Chapter 22: Object-Based Databases

Database System Concepts, 6th Ed.

Chapter 22: Object-Based 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

Chapter 22: Object-Based Databases

- 22.1 Overview
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- 22.4 Table Inheritance
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- 22.7 Implementing O-R Features
- 22.8 Persistent Programming Languages
- 22.9 Object-Relational Mapping
- 22.10 Object-Oriented versus Object-Relational

Complex Data Types

- Motivation:
  - Permit non-atomic domains (atomic $\equiv$ 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, 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

- 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

4NF Decomposition of Nested Relation

- Dependencies in *doc*
  - *title* $\rightarrow\rightarrow$ *author* (MVD)
  - *title* $\rightarrow\rightarrow$ *keyword*
  - *title* $\rightarrow$ *pub_name, pub_branch*

MVD: multi-valued dependency; $X \rightarrow\rightarrow Y$ means that a set of Y values is associated with each X value

- Decomposed version
  - 4NF (BCNF extended to include MVD)
  - Loose 1-to-1 correspondence between a tuple and a doc

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 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

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Structured Types and Inheritance in SQL [1/2]

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

  create type ***Name*** **as**
  (first*name* **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 and Inheritance in SQL [2/2]

- **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 CustomerType
```

- 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 *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**

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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;*

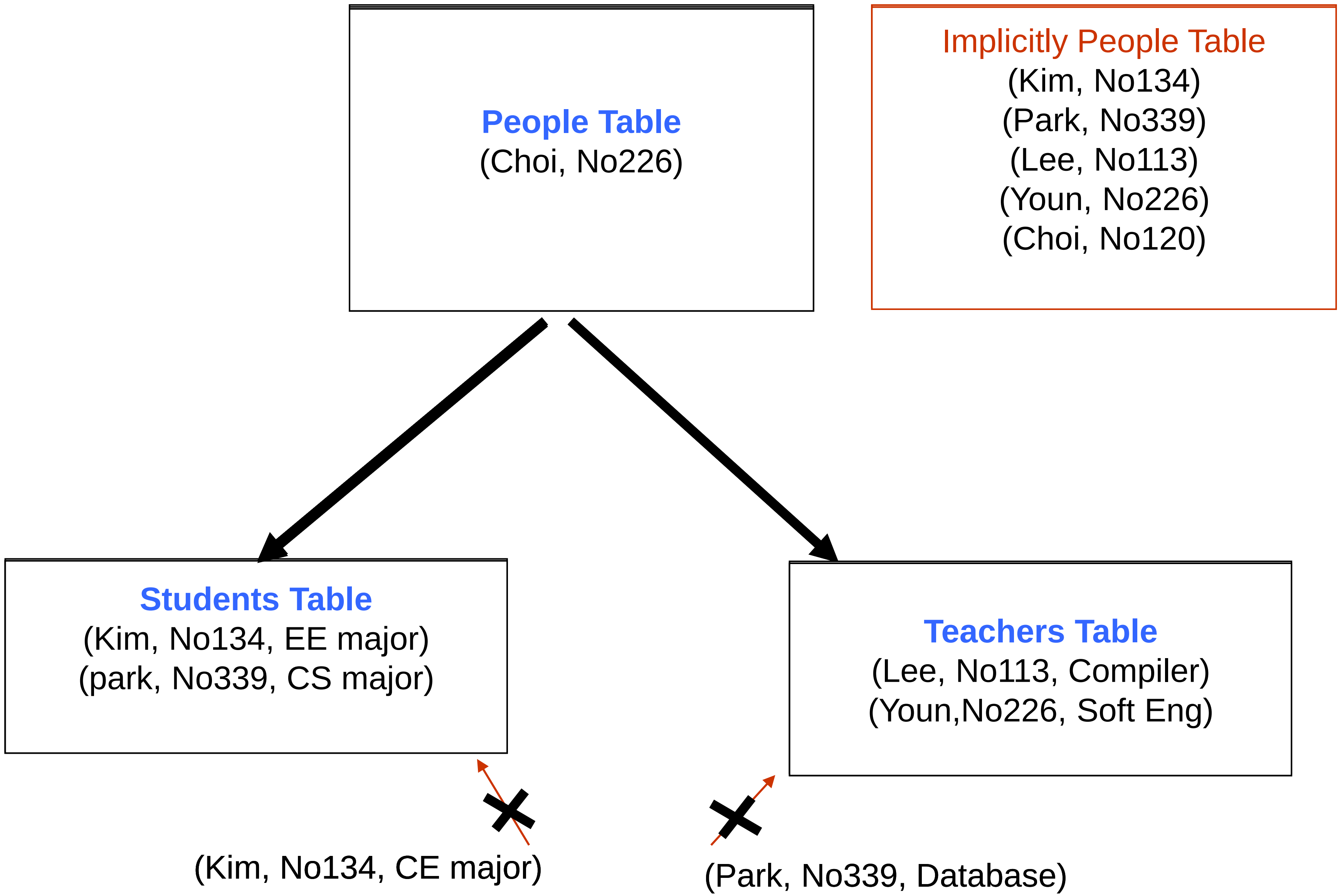
- Tuples added to a subtable are automatically visible to queries on the supertable
  - E.g. query on *people* also sees *students* and *teacher*s.
  - Similarly updates/deletes on *people* also result in updates/deletes on subtables
  - To override this behaviour, use “**only** *people”* in query
- 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



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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’]);

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

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 [1/3]

- **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 [2/3]

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 [3/3]

- 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*

Nesting & Unnesting

- Unnesting

```
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_set) as K
```

  - result is *flat_books*

- Nesting

```
select title, author,
    Publisher(pubname, pubbranch)
    as publisher, collectkeyword) as
    keyword_list
from flat_books
group by title, author, publisher
```

  - result is shown below

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

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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 [1/2]

- 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 [2/2]

- 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 [1/2]

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

Path Expressions [2/2]

- Dot (.) notation is used for composite attributes

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

- Pointer (→) notation is used for reference attributes

  select *head→name, head→address*

  from *departments*

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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

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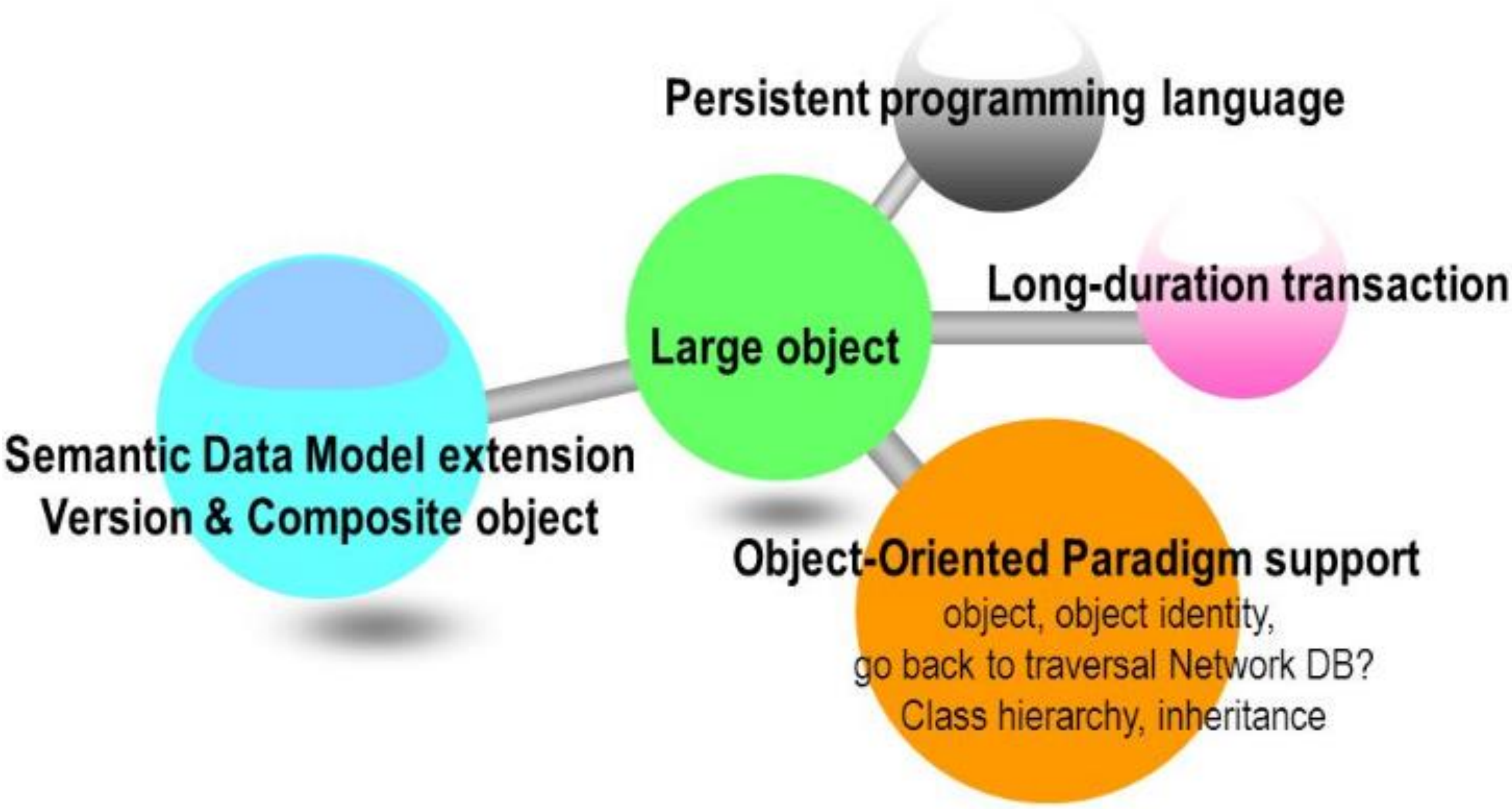
Persistent OO Programming Languages

- 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

Feature of OODBMS



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**)

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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

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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.