Chapter 5: Advanced SQL

- Accessing SQL From a Programming Language
- Functions and Procedural Constructs
- Triggers
- Recursive Queries
- Advanced Aggregation Features
- OLAP

Accessing SQL From a Programming Language

Accessing SQL From a Programming Language

- API (application-program interface) for a program to interact with a database server
- Application makes calls to
  - Connect with the database server
  - Send SQL commands to the database server
  - Fetch tuples of result one-by-one into program variables
- Various tools:
  - JDBC (Java Database Connectivity) works with Java
  - ODBC (Open Database Connectivity) works with C, C++, C#, and Visual Basic. Other API's such as ADO.NET sit on top of ODBC
  - Embedded SQL

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

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, and
    - check for errors
- 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, Java, and Cobol.
- 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/I.
- **EXEC SQL** statement is used to identify embedded SQL request to the preprocessor

  EXEC SQL <embedded SQL statement > END_EXEC

  Note: this varies by language (for example, the 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.

Extensions to SQL

Procedural Extensions and Stored Procedures

- SQL provides a **module** language
  - Permits definition of procedures in SQL, with if-then-else statements, for and while loops, etc.
- Stored Procedures
  - Can store procedures in the database
  - then execute them using the **call** statement
  - permit external applications to operate on the database without knowing about internal details
- Example: putObjectInShoppingCart() in e-commerce app
- Object-oriented aspects of these features are covered in Chapter 22 (Object Based Databases)

Functions and Procedures

- SQL:1999 supports functions and procedures
  - Functions/procedures can be written in SQL itself, or in an external programming language.
  - Functions are particularly useful with specialized data types such as images and geometric objects.
    - Example: functions to check if polygons overlap, compute distance between points, or compare images for similarity.
  - Some database systems support **table-valued functions**, which can return a relation as a result.
- SQL:1999 also supports a rich set of imperative constructs, including
  - Loops, if-then-else, assignment
- Many databases have proprietary procedural extensions to SQL that differ from SQL:1999.

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
```

- Find the department name and budget of all departments with more that 12 instructors.

```
select dept_name, budget
from department
where dept_count (dept_name ) > 1
```

SQL functions (Cont.)

- Compound statement: **begin … end**
  - May contain multiple SQL statements between **begin** and **end**.
- **returns** -- indicates the variable-type that is returned (e.g., integer)
- **return --** specifies the values that are to be returned as result of invoking the function
- SQL function are in fact parameterized views that generalize the regular notion of views by allowing parameters.

Table Functions

- SQL:2003 added functions that return a relation as a result
- Example: Return all accounts owned by a given customer

```
create function instructors_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 = instructors_of.dept_name)
```

- Usage

```
        select *
        from table (instructors_of ( 'Music' ))
```

SQL Procedures

- The *dept_count* function could instead be written as procedure:

  create procedure *dept_count_proc* (**in** *dept_name* **varchar**(20),
  out *d_count* **integer)**
  begin
  select count(*\) **into** *d_count*
  from *instructor*
  where *instructor.dept_name = dept_count_proc.dept_name*
  end

- 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*);

  Procedures and functions can be invoked also from dynamic SQL

- SQL:1999 allows more than one function/procedure of the same name (called name **overloading**), as long as the number of arguments differ, or at least the types of the arguments differ

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

Procedural Constructs (Cont.)

- **For** loop
  - Permits iteration over all results of a query
  - Example:

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

Procedural Constructs (cont.)

- Conditional statements (**if-then-else**)
  SQL:1999 also supports a **case** statement similar to C case statement
- Example procedure: registers student after ensuring classroom capacity is not exceeded
  - Returns 0 on success and -1 if capacity is exceeded
  - See book 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
  …
  .. **signal** *out_of_classroom_seats*
  end

  - The handler here is **exit** -- causes enclosing **begin..end** to be exited
  - Other actions possible on exception

External Language Functions/Procedures

- SQL:1999 permits the use of functions and procedures written in other languages such as C or C++
- 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
  - Use **sandbox** techniques
    - that is use a safe language like Java, which cannot be used to access/damage other parts of the database code.
  - Or, 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

- 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

Triggering Events and Actions in SQL

- Triggering event can be **insert**, **delete** or **update**
- Triggers on update can be restricted to specific attributes
  - **E.g., after update of** *takes* **on** *grade*
- Values of attributes before and after an update can be referenced
  - **referencing old row as** : for deletes and updates
  - **referencing new row as** : for inserts and updates
- Triggers can be activated before an event, which can serve as extra constraints. E.g. convert blank grades to null.

```
create trigger setnull_trigger before update of takes
referencing new row as nrow
for each row
when (nrow.grade = ' ')
 begin atomic
          set nrow.grade = null;
 end;
```

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

- 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
- 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

Note: 1st printing of 6th ed erroneously used c_prereq in place of rec_prereq in some places

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
- Computing transitive closure using iteration, adding successive tuples to *c_prereq*
  - The next slide shows a *prereq* relation
  - Each step of the iterative process constructs an extended version of *c_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 *c_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-101
CS-319	CS-101
CS-347	CS-101
EE-181	PHY-101

Iteration Number	Tuples in cl
0	
1	(CS-301)
2	(CS-301), (CS-201)
3	(CS-301), (CS-201)
4	(CS-301), (CS-201), (CS-101)
5	(CS-301), (CS-201), (CS-101)

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

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)*

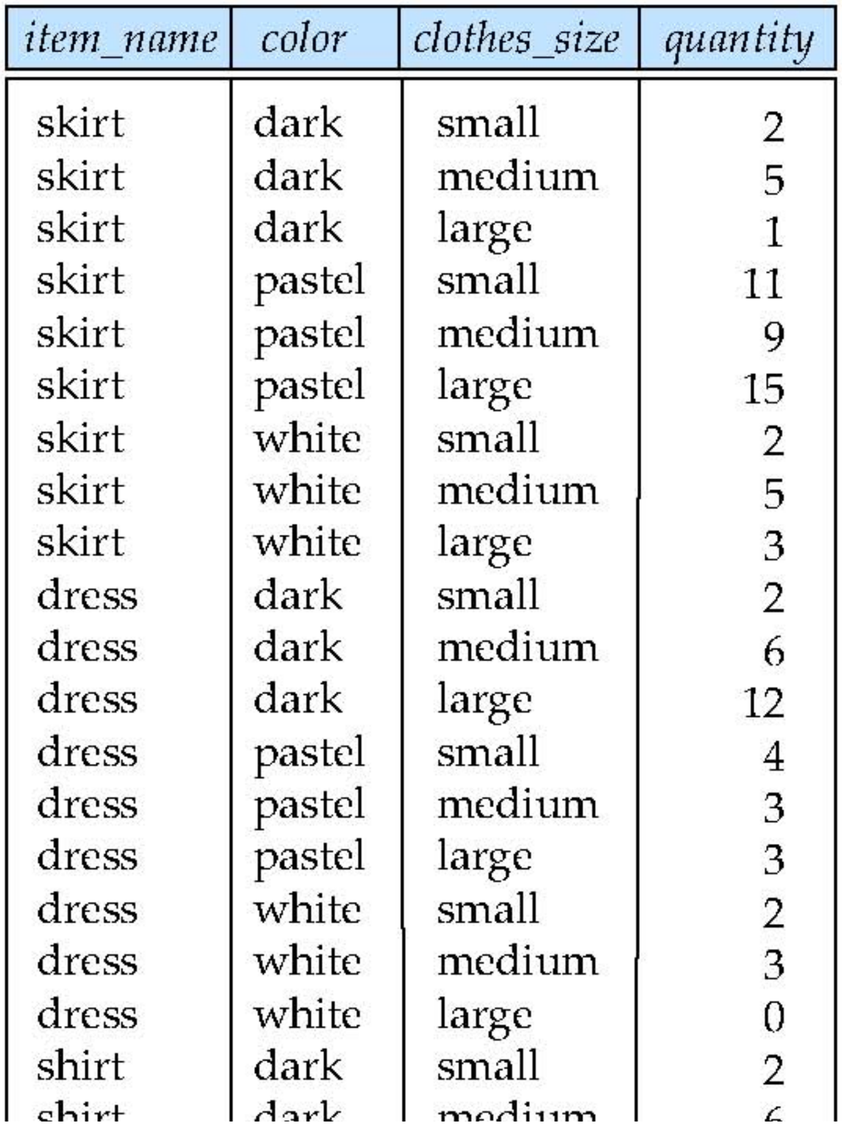
    select *date*, ***sum***(*value*) **over**
        (**order by** *date* **between rows** 1 **preceding and** 1 **following**)
    from *sales*
- Examples of other window specifications:
  - **between rows unbounded preceding and current**
  - **rows unbounded preceding**
  - **range between** 10 **preceding and current row**
    - All rows with values between current row value –10 to current value
  - **range interval** 10 **day preceding**
    - Not including current row

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., the 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**

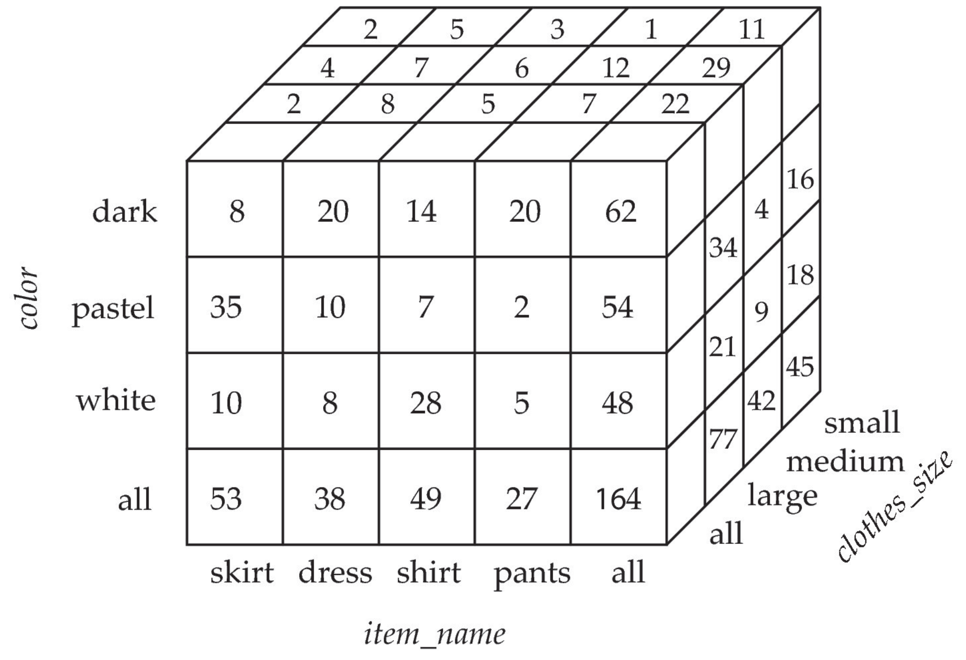
color

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.

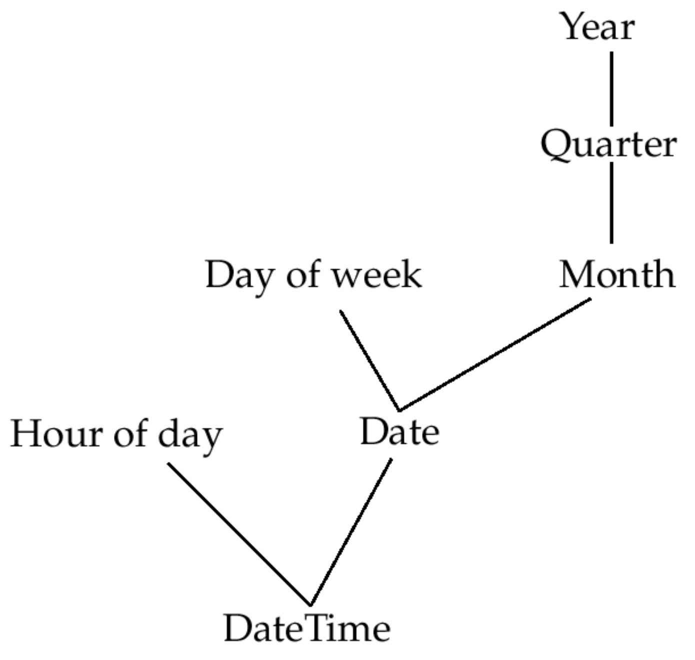
Data Cube

- 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

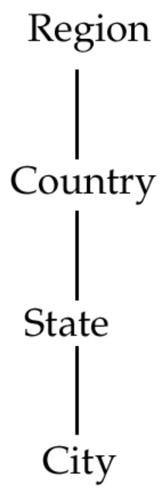


Hierarchies on Dimensions

- **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



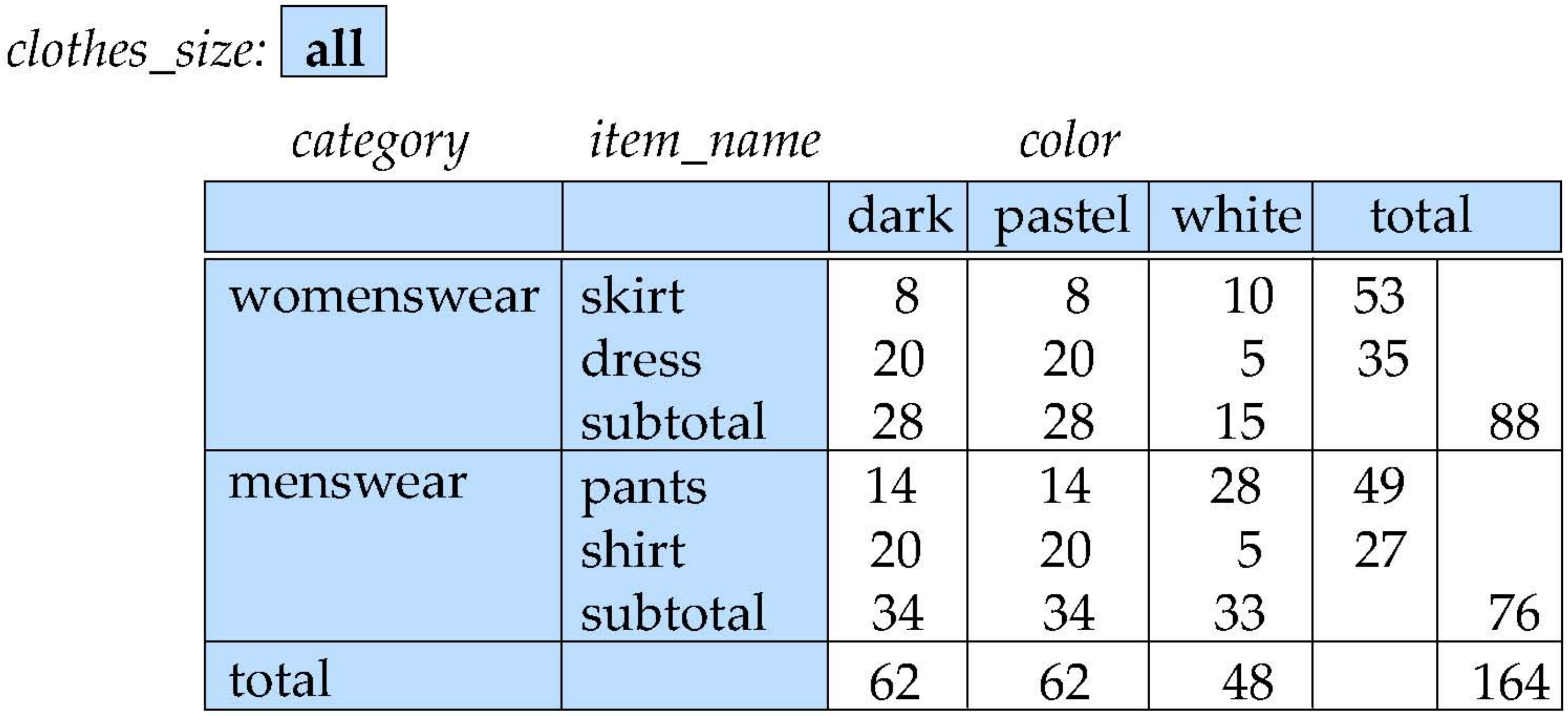
a) Time Hierarchy



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

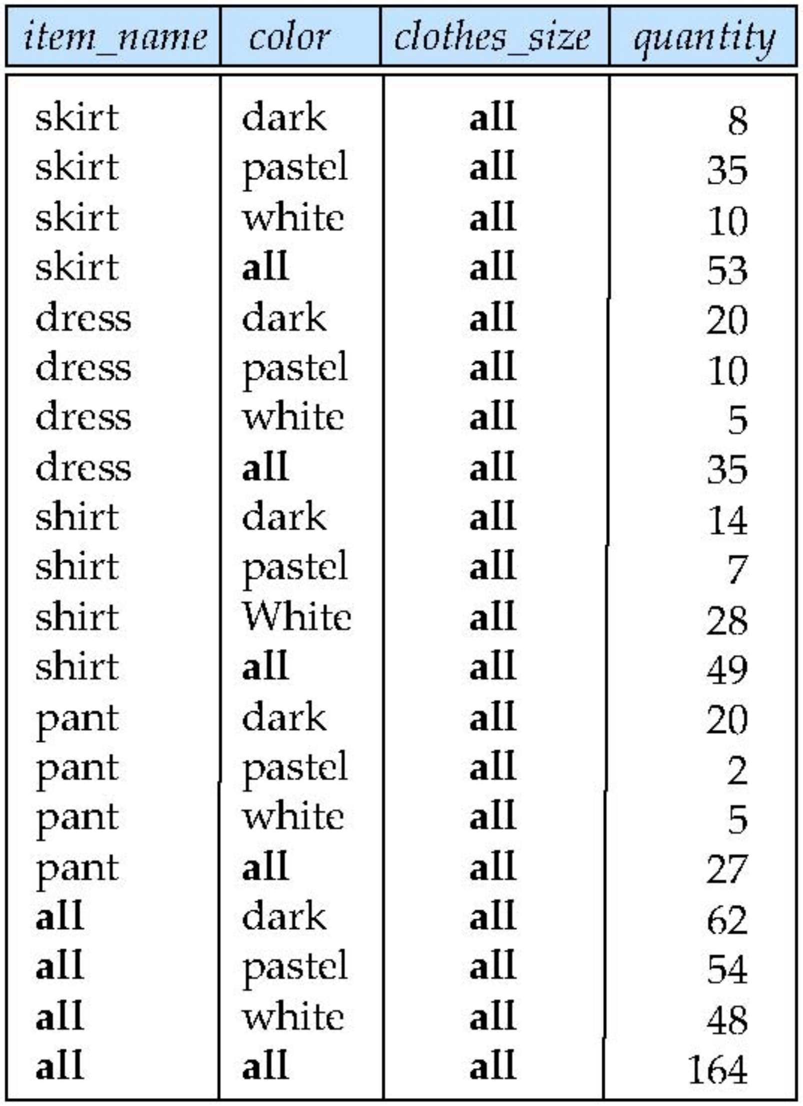


clothes_size: **all**

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

- **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.