SQL-99

The Standard Language for an ORDBMS (Object-Relational DBMS)

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Object-Relational Database Systems (ORDBS)

- Motivations
  - Allow DBMS to deal with specialized types
    – maps, signals, images, etc.
    – with their own specialized methods
  - Support specialized methods even on conventional relational data
  - Support structure more complex than "flat files"
  - …

⇨ Object-oriented ideas enter the relational world
  - Keep the *relation as the fundamental abstraction* whereas the OODBS use the class as the fundamental abstraction

ORDBS: New Features

- Structured types
  - Not only atomic types
  - ODL-like type system
    (Also: BLOB, CLOB, ADT, BFILE)
- Methods
  Special operations can be defined for a type
- Identifiers
  Allowing unique IDs for each tuple
- References
  Pointers to tuples

Nested Relations in an ORDBS

- Attributes may have non-atomic types
  - Nested-relational data models give up 1NF (atomic values)
  - A relation's type can be any schema consisting of one or more attributes
    An attribute may even have an own schema as type
- Example:
  `moviestar(name, address(street,city), birth, movies(title,year))`

<table>
<tr><th>name</th><th>address</th><th>birth</th><th>movie</th></tr>
<tr><td>Fisher</td><td><table><tr><th>street</th><th>city</th></tr><tr><td>Maple</td><td>Hollywood</td></tr><tr><td>5. Avenue</td><td>New York</td></tr></table></td><td>9/9/1950</td><td><table><tr><th>title</th><th>year</th></tr><tr><td>Star Wars</td><td>1977</td></tr><tr><td>Empire</td><td>1980</td></tr></table></td></tr>
<tr><td>Hamill</td><td><table><tr><th>street</th><th>city</th></tr><tr><td>Sunset Bvld</td><td>LA</td></tr></table></td><td>8/8/1962</td><td><table><tr><th>title</th><th>year</th></tr><tr><td>Star Wars</td><td>1977</td></tr><tr><td>Return</td><td>1983</td></tr></table></td></tr>
</table>

References in an ORDBS – I

- Non-normalized relation
- Introduce references to allow a tuple *t* refer to a tuple *s* rather than including *s* in *t*

name	address		birth	movie	
	street	**city**		**title**	**year**
Fisher	Maple	Hollywood	9/9/1950	Star Wars	1977
	5. Avenue	New York		Empire	1980
	street	**city**		**title**	**year**
Hamill	Sunset Blvd	LA	8/8/1962	Star Wars	1977
				Return	1983

References in an ORDBS – II

- If attribute *A* has a type that is a reference to a relation with schema *R*, we denote *A* as *A(*R)*
- If A is a set of references, we denote *A* as *A({*R})*
- Example:

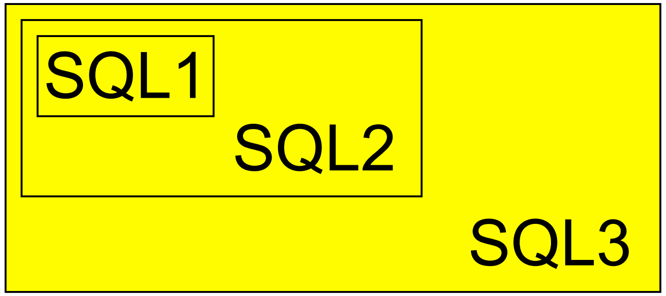
```
moviestar(name, address(street,city), birth, movie({*movies}))
movies(title,year)
```

name	**address**		**birth**	**movie**
	street	**city**		
Fisher	Maple	Hollywood	9/9/1950	
	5. Avenue	New York		
	street	**city**		
Hamil	Sunset Bvld	LA	8/8/1962	

title	**year**
Star Wars	1977
Empire	1980
Return	1883

SQL Development

- SQL-86 → SQL-89 (SQL1)
- SQL-92 (SQL2):
  - executable DDL
  - outer join
  - cascaded update and delete
  - temporary table
  - set operations: union, intersection, difference
  - domain definitions in schemes
  - new built-in data types
  - dynamic SQL via PREPARE and EXECUTE statements
  - transaction consistency levels
  - deferred constraint locking
  - scrolled cursors
  - SQL diagnostics
- SQL-99 (SQL3): SQL-92 + extensions



NOTE 1:
SQL-99 contains the functions from SQL-92

NOTE 2:
we are focusing on some of these extensions today

User-Defined Types

- As in previous SQL-standards, relations are still the core abstraction in SQL-99
- Classes from ODL are “translated” into *User-Defined Types* (UDTs)

- SQL-99 allows *UDT*s to play a dual role:
  1. They can be the types of relations (tables), i.e., the type of their tuple (sometimes called a *row type*)
  2. They can be the type of an attribute in a relation

Defining UDTs

- UDTs are analogous to ODL class declarations, but
  - key declarations are not part of the UDT –
    they are part of the table declaration
  - relationships are not properties –
    they must be represented by their own tables
- A simple form of a UDT consists of
  - keyword `CREATE TYPE`
  - name
  - keyword `AS`
  - a parenthesized, comma-separated list of attribute-type pairs
  - a comma-separated list of methods including argument and return type
- Syntax: `CREATE TYPE` *T* `AS (` < list of attribute-type pairs> `)`
  < list of methods> `;`

Bar–Beer–Sell (BBS) Example: Defining UDTs

```
CREATE TYPE BarType AS
(
    name CHAR(20),
    addr CHAR(20)
);

CREATE TYPE BeerType AS
(
    name CHAR(20),
    manf CHAR(20)
);
```

NOTE 1:
keyword `CREATE TYPE`

NOTE 2:
a name of the UDT

NOTE 3:
keyword `AS`

NOTE 4:
parenthesized, comma-separated list of attribute-type pair

NOTE 5:
additionally we may have methods (will be added later)

Creating Tables – I

- UDTs do not declare relations, but we might declare one (or more) relations whose tuples are the type of an UDT
- A simple form of relations defined from a UDT consists of
  - keyword `CREATE TABLE`
  - name
  - keyword `OF`
  - name of UDT
- Syntax: `CREATE TABLE` *S* `OF` *T*
- A relation must declare a key as keys are not part of the UDT
- Syntax:

```
CREATE TABLE S OF T (
        PRIMARY KEY (<list of key attributes>)
);
```

BBS Example: Creating Tables

```
CREATE TYPE BarType AS
(           name CHAR(20),
            addr CHAR(20)
);
CREATE TYPE BeerType AS
(           name CHAR(20),
            manf CHAR(20)
);
CREATE TABLE Bars OF BarType
(      PRIMARY KEY (name)
);
CREATE TABLE Beers OF BeerType
(      PRIMARY KEY (name)
);
```

NOTE 1:
keyword `OF` and name of UDTs are used in place of element lists in `CREATE TABLE` statements

NOTE 2:
primary key is defined by the keywords `PRIMARY KEY` followed by a parenthesized, comma-separated list of key attributes

NOTE 3:
other elements of a table declaration may be added similarly, e.g., foreign keys, tuple based constrains, etc., which apply to this table only, not the UDT

NOTE 4:
usually we have one relation per UDT, but we may have several

References – I

- If a table is created using a UDT, we may have a *reference column* serving as an *identity*
  - it can serve as a primary key
  - it can be a system generated, unique value
- To refer to tuples in a table with a reference column, an attribute may have as type a reference to another type
  - If `T` is a UDT, then `REF(T)` is the type of a reference to a `T` object
  - Unlike OODBS, references are values that can be seen by queries

References – II

- For a reference attribute to be able to refer to a relation, the relation must be referenceable
- A table is made referenceable by including a clause in the table declaration (this not part of the UDT)
- Syntax: REF IS <attribute name> <generated>
- The <attribute name> will serve as the object identifier
- The <generated> is telling how the id is generated, either:
  - SYSTEM GENERATED, the DBMS maintains a unique value in this column for each tuple
  - DERIVED, the DBMS uses the primary key of the relation to produce unique values for each tuple

BBS Example: References – I

```
CREATE TYPE BarType AS (
    name CHAR(20),
    addr CHAR(20),
    bestSeller REF(BeerType) SCOPE Beers
);
CREATE TYPE BeerType AS (
    name CHAR(20),
    manf CHAR(20)
);
CREATE TABLE Bars OF BarType (
    PRIMARY KEY (name)
);
CREATE TABLE Beers OF BeerType (
    REF IS beerID SYSTEM GENERATED
    PRIMARY KEY (name)
);
```

NOTE 1:
`bestSeller` is a reference to a `BeerType` object

NOTE 2:
`bestSeller` must refer to objects in the `Beers` relation whose type is `BeerType`

NOTE 3:
the relation `Beers` must be referenceable

NOTE 4:
the "ID" is system generated

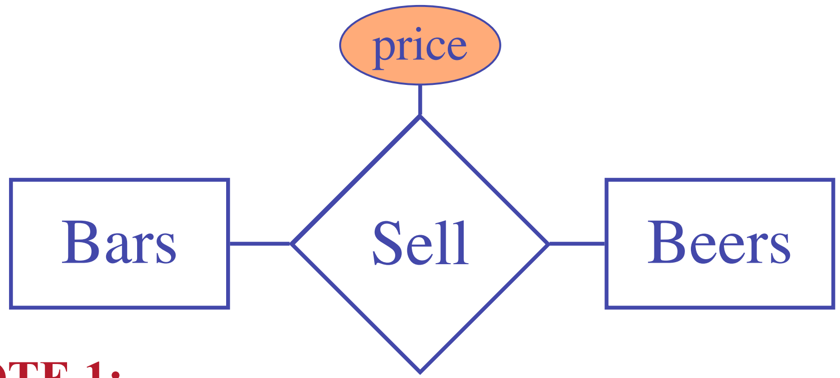
NOTE 5:
only single references are possible this way, not sets

BBS Example: References – II

```
CREATE TYPE BarType AS
(   name CHAR(20),
    addr CHAR(20)
);

CREATE TYPE BeerType AS
(   name CHAR(20),
    manf CHAR(20)
);

CREATE TYPE MenuType AS
(   bar   REF(BarType),
    beer  REF(BeerType)
);
```



NOTE 1:
Bars sell beers (and beers are sold at bars), but we cannot directly represent this SET relationship in type bar and beer as in ODL

NOTE 2:
we need a separate relation to represent such sets, with references to the two types (possibly with a scope)

NOTE 3:
if the relationship has properties as price, even in ODL we must have a separate class

References – III

- References may be given a *scope*, i.e., the name of the relation to whose tuples are referred to
- Syntax: `S REF(T) SCOPE R` –
  (an attribute `S` of type `REF(T)` refers to a tuple in relation `R`)
- If no scope is given, the reference can go to tuples of any relation of type `T`
- Example

```
CREATE TYPE MenuType AS (
     bar   REF(BarType) SCOPE Bars,
     beer  REF(BeerType) SCOPE Beers,
     price FLOAT
 );
```

NOTE:
`Bars` and `Beers` are relations defined using the `BarType` and `BeerType`, respectively

Methods – I

- UDTs can have associated methods.
  They work on objects whose type is the UDT
  (applied on tuples)

- They are similar to *Persistent Stored Modules* (PSM), which are general purpose functions allowed to be stored together with the schema and used in SQL (described in Chapter 8)

- There are two ways to define methods. They may be
  - declared in the UDT using a `METHOD` clause
  - defined separately in a `CREATE METHOD` statement

Methods – II

- There is a special tuple variable `SELF` that refers to that object to which the method is applied, i.e., can use `SELF.a` to access the object attribute `a`
- In the method declaration, arguments need a mode, like `IN`, `OUT`, or `INOUT`, but the mode does not appear in the definition.
- Many methods will take no arguments (relying on `SELF`)
- All methods must return a value of some type
- A method is applied using "dot", e.g., `t.updatePrice(...)`

Methods: Declaration

- A declaration of a method for a UDT consists of
  - keyword `METHOD`
  - name of the method
  - keyword `RETURNS`
  - the return type

- Declaration syntax:

  `METHOD` <name> `RETURNS` <return type>;

Methods: Definitions

- A definition of a method for a UDT consists of
  - keywords `CREATE METHOD`
  - name of the method including arguments and their type
  - keyword `RETURNS` and the return type
  - keyword `FOR` and the name of the UDT in which the method is declared
  - body of the method (as PSM functions)
- Definition syntax (body):

```
CREATE METHOD <name> RETURNS <return type> FOR <name of UDT>
BEGIN
        <method body>
END
```

Methods: Declaration and Definition Example

```
CREATE TYPE MenuType AS (
bar   REF(BarType) SCOPE Bars,
beer  REF(BeerType) SCOPE Beers,
price FLOAT
)

METHOD updatePrice ( IN p float )
RETURNS BOOLEAN;

CREATE METHOD updatePrice
( p float )
RETURNS BOOLEAN FOR MenuType
BEGIN
   <body>
END;
```

NOTE 1:
Declaration in UDT

NOTE 2:
Definition separately, outside the UDT

NOTE 3:
parameters, mode only in declaration

NOTE 4:
the body is written in the same language as the PSM functions, e.g., SQL/PSM used in the book

NOTE 5:
can use built-in `SELF`

NOTE 6:
p necessary, as it is used to change the value of the price attribute, e.g., `p` is added to `SELF.price`

New Operations in SQL-99

- All appropriate SQL operations applying to tables defined using UDTs are allowed, but there are also some new features:
  - using references
  - accessing UDT attributes
  - creating UDT objects
  - order relationships

Following References – I

- If *x* is a value of type `REF(T)`, then `x` refers to some tuple *t* of type `T`
- The attributes of tuple *t* can be obtained by using the `->` operator
  - essentially as in C
  - if *x* is a reference to tuple *t* and *a* is an attribute in *t*, then `x->a` is the value if attribute *a* in *t*
- Example: Find the beers served at “Joe’s”

```
SELECT beer->name
FROM Sells
WHERE bar->name = 'Joe''s';
```

NOTE 1:
`Sells` is a table with `MenuType` as type

NOTE 2:
the attributes of a tuple is accessed using the `->` operator

NOTE 3:
single-quoted strings

Following References – II

- The tuple t can be obtained by using the `DEREF` operator if x is a reference
- Example:
  Find the bars (all attributes) serving "Bud"

```
SELECT DEREF(bar)
FROM Sells
WHERE beer->name = 'Bud';
```

NOTE 1:
`Bar` is reference to a tuple in table `Bars`

NOTE 2:
`DEREF(bar)` gets the referenced tuples

```
SELECT bar
From Sells
Where beer->name = 'Bud';
```

NOTE 3:
`SELECT bar`, without `DEREF`, would return only system-generated values serving as the IDs of the tuples – not the information in the tuples themselves

Accessing UDT Attributes

- A tuple defined by a UDT is analogous to an object – not a list of components corresponding to the attributes of a UDT
- Example:
  the relation `bars` is defined using the UDT `barType`
  - this UDT has two attributes, i.e., `name` and `addr`,
  - a tuple `t` in `bars` has only one component, i.e., the object itself
- Every UDT has implicitly defined *observer methods* for each attribute.
  - `x()` is the name of the observer method for an attribute `x`
  - returns the value of attribute `x` in the UDT
  - is applied as all other methods on this UDT, i.e., using "dot"
  - if `t` is of UDT type `T` and `x` is an attribute of `T`, then `t.x()` is the value of `x` in `t`

Creating Data Elements

- *Generator methods* create objects of UDT type `T`:
  - same name as the UDT itself, i.e., `T()`
  - takes no arguments
  - invoked without being applied to objects
  - returns an object of type `T` with no values in the various components

Updating Data Elements

- *Mutator methods* update attributes in objects of UDT type `T`:
  - for each attribute `x` in `T`, there is a mutator method `x(v)`
  - when applied to an object `T`, `x(v)` changes the value of `x` to `v`
- Note: the *mutator* (`x(v)`) and *observer* (`x()`) methods for an attribute `x` have the same name, but only the *mutator* method has a parameter

Creating and Updating Data Elements

- Example:
  PSM procedure inserting new bars into the `Bars` relation

```
CREATE PROCEDURE insertBar (
      IN n CHAR(20),
      IN a CHAR(20)
)
DECLARE newBar BarType;
BEGIN
      SET newBar = BarType();
      newBar.name(n);
      newBar.addr(a);
      INSERT INTO Bars VALUES(newBar);
END;
```

NOTE 1:
the UDT `BarType` has two attributes, i.e., `name` and `addr`, which are parameters

NOTE 2:
declaration of a variable of type `BarType`

NOTE 3:
`newBar` is assigned a value of an empty `BarType` object using the `BarType()` generator method

NOTE 4: we apply mutator methods for the attributes in `BarType` UDT, i.e, `name(n)` and `addr(a)`, on the `newBar` object using "dot" notation

NOTE 5: we insert the object newBar of type BarType into the table Bars. NB! Simpler ways may exist to insert objects

Comparing Objects – I

- There are no operations to compare two objects whose type is some UDT *by default,* i.e, we cannot
  - eliminate duplicates
  - use `WHERE` clauses
  - use `ORDER BY` clauses

- SQL-99 allows to specify comparison or ordering using `CREATE ORDERING` statements for UDTs

Comparing Objects – II

- Equality for an UDT named `T`:
  `CREATE ORDERING FOR T EQUALS ONLY BY STATE`
  (equal if all corresponding components have the same value)

- Apply all comparison operators for an UDT named `T`:
  `CREATE ORDERING FOR T ORDERING FULL BY RELATIVE`
  `WITH F`
  (all comparison operators - <, <=, >, >=, =, and <> - may be applied on two objects using an integer function `F` which *must be implemented* separately)

  Example:
  $< \; : \; F(x_1, x_2) < 0 \quad \text{if} \; x_1 < x_2$
  $> \; : \; F(x_1, x_2) > 0 \quad \text{if} \; x_1 > x_2$
  $= \; : \; F(x_1, x_2) = 0 \quad \text{if} \; x_1 = x_2$
  etc.

UDTs (revisited) – Type of a Column

- A UDT can also be the type of a column
- Example:
  Let's create an address type to use in bars (replacing the string)

```
CREATE TYPE AddrType AS (
     street CHAR(30),
     city CHAR(20),
     zip INTEGER
);

CREATE TYPE BarType AS (
     name CHAR(20),
     addr AddrType
);
```

NOTE 1:
the `addr` attribute of the UDT `BarType` has changed to an own UDT – composite types

- Problem: how can we sort all bars alphabetically?
- We need a way to compare the objects

Comparing Objects – lexicographical ordering – I

- First, the UDT `AddrType`:

```
CREATE ORDERING FOR AddrType
ORDER FULL BY RELATIVE WITH AddrComp;

CREATE FUNCTION AddrComp (
     IN x1 AddrType,
     IN x2 AddrType
) 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(1)
ELSE RETURN(0)
END IF;
```

NOTE 1: all comparison operators may be applied

NOTE 2: comparison is performed in function `AddrComp`

NOTE 3: we first compare `city`, if equal we look at `street`

NOTE 4: if `x1.a > x2.a` **return 1**

NOTE 5: if `x1.a < x2.a` **return -1**

NOTE 6: if all `x1.a = x2.a` **return 0**

NOTE 7: has to use observer methods to get value

Comparing Objects – lexicographical ordering – II

- Second, the UDT `BarType`:

```
CREATE ORDERING FOR BarType
ORDER FULL BY RELATIVE WITH BarComp;
```

NOTE 1:
all comparison operators may be applied

```
CREATE FUNCTION BarComp (
     IN x1 BarType,
     IN x2 BarType
) RETURNS INTEGER
IF          x1.name() < x2.name()  THEN RETURN(-1)
ELSEIF      x1.name() > x2.name()  THEN RETURN(1)
ELSEIF      x1.addr() < x2.addr()  THEN RETURN(-1)
ELSEIF      x1.addr() > x2.addr()  THEN RETURN(1)
ELSE RETURN(0)
END IF;
```

NOTE 2:
we first compare `name`, if equal we look at `addr`

NOTE 3:
as the `addr` itself is a UDT, it will again use the its own comparison function `AddrComp`

BBS Example: Using Methods – I

- Example:
  add method for retrieving price including tip

```
CREATE TYPE MenuType AS (
      bar   REF(BarType) SCOPE Bars,
      beer  REF(BeerType) SCOPE Beers,
      price FLOAT
)
METHOD priceTip (IN p float)
RETURNS FLOAT;

CREATE METHOD priceTip (p float)
RETURNS FLOAT FOR MenuType
BEGIN
      RETURN (1 + p) *   SELF.price;
END;
CREATE TABLE Sells OF MenuType;
```

NOTE 1:
tip is given in percent

NOTE 2:
the value returned is the price, found by using `SELF`, increased by p percent (`FLOAT`)

NOTE 3:
create table `sells` from UDT `MenuType`

BBS Example: Using Methods – II

- Example:
  find beers and price with and without tip on "Joe's" bar

```
         2    4
SELECT s.beer->name(),s.price(),s.priceTip(0.15)
                        4         5
FROM Sells s1
          2    4    3
WHERE s.bar->name() = 'Joe''s'
```

NOTE 1:
Renaming allowed

NOTE 2:
since `beer` and `bar` are references we have to use the `->` operator

NOTE 3:
`bar` is a reference to an object whose type is a UDT. However, the value returned by the `name()` observer method is a text string. Thus, NO comparison operators have to be defined – use only traditional text comparison

NOTE 4:
since `Sells` objects have a UDT type and `beer` and `bar` are references to objects whose types are UDTs, we must use observer methods to retrieve the attribute values

NOTE 5:
methods are applied using "dot" notation

Data Models & Database System Architectures - Chronological Overview -

- Network Data Models (1964)
- Hierarchical Data Models (1968)
- Relational Data Models (1970)
- Object-oriented Data Models (~ 1985)
- Object-relational Data Models (~ 1990)
- Semistructured Data Models (XML 1.0) (~1998)

OODBS vs. ORDBS - I

Two ways to integrate object-orientation into DBS
Both directions (OODBS and ORDBS) are also reflected in the standard developments

Several vendors:

commercial OODBS:
- GemStone
- O2 (now: Ardent)
- ObjectivityDB
- ObjectStore
- ONTOS
- POET
- Versant
- ...

commercial ORDBS:
- ORACLE
- Sybase
- Illustra
- UNISQL
- ...

OODBS vs. ORDBS - II

- Objects/tuples:
  Both objects and tuples are structs with components for attributes and relationships
- Extents/relations:
  Both may share the same declaration among several collections
- Methods:
  Both has the same ability to declare and define methods associated with a type
- Type systems:
  Both are based on atomic types and constructions of new types by structs and collection types
- References/OID:
  OODBS OID hidden – ORDBS ID visible (may be part of type)
- Backwards Compatibility:
  Migrating existing applications to an OODBS require extensive rewriting, but ORDBSes have maintained backward compatibility

OODBS vs. ORDBS - III

OODBS:

- simpler way for programmers to use DBS (familiar with OOPLs)
- “seamlessness”, no “impedance mismatch”
- OO functionality + DBS functionality → higher performance for specific applications
- “revolutionary” approach, no legacy problems
- ...

ORDBS:

- substancial investment in SQL-based relational DBSs → evolutionary approach
- systems are more robust due to many years of usage and experience
- application development tools
- transaction processing performance
- ...

Prediction: both kinds of systems will exist, used for different kinds of applications