Object-Relational Databases and OR Extensions

University of California, Berkeley

School of Information

IS 257: Database Management

Lecture Outline

- Object-Relational DBMS
  - OR features in Oracle and MySQL
    - Functions and Triggers
  - OR features in PostgreSQL
- Extending OR databases (examples from PostgreSQL)

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Object Relational Databases

- Background
- Object Definitions
  - inheritance
- User-defined datatypes
- User-defined functions

Object Relational Databases

- Began with UniSQL/X unified object-oriented and relational system
- Some systems (like OpenODB from HP) were Object systems built on top of Relational databases
- Postgres project at Berkeley
- Miro/Montage/Illustra built on Postgres.
- Informix Buys Illustra. (DataBlades)
- Oracle Hires away Informix Programmers. (Cartridges)
- Informix bought by IBM (you can still get it)

Object Relational Data Model

- Class, instance, attribute, method, and integrity constraints
  - Class ≈ Relation, instance ≈ tuple, attribute…
- OID per instance
- Encapsulation
- Multiple inheritance hierarchy of classes
- Class references via OID object references
- Set-Valued attributes
- Abstract Data Types

Object Relational Extended SQL (Illustra)

- CREATE TABLE tablename {OF TYPE Typename}|{OF NEW TYPE typename} (attr1 type1, attr2 type2,…,attrn typen) {UNDER parent_table_name};
- CREATE TYPE typename (attribute_name type_desc, attribute2 type2, …, attrn typen);
- CREATE FUNCTION functionname (type_name, type_name) RETURNS type_name AS sql_statement

Object-Relational SQL in ORACLE

- CREATE (OR REPLACE) TYPE typename AS OBJECT (attr_name, attr_type, …);

- CREATE TABLE OF typename;

Example

- CREATE TYPE ANIMAL_TY AS OBJECT (Breed VARCHAR2(25), Name VARCHAR2(25), Birthdate DATE);
  – Creates a new type
- CREATE TABLE Animal of Animal_ty;
  – Creates "Object Table"

Constructor Functions

- INSERT INTO Animal values (ANIMAL_TY('Mule', 'Frances', TO_DATE('01-APR-1997', 'DD-MM-YYYY')));
  - Insert a new ANIMAL_TY object into the table, i.e., the type name is a "constructor"

Selecting from an Object Table

- Just use the columns in the object…

- SELECT Name from Animal;

More Complex Objects

- CREATE TYPE Address_TY as object (Street VARCHAR2(50), City VARCHAR2(25), State CHAR(2), zip NUMBER);
- CREATE TYPE Person_TY as object (Name VARCHAR2(25), Address ADDRESS_TY);
- CREATE TABLE CUSTOMER (Customer_ID NUMBER, Person PERSON_TY);

What Does the Table Look like?

- DESCRIBE CUSTOMER;
- NAME TYPE
- --
- CUSTOMER_ID NUMBER
- PERSON NAMED TYPE

Inserting

- INSERT INTO CUSTOMER VALUES (1, PERSON_TY('John Smith' , ADDRESS_TY('57 Mt Pleasant St.' , 'Finn' , 'NH' , 111111)));

Selecting from Abstract Datatypes

- SELECT Customer_ID from CUSTOMER;
- SELECT * from CUSTOMER;

```
CUSTOMER_ID   PERSON(NAME, ADDRESS(STREET, CITY, STATE ZIP))
-----------------------------------------------------------------------------------------------
1                    PERSON_TY( 'JOHN SMITH', ADDRESS_TY( '57...
```

Selecting from Abstract Datatypes

- SELECT Customer_id, person.name from Customer;
- SELECT Customer_id, person.address.street from Customer;

Updating

- UPDATE Customer SET person.address.city = ‘HART’ where person.address.city = ‘Briant’;

MySQL

- So far, no data type definitions in MySQL
  - But would not be surprised to see them before too long
  - There are already spatial extensions and types
  - User-defined data types are in the current SQL standard, so they will probably make it into MySQL eventually
  - *But user-defined functions and triggers are in MySQL*

User-Defined Functions (Oracle)

- CREATE [OR REPLACE] FUNCTION funcname (argname [IN | OUT | IN OUT] datatype …) RETURN datatype (IS | AS) {block | external body}

Example

```
Create Function BALANCE_CHECK
   (Person_name IN Varchar2) RETURN NUMBER
   is BALANCE NUMBER(10,2)
BEGIN
   SELECT sum(decode(Action, ‘BOUGHT’,
   Amount, 0)) - sum(decode(Action, ‘SOLD’,
   amount, 0)) INTO BALANCE FROM LEDGER
   where Person = PERSON_NAME;
   RETURN BALANCE;
END;
```

Example

Select NAME, BALANCE_CHECK(NAME) from Worker;

- Would return the name and balance for each worker

Functions and Procedures - MySQL

- **CREATE** [DEFINER = { *user* | CURRENT_USER }] **PROCEDURE** *sp_name* ([*proc_parameter*[,...]]) [*characteristic* ...] *routine_body*
- **CREATE** [DEFINER = { *user* | CURRENT_USER }] **FUNCTION** *sp_name* ([*func_parameter*[,...]]) **RETURNS** *type* [*characteristic* ...] *routine_body*

- ***proc_parameter***: [IN | OUT | INOUT] *param_name type*
- ***func_parameter***: *param_name type*
- ***type***: *Any valid MySQL data type*
- ***characteristic***: LANGUAGE SQL | [NOT] DETERMINISTIC | { CONTAINS SQL | NO SQL | READS SQL DATA | MODIFIES SQL DATA } | SQL SECURITY { DEFINER | INVOKER } | COMMENT '*string*'
- ***routine_body***: *Valid SQL procedure statement*

Defining a MySQL procedure

```
mysql> delimiter //
mysql> CREATE PROCEDURE simpleproc (OUT param1 INT)
 -> BEGIN
 -> SELECT COUNT(*) INTO param1 FROM t;
 -> END//
Query OK, 0 rows affected (0.00 sec)
mysql> delimiter ;
mysql> CALL simpleproc(@a);
Query OK, 0 rows affected (0.00 sec)
mysql> SELECT @a;
+------+
| @a   |
+------+
|  3   |
+------+
1 row in set (0.00 sec)
```

Defining a MySQL Function

```
mysql> CREATE FUNCTION hello (s CHAR(20))
       RETURNS CHAR(50) DETERMINISTIC
->     RETURN CONCAT('Hello, ',s,'!');
 Query OK, 0 rows affected (0.00 sec)
mysql> SELECT hello('world');
+----------------+
| hello('world') |
+----------------+
| Hello, world!  |
+----------------+
1 row in set (0.00 sec)
```

DETERMINISTIC means the function always produces the same result for the same input parameters

TRIGGERS (Oracle)

- Create TRIGGER UPDATE_LODGING INSTEAD OF UPDATE on WORKER_LODGING for each row BEGIN

  if :old.name <> :new.name then update worker set name = :new.name where name = :old.name;

 end if;

if :old.lodging <> … etc...

Triggers in MySQL

- CREATE
  [DEFINER = { user | CURRENT_USER }]
  TRIGGER trigger_name trigger_time trigger_event
  ON tbl_name FOR EACH ROW trigger_stmt
- trigger_event can be INSERT, UPDATE, or DELETE
- trigger_time can be BEFORE or AFTER.

Triggers in MySQL

```
CREATE TABLE test1(a1 INT);
CREATE TABLE test2(a2 INT);
CREATE TABLE test3(a3 INT NOT NULL
   AUTO_INCREMENT PRIMARY KEY);
CREATE TABLE test4( a4 INT NOT NULL
   AUTO_INCREMENT PRIMARY KEY, b4 INT DEFAULT
   0 );
delimiter |
CREATE TRIGGER testref BEFORE INSERT ON test1
   FOR EACH ROW
   BEGIN
      INSERT INTO test2 SET a2 = NEW.a1;
      DELETE FROM test3 WHERE a3 = NEW.a1;
      UPDATE test4 SET b4 = b4 + 1 WHERE a4 =
   NEW.a1;
END |
delimiter ;
```

Triggers in MySQL (cont)

```
mysql> INSERT INTO test3 (a3) VALUES
(NULL), (NULL), (NULL), (NULL), (NULL), (NULL), (NULL), (NULL), (NULL),
(NULL);
mysql> INSERT INTO test4 (a4) VALUES (0), (0), (0), (0), (0), (0), (0), (0),
(0), (0);
mysql> INSERT INTO test1 VALUES
    -> (1), (3), (1), (7), (1), (8), (4), (4);
mysql> SELECT * FROM test1;
+------+
| a1   |
+------+
|    1 |
|    3 |
|    1 |
|    7 |
|    1 |
|    8 |
|    4 |
|    4 |
+------+
```

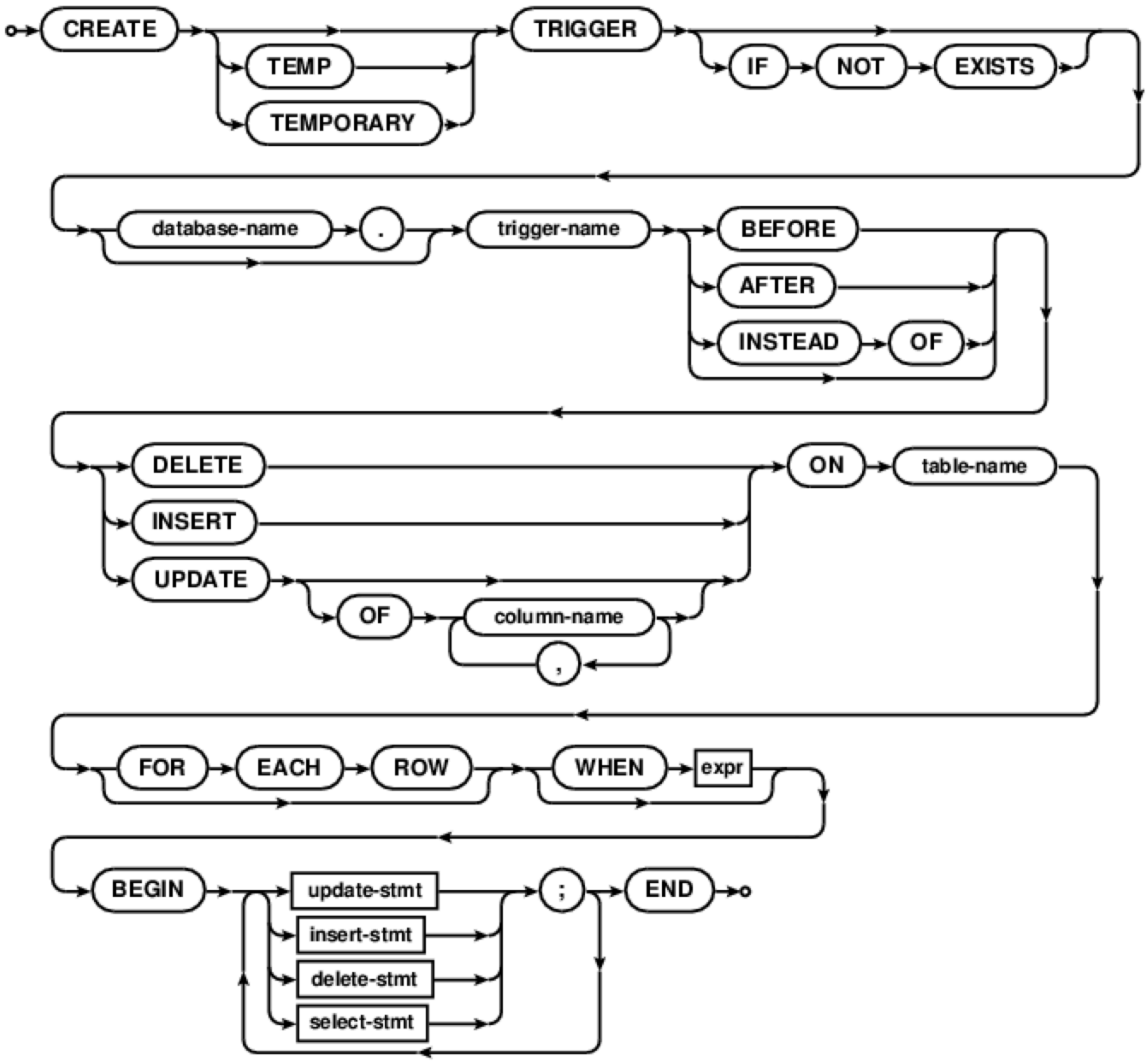
Triggers in MySQL (cont.)

```
mysql> SELECT * FROM test2;
+------+
| a2   |
+------+
|    1 |
|    3 |
|    1 |
|    7 |
|    1 |
|    8 |
|    4 |
|    4 |
+------+
```

```
mysql> SELECT * FROM test3;
+----+
| a3 |
+----+
|  2 |
|  5 |
|  6 |
|  9 |
| 10 |
+----+
```

```
mysql> SELECT * FROM test4;
+----+------+
| a4 | b4   |
+----+------+
|  1 |    3 |
|  2 |    0 |
|  3 |    1 |
|  4 |    2 |
|  5 |    0 |
|  6 |    0 |
|  7 |    1 |
|  8 |    1 |
|  9 |    0 |
| 10 |    0 |
+----+------+
```

Triggers in SQLite



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PostgreSQL

- Derived from POSTGRES
  - – Developed at Berkeley by Mike Stonebraker and his students (EECS) starting in 1986
- Postgres95
  - – Andrew Yu and Jolly Chen adapted POSTGRES to SQL and greatly improved the code base
- PostgreSQL
  - – Name changed in 1996, and since that time the system has been expanded to support all SQL standard features, plus unique extensions

PostgreSQL Classes

- The fundamental notion in Postgres is that of a class, which is a named collection of object instances. Each instance has the same collection of named attributes, and each attribute is of a specific type. Furthermore, each instance has a permanent object identifier (OID) that is unique throughout the installation. Because SQL syntax refers to tables, we will use the terms table and class interchangeably. Likewise, an SQL row is an instance and SQL columns are attributes.

Creating a Class

- You can create a new class by specifying the class name, along with all attribute names and their types:

```
CREATE TABLE weather (
    city            varchar(80),
    temp_lo         int,          -- low temperature
    temp_hi         int,          -- high temperature
    prcp            real,         -- precipitation
    date            date
);
```

PostgreSQL

- Postgres can be customized with an arbitrary number of user-defined data types. Consequently, *type names are not syntactical keywords*, except where required to support special cases in the SQL92 standard.
- So far, the Postgres CREATE command looks exactly like the command used to create a table in a traditional relational system. However, we will presently see that classes have properties that are extensions of the relational model.

PostgreSQL

- All of the usual SQL commands for creation, searching and modifying classes (tables) are available. With some additions…
- **Inheritance**
- **Non-Atomic Values**
- **User defined functions and operators**

Inheritance

```
CREATE TABLE cities (
    name            text,
    population      float,
    altitude        int     -- (in ft)
);

CREATE TABLE capitals (
    state           char(2)
) INHERITS (cities);
```

Inheritance

```
ray=# create table cities (name varchar(50), population float,
      altitude int);
CREATE TABLE
ray=# \d cities
             Table "public.cities"
   Column   |          Type          | Modifiers
------------+------------------------+-----------
 name       | character varying(50)  |
 population | double precision       |
 altitude   | integer                |

ray=# create table capitals (state char(2)) inherits (cities);
CREATE TABLE
ray=# \d capitals
            Table "public.capitals"
   Column   |          Type          | Modifiers
------------+------------------------+-----------
 name       | character varying(50)  |
 population | double precision       |
 altitude   | integer                |
 state      | character(2)           |
Inherits: cities
```

Inheritance

- In Postgres, a class can inherit from zero or more other classes.
- A query can reference either
  – all instances of a class
  – or all instances of a class ***plus all of its descendants***

Inheritance

- For example, the following query finds all the cities that are situated at an attitude of 500ft or higher:

```
SELECT name, altitude
   FROM cities
   WHERE altitude > 500;
+----------+----------+
|name      | altitude |
+----------+----------+
|Las Vegas | 2174     |
+----------+----------+
|Mariposa  | 1953     |
+----------+----------+
```

Inheritance

- On the other hand, to find the names of all cities, including state capitals, that are located at an altitude over 500ft, the query is:

```
SELECT c.name, c.altitude
  FROM cities* c
   WHERE c.altitude > 500;
```

which returns:

name	altitude
Las Vegas	2174
Mariposa	1953
Madison	845

Inheritance

- The "*" after cities in the preceding query indicates that the query should be run over *cities and all classes below cities* in the inheritance hierarchy
- Many of the PostgreSQL commands (SELECT, UPDATE and DELETE, etc.) support this inheritance notation using "*"

Non-Atomic Values

- One of the tenets of the relational model is that the attributes of a relation are **atomic**
  - I.e. only a single value for a given row and column (I.e., 1st Normal Form)
- Postgres does not have this restriction: attributes can themselves contain sub-values that can be accessed from the query language
  - Examples include arrays and other complex data types.

Non-Atomic Values - Arrays

- Postgres allows attributes of an instance to be defined as fixed-length or variable-length multi-dimensional arrays. Arrays of any base type or user-defined type can be created. To illustrate their use, we first create a class with arrays of base types.

```
CREATE TABLE SAL_EMP (
   name             text,
   pay_by_quarter  int4[],
   schedule         text[][]
);
```

Non-Atomic Values - Arrays

- The preceding SQL command will create a class named SAL_EMP with a text string (name), a one-dimensional array of int4 (pay_by_quarter), which represents the employee's salary by quarter and a two-dimensional array of text (schedule), which represents the employee's weekly schedule
- Now we do some INSERTSs; note that when appending to an array, we enclose the values within braces and separate them by commas.

Inserting into Arrays

```
INSERT INTO SAL_EMP
    VALUES ('Bill',
    '{10000, 10000, 10000, 10000}',
    '{{"meeting", "lunch"}, {}}');

INSERT INTO SAL_EMP
    VALUES ('Carol',
    '{20000, 25000, 25000, 25000}',
    '{{"talk", "consult"}, {"meeting"}}');
```

Querying Arrays

- This query retrieves the names of the employees whose pay changed in the second quarter:

```
SELECT name
    FROM SAL_EMP
    WHERE SAL_EMP.pay_by_quarter[1] <>
    SAL_EMP.pay_by_quarter[2];
```

```
+------+
|name  |
+------+
|Carol |
+------+
```

Querying Arrays

- This query retrieves the third quarter pay of all employees:

```
SELECT SAL_EMP.pay_by_quarter[3] FROM
   SAL_EMP;
+---------------+
|pay_by_quarter |
+---------------+
|10000          |
+---------------+
|25000          |
+---------------+
```

Querying Arrays

- We can also access arbitrary slices of an array, or subarrays. This query retrieves the first item on Bill's schedule for the first two days of the week.

```
SELECT SAL_EMP.schedule[1:2][1:1]
   FROM SAL_EMP
   WHERE SAL_EMP.name = 'Bill';
+-------------------+
|schedule           |
+-------------------+
|{{"meeting"},{""}} |
+-------------------+
```

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PostgreSQL Extensibility

- Postgres is extensible because its operation is catalog-driven
  – RDBMS store metadata, or information about databases, tables, columns, etc., in what are commonly known as system catalogs. (Some systems call this the data dictionary).
- One key difference between Postgres and standard RDBMS is that Postgres stores much **more** information in its catalogs
  – not only information about tables and columns, but also information about its types, functions, access methods, etc.
- These classes can be modified by the user, and since Postgres bases its internal operation on these classes, this means that Postgres can be extended by users
  – By comparison, conventional database systems can only be extended by changing hardcoded procedures within the DBMS or by loading modules specially-written by the DBMS vendor.

Postgres System Catalogs

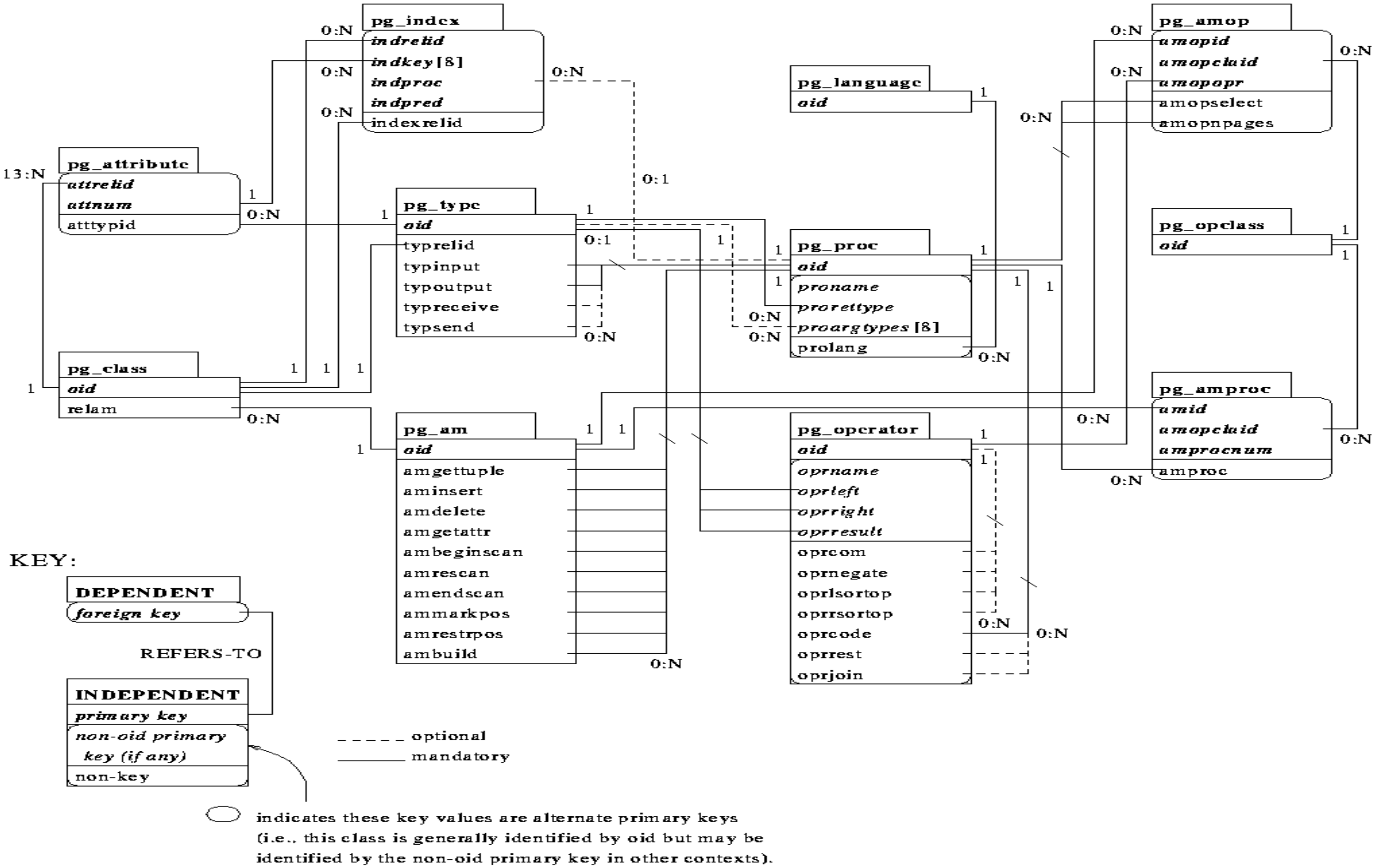


Figure 3. The major POSTGRES system catalogs.

User Defined Functions

- CREATE FUNCTION allows a Postgres user to register a function with a database. Subsequently, this user is considered the *owner* of the function

```
CREATE FUNCTION name ( [ ftype [, ...] ] )
   RETURNS rtype
   AS {SQLdefinition}
   LANGUAGE 'langname'
   [ WITH ( attribute [, ...] ) ]

CREATE FUNCTION name ( [ ftype [, ...] ] )
   RETURNS rtype
   AS obj_file , link_symbol
   LANGUAGE 'C'
   [ WITH ( attribute [, ...] ) ]
```

Simple SQL Function

- CREATE FUNCTION one() RETURNS int4
  AS 'SELECT 1 AS RESULT'
  LANGUAGE 'sql';

SELECT one() AS answer;

```
answer
---------
     1
```

A more complex function

- To illustrate a simple SQL function, consider the following, which might be used to debit a bank account:

```
create function TP1 (int4, float8) returns int4
   as ‘update BANK set balance = BANK.balance - $2
      where BANK.acctountno = $1;
      select balance from bank
        where accountno = $1; ‘  language 'sql';
```

- A user could execute this function to debit account 17 by $100.00 as follows:

```
select (x = TP1( 17,100.0));
```

SQL Functions on Composite Types

- When creating functions with composite types, you have to include the attributes of that argument. If EMP is a table containing employee data, (therefore also the name of the composite type for each row of the table) a function to double salary might be…

```
CREATE FUNCTION double_salary(EMP) RETURNS integer
   AS ' SELECT $1.salary * 2 AS salary; ' LANGUAGE SQL;

SELECT name, double_salary(EMP) AS dream FROM EMP WHERE
   EMP.cubicle ~= point '(2,1)';
name | dream
 ------+-------
 Sam | 2400
```

Notice the use of the syntax $1.salary to select one field of the argument row value. Also notice how the calling SELECT command uses a table name to denote the entire current row of that table as a composite value.

SQL Functions on Composite Types

- It is also possible to build a function that returns a composite type. This is an example of a function that returns a single EMP row:

```
CREATE FUNCTION new_emp() RETURNS
  EMP
  AS ' SELECT text ''None'' AS name,
  1000 AS salary,
  25 AS age,
  point ''(2,2)'' AS cubicle; ' LANGUAGE SQL;
```

External Functions

- This example creates a C function by calling a routine from a user-created shared library. This particular routine calculates a check digit and returns TRUE if the check digit in the function parameters is correct. It is intended for use in a CHECK contraint.

```
CREATE FUNCTION ean_checkdigit(bpchar, bpchar) RETURNS
    bool
   AS '/usr1/proj/bray/sql/funcs.so' LANGUAGE 'c';
CREATE TABLE product (
   id        char(8) PRIMARY KEY,
   eanprefix char(8) CHECK (eanprefix ~ '[0-9]{2} [0-9]{5}')
                  REFERENCES brandname(ean_prefix),
   eancode   char(6) CHECK (eancode ~ '[0-9]{6}'),
   CONSTRAINT ean    CHECK (ean_checkdigit(eanprefix,
    eancode)));
```

Creating new Types

- CREATE TYPE allows the user to register a new user data type with Postgres for use in the current data base. The user who defines a type becomes its owner. typename is the name of the new type and must be unique within the types defined for this database.

```
CREATE TYPE typename ( INPUT = input_function, OUTPUT =
    output_function
     , INTERNALLENGTH = { internallength | VARIABLE } [ ,
    EXTERNALLENGTH = { externallength | VARIABLE } ]
   [ , DEFAULT = "default" ]
   [ , ELEMENT = element ] [ , DELIMITER = delimiter ]
   [ , SEND = send_function ] [ , RECEIVE = receive_function ]
   [ , PASSEDBYVALUE ] )
```

New Type Definition

- This command creates the box data type and then uses the type in a class definition:

CREATE TYPE box (INTERNALLENGTH = 8, INPUT = my_procedure_1, OUTPUT = my_procedure_2);

CREATE TABLE myboxes (id INT4, description box);

New Type Definition

- In the external language (usually C) functions are written for
- Type input
  - From a text representation to the internal representation
- Type output
  - From the internal represenation to a text representation
- Can also define function and operators to manipulate the new type

New Type Definition Example

- A C data structure is defined for the new type:

```
typedef struct Complex {
    double      x;
    double      y;
} Complex;
```

New Type Definition Example

```
Complex *
    complex_in(char *str)
    {
        double x, y;
        Complex *result;
        if (sscanf(str, " ( %lf , %lf )", &x, &y) != 2) {
            elog(WARN, "complex_in: error in parsing”);
            return NULL;
        }
        result = (Complex *)palloc(sizeof(Complex));
        result->x = x;
        result->y = y;
        return (result);
    }
```

New Type Definition Example

```
char *
    complex_out(Complex *complex)
    {
        char *result;
        if (complex == NULL)
            return(NULL);
        result = (char *) palloc(60);
        sprintf(result, "(%g,%g)", complex->x,
                complex->y);
        return(result);
    }
```

New Type Definition Example

- Now tell the system about the new type…

```
CREATE FUNCTION complex_in(opaque)
   RETURNS complex
   AS 'PGROOT/tutorial/obj/complex.so'
   LANGUAGE 'c';

CREATE FUNCTION complex_out(opaque)
   RETURNS opaque
   AS 'PGROOT/tutorial/obj/complex.so'
   LANGUAGE 'c';

CREATE TYPE complex (
   internallength = 16,
   input = complex_in,
   output = complex_out);
```

Operator extensions

```
CREATE FUNCTION complex_add(complex,
   complex)
  RETURNS complex
   AS '$PWD/obj/complex.so'
   LANGUAGE 'c';

CREATE OPERATOR + (
   leftarg = complex,
   rightarg = complex,
   procedure = complex_add,
   commutator = + );
```

Create tables using the type

- CREATE TABLE test_complex (a complex, b complex);

- INSERT INTO test_complex (a,b) values (….);

Now we can do…

- SELECT (a + b) AS c FROM test_complex;

- +----------------+
- |c |
- +----------------+
- |(5.2,6.05) |
- +----------------+
- |(133.42,144.95) |
- +----------------+
-

Creating new Aggregates

```
CREATE AGGREGATE complex_sum (
   sfunc1 = complex_add,
   basetype = complex,
   stype1 = complex,
   initcond1 = '(0,0)');
SELECT complex_sum(a) FROM test_complex;
        +------------+
        |complex_sum |
        +------------+
        |(34,53.9)   |
        +------------+
```

Rules System

- CREATE RULE name AS ON event
  TO object [WHERE condition]
  DO [INSTEAD] [action | NOTHING]

- Rules can be triggered by any event (select, insert, update, delete, etc.) as opposed to triggers that can only apply to insert, update, delete and truncate

Triggers in PostgreSQL

- CREATE [CONSTRAINT] TRIGGER name { BEFORE | AFTER | INSTEAD OF } { event [OR ...] } ON table_name [FROM referenced_table_name]
  [NOT DEFERRABLE | [DEFERRABLE] { INITIALLY IMMEDIATE | INITIALLY DEFERRED }]
  [FOR [EACH] { ROW | STATEMENT }]
  [WHEN (condition)] EXECUTE PROCEDURE function_name (arguments)
- where event can be one of: INSERT UPDATE [OF column_name [, ...]] DELETE TRUNCATE

Views as Rules

- Views in Postgres are implemented using the rule system. In fact there is absolutely no difference between a

CREATE VIEW myview AS SELECT * FROM mytab;

- compared against the two commands

CREATE TABLE myview (same attribute list as for mytab);

CREATE RULE "_RETmyview" AS ON SELECT TO myview DO INSTEAD

SELECT * FROM mytab;

Extensions to Indexing

- Access Method extensions in Postgres
- GiST: A Generalized Search Trees
  - Joe Hellerstein, UC Berkeley

Indexing in OO/OR Systems

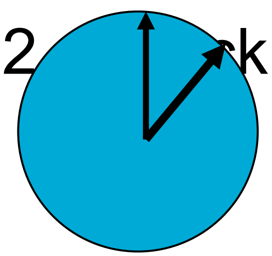
- Quick access to user-defined objects
- Support queries natural to the objects
- Two previous approaches
  - Specialized Indices ("ABCDEFG-trees")
    - redundant code: most trees are very similar
    - concurrency control, etc. tricky!
  - Extensible B-trees & R-trees (Postgres/ Illustra)
    - B-tree or R-tree lookups only!
    - E.g. 'WHERE movie.video < 'Terminator 2'

GiST Approach

- A generalized search tree. Must be:
- Extensible in terms of queries
- General (B+-tree, R-tree, etc.)
- Easy to extend
- Efficient (match specialized trees)
- Highly concurrent, recoverable, etc.

GiST Applications

- New indexes needed for new apps...
  - find all supersets of S
  - find all molecules that bind to M
  - your favorite query here (multimedia?)
  - Keyword text indexes?
- ...and for new queries over old domains:
  - find all points in region from 12 to 2 o'clock



  - find all text elements estimated relevant to a query string