Chapter 5: Advanced SQL

Database System Concepts, 7th Ed.

Connector/Python

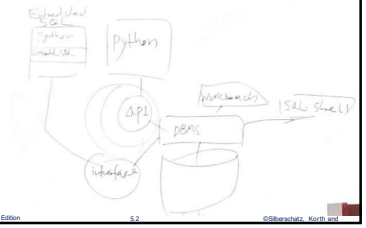
Run Python to connect MySQL (cont.)

```
>>>cursorA.close()     ## release the memory space
>>>cursorB.close()
>>>myconnect.close()    ## close the connection with MySQL server
```

- Summary of Using MySQL
  1. Import mysql.connector
  2. create connection object to the database
  3. Create cursor object using connection object
  4. Deliver SQL statement to database via cursor object
  5. Processing the result returned from the database
  6. Close cursor, close connection if no need to use the database

Outline

- Accessing SQL From a Programming Language
- Functions and Procedures
- Triggers
- Recursive Queries



MySQL connector/python

- Connect to mysql server using python

```
>>> import mysql.connector      ## import the connector module
>>> myconnect=mysql.connector.connect(host='localhost',
                                      database='mysql',
                                      user='root',
                                      password='mypassword')
>>> mycursor=myconnect.cursor(buffered=True)
>>>mycursor.execute('show databases')
>>>for x in mycursor:
        print(x)
>>>mycursor.close()
>>>myconnect.close()
```


JDBC(skipped)

Accessing SQL from a Programming Language

There are two approaches to accessing SQL from a general-purpose programming language (C++, java, python)

- Dynamic SQL -- general programming language can connect to and communicate with a database server using a collection of functions (API)
  - ODBC: C, C++ programme
  - JDBC: java programme
  - MySQL
    - connector/python: python
    - connector/J: java
- Embedded SQL -- provides a means by which a program can interact with a database server by embedding SQL in the general language.
  - 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.

Run Python to connect MySQL (cont.)

```
>>> connection = mysql.connector.connect(host='localhost',
                                         database='university',     ## can omit
                                         user='root',
                                         password='mypassword')
>>> p1='history'
>>> cursorA = connection.cursor(buffered=True)
>>> cursorA.execute("select * from university.department where name = %s" ,(p1,))
>>> for x in cursorA:
        print(x)
>>>cursorB=connection.cursor(buffered=True)
>>>cursorB.execute("select name, salary from instructor")
>>>for (n,s) in cursorB:
        s=s/12      ## any processing of the values
        print(n,s)
```


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:mysql://localhost:3306/university", userid, passwd);
           Statement stmt = conn.createStatement();
          )
     {
          … Do Actual Work ….
     }
     catch (SQLException sqle) {
        System.out.println("SQLException : " + sqle);
     }
  }
```

NOTE: Above syntax works with Java 7, and JDBC 4 onwards. Resources opened in "try (….)" syntax ("try with resources") are automatically closed at the end of the try block

JDBC Code for Older Versions of Java/JDBC

```
public static void JDBCexample(String dbid, String userid, String passwd)
  {
    try {
        Class.forName ("com.mysql.cj.jdbc.Driver");
        Connection conn = DriverManager.getConnection(
              "jdbc:mysql://localhost:3306/university", userid, passwd);
        Statement stmt = conn.createStatement();
          … Do Actual Work ….
        stmt.close();
        conn.close();
    }
    catch (SQLException sqle) {
        System.out.println("SQLException : " + sqle);
    }
  }
```

NOTE: Class.forName is not required from JDBC 4 onwards. The try with resources syntax in prev slide is preferred for Java 7 onwards.

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));
}
```


A Complete Example

```
import java.sql.*;
import java.lang.*;

public class jdbcExample {
    public static void main(String[] args) {
        try {
            Connection conn =    DriverManager.getConnection("jdbc:mysql://localhost:3306/university","root",
"mypassword");
            Statement stmt = conn.createStatement();
            ResultSet rs = stmt.executeQuery("select * from instructor");
            while (rs.next()) {
                // Retrieve by column name
                System.out.print("ID: " + rs.getString("ID"));
                System.out.print(", name: " + rs.getString("name"));
                System.out.print(", department name: " + rs.getString("dept_name"));
                System.out.println(", salary: " + rs.getFloat("salary"));
            }
            conn.close();
        } catch (Exception ex) {
            // handle the error
            System.out.print(ex);
        }
    }
}
```

Remark: need to install the jdbc driver for MySQL: connector/J

JDBC SUBSECTIONS

- Connecting to the Database
- Shipping SQL Statements to the Database System
- Exceptions and Resource Management
- Retrieving the Result of a Query
- Prepared Statements
- Callable Statements
- Metadata Features
- Other Features
- Database Access from Python

JDBC Code Details

- Getting result fields:
  - rs.getString("dept_name") and rs.getString(1) equivalent if dept_name 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");
```


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
  - "insert into instructor values(" " + ID + " ', ' " + name + " ', " + " ' " + dept name + " ', " ' balance + ')"
  - What if name is "D'Souza"?

SQL Injection

- 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 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; --
- Prepared stament internally uses:
  "select * from instructor where name = 'X\' or \'Y\' = \'Y'
  - 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));
    }
- How is this useful?

Metadata (Cont)

- Database metadata
- DatabaseMetaData dbmd = conn.getMetaData();

```
// 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
// The value null indicates all Catalogs/Schemas.
// The value "" indicates current catalog/schema
// The value "%" has the same meaning as SQL like clause
ResultSet rs = dbmd.getColumns(null, "univdb", "department", "%");
  while( rs.next()) {
      System.out.println(rs.getString("COLUMN_NAME"),
                         rs.getString("TYPE_NAME");
  }
```

- And where is this useful?

Metadata (Cont)

- Database metadata
- DatabaseMetaData dbmd = conn.getMetaData();

```
// Arguments to getTables: Catalog, Schema-pattern, Table-pattern,
// and Table-Type
// Returns: One row for each table; row has a number of attributes
// such as TABLE_NAME, TABLE_CAT, TABLE_TYPE, ..
// The value null indicates all Catalogs/Schemas.
// The value "" indicates current catalog/schema
// The value "%" has the same meaning as SQL like clause
// The last attribute is an array of types of tables to return.
//   TABLE means only regular tables
ResultSet rs = dbmd.getTables ("", "", "%", new String[] {"TABLES"});
  while( rs.next()) {
      System.out.println(rs.getString("TABLE_NAME"));
  }
```

- And where is this useful?

Finding Primary Keys

- DatabaseMetaData dmd = connection.getMetaData();

```
// Arguments below are:  Catalog, Schema, and Table
// The value ""  for Catalog/Schema indicates current catalog/schema
//  The value null indicates all catalogs/schemas
ResultSet rs = dmd.getPrimaryKeys("", "", tableName);

while(rs.next()){
   // KEY_SEQ indicates the position of the attribute in
   // the primary key, which is required if a primary key has multiple
   // attributes
   System.out.println(rs.getString("KEY_SEQ"),
                      rs.getString("COLUMN_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.

Other JDBC Features

- Calling functions and procedures
  - CallableStatement cStmt1 = conn.prepareCall("{? = call some function(?)}");
  - CallableStatement cStmt2 = conn.prepareCall("{call some procedure(?,?)}");
- Handling large object types
  - getBlob() and getClob() that are similar to the getString() method, but return objects of type Blob and Clob, respectively
  - get data from these objects by getBytes()
  - associate an open stream with Java Blob or Clob object to update large objects
    - blob.setBlob(int parameterIndex, InputStream inputStream).

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 deptInfolter (String dept name, int avgSal);

```
deptInfolter iter = null;
#sql iter = { select dept_name, avg(salary) 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();
```


ODBC(skipped)

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

Embedded SQL (skipped)

- 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)*
- 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
 END_EXEC
```


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* END_EXEC

  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* ;

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

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 (as illustrated earlier), and after fetching each tuple we execute the following code:

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


Functions and Procedures

Functions and Procedures

- Built in functions of MySQL
  - select version();
    select database();
- MySQL allow users to define more functions by themselves
  - set global log_bin_trust_function_creators=1; (DB security issues)
- Functions and procedures: special programmes stored in the database and executed from SQL statements.
- Defined either using 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.
- MySQL
  - https://dev.mysql.com/doc/refman/8.0/en/create-procedure.html

Declaring 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 int
reads sql data
begin
    declare d_count int;
    select count(*) into d_count
    from instructor
    where instructor.dept_name = dept_name;
return d_count;
end
```

- The function *dept_count* can be used to find the department names and budget of all departments with more that 12 instructors.

```
select dept_name, budget
from department
where dept_count (dept_name ) > 12
```

- Show function status
  - List all functions

Table Functions (no supported by MySQL)

- The SQL standard supports functions that can return tables as results; such functions are called table functions
- Example: Return all instructors in a given department

```
create function instructor_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 = instructor_of.dept_name)
```

- Usage

```
select *
from table (instructor_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_name
end
```

- The keywords in and out are parameters that are expected to have values assigned to them and parameters whose values are set in the procedure in order to return results.
- 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);
```

- show procedure status
  - List all procedures

SQL Procedures (Cont.)

- Procedures and functions can be invoked also from dynamic SQL
- SQL allows more than one procedure with the same name so long as the number of arguments of the procedures with the same name is different.
- The name, along with the number of arguments, is used to identify the procedure.

Language Constructs for Procedures & Functions

- SQL supports constructs that gives it almost all the power of a general-purpose programming language.
  - Warning: most database systems implement their own variant of the standard syntax below.
- 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:
  - while boolean expression do
    sequence of statements ;
    end while
  - repeat
    sequence of statements ;
    until boolean expression
    end repeat

Language Constructs (Cont.)

- For loop
  - Permits iteration over all results of a query
- Example: Find the budget of all departments

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


Language Constructs – if-then-else

- 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
```


Example procedure

- Registers student after ensuring classroom capacity is not exceeded
  - Returns 0 on success and -1 if capacity is exceeded
  - See book (page 202) for details
- Signaling of exception conditions, and declaring handlers for exceptions

```
declare out_of_classroom_seats condition
declare exit handler for out_of_classroom_seats
begin
...
end
```

- The statements between the begin and the end can raise an exception by executing "signal *out_of_classroom_seats*"
- The handler says that if the condition arises he action to be taken is to exit the enclosing the begin end statement.

External Language Routines

- SQL allows us to define functions in a programming language such as Java, C#, C or C++.
  - Can be more efficient than functions defined in SQL, and computations that cannot be carried out in SQL\can be executed by these functions.
- 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, we can do on of the following:
  - Use sandbox techniques
    - That is, use a safe language like Java, which cannot be used to access/damage other parts of the database code.
  - 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

Triggering Events and Actions in MySQL

- Triggers can be activated before an event, which can serve as extra constraints. For example. convert blank grades to null.

```
create trigger setnull_trigger before update on takes
for each row
  begin
    if new.grade = ' ' then
      set new.grade = null;
    end if;
  end;
```

- Other actions
  after update on, after delete on, before insert on, before update on, before delete on
- the new value and old value: new.grade, old.grade
- For each row
  - For each changed row, perform the action
- For each statement
  - For each SQL statement, perform the action
- Drop trigger *setnull_trigger*
- Show triggers , show triggers in *takes*

Trigger to Maintain credits_earned value

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

- 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

Triggers

- A trigger is a statement that is executed automatically by the system as a side effect of a modification to the database.
- 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.
  - Syntax illustrated here may not work exactly on your database system; check the system manuals
- MySQL trigger
  - https://dev.mysql.com/doc/refman/8.0/en/trigger-syntax.html

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

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 managers
    - 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

The Power of Recursion

- Computing transitive closure using iteration, adding successive tuples to *rec_prereq*
  - The next slide shows a *prereq* relation
  - Each step of the iterative process constructs an extended version of *rec_prereq* 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 *prereq* the view *rec_prereq* contains all of the tuples it contained before, plus possibly more

Example of Fixed-Point Computation

course_id	*prereq_id*
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-190
CS-319	CS-101
CS-319	CS-315
CS-347	CS-319

[CS-347]

Iteration Number	*Tuples in c1*
0	
1	(CS-319)
2	(CS-319), (CS-315), (CS-101)
3	(CS-319), (CS-315), (CS-101), (CS-190)
4	(CS-319), (CS-315), (CS-101), (CS-190)
5	done

Ranking

- Ranking is done in conjunction with an order by specification.
- Suppose we are given a relation
  student_grades(ID, GPA)
  giving the grade-point average of each student
- Find the rank of each student.
  - select *ID*, rank() over (order by *GPA* desc) as *s_rank*
    from *student_grades*
- An extra order by clause is needed to get them in sorted order
  - select *ID*, rank() over (order by *GPA* desc) as *s_rank*
    from *student_grades*
    order by *s_rank*
- Ranking may leave gaps: e.g. if 2 students have the same top GPA, both have rank 1, and the next rank is 3
  - dense_rank does not leave gaps, so next dense rank would be 2

Advanced Aggregation Features (skipped)

Ranking

- Ranking can be done using basic SQL aggregation, but resultant query is very inefficient

```
select ID, (1 + (select count(*)
                 from student_grades B
                 where B.GPA > A.GPA)) as s_rank
from student_grades A
order by s_rank;
```


Ranking (Cont.)

- Ranking can be done within partition of the data.
- "Find the rank of students within each department."

```
select ID, dept_name,
    rank () over (partition by dept_name order by GPA desc)
        as dept_rank
from dept_grades
order by dept_name, dept_rank;
```

- Multiple rank clauses can occur in a single select clause.
- Ranking is done *after* applying group by clause/aggregation
- Can be used to find top-n results
  - More general than the limit *n* clause supported by many databases, since it allows top-n within each partition

Ranking (Cont.)

- Other ranking functions:
  - percent_rank (within partition, if partitioning is done)
  - cume_dist (cumulative distribution)
    - fraction of tuples with preceding values
  - row_number (non-deterministic in presence of duplicates)
- SQL:1999 permits the user to specify nulls first or nulls last

```
select ID,
    rank ( ) over (order by GPA desc nulls last) as s_rank
from student_grades
```

Ranking (Cont.)

- For a given constant *n*, the ranking the function *ntile*(*n*) takes the tuples in each partition in the specified order, and divides them into *n* buckets with equal numbers of tuples.
- E.g.,

```
select ID, ntile(4) over (order by GPA desc) as quartile
from student_grades;
```


Windowing

- Used to smooth out random variations.
- E.g., moving average: "Given sales values for each date, calculate for each date the average of the sales on that day, the previous day, and the next day"
- Window specification in SQL:
  - Given relation *sales(date, value)*

```
select date, sum(value) over
    (order by date between rows 1 preceding and 1 following)
from sales
```


Windowing

- Examples of other window specifications:
  - between rows unbounded preceding and current
  - rows unbounded preceding
  - range between 10 preceding and current row
    - All rows with values between current row value –10 to current value
  - range interval 10 day preceding
    - Not including current row

Windowing (Cont.)

- Can do windowing within partitions
- E.g., Given a relation *transaction* (*account_number, date_time, value*), where value is positive for a deposit and negative for a withdrawal
  - "Find total balance of each account after each transaction on the account"

```
select account_number, date_time,
  sum (value) over
      (partition by account_number
      order by date_time
      rows unbounded preceding)
  as balance
from transaction
order by account_number, date_time
```


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*

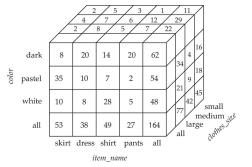
clothes_size **all**

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.

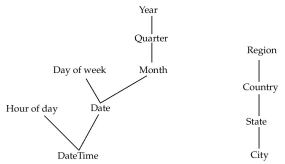
Data Cube

- 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



Hierarchies on Dimensions

- Hierarchy on dimension attributes: lets dimensions to be viewed at different levels of detail
  - E.g., the dimension DateTime can be used to aggregate by hour of day, date, day of week, month, quarter or year



a) Time Hierarchy

b) Location Hierarchy

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*	*color*				
		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.

Online Analytical Processing Operations

- Relational representation of cross-tab that we saw earlier, but with *null* in place of all, can be computed by

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

- The function grouping() can be applied on an attribute
  - Returns 1 if the value is a null value representing all, and returns 0 in all other cases.

```
select item_name, color, size, sum(number),
grouping(item_name) as item_name_flag,
grouping(color) as color_flag,
grouping(size) as size_flag,
from sales
group by cube(item_name, color, size)
```


Online Analytical Processing Operations

- Can use the function decode() in the select clause to replace such nulls by a value such as all
  - E.g., replace *item_name* in first query by
    decode(grouping(item_name), 1, 'all', *item_name*)

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

OLAP Implementation

- The earliest OLAP systems used multidimensional arrays in memory to store data cubes, and are referred to as multidimensional OLAP (MOLAP) systems.
- OLAP implementations using only relational database features are called relational OLAP (ROLAP) systems
- Hybrid systems, which store some summaries in memory and store the base data and other summaries in a relational database, are called hybrid OLAP (HOLAP) systems.

OLAP Implementation (Cont.)

- Early OLAP systems precomputed *all* possible aggregates in order to provide online response
  - Space and time requirements for doing so can be very high
    - 2^n combinations of group by
  - It suffices to precompute some aggregates, and compute others on demand from one of the precomputed aggregates
    - Can compute aggregate on (*item_name, color*) from an aggregate on (*item_name, color, size*)
      - For all but a few "non-decomposable" aggregates such as *median*
      - is cheaper than computing it from scratch
- Several optimizations available for computing multiple aggregates
  - Can compute aggregate on (*item_name, color*) from an aggregate on (*item_name, color, size*)
  - Can compute aggregates on (*item_name, color, size*), (*item_name, color*) and (*item_name*) using a single sorting of the base data

End of Chapter 5