Chapter 5: Advanced SQL

Outline

- 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.
- 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 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

Embedded SQL (Cont.)

- 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

- The variable *c* (used in the cursor declaration) is used to identify the query

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
```

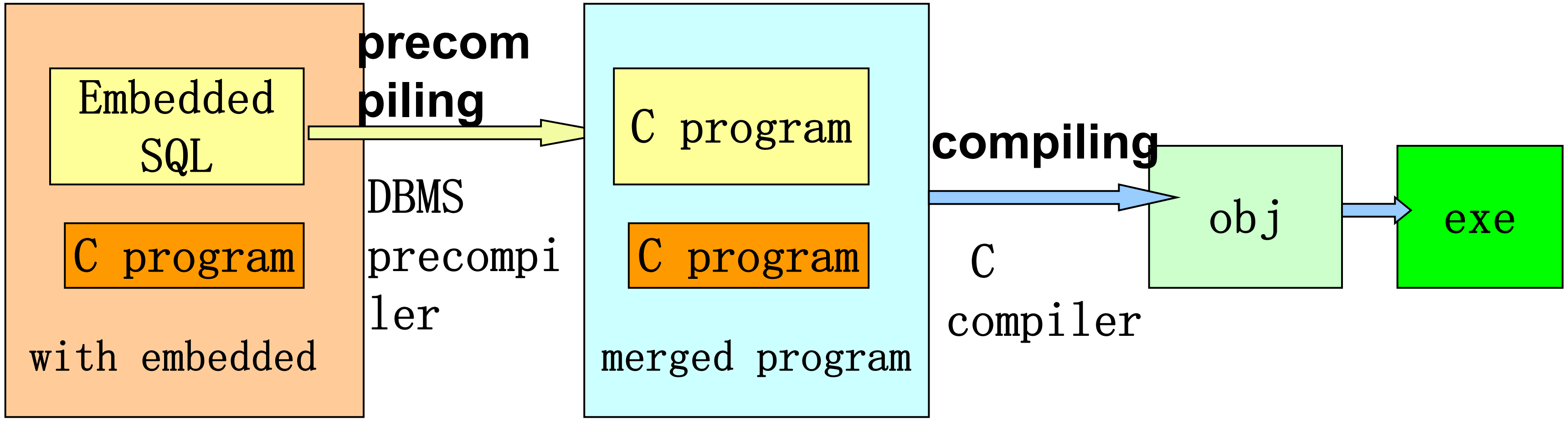

A Mini Embedded SQL example

Example: Query and print the grade of each student

```
EXEC SQL INCLUDE SQLCA;          /* (1) define SQLcommunication area */
EXEC SQL BEGIN DECLARE SECTION;        /* (2) declare main variable */
     CHAR  Sno(5);
     CHAR  Cno(3);
     INT     grade;
EXEC SQL END DECLARE SECTION;
main()
  {
   EXEC SQL DECLARE  C1  CURSOR  FOR  /* (3) cursor definition)*/
       SELECT  Sno, Cno, grade FROM SC;  /* query Sno,Cno,Grade from
                                           table SC*/
   EXEC SQL OPEN  C1;          /* (4)open cusor*/
   for(;;)
    {
     EXEC  SQL  FETCH  C1 INTO :Sno, :Cno, :Grade;
       /* (5) get tuple as store values in main variables */
     if (sqlca.sqlcode < > SUCCESS)
       /* (6) using SQLSTATE in SQLCA to  judge when to exit the loop*/
         break;
     printf(" Sno: %s, Cno: %s, Grade:%d", Sno, Cno, Grade); /*print the result
   one by one*/
    }
   EXEC SQL CLOSE C1;          /* (7) close the cusor*/
   EXEC SQL DEALLOCATE C1;  /* (8) release the cusor*/
  }
```

Embedded SQL

- How to execute embedded SQL ?
  - extend host language, make it can process SQL statements
  - Precompile, transform SQL->host language(object code)

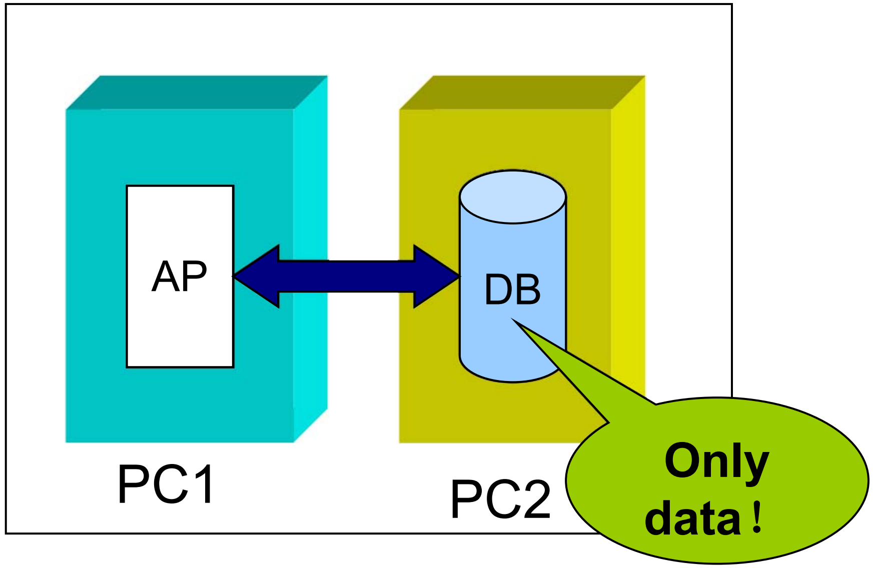


1. DBMS preprocess the source file, identifies SQL statements
2. Convert them into main language call statements so that the main language compiler can recognize them
3. he compiler of the main language compiles the whole source program into object program

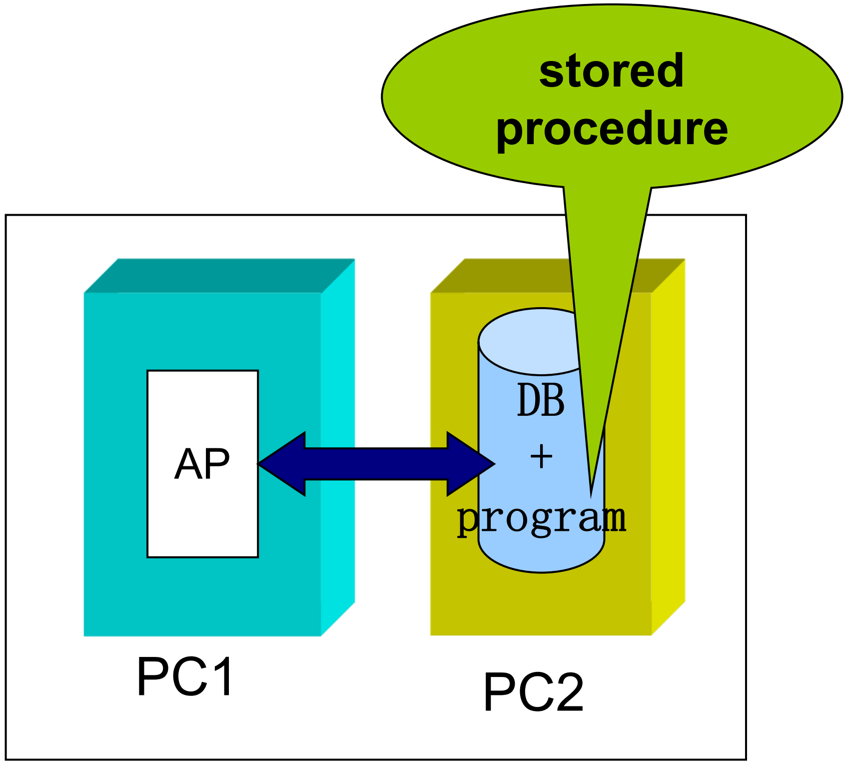
Extensions to SQL

Functions and Procedures

- SQL:1999 supports functions and procedures
  - Functions/procedures can be written in SQL itself, or in an external programming language (e.g., C, Java).
  - Functions written in an external languages are particularly useful with specialized data types such as images and geometric objects.
    - Example: functions to check if polygons overlap, or to 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.



Traditional mode



Mode with stored procedure

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

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 instructors in a given department

create function *instructor_of* (*dept_name* **char**(20))
    returns table (
        ID **varchar**(5),
        name **varchar**(20),
        dept_name **varchar**(20),
        salary **numeric**(8,2))
    return table
        (**select** *ID*, *name*, *dept_name*, *salary*
        from *instructor*
        where *instructor.dept_name* = *instructor_of.dept_name*)

- Usage

    select *
    from table (*instructor_of* ('Music'))

SQL Procedures

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

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

- 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

SQL Procedures

```
CREATE
    [DEFINER = { user | CURRENT_USER }]
  PROCEDURE sp_name ([proc_parameter[,...]])
    [characteristic ...] routine_body

proc_parameter:
    [ IN | OUT | INOUT ] param_name type

characteristic:
    COMMENT 'string'
  | LANGUAGE SQL
  | [NOT] DETERMINISTIC
  | { CONTAINS SQL | NO SQL | READS SQL DATA | MODIFIES SQL DATA }
  | SQL SECURITY { DEFINER | INVOKER }

routine_body:
    Valid SQL routine statement

[begin_label:] BEGIN
    [statement_list]
        ......
END [end_label]
```

Write Functions and Procedure in Mysql

```
delimiter $$
create procedure procedurename
(parameters)
Begin
   sequerce of  statements
end
$$
delimiter;
```

```
call  procedurename
```

```
delimiter $$
create function funcname
(parametertype)
returns types
Begin
   SQL statements;
   return parametertype;
end
$$
delimiter;
```

```
select funcname
```

Language Constructs for Procedures & Functions

- SQL supports constructs that gives it almost all the power of a general-purpose programming language.
  - Warning: most database systems implement their own variant of the standard syntax below.
- Compound statement: **begin … end**,
  - May contain multiple SQL statements between **begin** and **end**.
  - Local variables can be declared within a compound statements
- **While** and **repeat** statements:
  - **while** *boolean expression* **do**
    sequence of statements ;
    end while
  - **repeat**
    sequence of statements ;
    until *boolean expression*
    end repeat

Language Constructs (Cont.)

- **For** loop
  - Permits iteration over all results of a query
- Example: Find the budget of all departments

```
declare n integer default 0;
 for r as
       select budget from department
 do
          set n = n + r.budget
 end for
```

Language 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 (page 177) 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 Routines

- 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

- SQL:1999 allows the definition of procedures in an imperative programming language, (Java, C#, C or C++) which can be invoked from SQL queries.
- Functions defined in this fashion can be more efficient than functions defined in SQL, and computations that cannot be carried out in SQL can be executed by these functions.
- Declaring external language procedures and functions

create procedure dept_count_proc(**in** *dept_name* **varchar**(20),
 out count **integer**)
language C
external name ' /usr/avi/bin/dept_count_proc'

create function dept_count(*dept_name* **varchar**(20))
returns integer
language C
external name '/usr/avi/bin/dept_count'

External Language Routines (Cont.)

- Benefits of external language functions/procedures:
  - more efficient for many operations, and more expressive power.
- Drawbacks
  - Code to implement function may need to be loaded into database system and executed in the database system’s address space.
    - risk of accidental corruption of database structures
    - security risk, allowing users access to unauthorized data
  - There are alternatives, which give good security at the cost of potentially worse performance.
  - Direct execution in the database system’s space is used when efficiency is more important than security.

Security with External Language Routines

- To deal with security problems, we can do on of the following:
  - Use **sandbox** techniques
    - That is, use a safe language like Java, which cannot be used to access/damage other parts of the database code.
  - Run external language functions/procedures in a separate process, with no access to the database process' memory.
    - Parameters and results communicated via inter-process communication
- Both have performance overheads
- Many database systems support both above approaches as well as direct executing in database system address space.

Triggers

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

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

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

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

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

The Power of Recursion

- Computing transitive closure using iteration, adding successive tuples to *rec_prereq*
  - The next slide shows a *prereq* relation
  - Each step of the iterative process constructs an extended version of *rec_prereq* from its recursive definition.
  - The final result is called the *fixed point* of the recursive view definition.
- Recursive views are required to be **monotonic**. That is, if we add tuples to *prereq* the view *rec_prereq* contains all of the tuples it contained before, plus possibly more

Example of Fixed-Point Computation

course_id	*prereq_id*
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-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

Ranking (Cont.)

- Other ranking functions:
  - **percent_rank** (within partition, if partitioning is done)
  - **cume_dist** (cumulative distribution)
    - fraction of tuples with preceding values
  - **row_number** (non-deterministic in presence of duplicates)
- SQL:1999 permits the user to specify **nulls first** or **nulls last**

select *ID*,
        rank ( ) **over** (**order by** *GPA* **desc nulls last**) **as** *s_rank*
from *student_grades*

Ranking (Cont.)

- For a given constant *n*, the ranking the function *ntile*(*n*) takes the tuples in each partition in the specified order, and divides them into *n* buckets with equal numbers of tuples.
- E.g.,

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

Windowing

- Used to smooth out random variations.
- E.g., **moving average**: "Given sales values for each date, calculate for each date the average of the sales on that day, the previous day, and the next day"
- **Window specification** in SQL:
  - Given relation *sales(date, value)*

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

Windowing

- Examples of other window specifications:
  - **between rows unbounded preceding and current**
  - **rows unbounded preceding**
  - **range between** 10 **preceding and current row**
    - All rows with values between current row value –10 to current value
  - **range interval** 10 **day preceding**
    - Not including current row

Windowing (Cont.)

- Can do windowing within partitions
- E.g., Given a relation *transaction* (*account_number*, *date_time*, *value*), where value is positive for a deposit and negative for a withdrawal
  - "Find total balance of each account after each transaction on the account"

    select *account_number*, *date_time*,
        sum (*value*) **over**
                (**partition by** *account_number*
                order by *date_time*
                rows unbounded preceding)
       as *balance*
    from *transaction*
    order by *account_number*, *date_time*

OLAP

Data Analysis and OLAP

- **Online Analytical Processing (OLAP)**
  - Interactive analysis of data, allowing data to be summarized and viewed in different ways in an online fashion (with negligible delay)
- Data that can be modeled as dimension attributes and measure attributes are called **multidimensional data**.
  - **Measure attributes**
    - measure some value
    - can be aggregated upon
    - e.g., the attribute *number* of the *sales* relation
  - **Dimension attributes**
    - define the dimensions on which measure attributes (or aggregates thereof) are viewed
    - e.g., attributes *item_name*, *color*, and *size* of the *sales* relation

Example sales relation

item_name	*color*	*clothes_size*	*quantity*
skirt	dark	small	2
skirt	dark	medium	5
skirt	dark	large	1
skirt	pastel	small	11
skirt	pastel	medium	9
skirt	pastel	large	15
skirt	white	small	2
skirt	white	medium	5
skirt	white	large	3
dress	dark	small	2
dress	dark	medium	6
dress	dark	large	12
dress	pastel	small	4
dress	pastel	medium	3
dress	pastel	large	3
dress	white	small	2
dress	white	medium	3
dress	white	large	0
shirt	dark	small	2
shirt	dark	medium	6
...	...	...	...
...	...	...	...

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

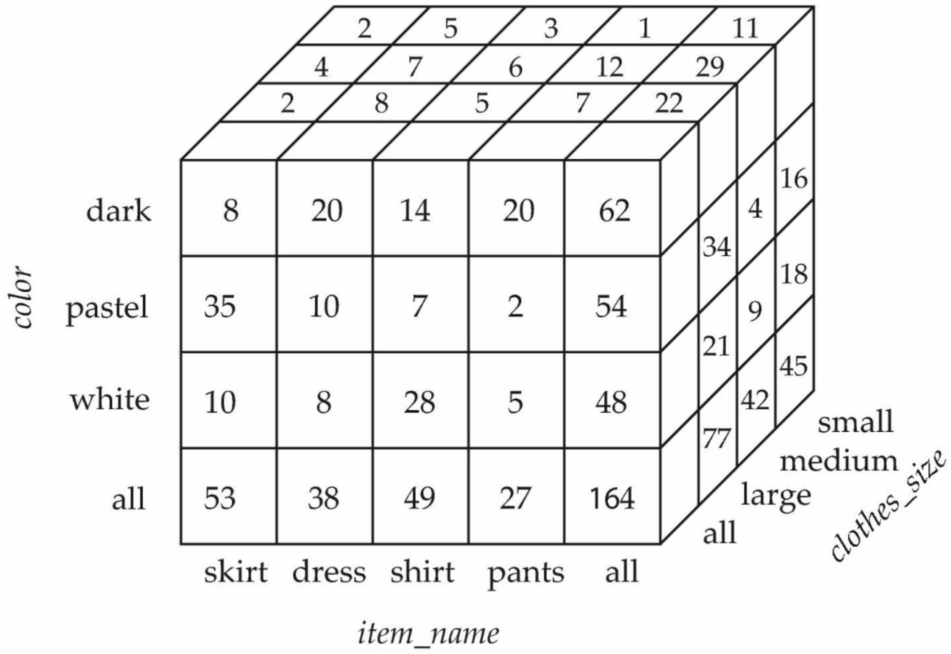
clothes_size **all**

item_name \ *color*	dark	pastel	white	total
skirt	8	35	10	53
dress	20	10	5	35
shirt	14	7	28	49
pants	20	2	5	27
total	62	54	48	164

- The table above is an example of a **cross-tabulation** (**cross-tab**), also referred to as a **pivot-table**.
  - Values for one of the dimension attributes form the row headers
  - Values for another dimension attribute form the column headers
  - Other dimension attributes are listed on top
  - Values in individual cells are (aggregates of) the values of the dimension attributes that specify the cell.

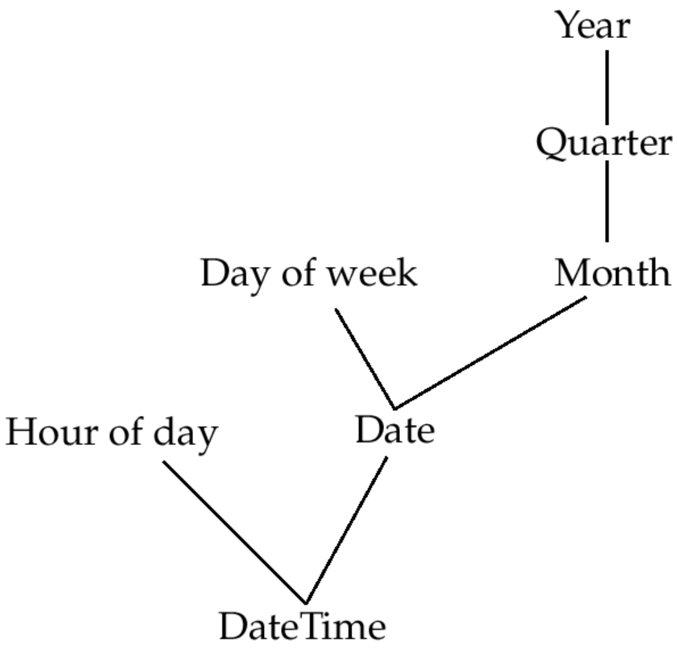
Data Cube

- A **data cube** is a multidimensional generalization of a cross-tab
- Can have *n* dimensions; we show 3 below
- Cross-tabs can be used as views on a data cube



Hierarchies on Dimensions

- **Hierarchy** on dimension attributes: lets dimensions to be viewed at different levels of detail
  - E.g., the dimension DateTime can be used to aggregate by hour of day, date, day of week, month, quarter or year



a) Time Hierarchy

b) Location Hierarchy

Cross Tabulation With Hierarchy

- Cross-tabs can be easily extended to deal with hierarchies
  - Can drill down or roll up on a hierarchy

clothes_size: **all**

category	*item_name*	*color*				
		dark	pastel	white	total	
womenswear	skirt	8	8	10	53	
	dress	20	20	5	35	
	subtotal	28	28	15		88
menswear	pants	14	14	28	49	
	shirt	20	20	5	27	
	subtotal	34	34	33		76
total		62	62	48		164

Relational Representation of Cross-tabs

- Cross-tabs can be represented as relations
  - We use the value **all** is used to represent aggregates.
  - The SQL standard actually uses null values in place of **all** despite confusion with regular null values.

item_name	*color*	*clothes_size*	*quantity*
skirt	dark	**all**	8
skirt	pastel	**all**	35
skirt	white	**all**	10
skirt	**all**	**all**	53
dress	dark	**all**	20
dress	pastel	**all**	10
dress	white	**all**	5
dress	**all**	**all**	35
shirt	dark	**all**	14
shirt	pastel	**all**	7
shirt	White	**all**	28
shirt	**all**	**all**	49
pant	dark	**all**	20
pant	pastel	**all**	2
pant	white	**all**	5
pant	**all**	**all**	27
all	dark	**all**	62
all	pastel	**all**	54
all	white	**all**	48
all	**all**	**all**	164

Extended Aggregation to Support OLAP

- The **cube** operation computes union of **group by**'s on every subset of the specified attributes
- Example relation for this section
  sales(*item_name*, *color*, *clothes_size*, *quantity*)
- E.g. consider the query

  select *item_name*, *color*, *size*, **sum**(*number*)
  from *sales*
  group by cube(*item_name*, *color*, *size*)

  This computes the union of eight different groupings of the *sales* relation:

  { (*item_name*, *color*, *size*), (*item_name*, *color*),
  (*item_name*, *size*), (*color*, *size*),
  (*item_name*), (*color*),
  (*size*), ( ) }

  where ( ) denotes an empty **group by** list.
- For each grouping, the result contains the null value for attributes not present in the grouping.

Online Analytical Processing Operations

- Relational representation of cross-tab that we saw earlier, but with *null* in place of **all**, can be computed by

```
select item_name, color, sum(number)
from sales
group by cube(item_name, color)
```

- The function **grouping()** can be applied on an attribute
  - Returns 1 if the value is a null value representing all, and returns 0 in all other cases.

```
select item_name, color, size, sum(number),
    grouping(item_name) as item_name_flag,
    grouping(color) as color_flag,
    grouping(size) as size_flag,
from sales
group by cube(item_name, color, size)
```

Online Analytical Processing Operations

- Can use the function **decode()** in the **select** clause to replace such nulls by a value such as **all**
  - E.g., replace *item_name* in first query by
    decode(**grouping**(item_*name*), 1, ‘all’, *item_name*)

Extended Aggregation (Cont.)

- The **rollup** construct generates union on every prefix of specified list of attributes
- E.g.,

  select *item_name*, *color*, *size*, **sum**(*number*)
  from *sales*
  group by rollup(*item_name, color, size*)

  Generates union of four groupings:

  { (*item_name, color, size*), (*item_name, color*), (*item_name*), ( ) }

- Rollup can be used to generate aggregates at multiple levels of a hierarchy.
- E.g., suppose table *itemcategory*(*item_name, category*) gives the category of each item. Then

  select *category, item_name*, **sum**(*number*)
  from *sales, itemcategory*
  where *sales.item_name* = *itemcategory.item_name*
  group by rollup(*category, item_name*)

  would give a hierarchical summary by *item_name* and by *category*.

Extended Aggregation (Cont.)

- Multiple rollups and cubes can be used in a single group by clause
  - Each generates set of group by lists, cross product of sets gives overall set of group by lists
- E.g.,

  select *item_name*, *color*, *size*, **sum**(*number*)
  from *sales*
  group by rollup(*item_name*), **rollup**(*color*, *size*)

  generates the groupings

  {*item_name*, ()} X {(*color*, *size*), (*color*), ()}

  = { (*item_name*, *color*, *size*), (*item_name*, *color*), (*item_name*),
  (*color*, *size*), (*color*), ( ) }

Online Analytical Processing Operations

- **Pivoting:** changing the dimensions used in a cross-tab is called
- **Slicing:** creating a cross-tab for fixed values only
  - Sometimes called **dicing**, particularly when values for multiple dimensions are fixed.
- **Rollup:** moving from finer-granularity data to a coarser granularity
- **Drill down:** The opposite operation - that of moving from coarser-granularity data to finer-granularity data

OLAP Implementation

- The earliest OLAP systems used multidimensional arrays in memory to store data cubes, and are referred to as **multidimensional OLAP (MOLAP)** systems.
- OLAP implementations using only relational database features are called **relational OLAP (ROLAP)** systems
- Hybrid systems, which store some summaries in memory and store the base data and other summaries in a relational database, are called **hybrid OLAP (HOLAP)** systems.

OLAP Implementation (Cont.)

- Early OLAP systems precomputed *all* possible aggregates in order to provide online response
  - Space and time requirements for doing so can be very high
    - 2^n combinations of **group by**
  - It suffices to precompute some aggregates, and compute others on demand from one of the precomputed aggregates
    - Can compute aggregate on (*item_name*, *color*) from an aggregate on (*item_name*, *color*, *size*)
      - For all but a few "non-decomposable" aggregates such as *median*
      - is cheaper than computing it from scratch
- Several optimizations available for computing multiple aggregates
  - Can compute aggregate on (*item_name*, *color*) from an aggregate on (*item_name*, *color*, *size*)
  - Can compute aggregates on (*item_name*, *color*, *size*), (*item_name*, *color*) and (*item_name*) using a single sorting of the base data

End of Chapter 5

Database System Concepts, 6th Ed.