# Chapter 5: Advanced SQL

Database System Concepts, 7th Ed.

# Outline

Python / Java / C

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

# 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.

# Connector/Python

# MySQL connector/python

- Connect to mysql server using python

>>> import mysql.connector ## import the connector module

>>> myconnect=mysql.connector.connect(host='localhost',

database='mysql', data manged in database

user='root',

object: space to keep a table

password='mypassword')

connection

buffered there in the main memory

>>> mycursor=myconnect.cursor(buffered=True) but not lost

specific passport.

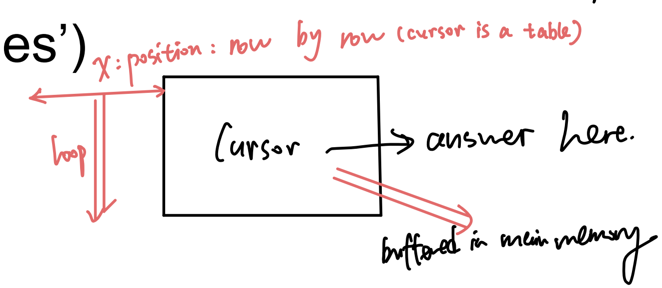
Command to tell server

>>>mycursor.execute('show databases')

Print out the result

>>>for x in mycursor:

print(x)




>>>mycursor.close()

No nail biting

>>>myconnect.close()

query here

# Run Python to connect MySQL (cont.)

DB logi

```
>>> connection = mysql.connector.connect(host='localhost',
                                     database='university',      ## can omit
                                     user='root',
                                     password='mypassword')
```

variable in Python

```
>>> p1='history'
>>> cursorA = connection.cursor(buffered=True)
```

Business logic

```
>>> cursorA.execute("select * from university.department where name = %s" ,(p1,))
>>> for x in cursorA:
                print(x)
```

print out results

```
>>>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)
```

salary/12

maybe transfered into monthly salary.

# 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

2.
```
>>> connection = mysql.connector.connect(host='localhost',
                    database='university',      ## can omit
                    user='root',
                    password='mypassword')
```

in Python

3.
```
>>> cursorA = connection.cursor(buffered=True)
```

4.
```
>>> cursorA.execute("select * from university.department where name = %s" ,(p1,))
```

5.
```
>>> for x in cursorA:
        print(x)
```

Print out results

6.
```
>>>cursorA.close()      ## release the memory space
>>>cursorB.close()
>>>myconnect.close()    ## close the connection with MySQL server
```

# **JDBC**(skipped)

# 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

```java
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 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();
```

# **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.

return's type

```
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
```

function name

SQL Procedure, not in sd. SQL

more safe compared to procedure, because only read data but not update

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

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

function like "print" in Python

find

from target

condition

select dept_count("history");

- **Show function status**
  - List all functions

return table — allow in sd. SQL

— Not allow in MySQL

# 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
```

Not encourage to use
not safe in sec for
data

system don't know
read or update, too free, not safe.

- 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);
```

→ declare int types;

Select 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*<br>
  **then** *statement or compound statement*<br>
  **elseif** *boolean expression*<br>
  **then** *statement or compound statement*<br>
  **else** *statement or compound statement*<br>
  **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

Some events may cause some functions

# 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

# 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.

we are creating trigger — name

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

one by one — Condition — Action — space, because it is not null

- Other actions
  **after update on**, **after delete on**, **before insert on**, **before update on**, **before delete on**

  after/before update/delete/insert 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* don't want anymore
- **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;
```

update another table

add additional credits

trigger makes things complicated when trigger is too many

If not compulsory, don't use it.

# 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

# 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*;

儿子 之 父    父 之 子

$\bowtie$ $\bowtie$ $\bowtie$ .... no changes

final Union $\emptyset$

This example view, *rec_prereq,* is called the *transitive closure* of the *prereq* relation

E4-3052-3056

prereq( course_id, prerequis_id )

① initial rec_prereq = prereq

② rec_prereq $\bowtie$ prereqs
rec_prereqs.prerequis_id = prereq.course_id

③ until the table remains constant

# 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 |

# Advanced Aggregation Features (skipped)

# 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 (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**

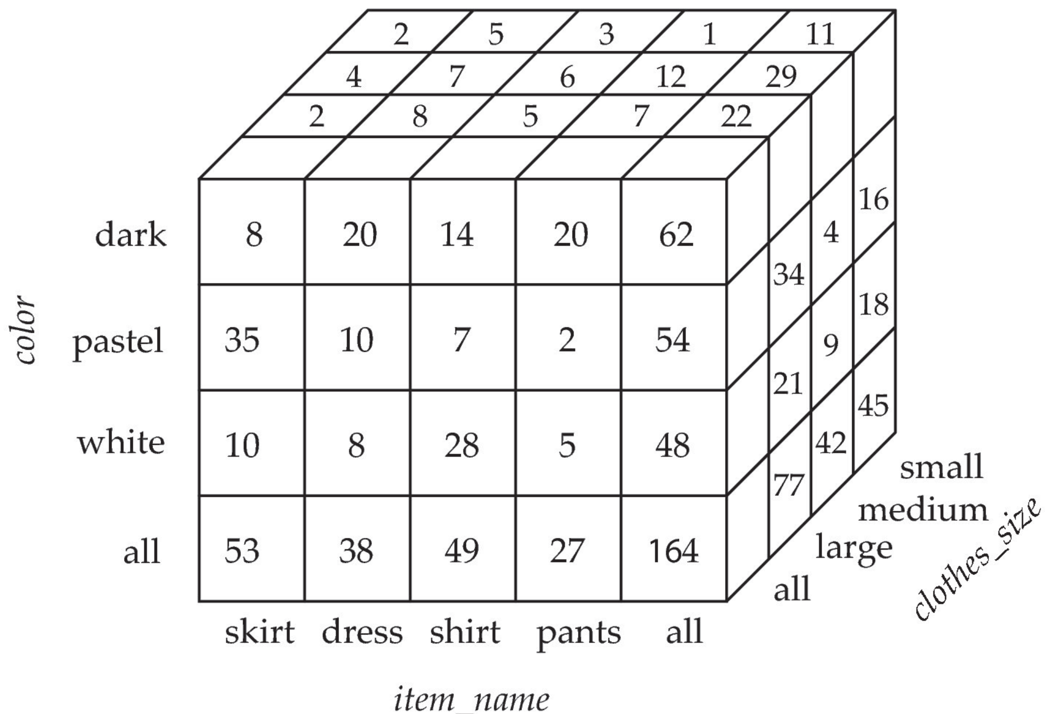
*color*

| *item_name* | 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.

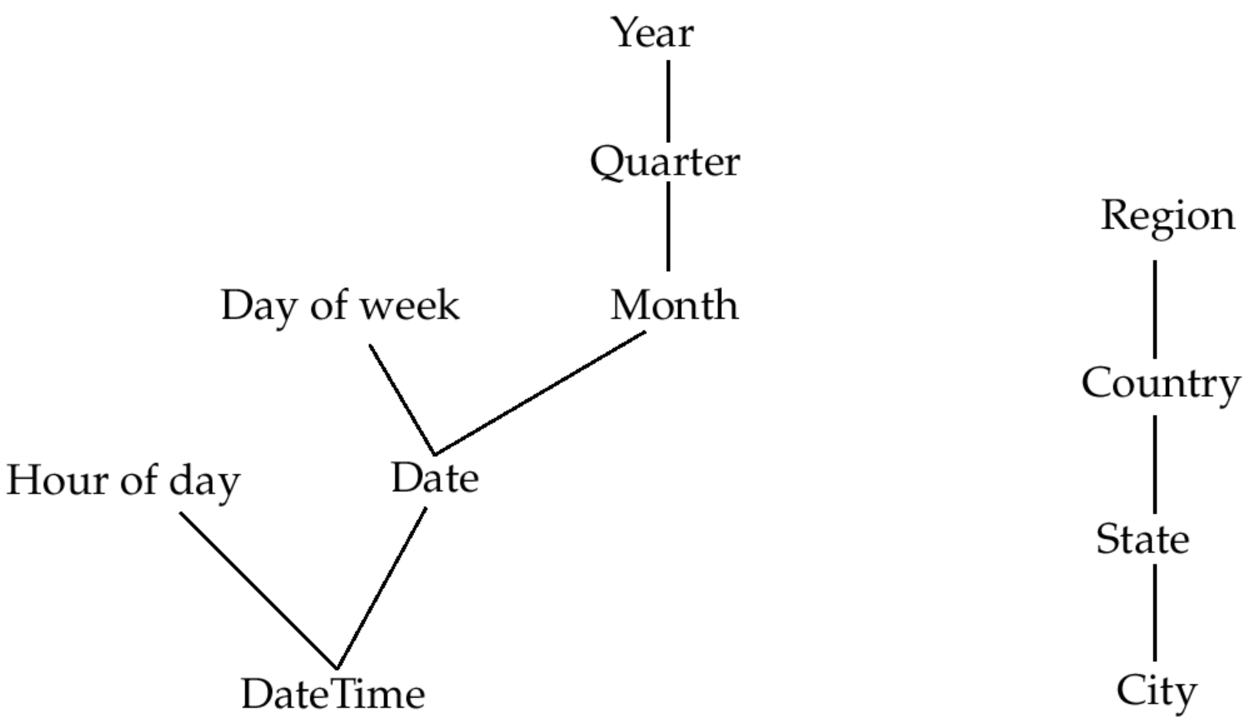
# Data Cube

- 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