Chapter 5: Advanced SQL

Outline

- Accessing SQL From a Programming Language
- Functions and Procedures
- *Triggers
- **Recursive Queries
- **Advanced Aggregation Features

Accessing SQL from a Programming Language

A database programmer must have access to a general-purpose programming language for at least two reasons

- Not all queries can be expressed in SQL, since SQL does not provide the full expressive power of a general-purpose language.
- Non-declarative actions -- such as printing a report, interacting with a user, or sending the results of a query to a graphical user interface -- cannot be done from within SQL.

Accessing SQL from a Programming Language (Cont.)

There are two approaches to accessing database from a general-purpose programming language

- API（Application Program Interface）- - A general-purpose program can connect to and communicate with a database server using a collection of functions.
- Embedded SQL -- provides a means by which a program can interact with a database server.
  - The SQL statements are translated at compile time into function calls.
  - At runtime, these function calls connect to the database using an API that provides dynamic SQL facilities.

JDBC and ODBC

- 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#
- JDBC (Java Database Connectivity) works with Java
- Embedded SQL in C
- SQLJ - embedded SQL in Java
- JPA(Java Persistence API) - OR mapping of Java

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 {
        Connection conn = DriverManager.getConnection(
              "jdbc:oracle:thin:@db.yale.edu:2000:univdb", 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 instructor values('77987', 'Kim', 'Physics', 98000)");
} catch (SQLException sqle)
{
   System.out.println("Could not insert tuple. " + sqle);
}
```

Execute query and fetch and print results

```
    ResultSet rset = stmt.executeQuery(
                        "select dept_name, avg (salary)
                         from instructor
                         group by dept_name");
    while (rset.next()) {
        System.out.println(rset.getString("dept_name") + " " +
                                 rset.getFloat(2));
    }
```

JDBC Code Details

Getting result fields:

rset.getString("dept_name") and rset.getString(1) equivalent if dept_name is the first argument of select result.

Dealing with Null values

```
int a = rset.getInt("a");
if (rset.wasNull()) Systems.out.println("Got null value");
```

Prepared Statement

```
PreparedStatement pStmt = conn.prepareStatement(
                          "insert into instructor values(?,?,?,?)");
pStmt.setString(1, "88877");     pStmt.setString(2, "Perry");
pStmt.setString(3, "Finance");   pStmt.setInt(4, 125000);
pStmt.executeUpdate();
pStmt.setString(1, "88878");
pStmt.executeUpdate();
```

WARNING: always use prepared statements when taking an input from the user and adding it to a query

NEVER create a query by concatenating strings which you get as inputs

"insert into instructor values(' " + ID + " ', ' " + name + " ', " + " ' " + dept name + " ', " + salary + ")"

What if name is "D'Souza"?

SQL Injection(SQL 注入)

Suppose query is constructed using

"select * from instructor where name = '" + name + " ' "

Suppose the user, instead of entering a name, enters:

X' or 'Y' = 'Y

then the resulting string of the statement becomes:

"select * from instructor where name = '" + "X' or 'Y' = 'Y" + "'"

which is:

- select * from instructor where name = 'X' or 'Y' = 'Y'

User could have even used

- X'; update instructor set salary = salary + 10000;

then →

- select * from instructor where name = 'X';
  update instructor set salary = salary + 10000;

Always use prepared statements, with user inputs as parameters

Metadata Features

ResultSet metadata

E.g., after executing query to get a ResultSet rs:

```
ResultSetMetaData rsmd = rs.getMetaData();
for(int i = 1; i <= rsmd.getColumnCount(); i++) {
    System.out.println(rsmd.getColumnName(i));
    System.out.println(rsmd.getColumnTypeName(i));
}
```

Metadata (Cont)

Database metadata

```
DatabaseMetaData dbmd = conn.getMetaData();
ResultSet rs = dbmd.getColumns(null, "univdb", "department", "%");
// Arguments to getColumns: Catalog, Schema-pattern, Table-pattern,
// and Column-Pattern
// Returns: One row for each column; row has a number of attributes
// such as COLUMN_NAME, TYPE_NAME
while( rs.next()) {
    System.out.println(rs.getString("COLUMN_NAME"),
                       rs.getString("TYPE_NAME");
}
```

Transaction Control in JDBC

By default, each SQL statement is treated as a separate transaction that is committed automatically

bad idea for transactions with multiple updates

Can turn off automatic commit on a connection

```
conn.setAutoCommit(false);
```

Transactions must then be committed or rolled back explicitly

```
conn.commit();     or
conn.rollback();
```

conn.setAutoCommit(true) turns on automatic commit.

JDBC Resources

JDBC Basics Tutorial

https://docs.oracle.com/javase/tutorial/jdbc/index.html

SQLJ

JDBC is overly dynamic, errors cannot be caught by compiler

SQLJ: embedded SQL in Java

```
#sql iterator deptInfoIter ( String dept name, int avgSal);
deptInfoIter iter = null;
#sql iter = { select dept_name, avg(salary) as avgSal from instructor
              group by dept name };
while (iter.next()) {
    String deptName = iter.dept_name();
    int avgSal = iter.avgSal();
    System.out.println(deptName + " " + avgSal);
}
iter.close();
```

SQLJ Resources

SQLJ Developer's Guide

https://docs.oracle.com/en/database/oracle/oracle-database/20/jsqlj/toc.htm

ODBC

Open DataBase Connectivity(ODBC) standard

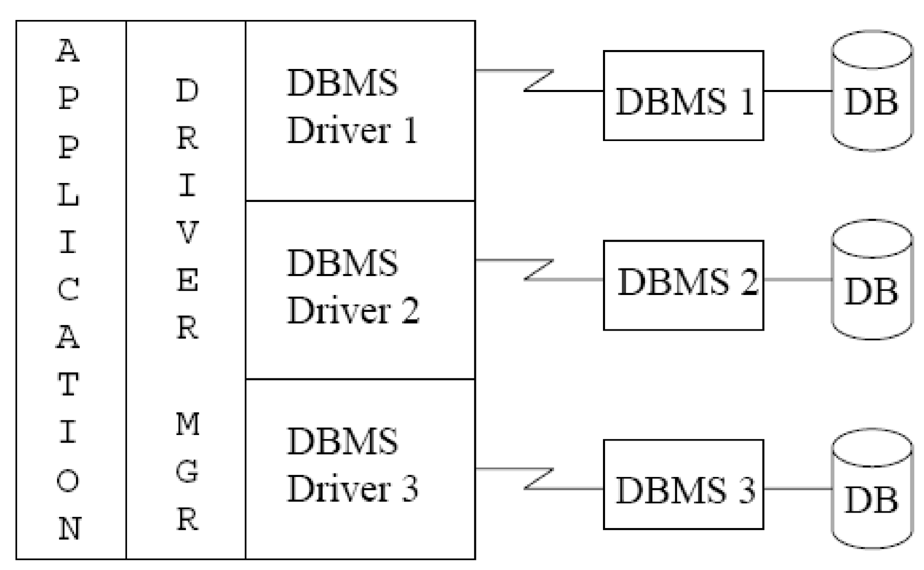
- standard for application program to communicate with a database server.
- application program interface (API) to
  - open a connection with a database,
  - send queries and updates,
  - get back results.

Applications such as GUI, spreadsheets, etc. can use ODBC

Was defined originally for Basic and C, versions available for many languages.

ODBC (Cont.)

Each database system supporting ODBC provides a "driver" library that must be linked with the client program.



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, "db.yale.edu", 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 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 deptname[80];
float salary;
int lenOut1, lenOut2;
HSTMT stmt;
char * sqlquery = "select dept_name, sum (salary)
                   from instructor
                   group by dept_name";
SQLAllocStmt(conn, &stmt);
error = SQLExecDirect(stmt, sqlquery, SQL_NTS);
if (error == SQL SUCCESS) {
      SQLBindCol(stmt, 1, SQL_C_CHAR, deptname , 80, &lenOut1);
      SQLBindCol(stmt, 2, SQL_C_FLOAT, &salary, 0 , &lenOut2);
      while (SQLFetch(stmt) == SQL_SUCCESS) {
           printf (" %s %g\n", deptname, salary);
      }
}
SQLFreeStmt(stmt, SQL_DROP);
```

ODBC Prepared Statements

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

To prepare a statement

SQLPrepare(stmt, <SQL String>);

To bind parameters

SQLBindParameter(stmt, <parameter#>,
    … type information and value omitted for simplicity..)

To execute the statement

retcode = SQLExecute(stmt);

More ODBC Features

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 Resources

MySQL Connector/ODBC Developer Guide

https://docs.oracle.com/cd/E17952_01/connector-odbc-en/index.html

Embedded SQL

The SQL standard defines embeddings of SQL in a variety of programming languages such as C, C++, Java, Fortran, and PL/1,

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/1.

EXEC SQL statement is used in the host language to identify embedded SQL request to the preprocessor

    EXEC SQL <embedded SQL statement >;

Note: this varies by language:

- In some languages, like COBOL, the semicolon is replaced with END-EXEC
- In Java embedding uses # SQL { …. };

Embedded SQL (Cont.)

Before executing any SQL statements, the program must first connect to the database. This is done using:

EXEC-SQL **connect to** *server* **user** *user-name* **using** *password*;

Here, *server* identifies the server to which a connection is to be established.

Variables of the host language can be used within embedded SQL statements. They are preceded by a colon (:) to distinguish from SQL variables (e.g., :*credit_amount*)

Host Variables used as above must be declared within DECLARE section, as illustrated below. The syntax for declaring the variables, however, follows the usual host language syntax.

```
EXEC-SQL BEGIN DECLARE SECTION
    int credit-amount ;
EXEC-SQL END DECLARE SECTION;
```

Embedded SQL (Cont.)

To write an embedded SQL query, we use the

declare *c* **cursor for <SQL query>**

statement. The variable *c* is used to identify the query

Example:

- From within a host language, find the ID and name of students who have completed more than the number of credits stored in variable credit_amount in the host langue
- Specify the query in SQL as follows:

```
EXEC SQL
  declare c cursor for
  select ID, name
  from student
  where tot_cred > :credit_amount;
```

Embedded SQL (Cont.)

The **open** statement for our example is as follows:

    EXEC SQL open c ;

This statement causes the database system to execute the query and to save the results within a temporary relation. The query uses the value of the host-language variable *credit-amount* at the time the **open** statement is executed.

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 :si, :sn ;

Repeated calls to fetch get successive tuples in the query result

Embedded SQL (Cont.)

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 ;

Updates Through Embedded SQL

Embedded SQL expressions for database modification (**update**, **insert**, and **delete**)

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

```
EXEC SQL
  declare c cursor for
    select *
    from instructor
    where dept_name = 'Music'
    for update
```

We then iterate through the tuples by performing **fetch** operations on the cursor , and after fetching each tuple we execute the following code:

```
update instructor
set salary = salary + 1000
where current of c
```

Embedded SQL Resources

Oracle Database Programmer's Guide - Embedded SQL

https://docs.oracle.com/en/database/oracle/oracle-database/20/lnpcc/embedded-SQL.html#GUID-C671CABF-202A-4503-A16B-DC78D3F1AB13

Procedural Constructs in SQL

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.
- 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

Functions and Procedures

- Functions and procedures allow "business logic" to be stored in the database and executed from SQL statements.
- These can be defined either by the procedural component of SQL or by an external programming language such as Java, C, or C++.
- The syntax we present here is defined by the SQL standard.
  - Most databases implement nonstandard versions of this syntax.

SQL Functions

- Define a function that, given the name of a department, returns the count of the number of instructors in that department.

```
create function dept_count (dept_name varchar(20))
 returns integer
 begin
     declare d_count integer;
     select count (* ) into d_count
     from instructor
     where instructor.dept_name = dept_name
     return d_count;
  end
```

- Find the department name and budget of all departments with more that 12 instructors.

```
select dept_name, budget
from department
where dept_count (dept_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 instructors_of (dept_name char(20) )
      returns table (  ID varchar(5),
                       name varchar(20),
                       dept_name varchar(20),
                       salary numeric(8,2))
return table
      (select ID, name, dept_name, salary
       from instructor
       where instructor.dept_name = instructors_of.dept_name)
```

- Usage

```
select *
from table (instructors_of ('Music'))
```

SQL Procedures

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

```
create procedure dept_count_proc (in dept_name varchar(20),
                                  out d_count integer)
begin
  select count(*) into d_count
  from instructor
  where instructor.dept_name = dept_count_proc.dept_name
end
```

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

```
declare d_count integer;
call dept_count_proc( 'Physics', d_count);
```

- Procedures and functions can be invoked also from dynamic SQL

Procedural Constructs

- Warning: most database systems implement their own variant of the standard syntax below
  - read your system manual to see what works on your system
- 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:

```
declare n integer default 0;
for r as
      select budget from department
      where dept_name = 'Music'
do
      set n = n - r.budget
end for
```

Procedural Constructs (cont.)

Conditional statements (**if-then-else**)

```
if boolean expression
   then statement or compound statement
elseif boolean expression
   then statement or compound statement
else statement or compound statement
end if
```

SQL:1999 also supports a **case** statement similar to C case statement

Example procedure

```
create function registerStudent(
            in s_id varchar(5),
            in s_courseid varchar (8),
            in s_secid varchar (8),
            in s_semester varchar (6),
            in s_year numeric (4,0),
            out errorMsg varchar(100)
returns integer
begin
    declare currEnrol int;
    select count(*) into currEnrol
        from takes
        where course_id = s_courseid and sec_id = s_secid
            and semester = s_semester and year = s_year;
    declare limit int;
    select capacity into limit
        from classroom natural join section
        where course_id = s_courseid and sec_id = s_secid
            and semester = s_semester and year = s_year;
    if (currEnrol < limit)
        begin
            insert into takes values
                (s_id, s_courseid, s_secid, s_semester, s_year, null);
            return(0);
        end
    - - Otherwise, section capacity limit already reached
    set errorMsg = 'Enrollment limit reached for course ' || s_courseid
        || ' section ' || s_secid;
    return(-1);
end;
```

– – Registers a student after ensuring
– –   classroom capacity is not exceeded.
– – Returns 0 on success, and -1 if
– –   capacity is exceeded.

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 dept_count_proc(**in** *dept_name* **varchar**(20),
out count **integer**)
language C
external name ' /usr/avi/bin/dept_count_proc'

create function dept_count(*dept_name* **varchar**(20))
returns integer
language C
external name '/usr/avi/bin/dept_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.

Triggers

Triggers

A **trigger** is a statement that is executed automatically by the system as a side effect of a modification to the database.

Trigger - ECA rule

- E: Event （**insert**, **delete**，**update**）
- C: Condition
- A: Action

To design a trigger mechanism, we must:

- Specify the conditions under which the trigger is to be executed.
- Specify the actions to be taken when the trigger executes.

Triggers introduced to SQL standard in SQL:1999, but supported even earlier using non-standard syntax by most databases.

Trigger Example

account_log(account, amount, datetime)

```
create trigger account_trigger after update of account on balance
referencing new row as nrow
referencing   old row as orow
for each row
when nrow.balance - orow.balance > =200000 or
        orow.balance  -nrow.balance >=50000
begin
       insert into account_log values (nrow.account-number,
                       nrow.balance-orow.balance , current_time() )
end
```

Trigger Example

E.g. *time_slot_id* is not a primary key of *timeslot,* so we cannot create a foreign key constraint from *section* to *timeslot.*

Alternative: use triggers on *section* and *timeslot* to enforce integrity constraints

```
create trigger timeslot_check1 after insert on section
referencing new row as nrow
for each row
when (nrow.time_slot_id not in (
            select time_slot_id
            from time_slot)) /* time_slot_id not present in time_slot */
begin
   rollback
end;
```

Trigger Example Cont.

```
create trigger timeslot_check2 after delete on timeslot
    referencing old row as orow
    for each row
    when (orow.time_slot_id not in (
              select time_slot_id
              from time_slot)
                          /* last tuple for time slot id deleted from time slot */
          and orow.time_slot_id in (
              select time_slot_id
              from section))
                          /* and time_slot_id still referenced from section*/
    begin
       rollback
    end;
```

Triggering Events and Actions in SQL

Triggering event can be **insert**, **delete** or **update**

Triggers on update can be restricted to specific attributes

E.g., after update of *takes* **on** *grade*

Values of attributes before and after an update can be referenced

referencing old row as : for deletes and updates

referencing new row as : for inserts and updates

Triggers can be activated before an event, which can serve as extra constraints. E.g. convert blank grades to null.

```
create trigger setnull_trigger before update of takes
referencing new row as nrow
for each row
when (nrow.grade = ' ')
 begin atomic
        set nrow.grade = null;
 end;
```

Trigger to Maintain credits_earned value

```
create trigger credits_earned after update of takes on grade
referencing new row as nrow
referencing old row as orow
for each row
when nrow.grade <> 'F' and nrow.grade is not null
   and (orow.grade = 'F' or orow.grade is null)
begin atomic
    update student
    set tot_cred= tot_cred +
         (select credits
          from course
          where course.course_id= nrow.course_id)
    where student.id = nrow.id;
end;
```

Statement Level Triggers

Instead of executing a separate action for each affected row, a single action can be executed for all rows affected by a transaction

Use **for each statement** instead of **for each row**

Use **referencing old table** or **referencing new table** to refer to temporary tables (called ***transition tables***) containing the affected rows

Can be more efficient when dealing with SQL statements that update a large number of rows

Statement Level Triggers

```
create trigger grade_trigger after update of takes on grade
referencing new table as new_table
for each statement
when  exists( select avg(grade)
                from new_table
                group by course_id, sec_id, semester, year
                having avg(grade)< 60 )
begin
      rollback
end
```

When Not To Use Triggers

Triggers were used earlier for tasks such as

maintaining summary data (e.g., total salary of each department)

Replicating databases by recording changes to special relations (called **change** or **delta** relations) and having a separate process that applies the changes over to a replica

There are better ways of doing these now:

Databases today provide built in materialized view facilities to maintain summary data

Databases provide built-in support for replication

Encapsulation facilities can be used instead of triggers in many cases

Define methods to update fields

Carry out actions as part of the update methods instead of through a trigger

When Not To Use Triggers

- Risk of unintended execution of triggers, for example, when
  - loading data from a backup copy
  - replicating updates at a remote site
  - Trigger execution can be disabled before such actions.
- Other risks with triggers:
  - Error leading to failure of critical transactions that set off the trigger
  - Cascading execution

Recursive Queries

Recursion in SQL

- SQL:1999 permits recursive view definition
- Example: find which courses are a prerequisite, whether directly or indirectly, for a specific course

```
with recursive rec_prereq(course_id, prereq_id) as (
        select course_id, prereq_id
        from prereq
    union
        select rec_prereq.course_id, prereq.prereq_id,
        from rec_prereq, prereq
        where rec_prereq.prereq_id = prereq.course_id
    )
select ∗
from rec_prereq;
```

- This example view, *rec_prereq,* is called the *transitive closure* of the *prereq* 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 *prereq* with itself
    - This can give only a fixed number of levels of prerequisites.
    - Given a fixed non-recursive query, we can construct a database with a greater number of levels of prerequisites on which the query will not work
    - Alternative: write a procedure to iterate as many times as required
      - See procedure *findAllPrereqs* in book on Page.189

The Power of Recursion

```
create function findAllPrereqs(cid varchar(8))
    – – Finds all courses that are prerequisite (directly or indirectly) for cid
returns table (course_id varchar(8))
    – – The relation prereq(course_id, prereq_id) specifies which course is
    – – directly a prerequisite for another course.
begin
    create temporary table c_prereq (course_id varchar(8));
        – – table c_prereq stores the set of courses to be returned
    create temporary table new_c_prereq (course_id varchar(8));
        – – table new_c_prereq contains courses found in the previous iteration
    create temporary table temp (course_id varchar(8));
        – – table temp is used to store intermediate results
    insert into new_c_prereq
        select prereq_id
        from prereq
        where course_id = cid;
    repeat
        insert into c_prereq
            select course_id
            from new_c_prereq;

        insert into temp
            (select prereq.course_id
                from new_c_prereq, prereq
                where new_c_prereq.course_id = prereq.prereq_id
            )
            except (
                select course_id
                from c_prereq
            );
        delete from new_c_prereq;
        insert into new_c_prereq
            select *
            from temp;
        delete from temp;

    until not exists (select * from new_c_prereq)
    end repeat;
    return table c_prereq;
end
```

OLAP**

Data Analysis and OLAP

- **Online Analytical Processing (OLAP)**
  - Interactive analysis of data, allowing data to be summarized and viewed in different ways in an online fashion (with negligible delay)
- Data that can be modeled as dimension attributes and measure attributes are called **multidimensional data**.
  - **Measure attributes**
    - measure some value
    - can be aggregated upon
    - e.g., the attribute *number* of the *sales* relation
  - **Dimension attributes**
    - define the dimensions on which measure attributes (or aggregates thereof) are viewed
    - e.g., attributes *item_name, color,* and *size* of the *sales* relation

Example sales relation

item_name	*color*	*clothes_size*	*quantity*
skirt	dark	small	2
skirt	dark	medium	5
skirt	dark	large	1
skirt	pastel	small	11
skirt	pastel	medium	9
skirt	pastel	large	15
skirt	white	small	2
skirt	white	medium	5
skirt	white	large	3
dress	dark	small	2
dress	dark	medium	6
dress	dark	large	12
dress	pastel	small	4
dress	pastel	medium	3
dress	pastel	large	3
dress	white	small	2
dress	white	medium	3
dress	white	large	0
shirt	dark	small	2
shirt	dark	medium	6
...	...	...	...
...	...	...	...

Cross Tabulation of *sales* by *item_name* and *color*

clothes_size **all**

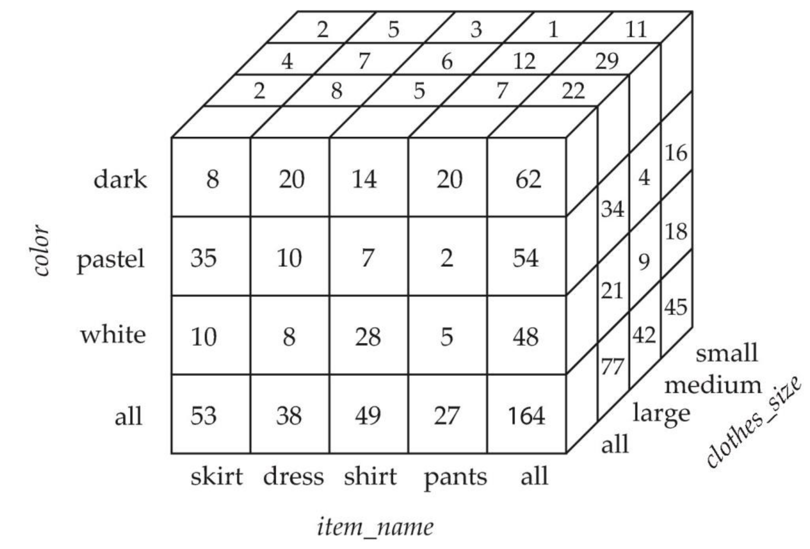
item_name \ *color*	dark	pastel	white	total
skirt	8	35	10	53
dress	20	10	5	35
shirt	14	7	28	49
pants	20	2	5	27
total	62	54	48	164

The table above is an example of a **cross-tabulation** (**cross-tab**), also referred to as a **pivot-table**.

- Values for one of the dimension attributes form the row headers
- Values for another dimension attribute form the column headers
- Other dimension attributes are listed on top
- Values in individual cells are (aggregates of) the values of the dimension attributes that specify the cell.

Data Cube

- A **data cube** is a multidimensional generalization of a cross-tab
- Can have *n* dimensions; we show 3 below
- Cross-tabs can be used as views on a data cube



Cross Tabulation With Hierarchy

- Cross-tabs can be easily extended to deal with hierarchies
  - Can drill down or roll up on a hierarchy

clothes_size: **all**

category	*item_name*	dark	pastel	white	total	
womenswear	skirt	8	8	10	53	
	dress	20	20	5	35	
	subtotal	28	28	15		88
menswear	pants	14	14	28	49	
	shirt	20	20	5	27	
	subtotal	34	34	33		76
total		62	62	48		164

Relational Representation of Cross-tabs

- Cross-tabs can be represented as relations
  - We use the value **all** is used to represent aggregates.
  - The SQL standard actually uses null values in place of **all** despite confusion with regular null values.

item_name	*color*	*clothes_size*	*quantity*
skirt	dark	**all**	8
skirt	pastel	**all**	35
skirt	white	**all**	10
skirt	**all**	**all**	53
dress	dark	**all**	20
dress	pastel	**all**	10
dress	white	**all**	5
dress	**all**	**all**	35
shirt	dark	**all**	14
shirt	pastel	**all**	7
shirt	White	**all**	28
shirt	**all**	**all**	49
pant	dark	**all**	20
pant	pastel	**all**	2
pant	white	**all**	5
pant	**all**	**all**	27
all	dark	**all**	62
all	pastel	**all**	54
all	white	**all**	48
all	**all**	**all**	164

Extended Aggregation to Support OLAP

- The **cube** operation computes union of **group by**'s on every subset of the specified attributes
- Example relation for this section
  sales(item_name, color, clothes_size, quantity)
- E.g. consider the query

  select *item_name, color, size,* **sum**(*number*)
  from *sales*
  group by cube(*item_name, color, size*)

  This computes the union of eight different groupings of the *sales* relation:

  { (*item_name, color, size*), (*item_name, color*),
  (*item_name, size*), (*color, size*),
  (*item_name*), (*color*),
  (*size*), ( ) }

  where ( ) denotes an empty **group by** list.
- For each grouping, the result contains the null value for attributes not present in the grouping.

Extended Aggregation (Cont.)

- The **rollup** construct generates union on every prefix of specified list of attributes
- E.g.,

  select *item_name*, *color*, *size*, **sum**(*number*)
  from *sales*
  group by rollup(*item_name, color, size*)

  Generates union of four groupings:

  { (*item_name, color, size*), (*item_name, color*), (*item_name*), ( ) }
- Rollup can be used to generate aggregates at multiple levels of a hierarchy.
- E.g., suppose table *itemcategory*(*item_name, category*) gives the category of each item. Then

  select *category, item_name*, **sum**(*number*)
  from *sales, itemcategory*
  where *sales.item_name = itemcategory.item_name*
  group by rollup(*category, item_name*)

  would give a hierarchical summary by *item_name* and by *category.*

Extended Aggregation (Cont.)

- Multiple rollups and cubes can be used in a single group by clause
  - Each generates set of group by lists, cross product of sets gives overall set of group by lists
- E.g.,

  select *item_name, color, size*, **sum**(*number*)
  from *sales*
  group by rollup(*item_name*), **rollup**(*color, size*)

  generates the groupings

  {*item_name, ()*} X {*(color, size), (color), ()*}

  = { (*item_name, color, size*), (*item_name, color*), (*item_name*), (*color, size*), (*color*), ( ) }

Online Analytical Processing Operations

- **Pivoting:** changing the dimensions used in a cross-tab is called
- **Slicing:** creating a cross-tab for fixed values only
  - Sometimes called **dicing**, particularly when values for multiple dimensions are fixed.
- **Rollup:** moving from finer-granularity data to a coarser granularity
- **Drill down:** The opposite operation - that of moving from coarser-granularity data to finer-granularity data

End of Chapter

Figure 5.22

item_name	*clothes_size*	*dark*	*pastel*	*white*
skirt	small	2	11	2
skirt	medium	5	9	5
skirt	large	1	15	3
dress	small	2	4	2
dress	medium	6	3	3
dress	large	12	3	0
shirt	small	2	4	17
shirt	medium	6	1	1
shirt	large	6	2	10
pant	small	14	1	3
pant	medium	6	0	0
pant	large	0	1	2

Figure 5.23

item_name	*quantity*
skirt	53
dress	35
shirt	49
pant	27

Figure 5.24

item_name	*color*	*quantity*
skirt	dark	8
skirt	pastel	35
skirt	white	10
dress	dark	20
dress	pastel	10
dress	white	5
shirt	dark	14
shirt	pastel	7
shirt	white	28
pant	dark	20
pant	pastel	2
pant	white	5

Another Recursion Example

Given relation
manager(*employee_name, manager_name*)

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 the *transitive closure* of the *manager* relation

Merge statement (now in Chapter 24)

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 5