Chapter 5: Advanced SQL

Database System Concepts, 6th Ed.

Chapter 5: Advanced SQL

- <u>5.1 Accessing SQL From a Programming Language</u>
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- 5.2 Functions and Procedures
- 5.3 Triggers
- 5.4 Recursive Queries**
- 5.5 Advanced Aggregation Features**
- 5.6 OLAP**

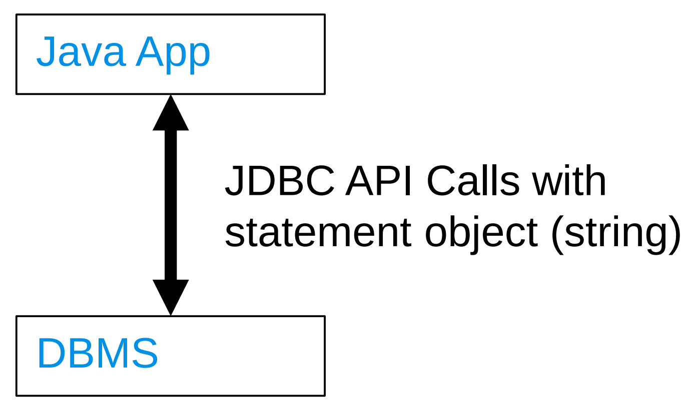
JDBC and ODBC

(Dynamic Binding between DB and PL)

- API (application-program interface) for a program to interact with a database server
- Application programs makes API calls to
  - Connect with the database server
  - Send SQL commands to the database server
  - Fetch tuples of result one-by-one into program variables
- Run-Time Binding between DB and PL
- ODBC (Open Database Connectivity)
  - ODBC 1.0 (1992), ODBC 3.0 (1995), ODBC 3.8 (2009)
  - Orginally designed for C, now works with C++, C#, and Visual Basic
  - Other API's such as ADO.NET sit on top of ODBC
  - ODBC drivers exist for most DBMSs
- JDBC (Java Database Connectivity) works with Java
  - JDBC driver was a part of Java Development Kit (JDK) 1.1 (1997)
  - Since then, a part of Java Platform, Standard Edition (Java SE)
  - JDBC 4.2 (2013)

JDBC

- **JDBC** is a Java API for communicating with database systems supporting SQL
  - supports a variety of features for querying and updating data, and for retrieving query results
  - supports metadata retrieval, such as querying about relations present in the database and the names and types of relation attributes
  - Dynamic (Run-time) Binding between application programs and DBMS
- JDBC Model for communicating with the database:
  - Open a connection
  - Create a “statement” object (string)
  - Execute queries using the Statement object to send queries and fetch results
  - Exception mechanism to handle errors

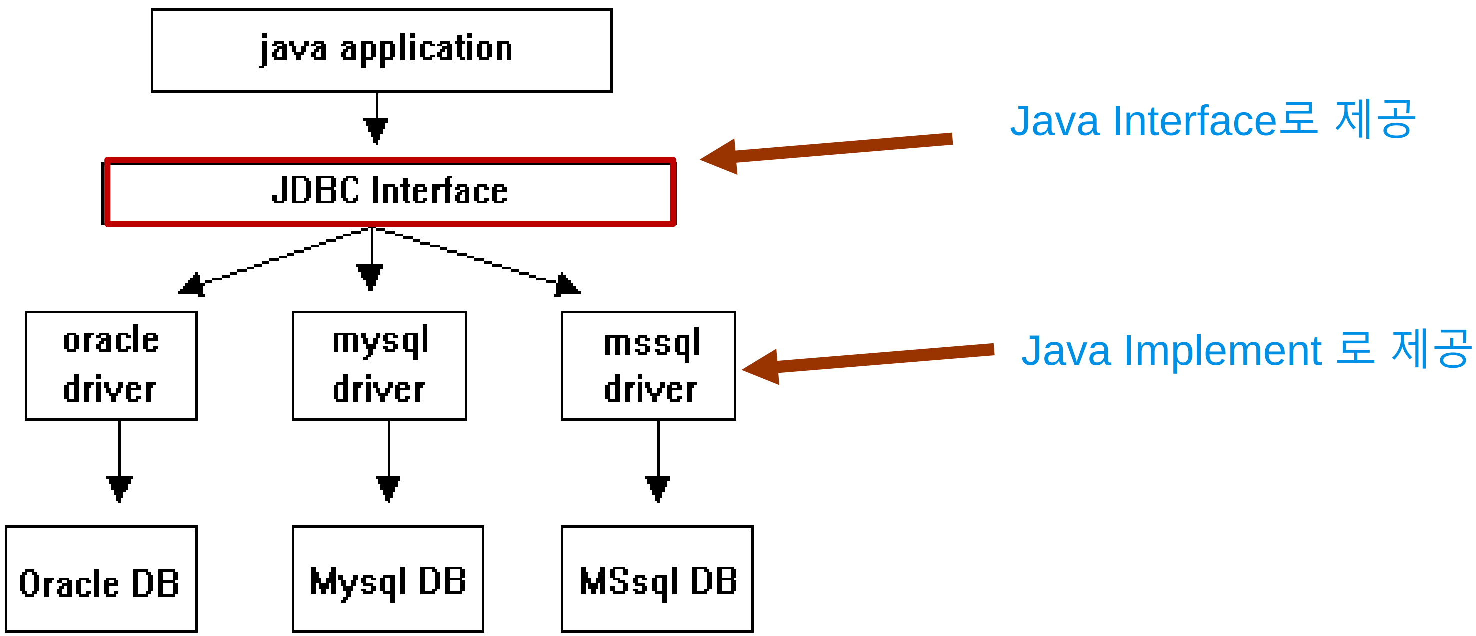


Overview

참고자료

JDBC란 Java DataBase Connectivity의 약자로 데이터베이스에 연결 및 작업을 하기 위한 자바 표준 인터페이스이다. 자바는 DBMS의 종류에 상관없이 하나의 JDBC API를 사용해서 데이터베이스 작업을 처리할 수 있다.

1. JDBC의 구조



자바언어에서 데이터베이스 표준 인터페이스를 정의하고, 각 데이터베이스 회사들은 JDBC 인터페이스를 제공받아 자신들의 데이터베이스에 맞게 구현한후 드라이버를 제공한다. 개발자가 JDBC API를 사용할 경우 DBMS에 알맞은 JDBC드라이버만 있으면 어떤 데이터베이스라도 사용할 수 있게 된다.

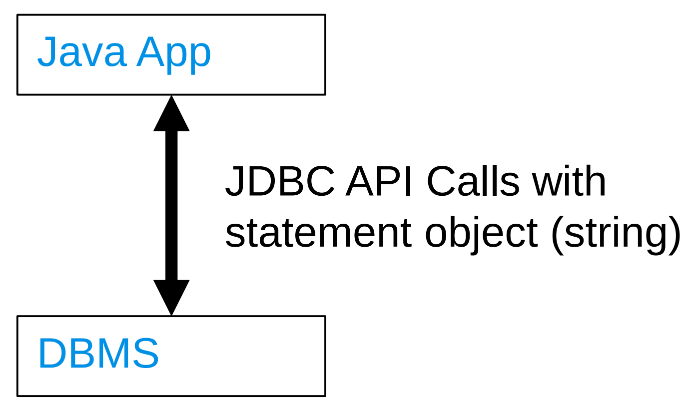
JDBC 드라이버는 각 밴드사에서 jar파일로 제공된다.

Sample Java Code with JDBC Calls

```java
String driver="oracle.jdbc.driver.OracleDriver";
String url="jdbc:oracle:thin:@localhost:1521:ORCL";
String sql = "select no, name from member";
Connection conn = null;
PreparedStatement pstmt = null;
ResultSet rs = null;
try {
    // ① JDBC 드라이버 로딩
    Class.forName(driver);
    // ② 데이터베이스 connection
    conn=DriverManager.getConnection(url,"scott","tiger");
    // ③ 쿼리(sql)문장을 실행하기 위한 객체 생성
    pstmt=conn.prepareStatement(sql);
    // ④ 쿼리 실행
    rs=pstmt.executeQuery();
    // ⑤ 쿼리 실행의 결과값(int, ResultSet) 사용
    while(rs.next()){
     out.println("<h3>"+rs.getInt(1)+","+rs.getString(2)+"</h3>");
    }
}catch(Exception e){
  out.println("<h3>데이터 가져오기에 실패하였습니다.</h3>");
  e.printStackTrace();
}finally{
  // ⑥ 사용된 객체 종료
  try{rs.close();}catch(Exception e){}
  try{pstmt.close();}catch(Exception e){}
  try{conn.close();}catch(Exception e){}
}
```

Try-Catch-Finally:
Run-time Error에 대한 Care!

- 어느 상황에서 Error가 발생했는지 detect
- Error가 발생해도 client server connection 유지



JDBC Code

```
public static void JDBCexample(String userid, String passwd)
{
    try {
        Class.forName ("oracle.jdbc.driver.OracleDriver"); // JDBC driver loading
        Connection conn = DriverManager.getConnection(
                        "jdbc:oracle:thin:@db.yale.edu:2000:univdb", userid, passwd);
        Statement stmt = conn.createStatement();
        … Update code in the next page….
        … Query and fetch code in the next page…..
        stmt.close();
        conn.close();
    }
    catch (Exception e) {
        System.out.println("Exception : " + e);
    }
}
```

“Update DB” Code Details

- Update to database

```
    try {
        stmt.executeUpdate(
                    "insert into instructor values(’77987’, ’Kim’, ’Physics’,
98000)");
     }
catch (SQLException sqle)
     {
          System.out.println("Could not insert a tuple. " + sqle);
     }
```

“Query & Fetch” Code Details

- Execute query and fetch & print result

```
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) );
    }
```

- Getting result fields:
  - **rset.getString(“dept_name”) and rset.getString(1) equivalent if dept_name is the first argument of select result.**

JDBC Feature: Prepared Statement

- Primary Functionality: Activating SQL Precompilation in Serverside DBMS from Clientside
  - DBMS built_in SQL Precompilation
    - The query is compiled once and then run multiple times with different parameter values
  - PreparedStatement의 ?자리에 나중에 입력되는 value가 들어가는 mechanism

```
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();
```

- Secondary Functionality: quotation mark handling
  - Many PLs and PL environments use single quote and double quote in a mixed manner
  - SQL의 string은 single quote로 둘러 싸여져 있어야 함
  - JDBC Prepared Statement has a special mechanism for handling single quote and double quote in making SQL statement string
    - Insert \ for a single quotation mark

"Potentially Dangerous" SQL Injection in JDBC [1]

- Java program이 입력창에서 data를 받아서 variable들에 binding하고 DBMS에 아래와 같은 string을 pass했다면

  " insert into instructor

  values(' " + ID + " ', ' " + name + " ', " + " ' + dept name + " ', " ' balance + ") "

  - What if name is D'Souza? ➔ single quotation mark will create a syntax error
- Java program이 입력창에서 name를 받아서 name variable에 binding하고 DBMS에 아래와 같은 string을 pass했다면 (SQL에서는 string은 single quote로 둘러싸여져 있어야 함)
  - " select * from instructor where name = '" + name + "' "
- Then, suppose the user, instead of entering a proper name, enters: X' or 'Y' = 'Y
  - then the resulting statement becomes:
    - " select * from instructor where name = ' " + " X' or 'Y' = 'Y " + " ' "
  - Then string concatenation이 정리된후에, the query to be inserted into DBMS would be:
    - Select * from instructor where name = ' X' or 'Y' = 'Y '
    - DBMS will return everything in instructor

- JDBC Prepared statement internally inserted \ for a single quotation mark:
  - 입력창에 들어온 Data에서 single quote는 \ 로 교체
  - then the resulting statement becomes:
    - select * from instructor where name = 'X\' or \'Y\' = \'Y'
  - This query will return an empty relation

“Potentially Dangerous” SQL Injection in JDBC [2]

- Even worse scenario!
- Suppose query is constructed using Java
  - “ select * from instructor where name = ’" + name + "’ "
- User could have even used instead of entering a name
  - X’ ; update instructor set salary = salary + 10000; ’
  - Then the query to be inserted into DBMS would be:
    - select * from instructor where name = ’ X’ ;

      update instructor set salary = salary + 10000; ’ ’
  - DBMS will increase the salary of every instructor

- JDBC Prepared statement internally uses \ for a single quotation mark:
    - select * from instructor where name = ’ X\’ ;

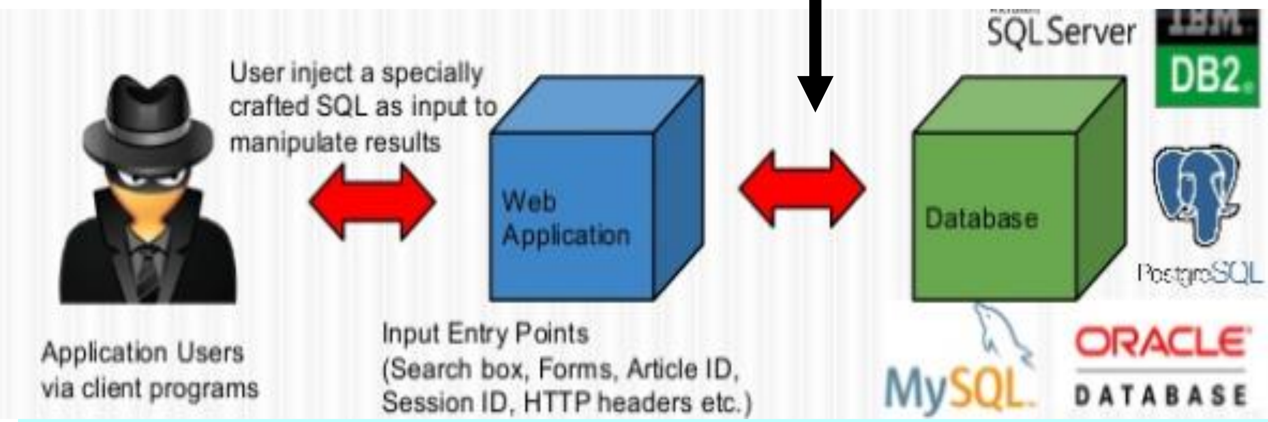
      update instructor set salary = salary + 10000; \’
  - This query will return an empty relation

- JDBC 의 PreparedStatement 기능은 Malicious user가 single quote를 가지고 위험한 string을 만들어도 execution이 안되도록 control 한다

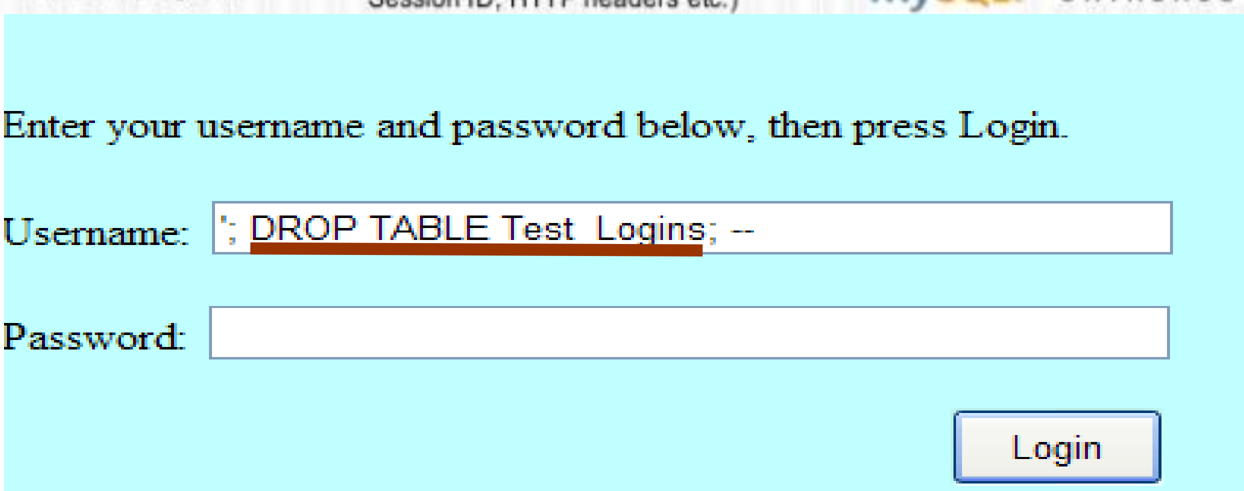
SQL Injection

- SQL 문장은 ; 로 나누어짐
- SQL에서 string은 single quote로 표현됨

JDBC API Calls with statement object (string)



Username	Password	Permit
Kim	5252	OK
Bob	1234	OK
John	2888	OK



"
Select Permit
From User-Check
Where Username = 'Bob'
and Password = '1234'
"

JDBC Feature: Meta Data Handling [1/2]

- Two types of JDBC Metadata
  - Meta data for a query
  - Meta data for the whole database

- ResultSetMetadata: meta data for query result

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? ➔ useful for printing out the formatted table for query result!

JDBC Feature: Meta Data Handling [2/2]

- DatabaseMetadata: meta data for the database itself

```
DatabaseMetaData dbmd = conn.getMetaData();
ResultSet rs = dbmd.getColumns(null, “univdb”, “department”, “%”);
// Arguments to getColumns: Catalog, Schema-pattern, Table-pattern, Column-Pattern
// Returns: One row for each column; row has a number of attributes
// such as COLUMN_NAME, TYPE_NAME
while( rs.next() ) {
    System.out.println(rs.getString(“COLUMN_NAME"), rs.getString("TYPE_NAME");
}
```

- And where is this useful? ➔ can be used for a database browser (or database GUI) that allows a user to navigate or examine tables

JDBC Feature: Transaction Control

- Updatable result sets
  - 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);
  - A group of transactions must then be committed or rolled back explicitly
    - conn.commit();   or
    - conn.rollback();
  - conn.setAutoCommit(true) turns on automatic commit

- Clientside JAVA application에서 Serverside DBMS에 있는 transaction control관련 command를 activate 시킬수 있다

Additional JDBC Features

- CallableStatement: invoking <u>SQL stored functions and procedures</u>
  - CallableStatement cStmt1 = conn.prepareCall("{? = call some function(?)}");
  - CallableStatement cStmt2 = conn.prepareCall("{call some procedure(?,?)}");
  - Java program 내부에서 cStmt1와 cStmt2를 수행할수 있다

- Handling large object types <u>without creating the large object in memory</u>
  - 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).
  - Database에 있는 large object들을 Java program에서 partial access, update등이 가능하게 한다

ODBC [1/2]

- Open Data Base Connectivity(ODBC) standard
  - Initially C language connection API to DBMS
  - 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

ODBC [2/2]

- Each database system supporting ODBC provides a "ODBC driver" library that must be linked with the client program.
- When client program makes an ODBC API call, the code in the library communicates with the server to carry out the requested action, and fetch results.
- ODBC program first allocates an SQL environment, then a database connection handle.
- Opens database connection using SQLConnect() with parameters as below
  - connection handle,
  - the server to which to connect
  - the user identifier,
  - password
- Must also specify types of arguments:
  - SQL_NTS denotes previous argument is a null-terminated string.

ODBC Code [1/3]

```
int ODBCexample()
  {
    RETCODE error;
    HENV    env;     /* environment */
    HDBC    conn;  /* database connection */
    SQLAllocEnv( &env );
    SQLAllocConnect( env, &conn );
            SQLConnect(conn, “db.yale.edu", SQL_NTS, "avi", SQL_NTS,
"avipasswd", SQL_NTS);
    { …Code in the next page… }

        SQLDisconnect( conn );
        SQLFreeConnect( conn );
        SQLFreeEnv( env );
    }
```

ODBC Code [2/3]

- Main body of program

```
char deptname[80];
float salary;
int lenOut1, lenOut2;
HSTMT stmt;
char * sqlquery = "select dept_name, sum (salary)
                  from instructor
                  group by dept_name";
SQLAllocStmt(conn, &stmt);
error = SQLExecDirect(stmt, sqlquery, SQL NTS);
if (error == SQL SUCCESS) {
    SQLBindCol (stmt, 1, SQL C CHAR, deptname , 80,   &lenOut1);
    SQLBindCol (stmt, 2, SQL C FLOAT, &salary, 0 ,    &lenOut2);
    while (SQLFetch(stmt) == SQL SUCCESS) {
        printf (" %s %g\n", deptname, salary);
    }
}
SQLFreeStmt(stmt, SQL DROP);
```

ODBC Code [3/3]

- Program sends SQL commands to the database by using SQLExecDirect
- Result tuples are fetched using SQLFetch()
- SQLBindCol() binds C language variables to attributes of the query result
  - When a tuple is fetched, its attribute values are automatically stored in corresponding C variables.
  - Arguments to SQLBindCol()
    - ODBC stmt variable, attribute position in query result
    - The type conversion from SQL to C.
    - The address of the variable.
    - For variable-length types like character arrays,
      - The maximum length of the variable
      - Location to store actual length when a tuple is fetched.
      - Note: A negative value returned for the length field indicates null value
- Good programming requires checking results of every function call for errors; we have omitted most checks for brevity.

ODBC Prepared Statements

- **Prepared Statement**
  - SQL statement prepared: compiled at the database
  - Can have placeholders: E.g. insert into account values(?,?,?)
  - Repeatedly executed with actual values for the placeholders
- To prepare a statement
  SQLPrepare(stmt, <SQL String>);
- To bind parameters
  SQLBindParameter(stmt, <parameter#>,
  … type information and value omitted for simplicity..)
- To execute the statement
  retcode = SQLExecute(stmt);
- To avoid SQL injection security risk, do not create SQL strings directly using user input; instead use prepared statements to bind user inputs

More ODBC Features

- **Metadata features**
  - finding all the relations in the database and
  - finding the names and types of columns of a query result or a relation in the database.

- Transaction control: By default, each SQL statement is treated as a separate transaction that is committed automatically.
  - Can turn off automatic commit on a connection
    - SQLSetConnectOption(conn, SQL_AUTOCOMMIT, 0)}
  - A group of transactions can be committed or rolled back explicitly by
    - SQLTransact(conn, SQL_COMMIT) or
    - SQLTransact(conn, SQL_ROLLBACK)

ODBC Conformance Levels

- Conformance levels specify subsets of the functionality defined by the standard.
  - Core
  - Level 1 requires support for metadata querying
  - Level 2 requires ability to send and retrieve arrays of parameter values and more detailed catalog information.
- SQL Call Level Interface (CLI) standard similar to ODBC interface, but with some minor differences.

ADO.NET

- MicroSoft Database connection API for Visual Basic .NET and C#

(part of MS .NET framework, similar to JDBC/ODBC)

- Partial example of ADO.NET code in C#

```
using System, System.Data, System.Data.SqlClient;
SqlConnection conn = new SqlConnection(
            "Data Source = <IPaddr>, Initial Catalog = <Catalog>");
conn.Open();
SqlCommand cmd = new SqlCommand("select * from students", conn);
SqlDataReader rdr = cmd.ExecuteReader();
while(rdr.Read()) {
    Console.WriteLine(rdr[0], rdr[1]); /* Prints first 2 attributes of result*/
}
rdr.Close();
conn.Close();
```

- Translated into ODBC calls
- Can also access non-relational data sources such as
  - OLE-DB
  - XML data
  - Entity framework

Embedded SQL [1/2]
(Static Binding of DB and PL)

- The SQL standard defines embeddings of SQL in PLs such as C, Java, and Cobol
  - ESQL/C, ESQL/Java, ESQL/Cobol
  - Compile-time binding between application program and relational DBMS
- 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
- System R: ESQL into PL/I, Most DBMSs: ESQL/C
- **EXEC SQL** statement is used to identify embedded SQL request to the preprocessor

  EXEC SQL <embedded SQL statement > ;

- From within a host language (Eg, C), find the ID and name of students who have completed more than the number of credits stored in variable credit_amount

Step1: Specify the query in SQL and declare a *cursor* for it

```
EXEC SQL
   declare c cursor for
      select ID, name
      from student
      where tot_cred > :credit_amount ;
```

Embedded SQL [2/2]

- The **open** statement causes the query to be evaluated

  EXEC SQL **open** *c* ***;***

- 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* ;

  Repeated calls to **fetch** get successive tuples in the query result

  - 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 Cursors in Embedded SQL

- 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 ;
```

- To update tuple at the current location of cursor *c*

```
EXEC SQL
    update instructor
    set salary = salary + 100
    where current of c ;
```

SQLJ [1/4]

- Alternative approach for ESQL/Java
- JDBC에 비해서 Java Syntax에 가깝게 표현되는 방식
- JDBC에 대한 wrapper로 보는것이 적절

- SQLJ part 0: ANSI (1998), “Object Language Bindings (SQL/OLB)”, SQL—Part 10
- SQLJ part 1: ANSI (1999), "SQL Routines Using the Java"
- SQLJ part 2: ANSI (2000), "SQL Types Using the Java”

- *Object Language Bindings (SQL/OLB) :* ISO (2000), *SQL—Part 10*
- *SQL Routines and Types Using the Java (SQL/JRT)*: ISO (2002), *SQL—Part 13*

- *Only DBMSs by IBM, Oracle support SQLJ*
  - *Translator from SQLJ code to JCBC code*

SQLJ [2/4]

- JDBC is overly dynamic, errors cannot be caught by compiler

  ➔ 그래서 JDBC db application program들은 Try … Catch.. 로 구성된다
- ESQL/C와 다른점: EXEC SQL 대신에 #sql, cursor대신에 iter
- 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();
```

SQLJ [3/4]

- Some advantages of SQLJ over JDBC include:
  - SQLJ commands tend to be shorter than equivalent JDBC programs
  - SQL syntax can be checked at compile time
  - The returned query results can also be checked strictly
  - Preprocessor might generate static SQL which performs better than dynamic SQL because query plan is created on program compile time, stored in database and reused at runtime

- Disadvantages include:
  - SQLJ requires a preprocessing step
  - Many IDEs do not have SQLJ support

SQLJ [4/4]

Single-row query

JDBC

```java
PreparedStatement stmt = conn.prepareStatement(
    "SELECT MAX(SALARY), AVG(SALARY)"
  + " FROM DSN8710.EMP");
rs = stmt.executeQuery();
if (!rs.next()) {
  // Error—no rows found
}
maxSalary = rs.getBigDecimal(1);
avgSalary = rs.getBigDecimal(2);
if (rs.next()) {
  // Error—more than one row found
}
rs.close();
stmt.close();
```

SQLJ

```sql
#sql [ctx] {
  SELECT MAX(SALARY), AVG(SALARY)
    INTO :maxSalary, :avgSalary
    FROM DSN8710.EMP
};
```

Chapter 5: Advanced SQL

- 5.1 Accessing SQL From a Programming Language
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- <u>5.2 Functions and Procedures</u>
- 5.3 Triggers
- 5.4 Recursive Queries**
- 5.5 Advanced Aggregation Features**
- 5.6 OLAP**

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
- OOP의 method 개념을 support
- Object-oriented aspects of these features are covered in Chapter 22 (Object Based Databases)

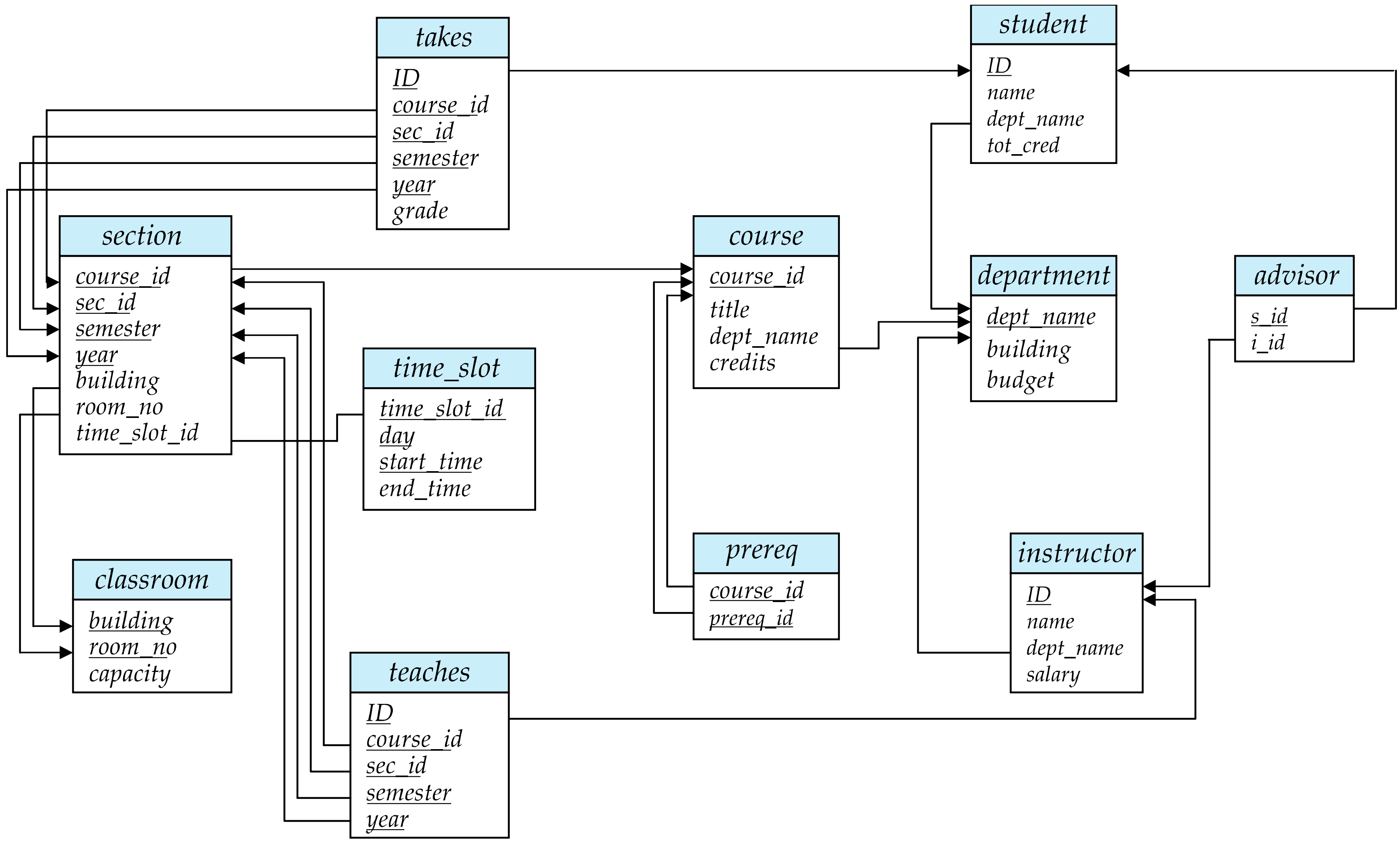
Functions and Procedures

- SQL:1999 supports functions and procedures
  - Functions/procedures can be written in SQL itself, or in an external PL
  - Functions 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 DBMSs have proprietary procedural extensions to SQL that differ from SQL:1999.

Schema Diagram for University Database



SQL Functions

- Input parameter declaration, Output data tupe declaration
- 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
```

- Calling a function within a query: 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 Table Functions

- SQL:2003 added functions that return a relation as a result
- Define a table function: 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*)

- Calling a table function:

    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

SQL Procedural Constructs [1/3]

- Warning: most DBMSs implement their own variant of the standard syntax below
  - read your system manual to see what works on your system
- 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:

```
declare n integer default 0;
while n < 10 do
    set n = n + 1
end while
```

```
repeat
    set n = n – 1
until n = 0
end repeat
```

- **For** loop

  Permits iteration over all results of a query

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

SQL Procedural Constructs [2/3]

- SQL:1999 Conditional statements: **if-then-else** and **case**
- Example procedure: registers student after ensuring classroom capacity is not exceeded: Returns 0 on success and -1 if capacity is exceeded

```
create function registerStudent(
        in s_id varchar(5),
        in s_courseid varchar (8),
        in s_secid varchar (8),
        in s_semester varchar (6),
        in s_year numeric (4,0),
        out errorMsg varchar(100)
returns integer
begin
    declare currEnrol int;
    select count(*) into currEnrol
        from takes
        where course_id = s_courseid and sec_id = s_secid
            and semester = s_semester and year = s_year;
    declare limit int;
    select capacity into limit
        from classroom natural join section
        where course_id = s_courseid and sec_id = s_secid
            and semester = s_semester and year = s_year;
    if (currEnrol < limit)
        begin
            insert into takes values
                (s_id, s_courseid, s_secid, s_semester, s_year, null);
            return(0);
        end
    -- Otherwise, section capacity limit already reached
    set errorMsg = 'Enrollment limit reached for course ' || s_courseid
        || ' section ' || s_secid;
    return(-1);
end;
```

SQL Procedural Constructs [3/3]

- Function이나 Procedure의 내부에 Exception Handling mechanism을 심을수 있다
  - SQL Shell에서 run-time error에 대한 대비책

- Signaling of exception conditions, and declaring handlers for exceptions

```
declare out_of_classroom_seats condition
declare exit handler for out_of_classroom_seats
begin
…
 some code
…..
if (자리가 더 이상 없으면) then signal out_of_classroom_seats
else continue
end
```

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

Functions/Procedures written in External PL [1/2]

- SQL:1999 permits the use of functions and procedures written in other languages such as C or C++
- Declaring external language procedures and functions inside SQL:1999

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’

여기부터는 SQL밖에서 Function과 Procedure를 만들어서 SQL안에서 call하는것을 allow하는 방식!

Functions/Procedures written in External PL [2/2]

- 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 allowed when efficiency is more important than security.

Convenience + Performance vs. Security

Security with External Language Routines

- To deal with security problems of SQL Functions and Procesure
  - A safe language like Java has the sandbox feature which cannot be used to access/damage other parts of the database code.
  - Some languages run external language functions/procedures in a separate process (different address space), 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.

- Java Sand Box Model: Java Compiler가 신뢰성이 확보되지 않은 코드를 load할 때 항상 바이트 코드를 검사하여, 신용이 확인되지 않은 코드는 자바환경전체에 아무런 해약이 미치지 못하는 'Sand Box'에서 수행시켜 Local System에 대한 전면적인 접근을 금지하는 기법.
- SQL address space 와 외부PL function의 address space를 분리

Java Security Model: Sandbox [1/2]

참고자료

- 외부에서 받은 프로그램을 SandBox라는 보호된 영역을 가진 프로그램을 만들어 프로그램설치를 SandBox 안에 가둔 뒤 작동시키는 방법으로 프로그램의 폭주 또는 악성 바이러스의 침투를 막는다

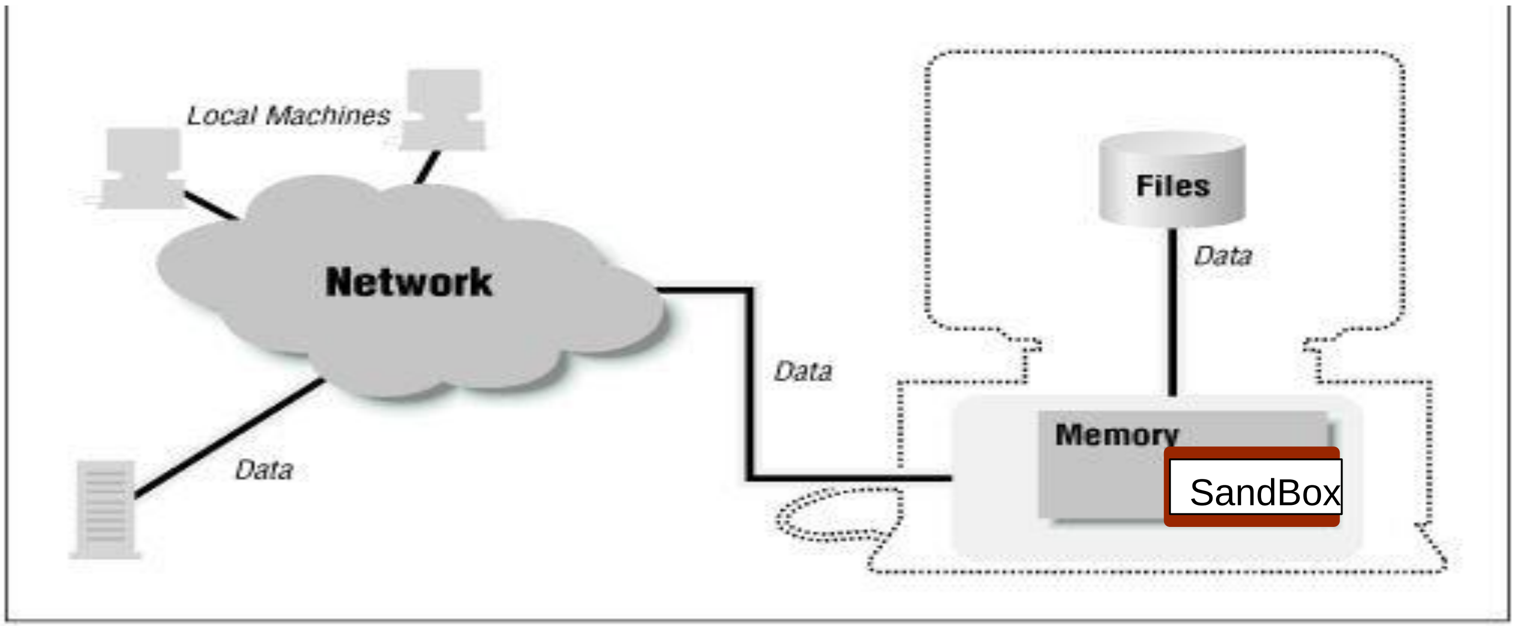


Figure 1-1. A machine has access to many resources

Java Security Model: Sandbox [2/2]

참고자료

- Different-sized sandboxes in which a Java program or Applet might run:
- A sandbox in which the program has access to the CPU, the screen, keyboard, and mouse, and to its own memory.
    - This is the minimal sandbox--it contains just enough resources for a program to run.
- A sandbox in which the program has access to the CPU and its own memory as well as access to the web server from which it was loaded.
    - This is often thought of as the default state for the sandbox.
- A sandbox in which the program has access to the CPU, its memory, its web server, and to a set of program-specific resources (local files, local machines, etc.).
    - A word-processing program, for example, might have access to the *docs* directory on the local filesystem, but not to any other files.
- An open sandbox, in which the program has access to whatever resources the host machine normally has access to.

Chapter 5: Advanced SQL

- 5.1 Accessing SQL From a Programming Language
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- 5.2 Functions and Procedures
- <u>5.3 Triggers</u>
- 5.4 Recursive Queries**
- 5.5 Advanced Aggregation Features**
- 5.6 OLAP**

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 were officially introduced to SQL standard in SQL:1999
- But triggers have been 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 Example [1/2]

- E.g. *time_slot_id* is not a primary key of *timeslot,* so we cannot create a foreign key constraint from *section* to *timeslot.*

- Alternative: use triggers on *section* and *timeslot* to enforce integrity constraints

create trigger *timeslot_check1* **after insert on** *section*
referencing new row as *nrow*
for each row
when (*nrow.time_slot_id* **not in** (
select *time_slot_id*
from *time_slot*)) /* *time_slot_id* not present in *time_slot* */
begin
rollback
end;

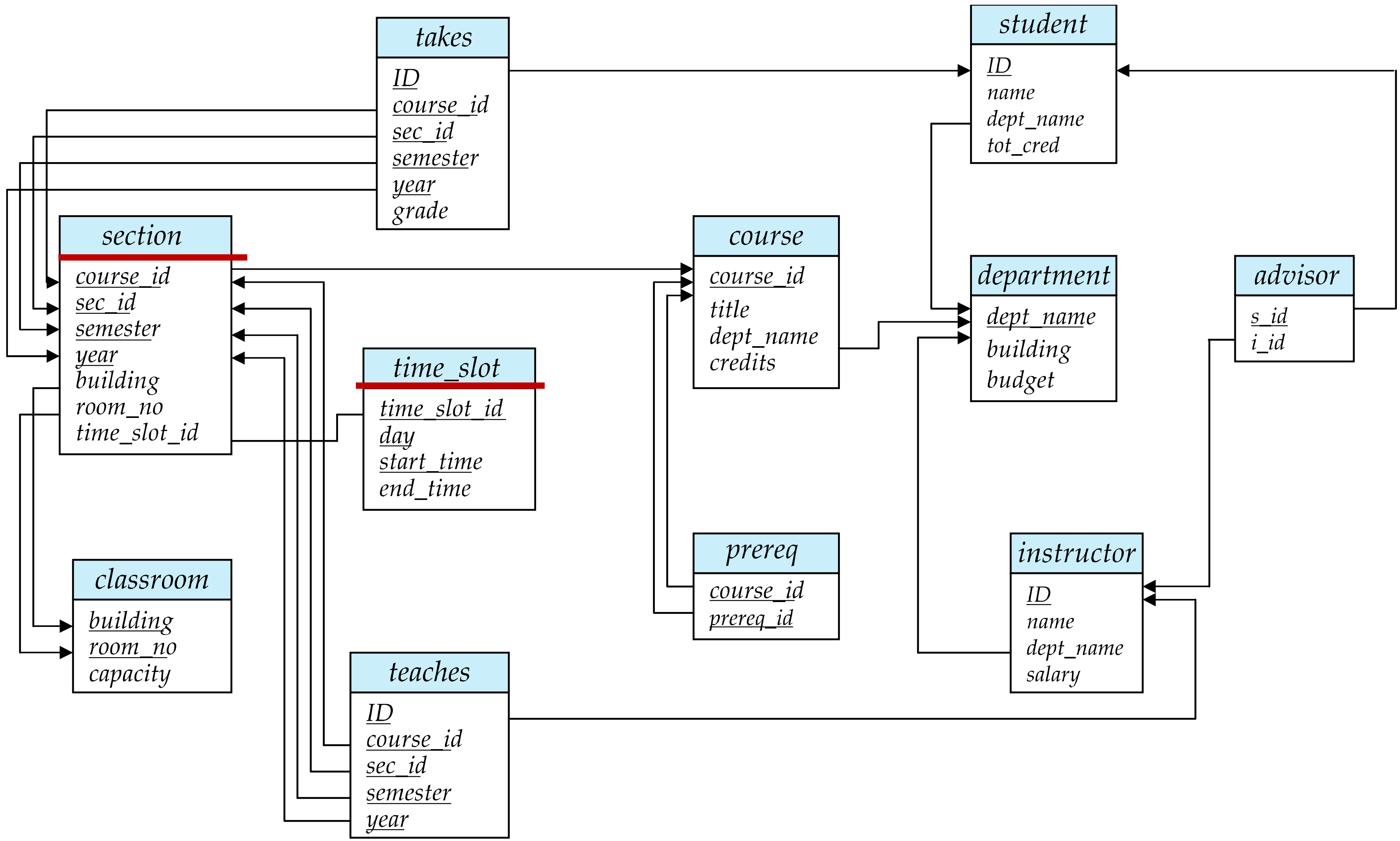
section

course_id	*sec_id*	*semester*	*year*	*building*	*room_number*	*time_slot_id*
BIO-101	1	Summer	2009	Painter	514	B
BIO-301	1	Summer	2010	Painter	514	A
CS-101	1	Fall	2009	Packard	101	H
CS-101	1	Spring	2010	Packard	101	F
CS-190	1	Spring	2009	Taylor	3128	E

Time_slot

time_slot_id	*day*	*start_time*	*end_time*
A	M	8:00	8:50
A	W	8:00	8:50
A	F	8:00	8:50
B	M	9:00	9:50
B	W	9:00	9:50

Schema Diagram for University Database



Trigger Example [2/2]

```
create trigger timeslot_check2 after delete on timeslot
    referencing old row as orow
    for each row
    when (orow.time_slot_id not in (
                select time_slot_id
                from time_slot )
                /* last tuple for time slot id deleted from time slot */
            and orow.time_slot_id in (
                select time_slot_id
                from section ) )        /* and time_slot_id still referenced from section*/
    begin
        rollback
    end;
```

section

course_id	sec_id	semester	year	building	room_number	time_slot_id
BIO-101	1	Summer	2009	Painter	514	B
BIO-301	1	Summer	2010	Painter	514	A
CS-101	1	Fall	2009	Packard	101	H
CS-101	1	Spring	2010	Packard	101	F
CS-190	1	Spring	2009	Taylor	3128	E

Time_slot

time_slot_id	day	start_time	end_time
A	M	8:00	8:50
A	W	8:00	8:50
A	F	8:00	8:50
B	M	9:00	9:50
B	W	9:00	9:50

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 can be referenced before and after an update
  - **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;
```

takes

ID	*course_id*	*sec_id*	*semester*	*year*	*grade*
00128	CS-101	1	Fall	2009	A
00128	CS-347	1	Fall	2009	A-
12345	CS-101	1	Fall	2009	C
12345	CS-190	2	Spring	2009	A
12345	CS-315	1	Spring	2010	A
12345	CS-347	1	Fall	2009	A

Trigger to Maintain credits_earned value

- Keep **tot_cred** up-to-date when grade attribute is uptodated
- create trigger *credits_earned* after update of *takes* on (*grade*)

```
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;
```

student

ID	name	dept_name	tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110

takes

ID	course_id	sec_id	semester	year	grade
00128	CS-101	1	Fall	2009	A
00128	CS-347	1	Fall	2009	A-
12345	CS-101	1	Fall	2009	C
12345	CS-190	2	Spring	2009	A
12345	CS-315	1	Spring	2010	A
12345	CS-347	1	Fall	2009	A

Statement Level Triggers

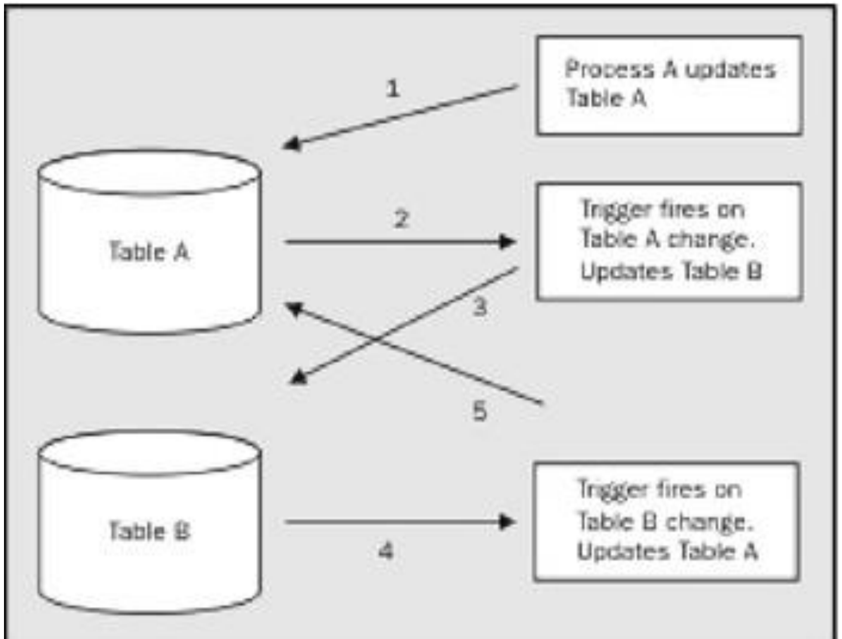
- Instead of executing a separate action for each affected row,

  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

Alternatives to Triggers [1/2]

- Triggers were used earlier for tasks such as
  - maintaining a derived attribute such as summary data (ex. 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
- Triggers should be written with great care
  - Loading data from a backup copy and replicating updates at a remote site may cause unintended execution of triggers
  - Trigger runtime error leading to failure of critical transactions that set off the trigger
  - Cascading execution of a chain of triggers may cause complication



Alternatives to Triggers [2/2]

- Triggers are best avoided when alternatives exit
- There are better ways of doing these in modern-day DBMS:
  - Integrity constraint enforcement를 위한 Trigger
    - Built-in DBMS materialized view facilities to maintain summary data
  - Multiple data copy들의 integrity maintenance를 위한 Trigger
    - Built-in DBMS support for data replication
  - Built-in DBMS support가 없는 상황에서도 Trigger를 사용하기 보다는
    - Function or procedures for update may encapsulate necessary actions
- 왜 그럴까?
  - Trigger는 user가 임의로 구현하므로 복잡하게 구현하다 보면 losing control
  - 가능하면 Built-in DBMS 기능으로 문제를 해결하는 게 바람직

Chapter 5: Advanced SQL

- 5.1 Accessing SQL From a Programming Language
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- 5.2 Functions and Procedures
- 5.3 Triggers
- <u>5.4 Recursive Queries**</u>
- 5.5 Advanced Aggregation Features**
- 5.6 OLAP**

Recursive View in SQL

- SQL:1999 permits recursive view definition
- Recursive views make it possible to write queries, such as transitive closure queries, that cannot be written without recursion or iteration.
- Example: find which courses are a prerequisite, whether directly or indirectly, for a specific course

```
with recursive c_prereq(course_id, prereq_id) as (
        select course_id, prereq_id
        from prereq
    union
        select prereq.prereq_id, c_prereq.course_id
        from prereq, c_prereq
        where prereq.course_id = c_prereq.prereq_id
    )
select ∗
from c_prereq;
```

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

Transitive Closure Computation on a Relation [1/3]

Self_Join $\bowtie$

prereq relation

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101

prereq copy

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101

Result_Relation

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101
CS-347	CS-201
CS-301	CS-101

2개의 새로운 tuple이 생성

Transitive Closure Computation on a Relation [2/3]

새로 생성된 Tuple들만
가지고 Result_Relation과 $\bowtie$

CS-347	CS-201
CS-301	CS-101

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101
CS-347	CS-201
CS-301	CS-101

Result_Relation

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101
CS-347	CS-201
CS-301	CS-101
CS-347	CS-101

1개의 새로운 tuple이 생성

Transitive Closure Computation on a Relation [3/3]

새로 생성된 Tuple만
가지고 Result_Relation과 $\bowtie$

CS-347	CS-101

?

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101
CS-347	CS-201
CS-301	CS-101
CS-347	CS-101

Result_Relation

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101
CS-347	CS-201
CS-301	CS-101
CS-347	CS-101

새로운 tuple이 생성되지
않으므로 최종 Result_Relation

Non-Recursive Method for Transitive Closure Query

- 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 prerequisites
    - 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

```
create function findAllPrereqs(cid varchar(8))
    -- Finds all courses that are prerequisite (directly or indirectly) for cid
returns table (course_id varchar(8))
    -- The relation prereq(course_id, prereq_id) specifies which course is
    -- directly a prerequisite for another course.
begin
    create temporary table c_prereq (course_id varchar(8));
        -- table c_prereq stores the set of courses to be returned
    create temporary table new_c_prereq (course_id varchar(8));
        -- table new_c_prereq contains courses found in the previous iteration
    create temporary table temp (course_id varchar(8));
        -- table temp is used to store intermediate results
    insert into new_c_prereq
        select prereq_id
        from prereq
        where course_id = cid;
    repeat
        insert into c_prereq
            select course_id
            from new_c_prereq;

        insert into temp
            (select prereq.course_id
                from new_c_prereq, prereq
                where new_c_prereq.course_id = prereq.prereq_id
            )
            except (
                select course_id
                from c_prereq
            );
        delete from new_c_prereq;
        insert into new_c_prereq
            select *
            from temp;
        delete from temp;

    until not exists (select * from new_c_prereq)
    end repeat;
    return table c_prereq;
end
```

Mission: Finding all prerequisites of a course!

- 1999년 이전에는 SQL만 가지고 불가능
- 1999에 SQL1999 (SQL3)에서 Procedural extension과 Recursive View 를 지원하면서 Transitive Closure 가능

Using procedural constructs SQL1999 such as repeat..until

Computing transitive closure using iteration on a Relation

prereq relation

Course_id	Prereq_id
BIO-301	BIO-101
BIO-399	BIO-101
CS-190	CS-101
CS-315	CS-101
CS-347	CS-301
EE-181	PHY-101
CS-301	CS-201
CS-201	CS-101

Prerequisite courses of cs-347

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

Fixed Point

CS-347, CS-301 → CS-347, CS-201 → CS-347, CS-101

Another Recursion Example

- Given relation
  manager(*employee_name, manager_name*)
- Find all employee-manager pairs, where the employee reports to the manager directly or indirectly (that is manager's manager, manager's manager's manager, etc.)

```
with recursive empl (employee_name, manager_name ) as (
        select employee_name, manager_name
        from   manager
    union
        select manager.employee_name, empl.manager_name
        from   manager, empl
        where manager.manager_name = empl.employe_name)
select *
from   empl
```

This example view, *empl,* is the *transitive closure* of the *manager* relation

Chapter 5: Advanced SQL

- 5.1 Accessing SQL From a Programming Language
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- 5.2 Functions and Procedures
- 5.3 Triggers
- 5.4 Recursive Queries**
- <u>5.5 Advanced Aggregation Features**</u>
- 5.6 OLAP**

Ranking [1/3]

- Ranking is done in conjunction with an order by specification.
- Suppose we have a relation ***student_grades(ID, GPA)***
- 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 can be done using basic SQL aggregation, but resultant query is 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 [2/3]

- Ranking can be done within partition of the data with **partition by** construct
- "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.
- 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 [3/3]

- 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
```

- For a given constant *n*, 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 [1/2]

- 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**
    - **Between을 써서 지금까지의 모든 row들을 표현**
  - **rows unbounded preceding**
    - **지금까지의 모든 rows**
  - **range between** 10 **preceding and current row**
    - **현재 값과 현재 값 – 10 사이에 있는 값들을 표현**
  - **range interval** 10 **day preceding**
    - **current row를 안쓰고 지난 10일간을 표현**

Windowing [2/2]

- Can do windowing within partitions with partition by construct
- 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
```

➔ (*account_number, date_time, balance*) 생성

Chapter 5: Advanced SQL

- 5.1 Accessing SQL From a Programming Language
  - Dynamic SQL
    - JDBC and ODBC
  - Embedded SQL
- 5.2 Functions and Procedures
- 5.3 Triggers
- 5.4 Recursive Queries**
- 5.5 Advanced Aggregation Features**
- <u>5.6 OLAP**</u>

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 quantity(*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
- OLAP on top of DBMS
- OLAP inside DBMS

Example: sales relation

Dimension attributes

Measure attribute

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
shirt	dark	large	6
shirt	pastel	small	4
shirt	pastel	medium	1
shirt	pastel	large	2
shirt	white	small	17
shirt	white	medium	1
shirt	white	large	10
pant	dark	small	14
pant	dark	medium	6
pant	dark	large	0
pant	pastel	small	1
pant	pastel	medium	0
pant	pastel	large	1
pant	white	small	3
pant	white	medium	0
pant	white	large	2

Item_name 4가지
Color 3가지
Clothes_size 3가지
총 36 combinations
➔ 36 tuples

Plain Queries for Basic Summary

item_name	*quantity*
skirt	53
dress	35
shirt	49
pants	27

Figure 5.23 Query result.

select *item_name*, **sum**(*quantity*)
from *sales*
group by *item_name*;

item_name	*color*	*quantity*
skirt	dark	8
skirt	pastel	35
skirt	white	10
dress	dark	20
dress	pastel	10
dress	white	5
shirt	dark	14
shirt	pastel	7
shirt	white	28
pants	dark	20
pants	pastel	2
pants	white	5

select *item_name*, *color*, **sum**(*quantity*)
from *sales*
group by *item_name*, *color*;

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

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

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

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

이런 SQL Query의 도움을 받아서!!!!

- The table above is an example of a **cross-tabulation (cross-tab)**, also referred to as a **pivot-table**.
- The table is a very typical summary table or report table in real world office environments

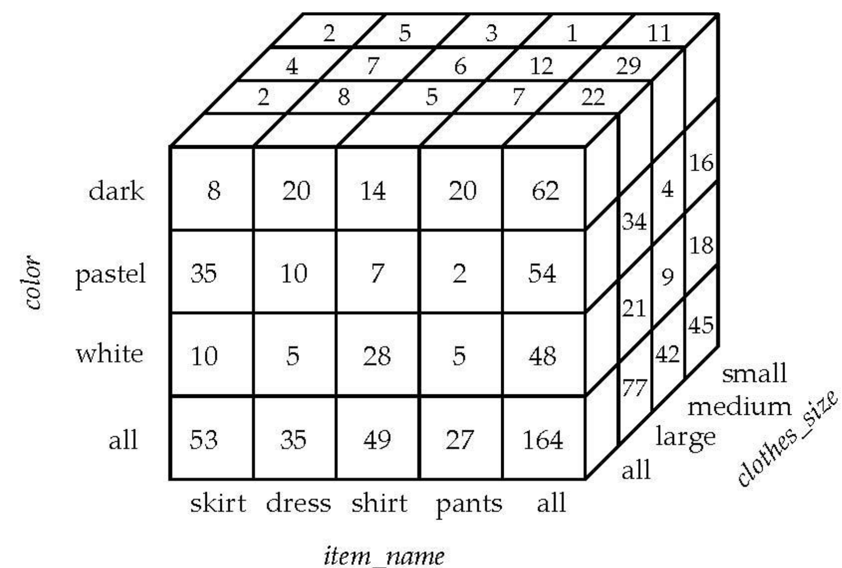
RDBMS vs OLAP

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

```
select item_name, color, clothes_size, sum(quantity)
from sales
group by cube(item_name, color, clothes_size);
```

이런 SQL Query의 도움을 받아서!!!!



3D Data Cube of sales relation

OLAP Operations

- **Cube: union of groups of every subset combination of specified attributes**
- **Pivoting:** changing the dimensions used in a cross-tab
- **Slicing:** creating a cross-tab for fixed values only
  - Sometimes called **dicing**, particularly when values for multiple dimensions are fixed.
- **Rollup:**
  - **union of groups of every prefix combination of specified attributes**
  - 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

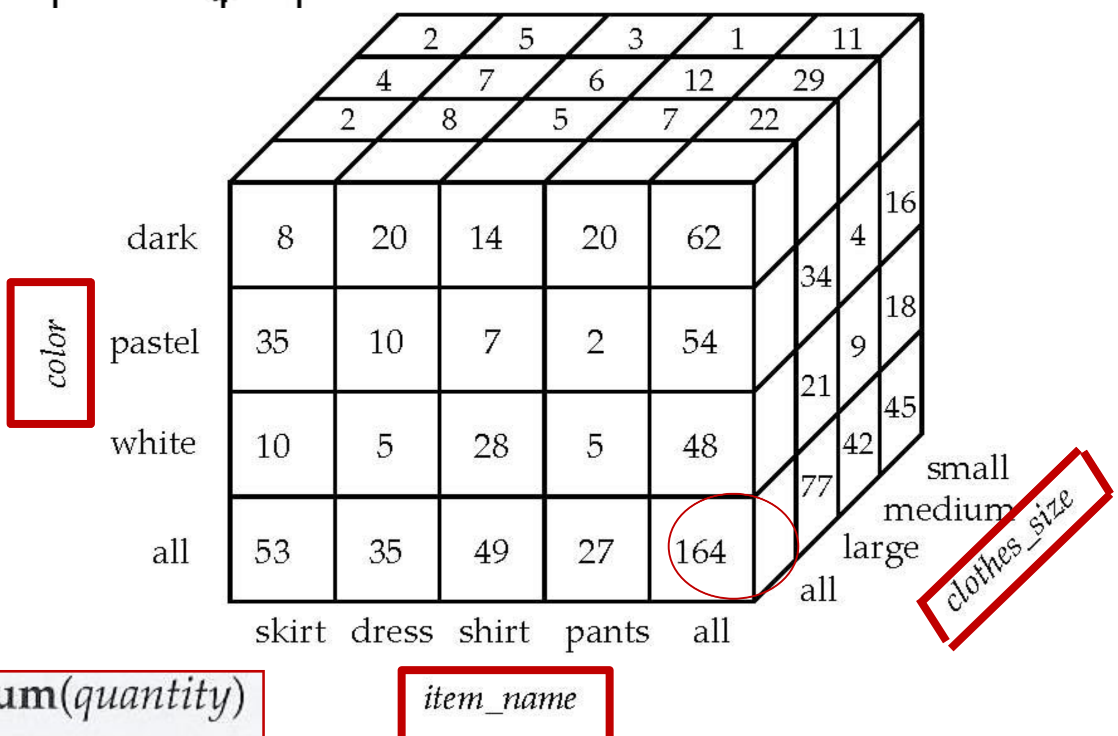
Data Cube

- 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

item_name	*color*	*clothes_size*	*quantity*
skirt	dark	small	2
skirt	dark	medium	5
skirt	dark	large	1

4 items, 3 colors, 3 sizes need (4+1)X(3+1)X(3+1) = 80 cells in the data cube

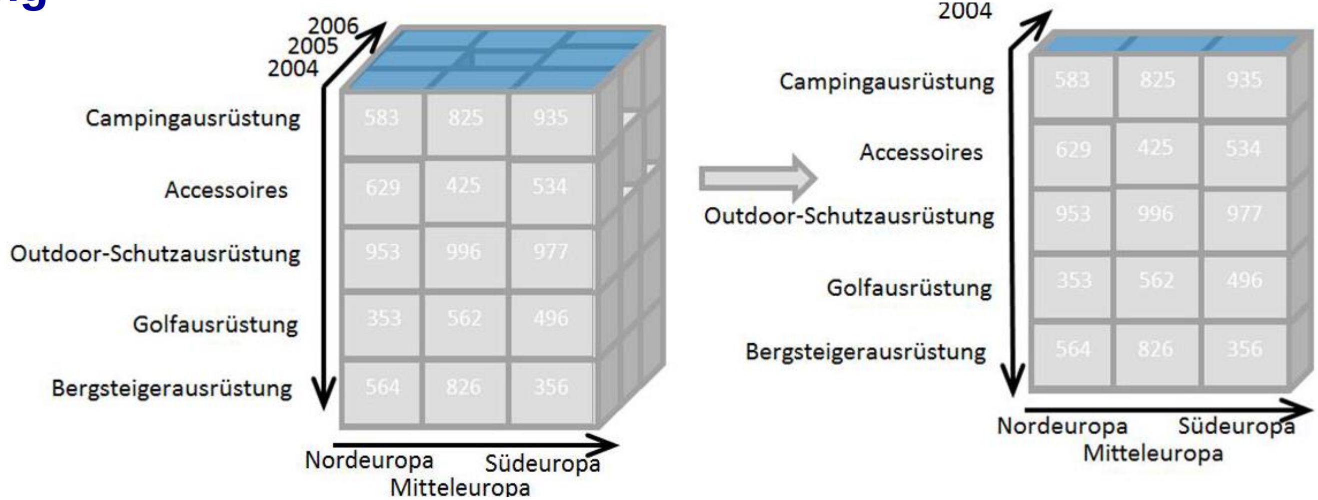
Dimension attributes
Measure attribute



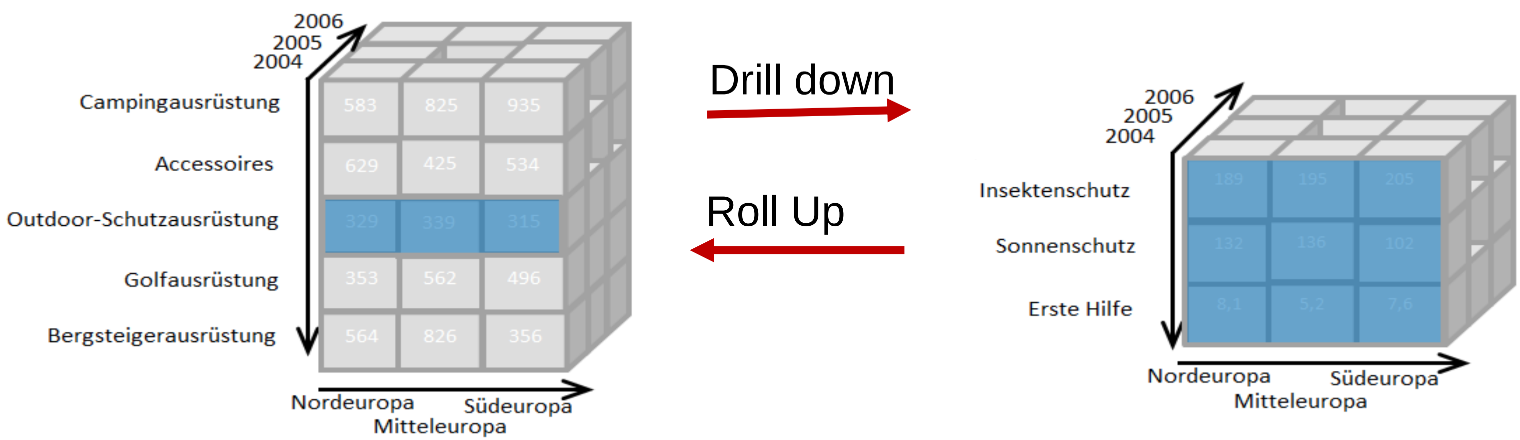

```
select item_name, color, clothes_size, sum(quantity)
from sales
group by cube(item_name, color, clothes_size);
```

OLAP Operations on Data Cube

- ## Slicing



- ## Rollup & Drill down



PIVOT operation in SQL

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
shirt	dark	large	6
shirt	pastel	small	4
shirt	pastel	medium	1
shirt	pastel	large	2
shirt	white	small	17
shirt	white	medium	1
shirt	white	large	10
pant	dark	small	14
pant	dark	medium	6
pant	dark	large	0
pant	pastel	small	1
pant	pastel	medium	0
pant	pastel	large	1
pant	white	small	3
pant	white	medium	0
pant	white	large	2

color attribute를 pivot으로 하고 sales relation을 재배치

```
select *
from sales
pivot (
    sum(quantity)
    for color in ('dark','pastel','white')
)
order by item_name;
```

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

Cube operation in SQL: Union of group by's on every subset of the specified attributes

- *sales*(*item_name, color, clothes_size, quantity*)
- E.g. consider the query

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

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

{ (*item_name, color, clothes_size*), # 3 dimension attributes

(*item_name, color*), (*item_name, clothes_size*), (*color, clothes_size*), # 2 dimension attributes

(*item_name*), (*color*), (*clothes_size*), # 1 dimension attribute

( ) } # 0 dimension attribute where ( ) denotes an empty **group by** list.

- For each grouping, the result contains the null value for attributes not present in the grouping.
- The resulting cube relation will have 80 cells from 4 items, 3 colors, 3 sizes data
  - 4 items, 3 colors, 3 sizes need (4+1)X(3+1)X(3+1) = 80 cells in the data cube
- Union of **group by**'s on every subset of the specified attributes
- 위 SQL Query 결과물은 80 cells

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

총 80 tuples

item_name, *color*, *clothes_size*, **sum**(*quantity*)
Item_name 4가지, Color 3가지, Clothes_size 3가지
총 36 combinations → 36 tuples

Original 36 tuples in sales relation

+

Item_name, color, "all", sum(quantity)
Item_name 4가지, Color 3가지, Clothes_size "all"
총 12 combinations → 12 tuples

skirt	dark	all	8
skirt	pastel	all	35
skirt	white	all	10
dress	dark	all	20
dress	pastel	all	10
dress	white	all	5
shirt	dark	all	14
shirt	pastel	all	7
shirt	White	all	28
pant	dark	all	20
pant	pastel	all	2
pant	white	all	5

Item_name, "all", *clothes_size*, sum(quantity)
Item_name 4가지, Color "all", Clothes_size 3가지
총 12 combinations → 12 tuples

"all", color, *clothes_size*, sum(quantity)
Item_name "all", Color 3가지, Clothes_size 3가지
총 12 combinations → 9 tuples

Item_name, "all", "all", sum(quantity)
Item_name 4가지, Color "all", Clothes_size "all"
총 12 combinations → 4 tuples

skirt	all	all	53
dress	all	all	35
shirt	all	all	49
pant	all	all	27

"all", color, "all", sum(quantity)
Item_name "all", Color 3가지, Clothes_size "all"
총 4 combinations → 3 tuples

"all", "all", *clothes_size* , sum(quantity)
Item_name "all", Color "all", Clothes_size 3가지
총 4 combinations → 3 tuples

"all", "all", "all", sum(quantity)
Item_name "all", Color "all", Clothes_size "all"
총 1 combination → 1 tuple

all	all	all	164

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

총 20 tuples

Item_name, color, “all”, sum(quantity)
Item_name 4가지, Color 3가지, Clothes_size “all”
총 12 combinations ➔ 12 tuples

Item_name, “all”, “all”, sum(quantity)
Item_name 4가지, Color “all”, Clothes_size “all”
총 12 combinations ➔ 4 tuples

“all”, color, “all”, sum(quantity)
Item_name “all”, Color 3가지, Clothes_size “all”
총 4 combinations ➔ 3 tuples

“all”, “all”, “all”, sum(quantity)
Item_name “all”, Color “all”, Clothes_size “all”
총 1 combination ➔ 1 tuple

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

Roll Up [1/2]

Union on every prefix of specified attributes

- E.g., **select** *item_name*, *color*, *clothes_size*, **sum**(*quantity*)
  from *sales*
  group by rollup(*item_name, color, clothes_size*)

총 36+17=
53 tuples

- Generates union of 4 groupings of every prefix of specified attributes:
  { (*item_name, color, clothes_size*), (*item_name, color*), (*item_name*), ( ) }

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
shirt	dark	large	6
shirt	pastel	small	4
shirt	pastel	medium	1
shirt	pastel	large	2
shirt	white	small	17
shirt	white	medium	1
shirt	white	large	10
pant	dark	small	14
pant	dark	medium	6
pant	dark	large	0
pant	pastel	small	1
pant	pastel	medium	0
pant	pastel	large	1
pant	white	small	3
pant	white	medium	0
pant	white	large	2

item_name, *color*, *clothes_size*, **sum**(*quantity*)
Item_name 4가지, Color 3가지, Clothes_size 3가지
총 36 combinations ➔ 36 tuples

\+

Item_name, color, “all”, sum(quantity)
Item_name 4가지, Color 3가지, Clothes_size “all”
총 12 combinations ➔ 12 tuples

\+

Item_name, “all”, “all”, sum(quantity)
Item_name 4가지, Color “all”, Clothes_size “all”
총 4 combinations ➔ 4 tuples

\+

“all”, “all”, “all”, sum(quantity)
Item_name “all”, Color “all”, Clothes_size “all”
총 1 combination ➔ 1 tuple

Original 36 tuples

\+

skirt	dark	all	8
skirt	pastel	all	35
skirt	white	all	10
dress	dark	all	20
dress	pastel	all	10
dress	white	all	5
shirt	dark	all	14
shirt	pastel	all	7
shirt	White	all	28
pant	dark	all	20
pant	pastel	all	2
pant	white	all	5
skirt	all	all	53
dress	all	all	35
shirt	all	all	49
pant	all	all	27
all	all	all	164

Roll Up [2/2]

- E.g., **select** *item_name*, *color*, **sum**(*quantity*)
  from *sales*
  group by rollup(*item_name, color*)
- Generates union of 3 groupings of every prefix of specified attributes:

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

총 17 tuples

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
shirt	dark	large	6
shirt	pastel	small	4
shirt	pastel	medium	1
shirt	pastel	large	2
shirt	white	small	17
shirt	white	medium	1
shirt	white	large	10
pant	dark	small	14
pant	dark	medium	6
pant	dark	large	0
pant	pastel	small	1
pant	pastel	medium	0
pant	pastel	large	1
pant	white	small	3
pant	white	medium	0
pant	white	large	2

Item_name, color, sum(quantity)
Item_name 4가지, Color 3가지, Clothes_size “all”
총 12 combinations ➔ 12 tuples

+

Item_name, “all”, sum(quantity)
Item_name 4가지, Color “all”, Clothes_size “all”
총 4 combinations ➔ 4 tuples

+

“all”, “all”, sum(quantity)
Item_name “all”, Color “all”, Clothes_size “all”
총 1 combination ➔ 1 tuple

skirt	dark	8
skirt	pastel	35
skirt	white	10
dress	dark	20
dress	pastel	10
dress	white	5
shirt	dark	14
shirt	pastel	7
shirt	White	28
pant	dark	20
pant	pastel	2
pant	white	5
skirt	all	53
dress	all	35
shirt	all	49
pant	all	27
all	all	164

Roll Up with Hierarchy

- E.g., suppose we have a table *itemcategory(category, item_name)* 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*

(category,	item_name)
wowenswear,	skirt
wowenswear,	dress
menswear,	pants
menswear,	pants

Item_name

category

Itemcategory hierarchy

womenswear	skirt	dark	8
womenswear	skirt	pastel	35
womenswear	skirt	white	10
womenswear	dress	dark	20
womenswear	dress	pastel	10
womenswear	dress	white	5
menswear	shirt	dark	14
menswear	shirt	pastel	7
menswear	shirt	White	28
menswear	pant	dark	20
menswear	pant	pastel	2
menswear	pant	white	5
womenswear	skirt	all	53
womenswear	dress	all	35
menswear	shirt	all	49
menswear	pant	all	27
	all	all	164

We can easily get this!

clothes_size: **all**

category	*item_name*	dark	pastel	white	total	
womenswear	skirt	8	8	35	53	
	dress	20	20	10	35	
	subtotal	28	28	45		88
menswear	pants	14	14	7	49	
	shirt	20	20	2	27	
	subtotal	34	34	9		76
total		62	62	54		164

Summary Table using Cube & Rollup

Sales Relation

Shop Addr	State	Year	amt_ paid
LA	CA	2011	300
SF	CA	2011	200
LA	CA	2012	350
SD	CA	2011	130
NY	NY	2012	300
Qeens	NY	2012	200
…	….	….	…..

Rollup

```
select state, year, sum(amt_paid)
from sales
group by rollup(state, year)
```

State	Year	Sum
CA	2011	20000
CA	2012	25000
CA	*	45000
NY	2012	15000
NY	*	15000
*	*	60000

{State, Year} {State} {} 를 subset으로 생성

Cube

```
select state, year, sum(amt_paid)
from sales
group by cube(state, year)
```

State	Year	Sum
CA	2011	20000
CA	2012	25000
CA	*	45000
NY	2012	15000
NY	*	15000
*	*	60000
*	2011	20000
*	2012	40000

{State, Year} {State} {Year} {} 를 subset으로 생성

Relation with "null" to Cross-tab with "all"

- Relational representation of cross-tab (in next slide) 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*)

- 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*)

Multiple Rollups & Cubes

- 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*), ( ) }

Figure 5.22: Result of SQL pivot operation on sales relation of Fig 5.16

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

Figure 5.23: Query Result

item_name	*quantity*
skirt	53
dress	35
shirt	49
pant	27

Figure 5.24: Query Result

item_name	*color*	*quantity*
skirt	dark	8
skirt	pastel	35
skirt	white	10
dress	dark	20
dress	pastel	10
dress	white	5
shirt	dark	14
shirt	pastel	7
shirt	white	28
pant	dark	20
pant	pastel	2
pant	white	5

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

- Early OLAP systems precomputed *all* possible aggregates in order to provide online response
  - Space and time requirements for doing so can be very high
    - Cube operation needs 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*)
    - Can compute aggregates on (*item_name, color, size*), (*item_name, color*) and (*item_name*) using a single sorting of the base data