



Chapter 5: Advanced SQL

Database System Concepts, 7th Ed.

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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
- 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
 - 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.isNull()) 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 statement internally uses:
"select * from instructor where name = 'X\' or \'Y\' = \'Y'"
 - **Always use prepared statements, with user inputs as parameters**



Metadata Features

- ResultSet metadata
- E.g. after executing query to get a ResultSet rs:
 - ```
ResultSetMetaData rsmd = rs.getMetaData();
for(int i = 1; i <= rsmd.getColumnCount(); i++) {
 System.out.println(rsmd.getColumnName(i));
 System.out.println(rsmd.getColumnTypeName(i));
}
```
- How is this useful?



# Metadata (Cont)

- Database metadata
- `DatabaseMetaData dbmd = conn.getMetaData();`
  - // Arguments to `getColumns`: Catalog, Schema-pattern, Table-pattern, and Column-Pattern
  - // Returns: One row for each column; row has a number of attributes such as `COLUMN_NAME`, `TYPE_NAME`
  - // The value `null` indicates all Catalogs/Schemas.
  - // The value `""` indicates current catalog/schema
  - // The value `"%"` has the same meaning as SQL **like** clause

```
ResultSet rs = dbmd.getColumns(null, "univdb", "department", "%");
while(rs.next()) {
 System.out.println(rs.getString("COLUMN_NAME"),
 rs.getString("TYPE_NAME"));
}
```
- And where is this useful?



# Metadata (Cont)

- Database metadata
- `DatabaseMetaData dbmd = conn.getMetaData();`
  - // Arguments to `getTables`: Catalog, Schema-pattern, Table-pattern, // and Table-Type
  - // Returns: One row for each table; row has a number of attributes // such as `TABLE_NAME`, `TABLE_CAT`, `TABLE_TYPE`, ..
  - // The value null indicates all Catalogs/Schemas.
  - // The value "" indicates current catalog/schema
  - // The value "%" has the same meaning as SQL **like** clause
  - // The last attribute is an array of types of tables to return.
  - // TABLE means only regular tables

```
ResultSet rs = dbmd.getTables ("", "", "%", new String[] {"TABLES"});
while(rs.next()) {
 System.out.println(rs.getString("TABLE_NAME"));
}
```
- And where is this useful?





# Finding Primary Keys

- DatabaseMetaData dmd = connection.getMetaData();

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

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



# Transaction Control in JDBC

- By default, each SQL statement is treated as a separate transaction that is committed automatically
  - bad idea for transactions with multiple updates
- Can turn off automatic commit on a connection
  - `conn.setAutoCommit(false);`
- Transactions must then be committed or rolled back explicitly
  - `conn.commit();`    or
  - `conn.rollback();`
- `conn.setAutoCommit(true)` turns on automatic commit.



# Other JDBC Features

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



# JDBC Resources

- JDBC Basics Tutorial
  - <https://docs.oracle.com/javase/tutorial/jdbc/index.html>



# SQLJ

- JDBC is overly dynamic, errors cannot be caught by compiler
- SQLJ: embedded SQL in Java

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



ODBC



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 language
 - 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'))



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, 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* \neq '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

- 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_rereq, 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



Example of Fixed-Point Computation

<i>course_id</i>	<i>prereq_id</i>
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

<i>Iteration Number</i>	<i>Tuples in c1</i>
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



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

<i>item_name</i>	<i>color</i>	<i>clothes_size</i>	<i>quantity</i>
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	4

...

... ...



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

clothes_size **all**

		<i>color</i>			
		dark	pastel	white	total
<i>item_name</i>	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

The diagram illustrates a 3D data cube with three dimensions: *color*, *item_name*, and *clothes_size*. The *color* dimension has categories: dark, pastel, white, and all. The *item_name* dimension has categories: skirt, dress, shirt, pants, and all. The *clothes_size* dimension has categories: small, medium, large, and all. The top face of the cube shows the counts for each combination of *color* and *item_name*. The right face shows counts for each combination of *color* and *clothes_size*. The bottom face shows counts for each combination of *item_name* and *clothes_size*.

		item_name					all
		skirt	dress	shirt	pants	all	
color	dark	8	20	14	20	62	16
	pastel	35	10	7	2	54	18
	white	10	8	28	5	48	45
	all	53	38	49	27	164	77



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**

		<i>color</i>				
<i>category</i>	<i>item_name</i>	dark	pastel	white	total	
womenswear	skirt	8	8	10	53	88
	dress	20	20	5	35	
	subtotal	28	28	15		
menswear	pants	14	14	28	49	76
	shirt	20	20	5	27	
	subtotal	34	34	33		
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.

<i>item_name</i>	<i>color</i>	<i>clothes_size</i>	<i>quantity</i>
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

$$\{item\_name, ()\} \times \{(color, size), (color), ()\}$$
$$= \{ (item\_name, color, size), (item\_name, color), (item\_name), (color, size), (color), () \}$$



# 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