Chapter 5: Advanced SQL

Database System Concepts, 7th Ed.

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

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

- 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

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 (select which database to use)
  - 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 ….
   }
  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 ("oracle.jdbc.driver.OracleDriver");
       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);
  }
}
```

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));
}
```

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();
```
- Each time the query is executed (with new values to replace the “?”s), the database system can reuse the previously compiled form of the query and apply the new values.
- 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 statement internally uses:
  "select * from instructor where name = 'X\' or \'Y\' = \'Y'
  - **Always use prepared statements, with user inputs as parameters**

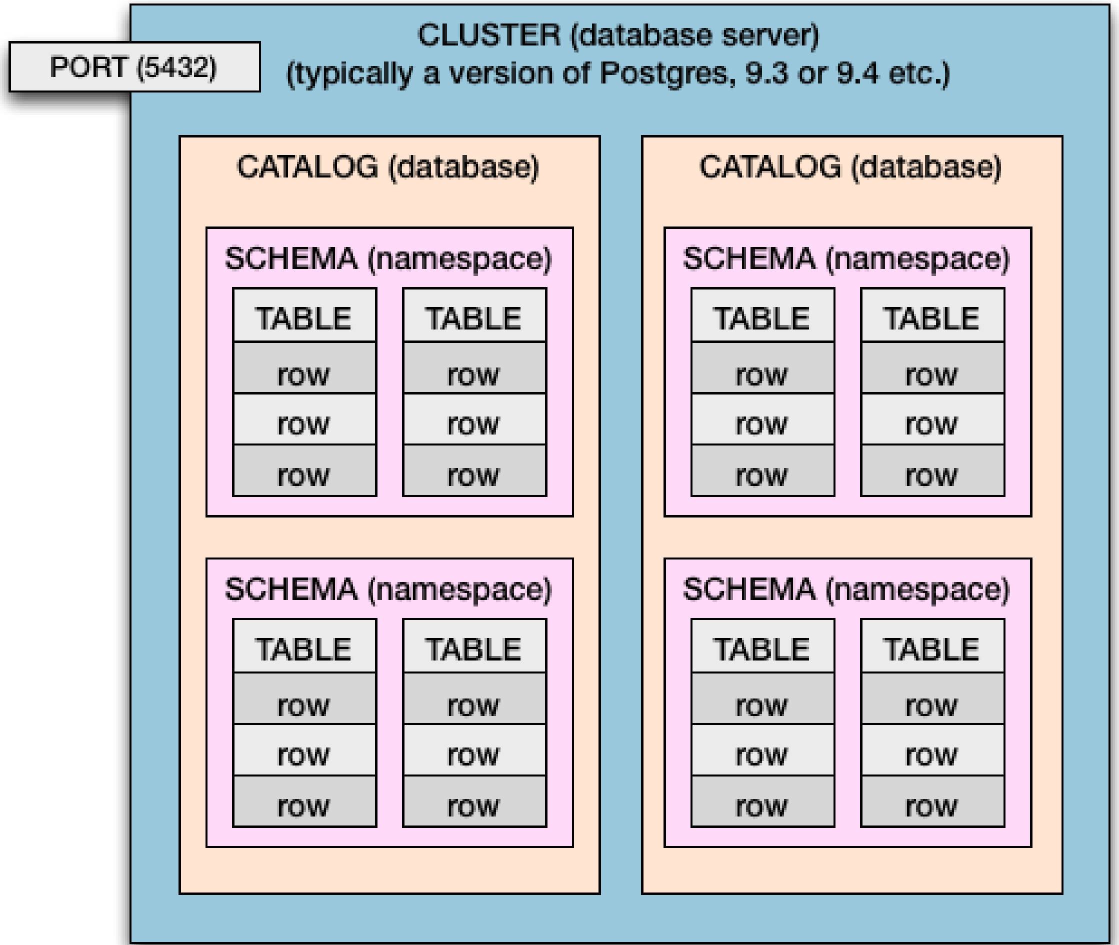
Metadata Features

- Java application program does not include declarations for data stored in the database (i.e., those SQL DDL statements).
- Therefore, a Java program that uses JDBC determine that information directly from the database system at runtime.
- ResultSet metadata
  - Recall that when we submit a query using the executeQuery method, the result of the query is contained in a ResultSet object.
- 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));          attribute name
    System.out.println(rsmd.getColumnTypeName(i));      data type of attribute
}
```

- How is this useful?
  - In this way, we can execute a query even if we have no idea of the schema of the result.

Metadata



Source: https://ithelp.ithome.com.tw/articles/10217068

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 provides a complete dynamic SQL interface from Java to relational databases. It 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) 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 fills a complementary role for static SQL. It can check your program for errors at translation-time rather than at run-time.
    ```

ODBC

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

- 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

- 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.

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 integer
begin
        declare d_count  integer;
                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 than 12 instructors.

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

Table Functions

- 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_count_proc.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);
```

SQL Procedures (Cont.)

- Procedures and functions can be invoked also from dynamic SQL.
- SQL allows more than one procedure of the 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

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'
```

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

Triggers

- Motivation
  - Assertions are powerful, but the database system often cannot tell when they need to be checked.
  - Attribute- and tuple-based checks are checked at known times but are not powerful.
  - Triggers let the user decide when to check for a powerful condition.
- 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

Ex., 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;
```

Event

Condition

Action

Event-Condition-Action Rules

- **Event:** Typically, a type of database modification.
  - The **after** can be **before**. Use **instead of** if the relation is a view.
  - Triggering event can be **insert**, **delete** or **update**. The **update** can be **update of** ... **on** a particular attribute.
- **Condition:** Any SQL Boolean-valued expression.
  - Any Boolean-valued condition is appropriate.
  - It is evaluated before or after the triggering event, depending on whether **before** or **after** is used in the event.
  - Access the new/old tuple or set of tuples through the names declared in the **referencing** clause.
- **Action:** Any SQL statements.
  - The **begin atomic** ... **end** clause can serve to collect multiple SQL statements into a single compound statement.
  - Queries make no sense in an action, so we are really limited to modifications.

Triggering Events and Actions in SQL

- Triggers on update can be restricted to specific attributes
  - For example, **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. For example, 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;
```

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

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 (an infinite chain of triggering)

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

Advanced Aggregation Features

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

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

- 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

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,* ***avg***(*value*) **over**
    (**order by** *date* **between rows** 1 **preceding and** 1 **following**)
    from *sales*

End of Chapter 5