Chapter 4: Advanced SQL

Database System Concepts, 5th Ed.

Chapter 4: Advanced SQL

- SQL Data Types and Schemas
- Integrity Constraints
- Authorization
- Embedded SQL
- Dynamic SQL
- Functions and Procedural Constructs**
- Recursive Queries**
- Advanced SQL Features**

Built-in Data Types in SQL

- **date:** Dates, containing a (4 digit) year, month and date
  - Example: **date** '2005-7-27'
- **time:** Time of day, in hours, minutes and seconds.
  - Example: **time** '09:00:30' **time** '09:00:30.75'
- **timestamp**: date plus time of day
  - Example: **timestamp** '2005-7-27 09:00:30.75'
- **interval:** period of time
  - Example: interval '1' day
  - Subtracting a date/time/timestamp value from another gives an interval value
  - Interval values can be added to date/time/timestamp values

Build-in Data Types in SQL (Cont.)

- Can extract values of individual fields from date/time/timestamp
  - Example: **extract** (**year from** r.starttime)

- Can cast string types to date/time/timestamp
  - Example: **cast** <string-valued-expression> **as date**
  - Example: **cast** <string-valued-expression> **as time**

User-Defined Types

- **create type** construct in SQL creates user-defined type

  create type *Dollars* **as numeric (12,2) final**

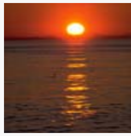
- **create domain** construct in SQL-92 creates user-defined domain types

  create domain *person_name* **char**(20) **not null**

- Types and domains are similar. Domains can have constraints, such as **not null**, specified on them.

Domain Constraints

- **Domain constraints** are the most elementary form of integrity constraint. They test values inserted in the database, and test queries to ensure that the comparisons make sense.
- New domains can be created from existing data types
  - Example: **create domain** *Dollars* **numeric**(12, 2)
    create domain *Pounds* **numeric**(12,2)
- We cannot assign or compare a value of type Dollars to a value of type Pounds.
  - However, we can convert type as below
    (**cast** *r.A* **as** *Pounds*)
    (Should also multiply by the dollar-to-pound conversion-rate)



Large-Object Types

- Large objects (photos, videos, CAD files, etc.) are stored as a *large object*:
  - **blob**: binary large object -- object is a large collection of uninterpreted binary data (whose interpretation is left to an application outside of the database system)
  - **clob**: character large object -- object is a large collection of character data
  - When a query returns a large object, a pointer is returned rather than the large object itself.

Integrity Constraints

- Integrity constraints guard against accidental damage to the database, by ensuring that authorized changes to the database do not result in a loss of data consistency.
  - A checking account must have a balance greater than $10,000.00
  - A salary of a bank employee must be at least $4.00 an hour
  - A customer must have a (non-null) phone number

Constraints on a Single Relation

- **not null**
- **primary key**
- **unique**
- **check** (*P*), where *P* is a predicate

Not Null Constraint

- Declare *branch_name* for *branch* is **not null**

  branch_name **char**(15) **not null**

- Declare the domain *Dollars* to be **not null**

  create domain *Dollars* **numeric**(12,2) **not null**

The Unique Constraint

- **unique** (A_1, A_2, …, A_m)
- The unique specification states that the attributes

  $A1$, $A2$, … Am

  form a candidate key.
- Candidate keys are permitted to be null (in contrast to primary keys).

The check clause

- **check** (*P*), where *P* is a predicate

Example: Declare *branch_name* as the primary key for *branch* and ensure that the values of *assets* are non-negative.

```
create table branch
    (branch_name   char(15),
     branch_city   char(30),
     assets        integer,
     primary key (branch_name),
     check (assets >= 0))
```

The check clause (Cont.)

- The **check** clause in SQL-92 permits domains to be restricted:
  - Use **check** clause to ensure that an hourly_wage domain allows only values greater than a specified value.

    create domain *hourly_wage* **numeric(5,2)**

    constraint *value_test* **check**(*value* > = 4.00)
  - The domain has a constraint that ensures that the hourly_wage is greater than 4.00
  - The clause **constraint** *value_test* is optional; useful to indicate which constraint an update violated.

Referential Integrity

- Ensures that a value that appears in one relation for a given set of attributes also appears for a certain set of attributes in another relation.
  - Example: If "Perryridge" is a branch name appearing in one of the tuples in the *account* relation, then there exists a tuple in the *branch* relation for branch "Perryridge".
- Primary and candidate keys and foreign keys can be specified as part of the SQL **create table** statement:
  - The primary key clause lists attributes that comprise the primary key.
  - The unique key clause lists attributes that comprise a candidate key.
  - The foreign key clause lists the attributes that comprise the foreign key and the name of the relation referenced by the foreign key. By default, a foreign key references the primary key attributes of the referenced table.

Referential Integrity in SQL – Example

create table *customer*
(*customer_name* **char**(20)**,**
customer_street **char**(30),
customer_city **char**(30),
primary key (*customer_name*))

create table *branch*
(branch_name **char**(15)**,**
branch_city **char**(30),
assets **numeric**(12,2),
primary key (*branch_name*))

Referential Integrity in SQL – Example (Cont.)

```
create table account
    (account_number char(10),
    branch_name     char(15),
    balance         integer,
    primary key (account_number),
    foreign key (branch_name) references branch )

create table depositor
    (customer_name  char(20),
    account_number  char(10),
    primary key (customer_name, account_number),
    foreign key (account_number ) references account,
    foreign key (customer_name ) references customer )
```

Assertions

- An **assertion** is a predicate expressing a condition that we wish the database always to satisfy.
- An assertion in SQL takes the form

  create assertion <assertion-name> **check** <predicate>

- When an assertion is made, the system tests it for validity, and tests it again on every update that may violate the assertion
  - This testing may introduce a significant amount of overhead; hence assertions should be used with great care.
- Asserting

  for all X, $P(X)$

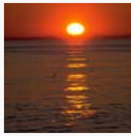
  is achieved in a round-about fashion using

  not exists X such that not $P(X)$

Assertion Example

- Every loan has at least one borrower who maintains an account with a minimum balance or $1000.00

```
create assertion balance_constraint check
    (not exists (
        select *
        from loan
        where not exists (
            select *
            from borrower, depositor, account
            where loan.loan_number = borrower.loan_number
                and borrower.customer_name = depositor.customer_name
                and depositor.account_number = account.account_number
                and account.balance >= 1000)))
```



Assertion Example

- The sum of all loan amounts for each branch must be less than the sum of all account balances at the branch.

```
create assertion sum_constraint check
    (not exists (select *
                 from branch
                 where (select sum(amount )
                        from loan
                        where loan.branch_name =
                              branch.branch_name )
                     >= (select sum (amount )
                        from account
                        where loan.branch_name =
                              branch.branch_name )))
```

Authorization

Forms of authorization on parts of the database:

- **Read** - allows reading, but not modification of data.
- **Insert** - allows insertion of new data, but not modification of existing data.
- **Update** - allows modification, but not deletion of data.
- **Delete** - allows deletion of data.

Forms of authorization to modify the database schema (covered in Chapter 8):

- **Index** - allows creation and deletion of indices.
- **Resources** - allows creation of new relations.
- **Alteration** - allows addition or deletion of attributes in a relation.
- **Drop** - allows deletion of relations.

Authorization Specification in SQL

- The **grant** statement is used to confer authorization

  grant <privilege list>

  on <relation name or view name> **to** <user list>

- <user list> is:
  - a user-id
  - **public**, which allows all valid users the privilege granted
  - A role (more on this in Chapter 8)
- Granting a privilege on a view does not imply granting any privileges on the underlying relations.
- The grantor of the privilege must already hold the privilege on the specified item (or be the database administrator).

Privileges in SQL

- **select:** allows read access to relation,or the ability to query using the view
  - Example: grant users U_1, U_2, and U_3 **select** authorization on the *branch* relation:

    grant select on *branch* **to** U_1, U_2, U_3

- **insert**: the ability to insert tuples
- **update**: the ability to update using the SQL update statement
- **delete**: the ability to delete tuples.
- **all privileges**: used as a short form for all the allowable privileges
- more in Chapter 8

Revoking Authorization in SQL

- The **revoke** statement is used to revoke authorization.

  revoke <privilege list>

  on <relation name or view name> **from** <user list>

- Example:

  revoke select on *branch* **from** U_1, U_2, U_3

- <privilege-list> may be **all** to revoke all privileges the revokee may hold.
- If <revokee-list> includes **public,** all users lose the privilege except those granted it explicitly.
- If the same privilege was granted twice to the same user by different grantees, the user may retain the privilege after the revocation.
- All privileges that depend on the privilege being revoked are also revoked.

Embedded SQL

- The SQL standard defines embeddings of SQL in a variety of programming languages such as C, Java, and Cobol.
- A language to which SQL queries are embedded is referred to as a **host language**, and the SQL structures permitted in the host language comprise *embedded* SQL.
- The basic form of these languages follows that of the System R embedding of SQL into PL/I.
- **EXEC SQL** statement is used to identify embedded SQL request to the preprocessor

  EXEC SQL <embedded SQL statement > END_EXEC

  Note: this varies by language (for example, the Java embedding uses # SQL { …. };)

Example Query

- From within a host language, find the names and cities of customers with more than the variable amount dollars in some account.

- Specify the query in SQL and declare a *cursor* for it

EXEC SQL

declare *c* **cursor for**
select *depositor.customer_name, customer_city*
from *depositor, customer, account*
where *depositor.customer_name = customer.customer_name*
and *depositor account_number = account.account_number*
and *account.balance > :amount*

END_EXEC

Embedded SQL (Cont.)

- The **open** statement causes the query to be evaluated

  EXEC SQL **open** *c* END_EXEC

- The **fetch** statement causes the values of one tuple in the query result to be placed on host language variables.

  EXEC SQL **fetch** *c* **into** :*cn*, :*cc* END_EXEC

  Repeated calls to **fetch** get successive tuples in the query result

- A variable called SQLSTATE in the SQL communication area (SQLCA) gets set to '02000' to indicate no more data is available

- The **close** statement causes the database system to delete the temporary relation that holds the result of the query.

  EXEC SQL **close** *c* END_EXEC

Note: above details vary with language. For example, the Java embedding defines Java iterators to step through result tuples.

Updates Through Cursors

- Can update tuples fetched by cursor by declaring that the cursor is for update

  declare *c* **cursor for**
    select *
    from *account*
    where *branch_name* = 'Perryridge'
  for update

- To update tuple at the current location of cursor *c*

  update *account*
  set *balance* = *balance* + 100
  where current of *c*

Dynamic SQL

- Allows programs to construct and submit SQL queries at run time.
- Example of the use of dynamic SQL from within a C program.

```
char *  sqlprog = “update account
                    set balance = balance * 1.05
                     where account_number = ?”
EXEC SQL prepare dynprog  from :sqlprog;
char account [10] = “A-101”;
EXEC SQL execute dynprog using :account;
```

- The dynamic SQL program contains a ?, which is a place holder for a value that is provided when the SQL program is executed.

ODBC and JDBC

- API (application-program interface) for a program to interact with a database server
- Application makes calls to
  - Connect with the database server
  - Send SQL commands to the database server
  - Fetch tuples of result one-by-one into program variables
- ODBC (Open Database Connectivity) works with C, C++, C#, and Visual Basic
- JDBC (Java Database Connectivity) works with Java

ODBC

- Open DataBase Connectivity(ODBC) standard
  - standard for application program to communicate with a database server.
  - application program interface (API) to
    - open a connection with a database,
    - send queries and updates,
    - get back results.
- Applications such as GUI, spreadsheets, etc. can use ODBC

ODBC (Cont.)

- Each database system supporting ODBC provides a "driver" library that must be linked with the client program.
- When client program makes an ODBC API call, the code in the library communicates with the server to carry out the requested action, and fetch results.
- ODBC program first allocates an SQL environment, then a database connection handle.
- Opens database connection using SQLConnect(). Parameters for SQLConnect:
  - connection handle,
  - the server to which to connect
  - the user identifier,
  - password
- Must also specify types of arguments:
  - SQL_NTS denotes previous argument is a null-terminated string.

ODBC Code

- ```
  int ODBCexample()
  {
      RETCODE error;
      HENV    env;     /* environment */
      HDBC    conn;  /* database connection */
      SQLAllocEnv(&env);
      SQLAllocConnect(env, &conn);
      SQLConnect(conn, "aura.bell-labs.com", SQL_NTS, "avi", SQL_NTS,
        "avipasswd", SQL_NTS);
      { …. Do actual work … }

      SQLDisconnect(conn);
      SQLFreeConnect(conn);
      SQLFreeEnv(env);
  }
  ```
  ```

ODBC Code (Cont.)

- Program sends SQL commands to the database by using SQLExecDirect
- Result tuples are fetched using SQLFetch()
- SQLBindCol() binds C language variables to attributes of the query result
  - When a tuple is fetched, its attribute values are automatically stored in corresponding C variables.
  - Arguments to SQLBindCol()
    - ODBC stmt variable, attribute position in query result
    - The type conversion from SQL to C.
    - The address of the variable.
    - For variable-length types like character arrays,
      - The maximum length of the variable
      - Location to store actual length when a tuple is fetched.
      - Note: A negative value returned for the length field indicates null value
- Good programming requires checking results of every function call for errors; we have omitted most checks for brevity.

ODBC Code (Cont.)

- Main body of program

```
char branchname[80];
float  balance;
int  lenOut1, lenOut2;
HSTMT   stmt;

SQLAllocStmt(conn, &stmt);
char * sqlquery = "select branch_name, sum (balance)
                   from account
                   group by branch_name";

error = SQLExecDirect(stmt, sqlquery, SQL_NTS);

if (error == SQL_SUCCESS) {
    SQLBindCol(stmt, 1, SQL_C_CHAR,   branchname , 80,
&lenOut1);
    SQLBindCol(stmt, 2, SQL_C_FLOAT, &balance,        0 ,
&lenOut2);

    while (SQLFetch(stmt) >= SQL_SUCCESS) {
        printf (" %s  %g\n", branchname, balance);
    }
}
SQLFreeStmt(stmt, SQL_DROP);
```

More ODBC Features

- **Prepared Statement**
  - SQL statement prepared: compiled at the database
  - Can have placeholders: E.g. insert into account values(?,?,?)
  - Repeatedly executed with actual values for the placeholders
- **Metadata features**
  - finding all the relations in the database and
  - finding the names and types of columns of a query result or a relation in the database.
- By default, each SQL statement is treated as a separate transaction that is committed automatically.
  - Can turn off automatic commit on a connection
    - SQLSetConnectOption(conn, SQL_AUTOCOMMIT, 0)}
  - transactions must then be committed or rolled back explicitly by
    - SQLTransact(conn, SQL_COMMIT) or
    - SQLTransact(conn, SQL_ROLLBACK)

ODBC Conformance Levels

- Conformance levels specify subsets of the functionality defined by the standard.
  - Core
  - Level 1 requires support for metadata querying
  - Level 2 requires ability to send and retrieve arrays of parameter values and more detailed catalog information.
- SQL Call Level Interface (CLI) standard similar to ODBC interface, but with some minor differences.

JDBC

- **JDBC** is a Java API for communicating with database systems supporting SQL
- JDBC supports a variety of features for querying and updating data, and for retrieving query results
- JDBC also supports metadata retrieval, such as querying about relations present in the database and the names and types of relation attributes
- Model for communicating with the database:
  - Open a connection
  - Create a “statement” object
  - Execute queries using the Statement object to send queries and fetch results
  - Exception mechanism to handle errors

JDBC Code

```
public static void JDBCexample(String dbid, String userid, String passwd)
{
    try {
        Class.forName ("oracle.jdbc.driver.OracleDriver");
        Connection conn = DriverManager.getConnection(
          "jdbc:oracle:thin:@aura.bell-labs.com:2000:bankdb", userid, passwd);
        Statement stmt = conn.createStatement();
            … Do Actual Work ….
        stmt.close();
        conn.close();
    }
    catch (SQLException sqle) {
        System.out.println("SQLException : " + sqle);
    }
}
```

JDBC Code (Cont.)

- Update to database

```
try {
    stmt.executeUpdate(  "insert into account values
                          ('A-9732', 'Perryridge', 1200)");
} catch (SQLException sqle) {
    System.out.println("Could not insert tuple. " + sqle);
}
```

- Execute query and fetch and print results

```
ResultSet rset = stmt.executeQuery( "select branch_name,
   avg(balance)
                                     from account
                                     group by branch_name");
while (rset.next()) {
     System.out.println(
            rset.getString("branch_name") + "  " + rset.getFloat(2));

}
```

JDBC Code Details

- Getting result fields:
  - **rs.getString("branchname") and rs.getString(1) equivalent if branchname is the first argument of select result.**
- Dealing with Null values

  int a = rs.getInt("a");

  if (rs.wasNull()) Systems.out.println("Got null value");

Procedural Extensions and Stored Procedures

- SQL provides a **module** language
  - Permits definition of procedures in SQL, with if-then-else statements, for and while loops, etc.
  - more in Chapter 9
- Stored Procedures
  - Can store procedures in the database
  - then execute them using the **call** statement
  - permit external applications to operate on the database without knowing about internal details
- These features are covered in Chapter 9 (Object Relational Databases)

Functions and Procedures

- SQL:1999 supports functions and procedures
  - Functions/procedures can be written in SQL itself, or in an external programming language
  - Functions are particularly useful with specialized data types such as images and geometric objects
    - Example: functions to check if polygons overlap, or to compare images for similarity
  - Some database systems support **table-valued functions**, which can return a relation as a result
- SQL:1999 also supports a rich set of imperative constructs, including
  - Loops, if-then-else, assignment
- Many databases have proprietary procedural extensions to SQL that differ from SQL:1999

SQL Functions

- Define a function that, given the name of a customer, returns the count of the number of accounts owned by the customer.

```
create function account_count (customer_name varchar(20))
returns integer
begin
    declare a_count integer;
    select count (* ) into a_count
    from depositor
    where depositor.customer_name = customer_name
    return a_count;
end
```

- Find the name and address of each customer that has more than one account.

```
select customer_name, customer_street, customer_city
from customer
where account_count (customer_name ) > 1
```

Table Functions

- SQL:2003 added functions that return a relation as a result
- Example: Return all accounts owned by a given customer

```
create function accounts_of (customer_name char(20)
        returns table (    account_number char(10),
                           branch_name char(15)
                           balance numeric(12,2))
return table
        (select account_number, branch_name, balance
         from account A
         where exists (
            select *
            from depositor D
            where D.customer_name = accounts_of.customer_name
                  and D.account_number = A.account_number ))
```

Table Functions (cont'd)

- Usage

  select *
  from table (*accounts_of* ('Smith'))

SQL Procedures

- The *author_count* function could instead be written as procedure:

  create procedure *account_count_proc* (**in** *title* **varchar**(20),
  out *a_count* **integer)**
  begin

  select count(*author*) **into** *a_count*
  from *depositor*
  where *depositor.customer_name* = *account_count_proc.customer_name*

  end

- Procedures can be invoked either from an SQL procedure or from embedded SQL, using the **call** statement.

  declare *a_count* **integer**;
  call *account_count_proc*('Smith', *a_count*);

  Procedures and functions can be invoked also from dynamic SQL

- SQL:1999 allows more than one function/procedure of the same name (called name **overloading**), as long as the number of arguments differ, or at least the types of the arguments differ

Procedural Constructs

- Compound statement: **begin ... end**,
  - May contain multiple SQL statements between **begin** and **end**.
  - Local variables can be declared within a compound statements
- **While** and **repeat** statements:

```
declare n integer default 0;
while n < 10 do
   set n = n + 1
end while

repeat
   set n = n – 1
until n = 0
end repeat
```

Procedural Constructs (Cont.)

- **For** loop
  - Permits iteration over all results of a query
  - Example: find total of all balances at the Perryridge branch

```
declare n integer default 0;
for r as
    select balance from account
    where branch_name = 'Perryridge'
do
    set n = n + r.balance
end for
```

Procedural Constructs (cont.)

- Conditional statements (**if-then-else**)
  E.g. To find sum of balances for each of three categories of accounts (with balance <1000, >=1000 and <5000, >= 5000)

  if *r*.*balance* < 1000
      then set *l* = *l* + *r*.*balance*
  elseif *r*.*balance* < 5000
      then set *m* = *m* + *r*.*balance*
  else set *h* = *h* + *r*.*balance*
  end if

- SQL:1999 also supports a **case** statement similar to C case statement
- Signaling of exception conditions, and declaring handlers for exceptions

  declare *out_of_stock* **condition**
  declare exit handler for *out_of_stock*
  begin
  …
  .. **signal** out-of-stock
  end

  - The handler here is **exit** -- causes enclosing **begin..end** to be exited
  - Other actions possible on exception

External Language Functions/Procedures

- SQL:1999 permits the use of functions and procedures written in other languages such as C or C++
- Declaring external language procedures and functions

create procedure account_count_proc(**in** *customer_name* **varchar**(20),
out count **integer**)
language C
external name ' /usr/avi/bin/account_count_proc'

create function account_count(*customer_name* **varchar**(20))
returns integer
language C
external name '/usr/avi/bin/author_count'

External Language Routines (Cont.)

- Benefits of external language functions/procedures:
  - more efficient for many operations, and more expressive power
- Drawbacks
  - Code to implement function may need to be loaded into database system and executed in the database system's address space
    - risk of accidental corruption of database structures
    - security risk, allowing users access to unauthorized data
  - There are alternatives, which give good security at the cost of potentially worse performance
  - Direct execution in the database system's space is used when efficiency is more important than security

Security with External Language Routines

- To deal with security problems
  - Use **sandbox** techniques
    - that is use a safe language like Java, which cannot be used to access/damage other parts of the database code
  - Or, run external language functions/procedures in a separate process, with no access to the database process' memory
    - Parameters and results communicated via inter-process communication
- Both have performance overheads
- Many database systems support both above approaches as well as direct executing in database system address space

Recursion in SQL

- SQL:1999 permits recursive view definition
- Example: find all employee-manager pairs, where the employee reports to the manager directly or indirectly (that is manager's manager, manager's manager's manager, etc.)

```
with recursive empl (employee_name, manager_name ) as (
        select employee_name, manager_name
        from   manager
   union
        select manager.employee_name, empl.manager_name
        from   manager, empl
        where manager.manager_name = empl.employe_name)
select *
from   empl
```

This example view, *empl,* is called the *transitive closure* of the *manager* relation

The Power of Recursion

- Recursive views make it possible to write queries, such as transitive closure queries, that cannot be written without recursion or iteration.
  - Intuition: Without recursion, a non-recursive non-iterative program can perform only a fixed number of joins of *manager* with itself
    - This can give only a fixed number of levels of managers
    - Given a program we can construct a database with a greater number of levels of managers on which the program will not work
- Computing transitive closure
  - The next slide shows a *manager* relation
  - Each step of the iterative process constructs an extended version of *empl* from its recursive definition.
  - The final result is called the *fixed point* of the recursive view definition.
- Recursive views are required to be *monotonic.* That is, if we add tuples to *manger* the view contains all of the tuples it contained before, plus possibly more

Example of Fixed-Point Computation

employee_name	*manager_name*
Alon	Barinsky
Barinsky	Estovar
Corbin	Duarte
Duarte	Jones
Estovar	Jones
Jones	Klinger
Rensal	Klinger

Iteration number	*Tuples in empl*
0	
1	(Duarte), (Estovar)
2	(Duarte), (Estovar), (Barinsky), (Corbin)
3	(Duarte), (Estovar), (Barinsky), (Corbin), (Alon)
4	(Duarte), (Estovar), (Barinsky), (Corbin), (Alon)

Advanced SQL Features**

- Create a table with the same schema as an existing table:

  create table *temp_account* **like** *account*

- SQL:2003 allows subqueries to occur *anywhere* a value is required provided the subquery returns only one value. This applies to updates as well
- SQL:2003 allows subqueries in the **from** clause to access attributes of other relations in the **from** clause using the **lateral** construct:

```
select C.customer_name, num_accounts
from customer C,
    lateral (select count(*)
                 from account A
                 where A.customer_name = C.customer_name )
              as this_customer (num_accounts )
```

Advanced SQL Features (cont'd)

- Merge construct allows batch processing of updates.
- Example: relation *funds_received* (*account_number, amount*) has batch of deposits to be added to the proper account in the *account* relation

merge into *account* **as** *A*
  using (**select** *
    from *funds_received* **as** *F*)
  on (A*.account_number* = *F.account_number*)
  when matched then
   update set *balance* = *balance* + *F.amount*

End of Chapter