTEM GENERATED`
    - `REF IS <OID_ATTRIBUTE> <VALUE_GENERATION_METHOD> ;`
    - Generation methods: `SYSTEM GENERATED` or `DERIVED`

Creating Tables Based on the UDTs

- **INSTANTIABLE**
  - Specify that UDT is instantiable
  - Causes one or more tables to be created

Encapsulation of Operations

- User-defined type
  - Specify methods (or operations) in addition to the attributes
  - Format:

```
CREATE TYPE <TYPE-NAME> (
<LIST OF COMPONENT ATTRIBUTES AND THEIR TYPES>
<DECLARATION OF FUNCTIONS (METHODS)>
);
```

Encapsulation of Operations (cont'd.)

- Constructor function **`TYPE_T( )`**
  - Returns a new object of that type
- Observer function *A* implicitly created for each attribute *A*
  - *A(X)* or *X.A* return the of attribute *A*
- User defined functions can internal (SQL) or external
  - External functions written in a host language

Specifying Inheritance and Overloading of Functions

- Inheritance rules:
  - All attributes inherited
  - Order of supertypes in UNDER clause determines inheritance hierarchy
  - Instance of a subtype can be used in every context in which a supertype instance used
  - Subtype can redefine any function defined in supertype
  - NOT FINAL: subtypes are allowed to be defined

Specifying Inheritance and Overloading of Functions (cont'd.)

- When a function is called, best match selected based on types of all arguments
- For dynamic linking, runtime types of parameters is considered

Specifying Relationships via Reference

- Component attribute of one tuple may be a **reference** to a tuple of another table
  - Specified using keyword **`REF`**
- Keyword **`SCOPE:`** Specify name of table whose tuples referenced (e.g, FK)
- **Dot notation:** Build path expressions
- **`–>`** Used for dereferencing

```
SELECT E.Employee -> Name
FROM EMPLOYMENT AS E
WHERE E.Company -> Name = 'Microsoft';
```

The ODMG Object Model and the Object Definition Language ODL

- ODMG object model
  - Data model for **object definition language (ODL)** and **object query language (OQL)**
- Objects and Literals
  - Basic building blocks of the object model
- Object has five aspects:
  - **Identifier**, **name**, **lifetime, structure**, and **creation**
- **Literal**
  - Value that does not have an object identifier

The ODMG Object Model and the ODL (cont'd.)

- **Behavior** refers to operations
- **State** refers to properties
- **Interface**
  - Specifies only behavior of an object type
  - Typically **noninstantiable**
- **Class**
  - Specifies both state (attributes) and behavior (operations) of an object type
  - **Instantiable**

Inheritance in the Object Model of ODMG

- **Behavior inheritance**
  - Also known as IS-A or interface inheritance
  - Specified by the colon (:) notation
- **EXTENDS inheritance**
  - Specified by keyword **`extends`**
  - Inherit both state and behavior strictly among classes
  - Multiple inheritance via extends not permitted

Built-in Interfaces and Classes in the Object Model

- **Collection objects**
  - Inherit the basic Collection interface
- `I = O.create_iterator()`
  - Creates an iterator object for the collection
- Collection objects further specialized into:
  - `set`, `list`, `bag`, `array`, and `dictionary`

Built-in Interfaces and Classes in the Object Model (cont'd.)

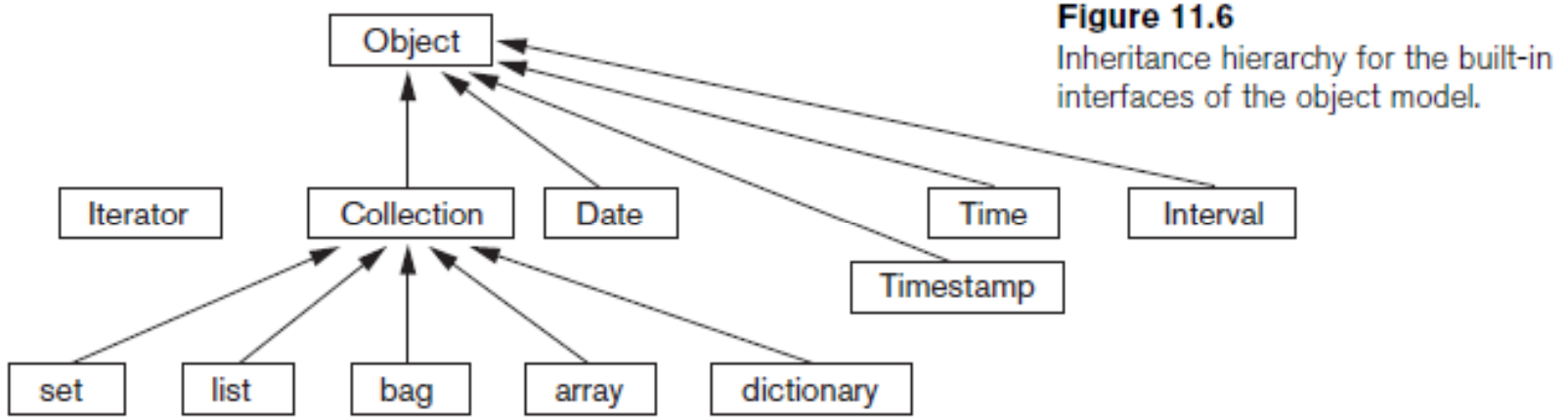

Figure 11.6
Inheritance hierarchy for the built-in interfaces of the object model.

Atomic (User-Defined) Objects

- Specified using keyword **`class`** in ODL
- **Attribute**
  - Property; describes some aspect of an object
- **Relationship**
  - Two objects in the database are related
  - Keyword **`inverse`**
    - Single conceptual relationship in inverse directions
- **Operation signature**:
  - Operation name, argument types, return value

Extents, Keys, and Factory Objects

- **Extent**
  - Contains all persistent objects of class
- **Key**
  - One or more properties whose values are unique for each object in extent
- **Factory object**
  - Used to generate or create individual objects via its operations

The Object Definition Language ODL

- Support semantic constructs of ODMG object model
- Independent of any particular programming language

Figure 11.10
Possible ODL schema for the UNIVERSITY database in Figure 11.8(b).

```
class PERSON
(   extent      PERSONS
    key         Ssn )
{   attribute   struct Pname {  string  Fname,
                                string  Mname,
                                string  Lname  }    Name;
    attribute   string                              Ssn;
    attribute   date                                Birth_date;
    attribute   enum Gender{M, F}                   Sex;
    attribute   struct Address {  short   No,
                                  string  Street,
                                  short   Apt_no,
                                  string  City,
                                  string  State,
                                  short   Zip  }    Address;
    short       Age();   };
class FACULTY extends PERSON
(   extent      FACULTY )
{   attribute   string          Rank;
    attribute   float           Salary;
    attribute   string          Office;
    attribute   string          Phone;
    relationship  DEPARTMENT    Works_in inverse DEPARTMENT::Has faculty;
    relationship  set<GRAD_STUDENT> Advises inverse GRAD_STUDENT::Advisor;
    relationship  set<GRAD_STUDENT> On_committee_of inverse GRAD_STUDENT::Committee;
    void        give_raise(in float raise);
    void        promote(in string new rank);  };
class GRADE
(   extent      GRADES  )
{
    attribute   enum GradeValues{A,B,C,D,F,I, P} Grade;
    relationship  SECTION Section inverse SECTION::Students;
    relationship STUDENT Student inverse STUDENT::Completed_sections;  };
```

Object Database Conceptual Design

- Differences between conceptual design of ODB and RDB, handling of:
  - Relationships
  - Inheritance
- Philosophical difference between relational model and object model of data
  - In terms of behavioral specification

Mapping an EER Schema to an ODB Schema

- Create ODL class for each EER entity type
- Add relationship properties for each binary relationship
- Include appropriate operations for each class
- ODL class that corresponds to a subclass in the EER schema
  - Inherits type and methods of its superclass in ODL schema

Mapping an EER Schema to an ODB Schema (cont'd.)

- Weak entity types
  - Mapped same as regular entity types
- Categories (union types)
  - Difficult to map to ODL
- An *n*-ary relationship with degree $n > 2$
  - Map into a separate class, with appropriate references to each participating class

The Object Query Language OQL

- Query language proposed for ODMG object model
- Simple OQL queries, database entry points, and iterator variables
  - Syntax: select ... from ... where ... structure
  - Entry point: named persistent object
  - Iterator variable: define whenever a collection is referenced in an OQL query

Query Results and Path Expressions

- Result of a query
  - Any type that can be expressed in ODMG object model
- OQL orthogonal with respect to specifying path expressions
  - Attributes, relationships, and operation names (methods) can be used interchangeably within the path expressions

Other Features of OQL

- **Named query**
  - Specify identifier of named query
- OQL query will return collection as its result
  - If user requires that a query only return a single element use **`element`** operator
- Aggregate operators
- Membership and quantification over a collection

Other Features of OQL (cont'd.)

- Special operations for ordered collections
- **Group by** clause in OQL
  - Similar to the corresponding clause in SQL
  - Provides explicit reference to the collection of objects within each group or **partition**
- **Having clause**
  - Used to filter partitioned sets

Overview of the C++ Language Binding in the ODMG Standard

- Specifies how ODL constructs are mapped to C++ constructs
- Uses prefix `d_` for class declarations that deal with database concepts
- Template classes
  - Specified in library binding
  - Overloads operation new so that it can be used to create either persistent or transient objects

Summary

- Overview of concepts utilized in object databases
  - Object identity and identifiers; encapsulation of operations; inheritance; complex structure of objects through nesting of type constructors; and how objects are made persistent
- Description of the ODMG object model and object query language (OQL)
- Overview of the C++ language binding