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 (Cont.)

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.
  - The dynamic SQL component of SQL allows programs to construct and submit SQL queries at runtime.
  - Enables flexible applications.
  - less efficient since access plans for dynamic statements are generated at run-time. **(even if they are created using the prepared statement feature).**
  - More security risks.
- Embedded SQL (static) -- 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.
  - Cannot change at run-time. Less flexible. Hard to debug..
  - More efficient execution.
  - More secure

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
  - 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

- some values are replaced by “?”, actual values will be provided later. The database system compiles the query when it is prepared.
- Primary advantage:: **Compile one, execute multiple times** with different input parameters
- PreparedStatement pStmt = conn.prepareStatement(
  "insert into instructor values(?,?,?,?)");

  // No execution yet..Only generate access plan.

```
pStmt.setString(1, "88877");
pStmt.setString(2, "Perry");
pStmt.setString(3, "Finance");
pStmt.setInt(4, 125000);
pStmt.executeUpdate();
pStmt.setString(1, "88878");
pStmt.executeUpdate();     // execute !!
```

- 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”? ==> Need prepared statement!!

SQL Injection

Even **Compile one, execute only 1 time. ==> use prepared statement for security!!**

- Suppose query is constructed using
  - "select * from instructor where name = '" + name + "'"

Application!!

- 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; --** + *name* + "'"

Inject another SQL!!

- Prepared stament internally uses:
  "select * from instructor where name = 'X\' or **\'Y\' = \'Y'** **'Y' = 'Y** **false!**
  - **Always use prepared statements, with user inputs as parameters.**

- **there have been a number of attacks in the real world using SQL injections; attacks on multiple financial sites have resulted in theft of large amounts of money by using SQL injection attacks.!!**

Metadata Features

- ResultSet metadata::: the number of columns in the result, the name of a specified column, or the type of a specified column.
- 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?
  - Enable to application more generic, search all cases..
  - code can work regardless of the actual query submitted.
    ```

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 all names
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?

- The metadata information can be used to make code used for applications generic:

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 ?? Why bad idea??
- 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:: the same role for functions a
  nd procedures as prepareStatement does for queries.
  - 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. **These objects hold only logical pointers to the actual large object in the database.**

  - 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

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
```

Embedded DBs

- access to the database through the application itself. NOT client-server architecture..
  - Java DB, SQLite, HSQLBD, embedded version of MySQL.
  - F.e. Derby has a small footprint -- about 3.5 megabytes for the base engine and embedded JDBC driver.
- lacks many of the features of full server-based database systems,

Functions and Procedures

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 that 12 instructors.

select t *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'))
```

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
```

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 (use of VM, no pointers..) 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

- 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

Trigger to Maintain credits_earned value

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

Statement Level Triggers

- Instead of executing a separate action for each affected row, a single action can be executed for all rows affected by a transaction
  - Use **for each statement** instead of **for each row**
  - Use **referencing old table** or **referencing new table** to refer to temporary tables (called ***transition tables***) containing the affected rows
  - Can be more efficient when dealing with SQL statements that update a large number of rows

When Not To Use Triggers

- **How about "on delete cascade" feature of a foreign-key constraint by using a trigger?**
- 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
    - Section_registration(course id, sec id, semester, year, total students) is an Mat View example.
      DB automatically updates data in the view. No need to write Triggers.
  - 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 ==> Do not execute trigger again
  - 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

Recommend to study

https://www.postgresqltutorial.com/

https://pgexercises.com/

Recursion in SQL

- SQL:1999 permits recursive view definition
- transitive closure examples:
  - organizations typically consist of several levels of organizational units...,
  - Machines consist of parts that in turn have subparts …,
  - flights(to, from) cities can be reached from which other cities by a direct flight,..
  - courses and prerequsites..***prereq (course_id*, *prereq_id)***
- 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;
```

Base query: Non-recursive part

recursive part use recursive view

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

- **How to find the prerequisites of a specific course, such as CS-347 ?**
  - **Put a selection (where clause) in outer or inner base query?**

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

- Computing transitive closure using iteration, adding successive tuples to *rec_prereq*
- 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.

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

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. Obviously !!
    - 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

Recommend to study

https://www.postgresqltutorial.com/

https://pgexercises.com/

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
    - Thus it will result 1,1,2,

Ranking

- Ranking can be done using basic SQL aggregation, but resultant query is much more inefficient as opposed to system impl of rank

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*;

Say we have 100 students, the smallest GPA results 99+1 rank value.

Ranking (Cont.)

- Ranking can be done within partition of the data.
- We have **dept grades(ID,dept_name, GPA)**
- "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.
  - F.e. We can obtain the overall rank and the rank within the department by using two rank operations in the same select clause.
- Ranking is done *after* applying **group by** clause/aggregation
- Ranking can be used to find **top-n results**
  - **limit** *n* clause supported by many databases with different meanings, <u>moreover</u> top-n within each partition is NOT possible with **limit n** operation
  - Ranking allows top-n within each partition

select *
from (select ID, rank() over (order by (GPA) desc) as s_rank from student_grades)
where s_rank <= 5;

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 as much as possible.
  - particularly useful for constructing histograms based on percentiles.
- E.g.,

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

  We will have 4 buckets with equal sizes, i.e. different GPA ranges but with same num of tuples at each bucket.

Exercise::

https://www.postgresqltutorial.com/postgresql-window-function/postgresql-ntile-function/

Windowing

- Useful for trend analysis.
- **Used to smooth out random variations.**:fluctuate widely from day to day, however, over a sufficiently long period of time, fluctuations might be less ! (dont miss big picture)
- 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
```

Not for a specific date. But whole dates..Not easy to write with classic SQL

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)
  - Common ops: Cross-tab (w/ pivoting), slicing, rollup, drilldown
- 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
  - We have a relation ***sales*(*item_name, color, clothes_size, quantity*)**
    - a shop wants to find out what kinds of clothes are popular.

Example sales relation & pivoting

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
...	...	...	...
...	...	...	...

values

select *
from sales
pivot (
sum(quantity)
for color in
('dark','pastel', 'white')
)

Values of pivot attr("color") become attributes

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

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

clothes_size **all**

Pivot attr.

color

This is NOT relation.

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

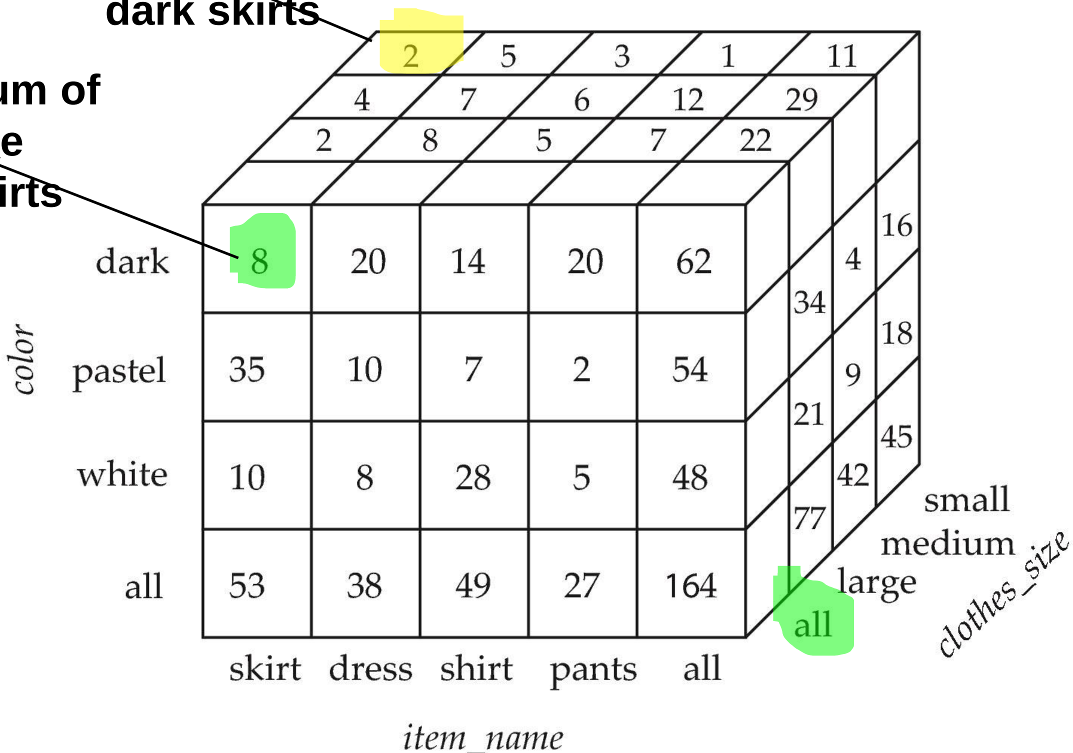
- The table above is an example of a **cross-tabulation** (**cross-tab**), also referred to as a **pivot-table**.
  - Values for one of the dimension attributes form the row headers
  - Values for another dimension attribute form the column headers
  - Other dimension attributes are listed on top **--> pivot attribute(s)**
  - Values in individual cells are (aggregates of) the values of the dimension attributes that specify the cell.
  - **Do we infer "num of <u>large</u> <u>skirts</u>" from this table?**

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
- The size of a cube for *n* attributes $A_1,...,A_n$ with cardinalities $|A_1|,...,|A_n|$ is $\pi|A_i|$. This size increases **exponentially with the number of attributes and linearly with the cardinalities of those attributes.**

Total num of small-size dark skirts

Total num of ALL-size dark skirts



Each cell holds the agg_val (sum, avg..) that specific combination of values occurs together in the database.

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

- We need **multiple group by queries to be run in a single query**!
- 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*)

- restricted groupings, more controlled way.
  - **S ..F.** group by **grouping sets** ((color, clothes size), (clothes size, item name));
- 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 including the empty prefix.
- 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 = ***Rollup*** or ***summarization*** of the data cube, can be done by traversing upwards
- **Drill down**: The opposite operation - that of moving from coarser-granularity data to finer-granularity data

- **Study the test case for rollup & drill down @ following::: http://www2.cs.uregina.ca/~dbd/cs831/notes/dcubes/dcubes.html**

- **https://www.javatpoint.com/olap-operations**

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