OBJECT-ORIENTED & OBJECT-RELATIONAL DATABASES

CS561-SPRING 2014
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Object-Relational Model

Oracle Link: http://docs.oracle.com/cd/B19306_01/appdev.102/b14260/toc.htm

SECOND APPROACH: OBJECT-RELATIONAL MODEL

- **Object-oriented model tries to bring the main concepts from relational model to the OO domain**
  - The heart is OO concepts with some extensions

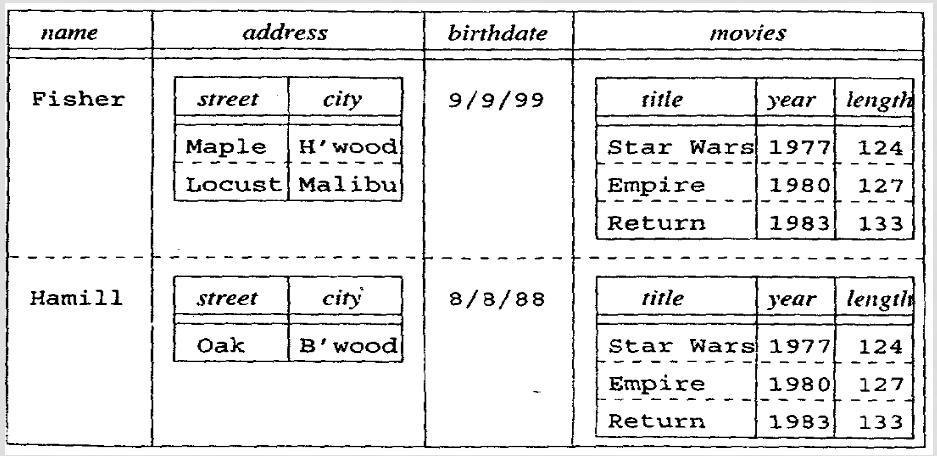
- **Object-relational model tries to bring the main concepts from the OO domain to the relational model**
  - The heart is the relational model with some extensions
  - Extensions through **user-defined types**

CONCEPTUAL VIEW OF OBJECT-RELATIONAL MODEL

- Relation is still the fundamental structure

- **Relational model extended with the following features**
  - **Type system with primitive and structure types (UDT)**
    - Including set, bag, array, list collection types
    - Including structures like records
  - **Methods**
    - Special operations can be defined over the user-defined types (UDT)
    - Specialized operators for complex types, e.g., images, multimedia, etc.
  - **Identifiers for tuples**
    - Unique identifiers even for identical tuples
  - **References**
    - Several ways for references and de-references

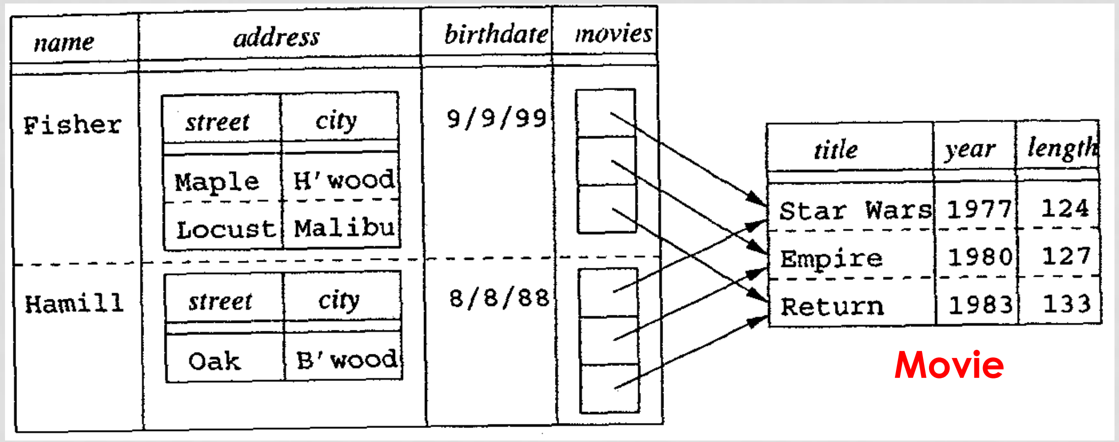
CONCEPTUAL VIEW OF OBJECT-RELATIONAL MODEL



name	address: street	address: city	birthdate	movies: title	movies: year	movies: length
Fisher	Maple	H'wood	9/9/99	Star Wars	1977	124
	Locust	Malibu		Empire	1980	127
				Return	1983	133
Hamill	Oak	B'wood	8/8/88	Star Wars	1977	124
				Empire	1980	127
				Return	1983	133

Star(name, address(street, city), birthdate,
movies(title, year, length))

- Allow of nested relations
- Repeating movies inside the stars records is redundancy
- To avoid redundancy, use pointers (references)



Star

SUPPORT FROM VENDORS

- Several major software companies including **IBM, Informix, Microsoft, Oracle,** and **Sybase** have all released object-relational versions of their products

- Extended SQL standards called SQL-99 or SQL3

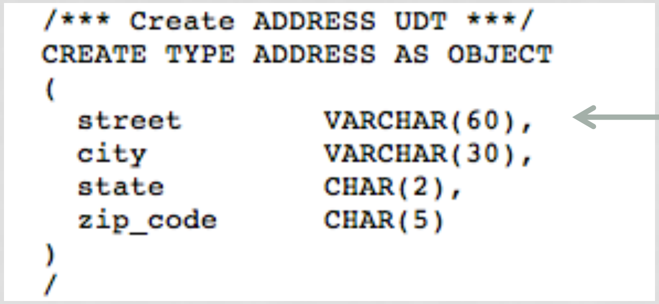
SQL-99: QUERY LANGUAGE FOR OBJECT-RELATIONAL MODEL

- User-defied types (UDT) replace the concept of classes

- Create relations on top of the UDTs
  - Multiple relations can be created on top of the same UDT

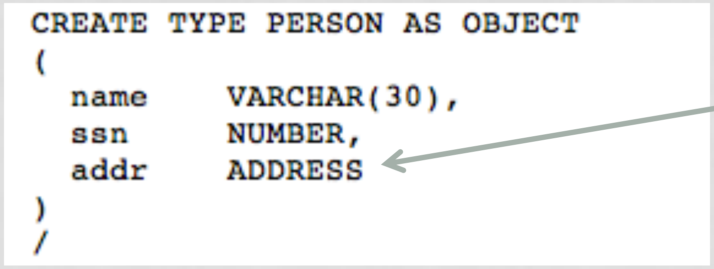
Create Type <*name*> AS (attributes and method declarations)

CREATING UDT



```
/*** Create ADDRESS UDT ***/
CREATE TYPE ADDRESS AS OBJECT
(
  street          VARCHAR(60),
  city            VARCHAR(30),
  state           CHAR(2),
  zip_code        CHAR(5)
)
/
```

Creating a type for the address of stars



```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

A hierarchy of types
(inheritance)

DEFINING METHODS

```
 CREATE TYPE PERSON AS OBJECT
 (
   name     VARCHAR(30),
   ssn      NUMBER,
   addr     ADDRESS,
   Member Function getName  return  varchar
);
/
```

← Create the type object (definition)

> If the we have member function, then we need to define the type body

```
  Create Type Body Person IS
      Member Function getName  return  varchar is
           Begin
                return name;
           End;
End;
/
```

CREATING RELATIONS

- Once types are created, we can create relations
- In general, we can create tables without types
  - But types provide encapsulation, inheritance, etc.

TABLES IN O-R MODEL (I)

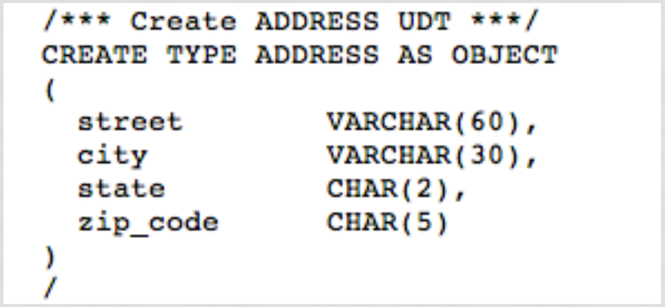
```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

Typed table

```
/*** Create a typed table for PERSON objects ***/
CREATE   TABLE   persons   OF   PERSON;
```

- Each record in the table is an object.
- That is not a relational table

TABLES IN OR MODEL (II)



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CREATE TYPE ADDRESS AS OBJECT
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  state           CHAR(2),
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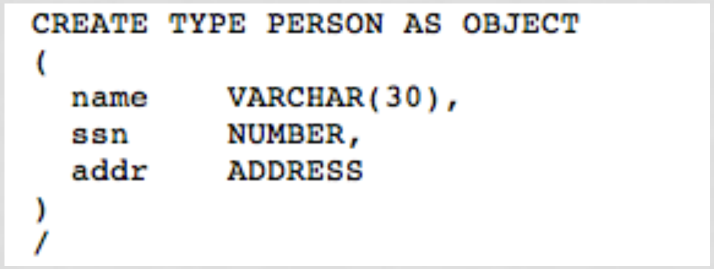
)
/
```

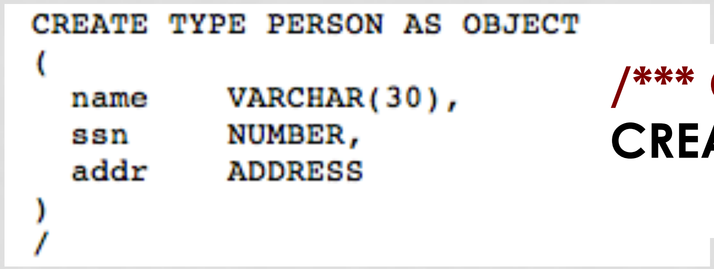


```
CREATE TYPE PERSON AS OBJECT
(
  name      VARCHAR(30),
  ssn       NUMBER,
  addr      ADDRESS
)
/
```

```
/*** Create a relational table with references to types***/
CREATE TABLE  employees
(
 empnumber            INTEGER PRIMARY KEY,
 person_data     REF  PERSON,
 manager        REF  PERSON,
 office_addr          ADDRESS,
 salary              NUMBER
)
```

Typed objects

INSERTING DATA (I)



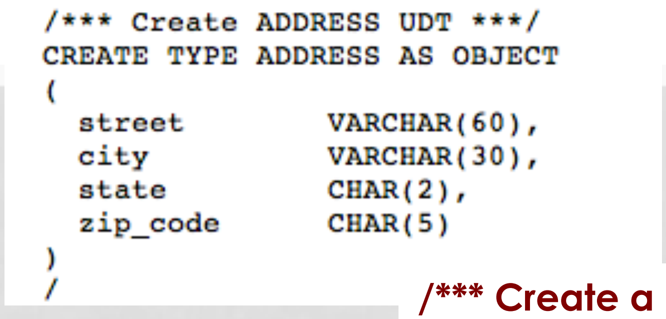
```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

```
/*** Create a typed table for PERSON objects ***/
CREATE  TABLE  persons  OF  PERSON;
```

```
/*** Insert some data--2 objects into the persons typed table ***/
INSERT INTO persons VALUES (
        PERSON('Wolfgang Amadeus Mozart', 123456,
          ADDRESS('Am Berg 100', 'Salzburg', 'AT','10424')))
/

INSERT INTO persons VALUES (
        PERSON('Ludwig van Beethoven', 234567,
          ADDRESS('Rheinallee', 'Bonn', 'DE', '69234')))
/
```

INSERTING DATA (II)



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```
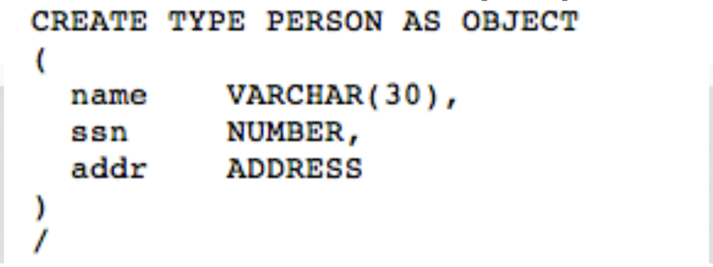



```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

```
/*** Create a relational table with references to types***/
CREATE TABLE  employees
(
  empnumber          INTEGER PRIMARY KEY,
  person_data     REF  PERSON,
  manager         REF  PERSON,
  office_addr        ADDRESS,
  salary          NUMBER
)
```

```
/** Put a row in the employees table **/
INSERT INTO employees (empnumber, office_addr, salary)
     VALUES (
          1001,
          ADDRESS('500 Oracle Parkway', 'Redwood Shores', 'CA', '94065'),
          50000)
/
```

UPDATING DATA (I)

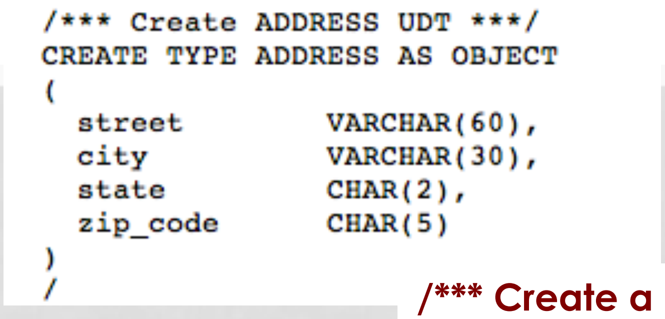
```
/*** Create ADDRESS UDT ***/
CREATE TYPE ADDRESS AS OBJECT
(
  street         VARCHAR(60),
  city           VARCHAR(30),
  state          CHAR(2),
  zip_code       CHAR(5)
)
/
```

```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

```
/*** Create a relational table with references to types***/
CREATE TABLE  employees
(
  empnumber          INTEGER PRIMARY KEY,
  person_data     REF  PERSON,
  manager         REF  PERSON,
  office_addr        ADDRESS,
  salary          NUMBER
)
```

```
/** Set the manager and PERSON REFs for the employee **/
UPDATE employees
   SET manager =
      (SELECT REF(p) FROM persons p
      WHERE p.name = 'Wolfgang Amadeus Mozart')
```

UPDATING DATA (II)



```
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CREATE TYPE ADDRESS AS OBJECT
(
  street          VARCHAR(60),
  city            VARCHAR(30),
  state           CHAR(2),
  zip_code        CHAR(5)
)
/
```
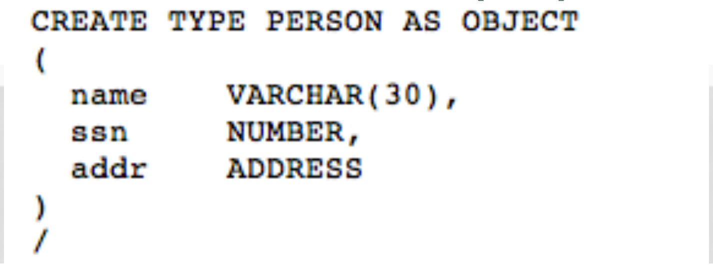



```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

```
/*** Create a relational table with references to types***/
CREATE TABLE  employees
(
  empnumber          INTEGER PRIMARY KEY,
  person_data    REF  PERSON,
  manager       REF  PERSON,
  office_addr       ADDRESS,
  salary            NUMBER
)
```

```
UPDATE employees
  SET person_data =
     (SELECT REF(p) FROM persons p
        WHERE p.name = 'Ludwig van Beethoven')
```

COLLECTIONS AND LARGE OBJECTS

- **Book Type contains collections**
  - Arrays of authors → capture the order of authors
  - Set of keywords

```
create type Book as
        (title          varchar(20),
         author-array   varchar(20) array [10],
         pub-date       date,
         publisher      Publisher,
         keyword-set    setof(varchar(20)))
```

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

    book-review **CLOB(10KB)**
  - **BLOB**: binary large objects

    image **BLOB(10MB)**

    movie **BLOB(2GB)**

Usually provide methods inside the UDT to manipulate CLOB & BLOB

COLLECTION TYPES IN ORACLE

- **Variable-Length Arrays**

```
CREATE TYPE typename IS VARRAY(n) OF datatype;
```

- **Nested Tables**

```
CREATE TYPE typename AS TABLE OF datatype;
```

EXAMPLE

```
CREATE TYPE PHONE_ARRAY IS VARRAY(10) OF varchar2(30)
/
```

```
CREATE TABLE employees
( empnumber          INTEGER PRIMARY KEY,
  person_data     REF  person,
  manager         REF  person,
  office_addr         address,
  salary          NUMBER,
  phone_nums          phone_array
)
/
```

EXAMPLE (CONT'D)

- **Inserting into the array**

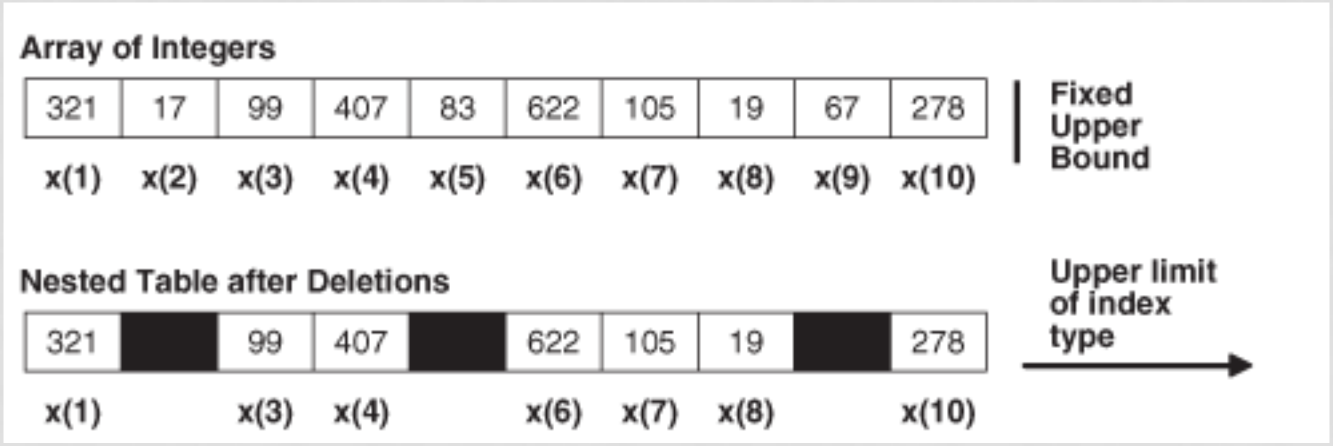
```
CREATE TABLE  employees
( empnumber          INTEGER PRIMARY KEY,
  person_data     REF  person,
  manager         REF  person,
  office_addr        address,
  salary          NUMBER,
  phone_nums         phone_array
)
/
```

```
/** Put a row in the employees table **/
INSERT INTO employees (empnumber, office_addr, phone_nums)
    VALUES (
        1001,
        ADDRESS('500 Oracle Parkway', 'Redwood Shores', 'CA', '94065'),
        phone_array('111-222-3333', '111-222-4444'))
/
```

NESTED TABLE VS. ARRAY

- **An array has a declared number of elements**
- **A nested table does not. The size of a nested table can increase dynamically.**

- **An array is always dense.**
- **A nested table is dense initially, but it can become sparse, because you can delete elements from it.**



Array of Integers
321 17 99 407 83 622 105 19 67 278
x(1) x(2) x(3) x(4) x(5) x(6) x(7) x(8) x(9) x(10)
Fixed Upper Bound
Nested Table after Deletions
321 99 407 622 105 19 278
x(1) x(3) x(4) x(6) x(7) x(8) x(10)
Upper limit of index type

ALTER TYPES

- **Using an ALTER TYPE statement, you can:**
  - Add and drop attributes
  - Add and drop methods
  - Modify a numeric attribute to increase its length, precision, or scale
  - Modify a varying length character attribute to increase its length
  - …

REFERENCES

- **Actual Object**
- **References without scope**
- **References with scope**

ACTUAL OBJECTS

```
CREATE TYPE PERSON AS OBJECT
(
  name     VARCHAR(30),
  ssn      NUMBER,
  addr     ADDRESS
)
/
```

```
/*** Create a typed table for PERSON objects ***/
CREATE  TABLE  persons  OF  PERSON;
```

addr is the entire object

```
/*** Insert some data--2 objects into the persons typed table ***/
INSERT INTO persons VALUES (
        PERSON('Wolfgang Amadeus Mozart', 123456,
          ADDRESS('Am Berg 100', 'Salzburg', 'AT','10424')))
/
```

The entire object

REFERENCE WITHOUT SCOPE

```
CREATE TYPE emp_person_typ AS OBJECT (
  name     VARCHAR2(30),
  manager  REF emp_person_typ );
/

CREATE TABLE emp_person_obj_table OF emp_person_typ;


INSERT INTO emp_person_obj_table VALUES (
   emp_person_typ ('John Smith', NULL));

INSERT INTO emp_person_obj_table
  SELECT emp_person_typ ('Bob Jones', REF(e))
    FROM emp_person_obj_table e
    WHERE e.name = 'John Smith';
```

- Reference to a type
- We did not specify from where the objects will come

REFERENCE WITH SCOPE

```
CREATE TABLE contacts_ref (
  contact_ref   REF person_typ SCOPE IS person_obj_table,
  contact_date  DATE );
```

- Reference to a type

- The scope is a table containing objects of that type

REFERENCE WITH SCOPE

```
CREATE TABLE contacts_ref (
  contact_ref   REF person_typ SCOPE IS person_obj_table,
  contact_date  DATE );
```

```
INSERT INTO contacts_ref
  SELECT REF(p), '26 Jun 2003'
    FROM person_obj_table p
    WHERE p.idno = 1;
```

WHAT'S NEXT

- **Second Approach: Object-Relational Model**
  - Conceptual view
  - Data Definition Language (Creating types, tables, and relationships)
  - **Querying object-relational database (SQL-99)**

QUERYING OBJECT-RELATIONAL DATABASE

- Most relational operators work on the object-relational tables
  - E.g., selection, projection, aggregation, set operations
- Some new operators and new syntax for some existing operators
- SQL-99 (SQL3): Extended SQL to operate on object-relational databases

EXAMPLES I

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

Q1: Find the year of movie 'King Kong'

```
Select m.year
From  Movie m
Where m.title = 'King Kong';
```

Variable *m* is important to reference the fields

Q2: Find the title of the best movie 'Jim Carry'

```
Select s.bestMovie->title
From  MovieStar s
Where s.name = 'Jim Carry';
```

Follow a reference (pointer) using → operator

EXAMPLES II: DE-REFERENCING

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

Q3: Find movies starred by 'Jim Carry'

```
Select DEREF(movie)
From  StarsIn
Where star->name = 'Jim Carry';
```

DEREF: Get the tuple pointed to by the given pointer

Q4: Find movies starred by 'Jim Carry' (Another way)

```
Select s.movie->title, s.movie->year, s.movie->inColor,
From  StarsIn s
Where s.star->name = 'Jim Carry';
```

*** Using a variable for StartsIn (s in Q4) is not necessary because the table is not based on type.

EXAMPLES III: COMPARISON

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

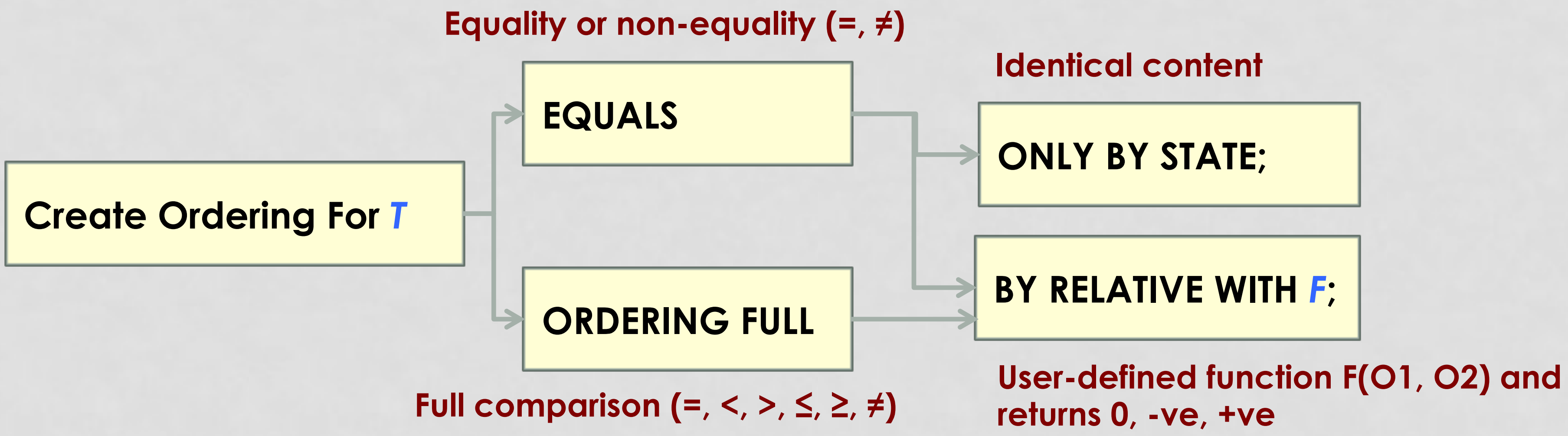
Q5: Find distinct movies starred by 'Jim Carry' or 'Mel Gibson'

```
Select Distinct DEREF(movie)
From  StarsIn
Where star->name = 'Jim Carry'
Or star->name = 'Mel Gibson';
```

- That is wrong because all objects of type MovieType are unique even if they have the same content
- Need a mechanism to define how objects compare to each other
  (needed for any comparison, e.g., ordering, duplicate elimination, grouping, etc.)

ORDERING RELATIONSHIPS

- Need to define how to compare objects of a given type *T*



Equality or non-equality (=, ≠)
Identical content
Create Ordering For *T*
EQUALS
ONLY BY STATE;
BY RELATIVE WITH *F*;
ORDERING FULL
Full comparison (=, <, >, ≤, ≥, ≠)
User-defined function F(O1, O2) and returns 0, -ve, +ve

ORDERING FUNCTION

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

```
CREATE ORDERING FOR AddressType
ORDER FULL BY RELATIVE WITH AddrLEG;
```

```
CREATE FUNCTION AddrLEG(
    x1 AddressType,
    x2 AddressType
) RETURNS INTEGER

IF x1.city() < x2.city() THEN RETURN(-1)
ELSEIF x1.city() > x2.city() THEN RETURN(1)
ELSEIF x1.street() < x2.street() THEN RETURN(-1)
ELSEIF x1.street() = x2.street() THEN RETURN(0)
ELSE RETURN(1)
END IF;
```

EXAMPLES IV: COMPARISON

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

Create Ordering For MovieType Equals Only By State;

Q5: Find distinct movies starred by ‘Jim Carry’ or ‘Mel Gibson’

```
Select Distinct DEREF(movie)
From  StarsIn
Where star->name = ‘Jim Carry’
Or star->name = ‘Mel Gibson’;
```

✓

EXAMPLES V: GROUPING & NESTING

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
    REF IS movieID SYSTEM GENERATED,
    PRIMARY KEY (title, year)
);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

Q6: Find stars who participated in less than 10 movies

```
Select DEREF(star)
From  StarsIn
Group by DEREF(star)
Having count(movie) < 10;
```

Create at least an equality ordering on StarType

Q7: Find movie titles in 2000 where 'Jim Carry' is not in

```
Select m
From  Movie m
Where m.year = 2000
And   m.title Not In (
              Select movie->title
              From  StarsIn
              Where star->name = 'Jim Carry'
              And movie->year = 2000);
```

QUERYING COLLECTIONS & ARRAYS

```
create type Book as
        (title          varchar(20),
         author-array   varchar(20) array [10],
         pub-date       date,
         publisher      Publisher,
         keyword-set    setof(varchar(20)))
```

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
```

find all books that have the word "database" as one of their keywords

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

Unnest returns a relation

Get 1st and 2nd authors of certain book

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

GENERATORS AND MUTATORS

- How to insert new new data into tables

- **Generators**
  - Like the constructors in OO programming
  - Create new objects

- **Mutators**
  - Modify the value of an existing object

- For each attribute x in UDT *T*, the system automatically creates:
  - Generator ***T()*** that returns an empty object of T
  - Mutator ***x(v)*** that sets the value of attribute x to value v

EXAMPLE

```
CREATE TYPE MovieType AS (
    title   CHAR(30),
    year    INTEGER,
    inColor BOOLEAN
);
```

```
CREATE TABLE Movie OF MovieType (
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);
```

```
CREATE TYPE StarType AS (
    name      CHAR(30),
    address   AddressType,
    bestMovie REF(MovieType) SCOPE Movie
);
```

```
CREATE TABLE MovieStar OF StarType (
    REF IS starID SYSTEM GENERATED
);
```

```
CREATE TABLE StarsIn (
    star    REF(StarType) SCOPE MovieStar,
    movie   REF(MovieType) SCOPE Movie
);
```

```
CREATE PROCEDURE InsertStar(
    IN s CHAR(50),
    IN c CHAR(20),
    IN n CHAR(30)
)
DECLARE newAddr AddressType;
DECLARE newStar StarType;

BEGIN
    SET newAddr = AddressType();
    SET newStar = StarType();
    newAddr.street(s);
    newAddr.city(c);
    newStar.name(n);
    newStar.address(newAddr);
    INSERT INTO MovieStar VALUES(newStar);
END;
```

```
CALL InsertStar('345 Spruce St.', 'Glendale', 'Gwyneth Paltrow');
```

If DBMS allows creating generators with parameters

```
INSERT INTO MovieStar VALUES(
    StarType('Gwyneth Paltrow',
        AddressType('345 Spruce St.', 'Glendale')));
```

CREATING RECORDS OF COMPLEX TYPES

- Collection and array types

```
create type Book as
        (title          varchar(20),
         author-array   varchar(20) array [10],
         pub-date       date,
         publisher      Publisher,
         keyword-set    setof(varchar(20)))
```

Array construction

```
array [ 'Silberschatz' ,`Korth' ,`Sudarshan' ]
```

Set value attributes

```
set( v1, v2, …, vn)
```

To insert the preceding tuple into the relation *books*

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

WHAT WE COVERED

- **First Approach: Object-Oriented Model**
  - Concepts from OO programming languages
  - ODL: Object Definition Language
  - What about querying OO databases???
    - OQL: Object Oriented Query Language

- **Second Approach: Object-Relational Model**
  - Conceptual view
  - Data Definition Language (Creating types, tables, and relationships)
  - Querying object-relational database (SQL-99)

Make use of the interesting features of Object-Oriented into database systems ➔ ODBMSs

WHEN TO CONSIDER OODBMS OR ORDBMS

- **Complex Relationships**
  - A lot of many-to-many relationships, tree structures or network (graph) structures.
- **Complex Data**
  - Multi-dimensional arrays, nested structures, or binary data, images, multimedia, etc.
- **Distributed Databases**
  - Need for free objects without the rigid table structure.
- **Repetitive use of Large Working Sets of Objects**
  - To make use of inheritance and reusability
- **Expensive Mapping Layer**
  - Expensive decomposition of objects (normalization) and re-composition at query time

OBJECT-ORIENTED VS. OBJECT-RELATIONAL

- **Object-oriented DBMSs**
  - Did not achieve much success (until now) in the market place
  - No query support (Indexing, optimization)
  - No security layer
- **Object-relational DBMSs**
  - Better support from big vendors
  - Tries to make use of all advances in RDBMSs
    - Indexes, views, triggers, query optimizations, security layer, etc.
    - **Work in progress --- Long way to go**

MODIFICATIONS TO RDBMS

- **Parsing**
  - Type-checking for methods pretty complex
- **Query Rewriting**
  - New rewriting rules including complex types and collections
- **Optimization**
  - New algebra operators needed for complex types.
  - Must know how to integrate them into optimization.
  - WHERE clause exprs can be expensive!
    - Selection pushdown may be a bad idea.

MODIFICATIONS TO RDBMS (CONT'D)

- **Execution**
  - New algebra operators for complex types.
  - OID generation & reference handling.
  - Dynamic linking and overriding.
  - Support objects bigger than 1 page.
  - Caching of expensive methods.
- **Access Methods**
  - Indexes on methods, not just columns.
  - Indexes over collection hierarchies.
  - Need indexes for new WHERE clause exprs (not just <, >, =)
- **Data Layout**
  - Clustering of nested objects.
  - Chunking of arrays.

COMPARISON

Criteria	RDBMS	ODBMS	ORDBMS
Product maturity	Relatively old and so very mature	This concept is few years old and so relatively matur feature	Still in development stage so immature
The use of SQL	Extensive supports SQL	OQL is similar to SQL, but with additional features like Complex objects and object-oriented features	SQL3 is being developed with OO features incorporated in it
Advantages	Its dependence on SQL, relatively simple query optimization hence good performance	It can handle all types of complex applications, reusability of code, less coding	Ability to query complex applications and ability to handle large and complex applications
Disadvantage	Inability to handle complex applications	Low performance due to complex query optimization, inability to support large-scale systems	Low performance in web application
Support from vendors	It is considered to be highly successful so the market size is very large but many vendors are moving towards ORDBMS	Presently lacking vendor support due to vast size of RDBMS market	All major RDBMS vendors are after this so has very good future

COMPARISON

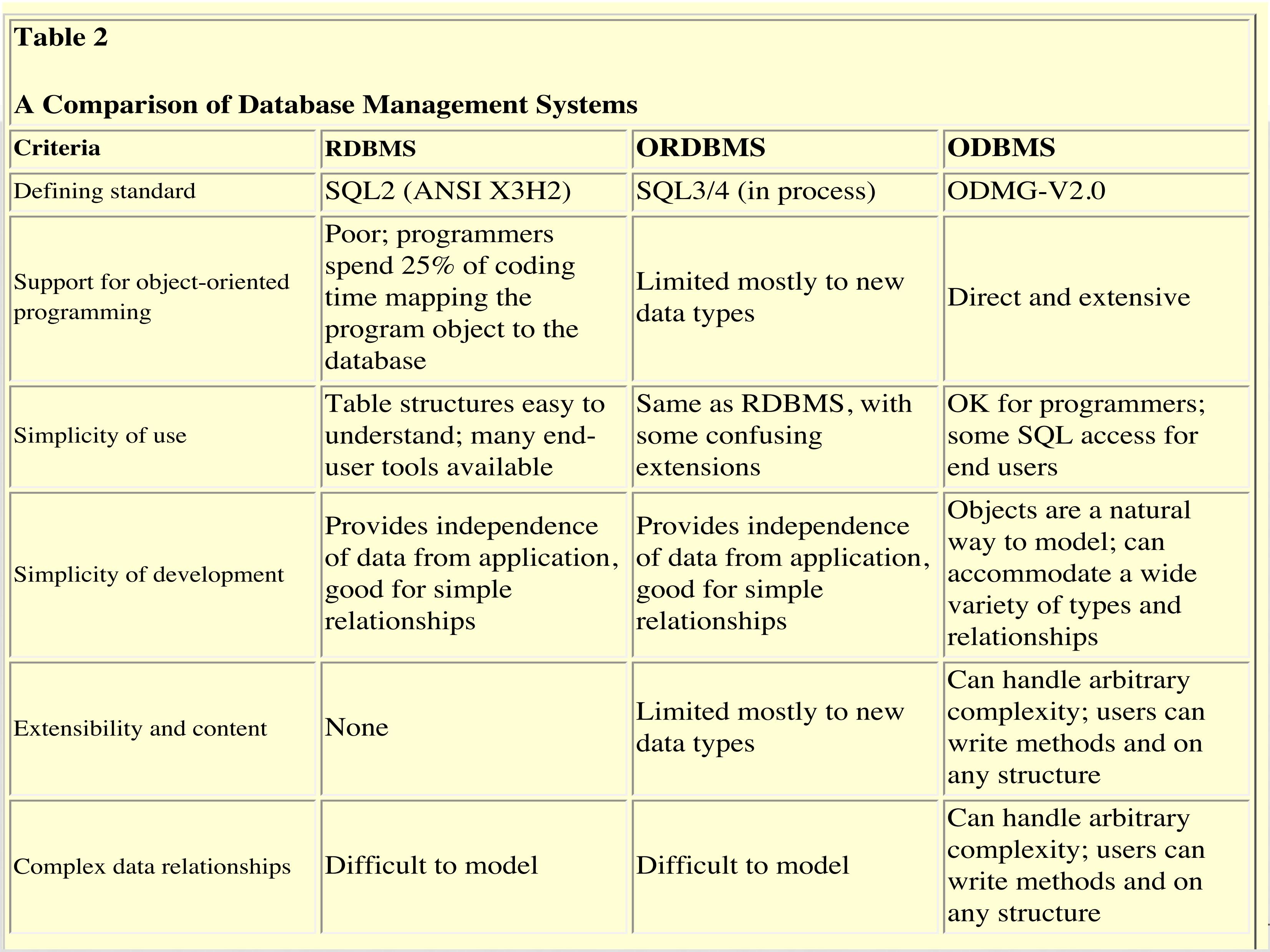

Table 2

A Comparison of Database Management Systems

Criteria	**RDBMS**	**ORDBMS**	**ODBMS**
Defining standard	SQL2 (ANSI X3H2)	SQL3/4 (in process)	ODMG-V2.0
Support for object-oriented programming	Poor; programmers spend 25% of coding time mapping the program object to the database	Limited mostly to new data types	Direct and extensive
Simplicity of use	Table structures easy to understand; many end-user tools available	Same as RDBMS, with some confusing extensions	OK for programmers; some SQL access for end users
Simplicity of development	Provides independence of data from application, good for simple relationships	Provides independence of data from application, good for simple relationships	Objects are a natural way to model; can accommodate a wide variety of types and relationships
Extensibility and content	None	Limited mostly to new data types	Can handle arbitrary complexity; users can write methods and on any structure
Complex data relationships	Difficult to model	Difficult to model	Can handle arbitrary complexity; users can write methods and on any structure