SQL

- Structured Query Language
- Declarative
  - Specify the properties that should hold in the result, not how to obtain the result
  - Complex queries have procedural elements
- International Standard
  - SQL1 (1986)
  - SQL2 (SQL-92)
  - SQL3 (pieces have started to appear; also known as SQL-99)
- Two components
  - DDL statements
  - DML statements

SQL DDL Statements

- Create schema

  CREATE SCHEMA Schema_Name **AUTHORIZATION** User_Name

- Create table
  - Specify a new relation scheme
  - General form

```
CREATE TABLE <Table_Name>
(Attribute_1 <Type>[DEFAULT <value>][<Null constraint>],
 Attribute_2 <Type>[DEFAULT <value>][<Null constraint>],
  …
 Attribute_n <Type>[DEFAULT <value>][<Null constraint>],
[<Constraints>])
```

Example

- Design
  Emp (Eno, Ename, Title, City)
  Project(Pno, Pname, Budget, City)
  Pay(Title, Salary)
  Works(Eno, Pno, Resp, Dur)
- Definition of **Project**

```
CREATE TABLE Project
  (Pno      CHAR(3),
   Pname    VARCHAR(20),
   Budget   DECIMAL(10,2)DEFAULT 0.00
   City     CHAR(9));
```

- Assume others are defined similarly.

Allowable Data Types

- Numeric
  - INT, SHORTINT
  - REAL (FLOAT), DOUBLE PRECISION
  - DECIMAL(*i*,*j*)
- Character-string
  - CHAR(*n*), VARCHAR(*n*)
- Bit-string
  - BIT(*n*), BIT VARYING(*n*)
- Date
  - YYYY-MM-DD
- Time
  - HH:MM:SS
- Timestamp
  - both DATE and TIME fields plus a minimum of six positions for fractions of seconds

User-Defined Types

- Create a DOMAIN

```
CREATE DOMAIN <domain_name> AS
  <primitive_type>
```

- Example

```
CREATE DOMAIN Gender AS CHAR(1)
```

- Generally useful only for easy modification of type specification.
- The value can be defaulted by the DEFAULT specification

Attribute Constraints

- Not null
  - Specifies that an attribute cannot contain null values
- Unique
  - Specifies that an attribute cannot contain duplicates
- Primary key
  - Designates a set of columns as the table's primary key
  - Implies UNIQUE and NOT NULL
- Foreign key
  - Designates a set of columns as the foreign key in a referential constraint

Example

- Given
  Emp (Eno, Ename, Title, City)
  Project(Pno, Pname, Budget, City)
  Pay(Title, Salary)
  Works(Eno, Pno, Resp, Dur)
- Enhance the previous definition of **Project**:

```
CREATE TABLE Project
  (Pno      CHAR(3),
   Pname    VARCHAR(20),
   Budget   DECIMAL(10,2)DEFAULT 0.00
   City     CHAR(9));
   PRIMARY KEY (PNO));
```

Referential Constraints

- REFERENTIALLY TRIGGERED ACTION
  - Referential integrity: A key of one relation appears as an attribute (foreign key) of another relation.
  - Example:
    Emp (Eno, Ename, Title, City)
    Pay(Title, Salary)
  - Deletion or update of primary key tuple requires action on the foreign key tuple. Specify constraint on delete or update.
  - How to manage?
    - reject
    - cascade: (on delete) automatically remove foreign keys if a referenced key is removed or (on update) change the foreign key value to the new value of the referenced key
    - set null
    - set default

Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Works(Eno, Pno, Resp, Dur)

- Definition of deposit

```
CREATE TABLE Works
  (Eno        CHAR(3),
   Pno        CHAR(3),
   Resp       CHAR(15),
   Dur        INT,
PRIMARY KEY (Eno,Pno),
FOREIGN KEY (Eno) REFERENCES Emp(Eno)
  ON DELETE SET NULL
  ON UPDATE CASCADE,
FOREIGN KEY (Pno) REFERENCES Project(Pno));
```

Other SQL DDL Commands

- DROP SCHEMA
  - Delete an entire schema
  - CASCADE: delete all the tables in the schema
  - RESTRICT: delete only if empty
- DROP TABLE
  - RESTRICT: delete only if not referenced in a constraint
- ALTER TABLE
  - change definition

SQL Queries

- Basic SQL structure

  SELECT $A_1, A_2, \ldots, A_n$
  FROM $R_1, R_2, \ldots, R_m$
  WHERE P

  where

  A_i are attributes from…

  R_i which are relations

  P is a predicate

  * can replace A_i's if all attributes are to be retrieved

What Kind of Predicates?

- Simple predicates:
  - Expression θ Value where Expression can be an attribute or an arithmetic expression involving attributes θ = {<, >, =, <=, >=, <>} and Value can be from one of the data types
  - Example:
    - Name = 'J. Doe'
    - (Age + 30) >= 65
- Compound predicates
  - Simple predicates combined with logical connectives AND, OR, NOT

Example Simple Queries

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- List names of all employees.

```
SELECT  Ename
FROM    Emp
```

- List names of all projects together with their budgets.

```
SELECT  Pname, Budget
FROM    Project
```

- Find all cities where at least one project exists.

```
SELECT  DISTINCT City
FROM    Project
```

Queries With Predicates

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find all professions that make more than $50,000.

```
SELECT Title
FROM   Pay
WHERE  Salary > 50000
```

- Find all employees who work on a project as managers for longer than 17 months.

```
SELECT Eno
FROM   Works
WHERE  Dur > 17 AND Resp='Manager'
```

Ordering the Results

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the names and budgets of all projects with budget greater than $250,000 and order the result in ascending order of budget values.

```
SELECT    Pname, Budget
FROM      Project
WHERE     Budget > 250000
ORDER BY  Budget
```

- Default is ascending order, but descending order can be specified by the DESC keyword.

Queries Over Multiple Relations

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- List the name and titles of all employees who work on a project for more than 17 months.

```
SELECT Ename, Title
FROM   Emp, Works
WHERE  Dur > 17
AND    Emp.Eno = Works.Eno
```

- Find the name and titles of all employees who work on a project located in Waterloo.

```
SELECT Ename, Title
FROM   Emp E,Works W,Project P
WHERE  P.City = 'Waterloo'
AND    E.Eno = W.Eno
AND    W.Pno = P.Pno
```

Queries Over Multiple Relations

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- List the pairs of employees and projects that are co-located.

```
SELECT  Eno, Pno
FROM    Emp, Project
WHERE   Emp.City = Project.City
```

- List the pairs of employee names who are located in the same city.

```
SELECT  E1.Ename, E2.Ename
FROM    Emp E1, Emp E2
WHERE   E1.City = E2.City
```

Queries Involving Set Operators

- UNION, EXCEPT (MINUS), INTERSECT
- Operands may be specified by
  - create temp relations

```
ASSIGN TO  temp-1                ASSIGN TO  temp-1
SELECT A1, ..., An               SELECT B1, ..., Bp
FROM   R1, ..., Rm               FROM   S1, ..., Sr
WHERE  P;                        WHERE  Q;
temp-1 UNION temp-2;
```

  - use parentheses

```
(SELECT A1, ..., An
FROM   R1, ..., Rm
WHERE  P)
UNION
(SELECT B1, ..., Bp
FROM   S1, ..., Sr
WHERE  Q);
```

Queries With Set Operators

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find all cities where there is either an employee or a project.

```
(SELECT    City
FROM       Emp)
UNION
(SELECT    City
FROM       Project)
```

- Find all cities in which an employee works but no projects are located.

```
(SELECT    City
FROM       Emp)
EXCEPT
(SELECT    City
FROM       Project)
```

Queries With Set Operators

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find all cities where there is both an employee and a project.

```
(SELECT    City
FROM       Emp)
INTERSECT
(SELECT    City
FROM       Project)
```

- List names of all projects and employees in Waterloo.

```
(SELECT    Ename
FROM       Emp
WHERE      City = 'Waterloo')
UNION ALL
(SELECT    Pname
FROM       Project
WHERE       City = 'Waterloo')
```

Queries With Nested Structures

- Queries within the WHERE clause of an outer query

```
SELECT
FROM
WHERE   OPERATOR
        (SELECT
         FROM
         WHERE)
```

- There can be multiple levels of nesting
- These can usually be written using other constructs (UNION, JOIN, etc).
- Three operators: IN, (NOT) EXISTS, [CONTAINS]

"IN" Construct

```
SELECT
FROM
WHERE A1, ..., An IN
                    (SELECT A1, ..., An
                     FROM   R1, ..., Rm
                     WHERE  P)
```

- Semantics: Tuples with attributes A_1, ..., A_n are found in the relation that is returned as a result of the calculation of the inner query.
- Other comparison operators {<, <=, >, >=, <>} can be used with ALL or with ANY in place of IN.

"IN" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find names of all employees who work in cities where projects with budgets less than $50,000 are located.

```
SELECT Ename
FROM   Emp
WHERE  City   IN
              (SELECT City
               FROM   Project
               WHERE  Budget < 50000)
```

"IN" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find names of all employees who work in a city where a project is located or are in a profession that pays more than $60,000.

```
SELECT  Ename
FROM    Emp
WHERE   City   IN (SELECT City
                   FROM   Project )
OR
        Title  IN (SELECT Title
                   FROM   Pay
                   WHERE  Salary > 60000)
```

"IN" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the names of all the projects that have budgets greater than all projects in Calgary.

```
SELECT    Pname
FROM      Project
WHERE     Budget   > ALL
                 (SELECT   Budget
                  FROM     Project
                  WHERE    City = 'Calgary')
```

- One can use ANY if what is desired is to find projects whose budget is greater than some project in Calgary.

"EXISTS" Construct

```
SELECT
FROM
WHERE (NOT) EXISTS
        (SELECT  *
         FROM    R1, ..., Rm
         WHERE   P)
```

- Semantics: For each tuple of the outer query, execute the inner query; if there is at least one (no) tuple in the result of the inner query, then retrieve that tuple of the outer query.
- This accounts for the "there exists" type of queries

"EXISTS" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the names of employees who work in a city in which some project is located.

```
SELECT   Ename
FROM     Emp
WHERE EXISTS (SELECT *
              FROM   Project
              WHERE  Emp.City=Project.City)
```

- Find the names of employees who work in a city in which no project is located.

```
SELECT   Ename
FROM     Emp
WHERE NOT EXISTS (SELECT *
                  FROM   Project
                  WHERE  Emp.City=Project.City)
```

"EXISTS" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the names and titles of all the employees who do not work in a project.

```
SELECT   Ename, Title
FROM     Emp
WHERE NOT EXISTS
         (SELECT *
          FROM   Works
          WHERE  Emp.Eno = Works.Eno)
```

"EXISTS" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find all the employees who work on every project.
  - Find all employees such that there is no project on which they do not work

```
SELECT *
FROM   Emp
WHERE NOT EXISTS
     (SELECT    Pno
      FROM      Project
      WHERE NOT EXISTS
        (SELECT *
         FROM   Works
         WHERE  Project.Pno=Works.Pno
         AND    Emp.Eno = Works.Eno))
```

Tuple Calculus and SQL

- Basic SQL Query:

  SELECT $A_1, A_2, \ldots, A_n$

  FROM $R_1, R_2, \ldots, R_m$

  WHERE $P(R_1, R_2, \ldots, R_m)$

- Tuple Calculus

$$\{t[A_1], \ldots, t[A_n] \mid \exists r_1 \in R_1, \ldots, \exists r_k \in R_k \; (\wedge_j \, t(A_j) = r_{ij}(A_j)) \wedge P(r_1, \ldots, r_k)\}$$

- Note: Basic SQL query uses only $\exists$; No explicit construct for $\forall$

Tuple Calculus & SQL

- Example: "Find all the employees who work on every project."
- Tuple Calculus

$$\{e \mid e \in \text{Emp} \ \wedge \forall\, p \in \text{Project}\ (\exists\, w \in \text{Works}\ (p[\text{Pno}] = w[\text{Pno}] \wedge w[\text{Pno}] = e[\text{Pno}]))\}$$

- Eliminate $\forall$: $\forall x\, F(x) \equiv \neg\exists x \neg F(x)$

$$\{e \mid e \in \text{Emp} \wedge \neg\exists\, p \in \text{Project}\ \neg(\exists\, w \in \text{Works}\ (p[\text{Pno}] = w[\text{Pno}] \wedge w[\text{Pno}] = e[\text{Pno}]))\}$$

Tuple Calculus & SQL

- Convert to SQL Query
  - Basic Rule: One level of nesting for each "¬ ∃"
- The corresponding SQL query becomes:

```
SELECT   *
FROM     Emp
WHERE NOT EXISTS
      (SELECT Pno
       FROM   Project
       WHERE NOT EXISTS
           (SELECT  *
            FROM  Works
            WHERE Project.Pno=Works.Pno
            AND   Emp.Eno = Works.Eno))
```

"CONTAINS" Construct

```
(SELECT A1, ..., An
FROM    R1, ..., Rm
WHERE   P)
CONTAINS
(SELECT B1, ..., Bp
FROM    S1, ..., Sr
WHERE   Q)
```

- Semantics: Compare the result relations of the two queries and return TRUE if the second one is a subset of the first.

"CONTAINS" Construct Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find all the employees who work on all the projects located in Edmonton.

```
SELECT   *
FROM     Emp
WHERE  (  (SELECT Pno
           FROM   Works
           WHERE  Emp.Eno = Works.Eno)
          CONTAINS
          (SELECT Pno
           FROM   Project
           WHERE  City = 'Edmonton'))
```

Aggregate Functions

- Specify a function that calculates a numeric value from a given relation.
  - The function is usually applied to an attribute.
  - COUNT, SUM, MAX, MIN, AVG

```
SELECT AggFunc(A_i), …, AggFunc(A_j)
FROM   R_1, ..., R_m
WHERE  P
```

Aggregate Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the total budgets of projects in Waterloo.

```
SELECT SUM(Budget)
FROM   Project
WHERE  City = 'Waterloo'
```

- Find the number of cities where there is a project on which employee E4 works.

```
SELECT COUNT(DISTINCT  City)
FROM   Project, Works
WHERE  Project.Pno = Works.Pno
AND    Works.Eno = E4'
```

Aggregate Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the names of projects which have budgets greater than the average budget of all the projects.

```
SELECT  Pname
FROM    Project
WHERE   Budget >
        (SELECT  AVG(Budget)
         FROM    Project)
```

Grouping Queries

- Group the results according to a set of attributes

```
SELECT  A_i, …, A_n
FROM    R_1, . . . , R_m
WHERE   P
GROUP BY A_j …, A_k
```

- Rules:
  - All of the attributes in the SELECT clause that are not involved in an aggregation operation have to be included in the GROUP BY clause.
  - GROUP BY can have more attributes ($k \geq n$)

Predicates on Groups

- Group the results according to a set of attributes if they satisfy a certain condition

```
SELECT   A_i, …, A_n
FROM     R_1, ..., R_m
WHERE    P
GROUP BY A_j …, A_k
HAVING   Q
```

- Rules:
  - Q must have a single value per group.
  - An attribute in Q has to either appear in an aggregation operator or be listed in the GROUP BY

Grouping Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the cities in which more than 2 employees live.

```
SELECT     City
FROM       Emp
GROUP BY   City
HAVING     COUNT(*) > 2
```

- Find the projects on which more than 2 employees share a responsibility.

```
SELECT DISTINCT      Pno
FROM       Works
GROUP BY   Pno,Resp
HAVING     COUNT(*) > 2
```

Grouping Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- For each city where there are more than three projects, find the names of projects.

```
SELECT    City, Pname
FROM      Project
WHERE     City IN
          (SELECT  City
           FROM    Project
           GROUP BY City
           HAVING  COUNT(*) > 3)
```

Grouping Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Find the cities and the total budget where the average project budget is greater than $120,000.

```
SELECT    City, SUM(Budget)
FROM      Project
GROUP BY  City
HAVING    AVG(Budget) > 120000
```

Grouping Query Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- For each project that employs more than 2 programmers, list the project number and the average duration of assignment of the programmers.

```
SELECT    Pno, AVG(Dur)
FROM      Works
WHERE     Resp = 'Programmer'
GROUP BY  Pno
HAVING    COUNT(*) > 2
```

Update Commands

- Assume $R(A_1, \ldots, A_n)$
- INSERT
  - Form

```
INSERT INTO R
VALUES      (value(A1), …, value(An))
```

  - Explicitly specify attribute names

```
INSERT INTO R(Ai, …, Ak)
VALUES      (value(Ai), …, value(Ak))
```

  - Insert a set of tuples as well

```
INSERT INTO R (
               QUERY)
```

Update Command Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Insert a new employee record for John Smith who is assigned number E24, is a programmer and works in Waterloo.

```
INSERT INTO Emp(Eno, Ename, Title, City)
VALUES ('E24','John Smith','Programmer,'Waterloo')
```

- Insert into Pay tuples for titles that exist in Emp; set salary to $0.

```
INSERT INTO Pay
            (SELECT    Title, 0
             FROM      Emp)
```

Update Commands

- DELETE

```
DELETE FROM   R
WHERE         P
```

- Delete all the employees who have worked on project P3 for less than 3 months.

```
DELETE FROM Emp
WHERE       Eno IN
            (SELECT   Eno
             FROM     Works
             WHERE    Dur < 3)
```

Update Commands

- Assume $R(A_1, \ldots, A_n)$
- UPDATE

```
UPDATE R
SET    A_i=value, …, A_k=value
WHERE  P
```

Update Command Examples

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Increase by 5% the budgets of projects that are located in Edmonton and employ 3 or more people.

```
UPDATE      Project
SET         Budget = Budget*1.05
WHERE       City = 'Edmonton'
AND         Pno IN
            (SELECT     Pno
             FROM       Works
             GROUP BY   Pno
             HAVING     COUNT(*) >= 3)
```

View Definition

- General form

```
CREATE VIEW    V[(A_i, …, A_k)]
AS     SELECT  A_1, …, A_n
       FROM    R_1, …, R_m
       WHERE   P
```

- In queries, treat view V as any base relation

```
SELECT A_j, …, A_l
FROM   V
WHERE  Q
```

- Updates of views may be restricted

View Definition Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Create a view Waterloo-Projects of projects that are located in Waterloo.

```
CREATE VIEW waterloo-projects
AS  SELECT  *
    FROM    Project
    WHERE   City = 'Waterloo'
```

- Create a view Rich-Employees consisting of employees who make more than $75,000.

```
CREATE VIEW rich-employees
AS  SELECT  Eno, Ename, Title, City
    FROM    Emp, Pay
    WHERE   Salary > 75000
    AND     Emp.Title = Pay.Title
```

View Definition Example

Emp (Eno, Ename, Title, City)
Project(Pno, Pname, Budget, City)
Pay(Title, Salary)
Works(Eno, Pno, Resp, Dur)

- Create a view project-employ that gives, for each project at each city, the number of employees who work on the project and their total employment duration.

```
CREATE VIEW  project-employ(Name, City, Number, Total)
AS  SELECT   Pname, City, COUNT(Eno), SUM(Dur)
    FROM     Project P, Works W
    WHERE    P.Pno = W.Pno
    GROUP BY City,Pname
```

View Update

- A view with a single defining table is updatable if the view attributes contain the primary key or some other (non-null) candidate key.
- Views defined on multiple tables using joins are generally not updatable.
- Views defined using aggregate functions are not updatable.

View Management

- Two strategies for view management
  - Query modification
    - A view is a virtual relation
    - Multiple queries on complex views
    - Query processor modifies a query on a view with the view definition
  - View materialization
    - View is a materialized table in the database
    - Incrementally update the view (update propagation)

Handling Nulls

- Attribute values can be `NULL`
- `NULL` is not a constant, nor can it be used as an operand
  - NAME = `NULL` Wrong!
  - `NULL` + 30 Wrong!
- Operating on variables with `NULL` values
  - If *x* is `NULL`
    - *x* <arithmetic op.> constant is `NULL`
    - *x* <arithmetic op.> *y* is `NULL`
  - Comparing a NULL value with any other value returns UNKNOWN (three-valued logic).
  - In SQL, UNKNOWN is sometimes treated as false (SELECT) and sometimes as true (constraints).

Outer Join

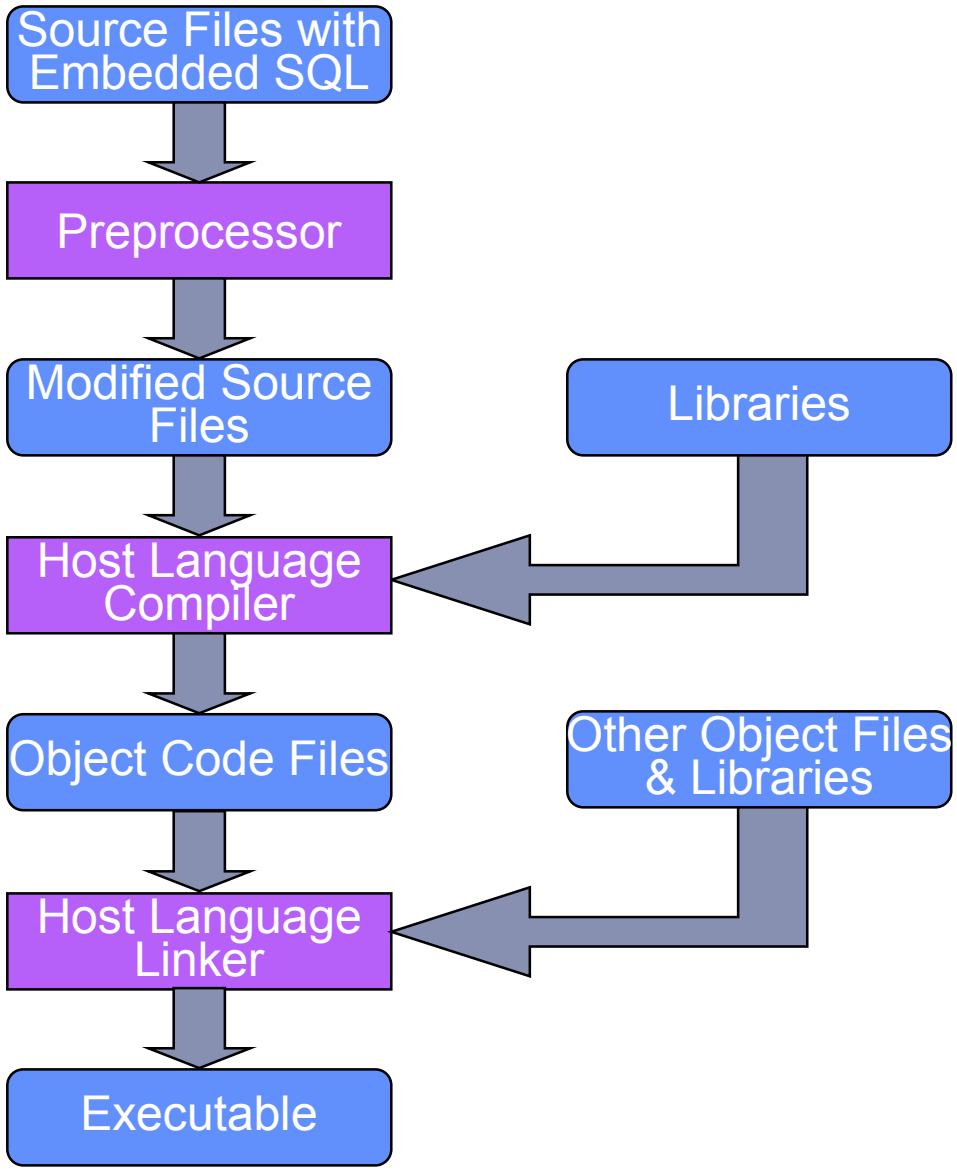
- Ensures that tuples from one or both relations that do not satisfy the join condition still appear in the final result with other relation's attribute values set to NULL
- Extend SQL2 join expression
  - `R [NATURAL] JOIN S [ON <condition>]`

  to provide
  - `R [NATURAL] FULL OUTER JOIN S [ON <condition>]`
  - `R [NATURAL] LEFT OUTER JOIN S [ON <condition>]`
  - `R [NATURAL] RIGHT OUTER JOIN S [ON <condition>]`
- Example: Find the employees and the projects that they work on.
  - `Emp NATURAL LEFT OUTER JOIN Works`
  - Produces employees even if they do not work on any project at the moment.

Embedded SQL

- Ability to access a database from within an application program.
- Why?
  - SQL is not sufficient to write general applications
- SQL has bindings for various programming languages.
  - C, C++, Java
  - Bindings describe how applications written in these host languages can interact with a DBMS.

Embedded SQL Application Development



Embedded SQL Issues

- Interface
  - The same as ad hoc SQL but with `EXEC SQL` command
- Using query results within the application program
  - Define shared variables using the format allowed in host language
  - Shared variables can be used in `INSERT`, `DELETE`, `UPDATE` as well as regular queries and schema modification statements
  - Retrieval queries require care
    - If the result relation has a single tuple: Each value in the SELECT statement requires a shared variable
    - If the result relation has a set of tuples: Cursor has to be defined

Example for Update

- Consider an example to transfer some amount from one project's budget to another project's budget.

```
#include <stdio.h>
EXEC SQL INCLUDE SQLCA;
main() {
     EXEC SQL WHENEVER SQLERROR GOTO error:
     EXEC SQL CONNECT TO Company;
     EXEC SQL BEGIN DECLARE SECTION;
       int pno1[3], pno2[3]; /* two project numbers */
       int amount; /* amount to be transferred */
     EXEC SQL END DECLARE SECTION;
     /* Code (omitted) to read the project numbers and amount */
     EXEC SQL UPDATE Project
       SET Budget = Budget + :amount
       WHERE Pno = :pno2;
     EXEC SQL UPDATE Project
       SET Budget = Budget - :amount
       WHERE Pno = :pno1;
     EXEC SQL COMMIT RELEASE;
     return(0);
 error:
     printf("update failed, sqlcode = %ld\n", SQLCODE);
     EXEC SQL ROLLBACK RELEASE;
     return(-1);
 }
```

Termination of SQL Queries

- COMMIT
  - If you want to make your update results permanent.
  - Embedded: `EXEC SQL COMMIT;`
- ROLLBACK
  - If you want to discard your results.
  - Embedded: `EXEC SQL ROLLBACK;`
- We will study the full semantics of these commands later when we look at transactions

Retrieval Queries

- If the result is only one tuple, follow the same approach.
- Example: For a given title, retrieve the salary.

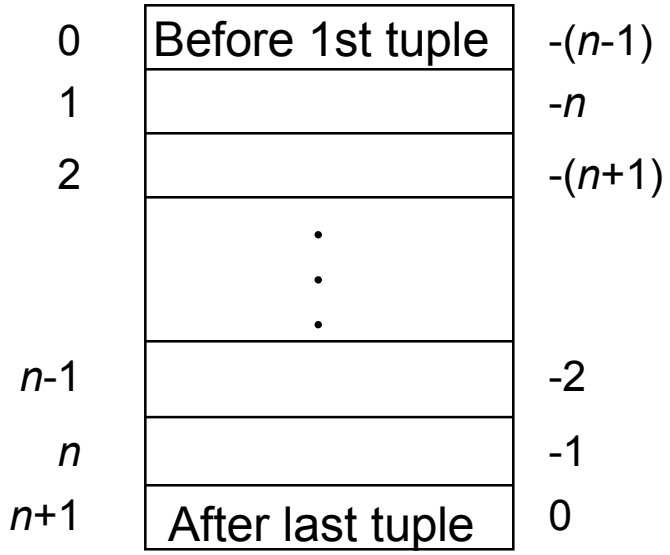
```
…
EXEC SQL BEGIN DECLARE SECTION;
  char title[15]; /* title to be input by user */
  real sal; /* salary */
EXEC SQL END DECLARE SECTION;
…
/* Code (omitted) to get the title from use */
EXEC SQL SELECT Salary
INTO :sal
FROM Pay
WHERE Title = :title;
/* Code (omitted) to print the result */
…
```

More General Retrieval Queries

```
…
EXEC SQL BEGIN DECLARE SECTION;
   <shared variable declarations>
EXEC SQL END DECLARE SECTION;
…
EXEC SQL DECLARE <cursor-name> [options] CURSOR FOR
   <query> [options]
…
EXEC SQL OPEN <cursor-name>
…
while(condition) {
   EXEC SQL FETCH FROM <cursor-name> INTO <shared-
   variable(s)>
   if(tuple exists) process it
   else break
}
EXEC SQL CLOSE <cursor-name>
…
```

Cursors

- Use when the embedded SQL query is expected to return a relation with more than one tuple
- Think about it almost as a pointer to successive tuples in the result relation. At a given moment, it can be
  - Before the first tuple
  - On a tuple
  - After the last tuple



Use of Cursors

1. Declare the cursor
   - Associates a cursor identifier with a query
2. Open the cursor
   - Causes (conceptually) the query to be evaluated, generating a result
3. Fetch one or more tuples using the cursor
   - Each FETCH returns values from the tuple that the cursor is currently "pointing to"
4. Close the cursor

Cursor Declaration &Access

- Declaration

```
EXEC SQL DECLARE <cursor-name>
  [INSENSITIVE][SCROLL] CURSOR FOR <query>
  ORDER BY <attribute(s)>[FOR READ ONLY];
```

INSENSITIVE: The cursor is insensitive to changes in the relations referred to in the query while the cursor is open.

SCROLL: Allows the subsequent FETCH command to retrieve tuples other than the default which is moving forward.

ORDER BY: Orders the results of the query according to some attribute(s).

FOR READ ONLY: Ensures that accesses to the underlying relation(s) via this cursor will not change the relation.

- Access

```
EXEC SQL FETCH[NEXT|PRIOR|FIRST|LAST|RELATIVE[+|-]n | ABSOLUTE[+|-]n]<cursor-name>
  [INTO <var1>,…, <varn>]
```

Cursor Example

- For each project that employs more than 2 programmers, list the project number and the average duration of assignment of programmers.

```
…
EXEC SQL BEGIN DECLARE SECTION;
   char pno[3]; /* project number */
   real avg-dur; /* average duration */
EXEC SQL END DECLARE SECTION;
…
EXEC SQL DECLARE duration CURSOR FOR
     SELECT  Pno, AVG(Dur)
     FROM    Works
     WHERE   Resp = 'Programmer'
     GROUP BY Pno
     HAVING  COUNT(*) > 2;
…
EXEC SQL OPEN duration;
…
while(1) {
   EXEC SQL FETCH FROM duration INTO :pno, :avg-dur
   if(strcmp(SQLSTATE, "02000") then break
   else print the info
}
EXEC SQL CLOSE duration
…
```

Dynamic (Embedded) SQL

- If the exact SQL statement to be executed is not known at the time the application is written, static embedding won't work.
  - E.g., forms-based applications
- In this case, the query can either be input dynamically or it can be parameterized
  - Immediate execution
  - Preparation for later (and multiple) executions
  - Parameterization

Immediate Execution

- General form

```
EXEC SQL EXECUTE IMMEDIATE :string
```

- Example

```
EXEC SQL BEGIN DECLARE SECTION;
char tup[] = "INSERT INTO EMP VALUES('E13', 'John
  Doe',...)";
EXEC SQL END DECLARE SECTION;
EXEC SQL EXECUTE IMMEDIATE :tup;
```

- Rules:
  - `:string` may not return an answer
  - `:string` may not contain parameters
  - Every time `:string` is executed, it is compiled ⇒ high overhead

Prepared Execution

- General form

```
EXEC SQL PREPARE stmt FROM :string
```

- Rules
  - `:string` may return results (it may be a query)
  - `:string` may contain parameters
  - `stmt` is not a host variable, but an identifier of the statement used by the preprocessor
- Example

```
EXEC SQL BEGIN DECLARE SECTION ;
char tup[] = "INSERT INTO EMP VALUES('E13', 'John
  Doe',...)";
EXEC SQL END DECLARE SECTION;
EXEC SQL PREPARE S1 FROM :tup;
EXEC SQL EXECUTE S1;
...
EXEC SQL EXECUTE S1;
```

Parametric Statements

- It is possible to parameterize the strings in dynamic SQL statements
- Use placeholders (or parameter markers) - ? - where literals can appear (not in place of relation names, column names, etc.
  - `INSERT INTO Emp VALUES (?, ?, ?, ?)`
- Indicate that host variable values will replace the placeholders
  - `EXEC SQL EXECUTE S1 USING :eno, :ename, :title, :city`
- USING cannot be used with EXECUTE IMMEDIATE; has to be used with previously prepared statements

Parametric Example - Update

```
…
EXEC SQL BEGIN DECLARE SECTION;
char tup[] = "INSERT INTO Emp VALUES (?,?,?,?);
char eno[3], ename[15], title[10], city[12];
EXEC SQL END DECLARE SECTION;
EXEC SQL PREPARE S1 FROM :tup;
/*code (omitted) to read values into :eno, etc */
EXEC SQL EXECUTE S1 USING :eno, :ename, :title,
   :city;
…
```

Parametric Example - Retrieval (Single Tuple)

```
…
EXEC SQL BEGIN DECLARE SECTION;
char tup[] = "SELECT Salary FROM Pay WHERE Title
= '?'";
char title[15]; /* title to be input by user */
real sal; /* salary */
EXEC SQL END DECLARE SECTION;
EXEC SQL PREPARE S1 FROM :tup;
while (…) {
      /*code (omitted) to read title from user
       into :title */
      EXEC SQL EXECUTE S1 INTO :sal USING :title;
      …
}
…
```

Note: DB2 does not allow this; use dynamic cursor (next slide)

Dynamic Cursors

- If the result is a relation with many tuples, then use dynamic cursors.
- Define dynamic cursors similar to their static counterparts, but use
  - USING to parameterize the input to the cursor query
  - INTO to hold the output parameters

```
EXEC SQL DECLARE cname CURSOR FOR stmt;
EXEC SQL OPEN cname USING :var1 [,…,:varn];
EXEC SQL FETCH cname INTO :out1 [,…,:outk];
EXEC SQL CLOSE cname;
```

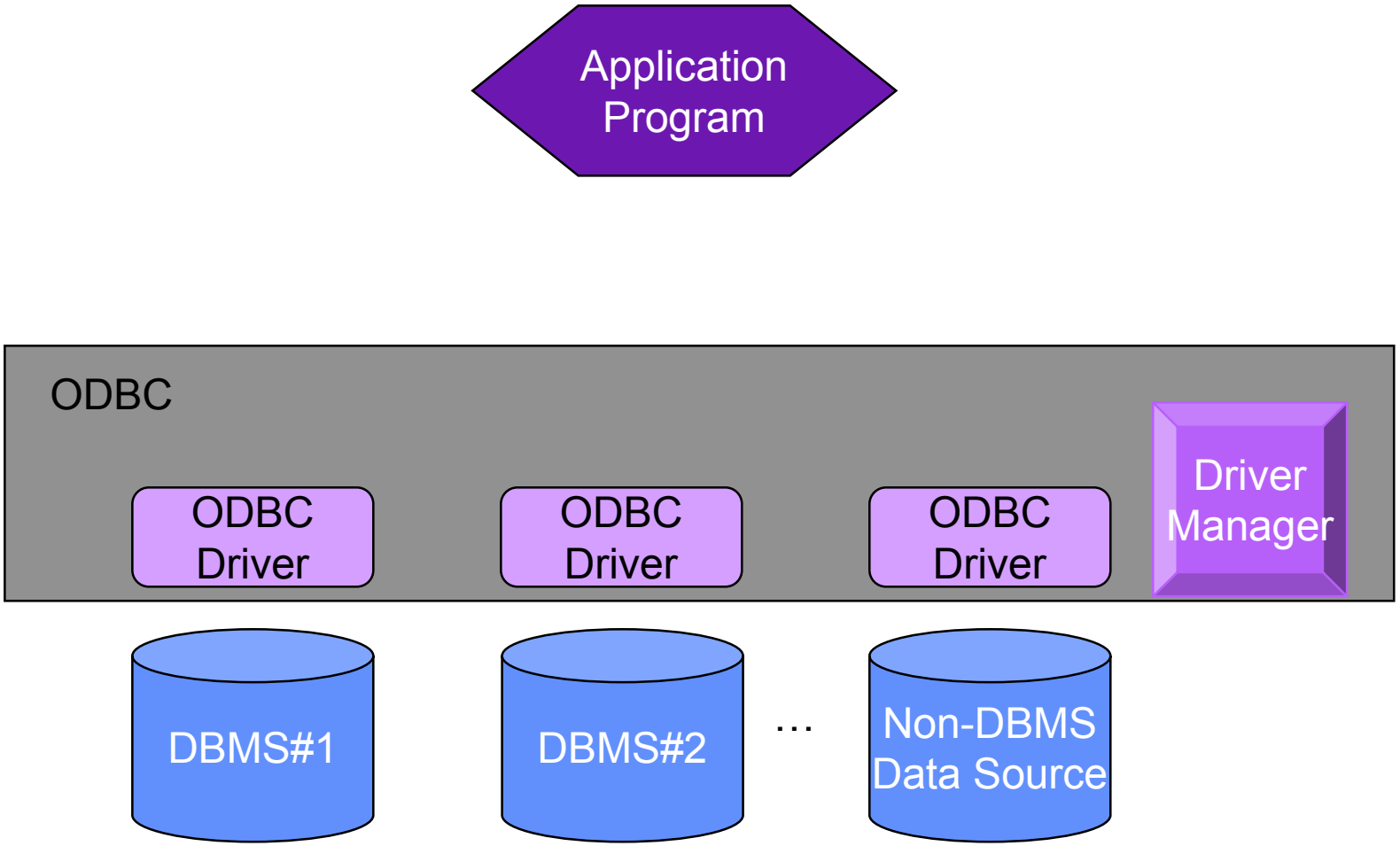
Dynamic Cursor Example

```
…
EXEC SQL BEGIN DECLARE SECTION;
  char resp[10]; /* responsibility to be input */
  char pno[3]; /* project number */
  real avg-dur; /* average duration */
  char s[] = "SELECT Pno, AVG(Dur) FROM Works WHERE
  Resp = '?' GROUP BY Pno, Eno HAVING COUNT(*) > 2";
EXEC SQL END DECLARE SECTION;
EXEC SQL PREPARE S1 FROM :s
EXEC SQL DECLARE duration CURSOR FOR S1;
read into :resp
EXEC SQL OPEN duration USING :resp;
while(1) {
  EXEC SQL FETCH FROM duration INTO :pno, :avg-dur
  if(strcmp(SQLSTATE, "02000") then break
  else print the info
}
EXEC SQL CLOSE duration
…
```

DBMS-Independent Application Development

- Call-Level Interface (CLI)
  - Vendor-neutral ISO standard programming interface for relational database systems.
  - Based on ODBC
- Open Database Connectivity (ODBC)
  - Microsoft developed programming interface for relational DBMSs with SQL interface.
- Java Database Connectivity (JDBC)
  - Collection of Java classes that provide an ODBC/CLI-like programming environment
- These provide object code-level portability from one DBMS to another, while embedded SQL provides only source code-level portability

ODBC Architecture



Attribute & Domain Constraints

- CHECK
  - specifies the condition that each row has to satisfy
- Enhance the previous definition of Project:

```
CREATE TABLE Project
  (Pno     CHAR(3),
   Pname   VARCHAR(20),
   Budget  DECIMAL(10,2)DEFAULT 0.00
           CHECK (BUDGET >= 0),
   City    CHAR(9));
PRIMARY KEY (Pno));
```

- Can be specified on domains as domain constraints

```
CREATE DOMAIN Gender AS CHAR(1) CHECK (VALUE IN
  ('F', 'M'));
```

Tuple Constraints

- Use CHECK command and specify condition
- The condition is checked every time a tuple is inserted or updated and the action rejected if the condition is false
- Example

```
CREATE TABLE Works
  (Eno  CHAR(3),
   Pno  CHAR(3),
   Resp CHAR(15),
   Dur  INT,
PRIMARY KEY (Eno,Pno),
FOREIGN KEY (Eno) REFERENCES Emp(Eno)
  ON DELETE SET NULL
  ON UPDATE CASCADE,
FOREIGN KEY (Pno) REFERENCES Project(Pno),
CHECK (NOT(PNO<'P5') OR Dur>18));
```

More Complex Tuple Constraints

- Example: No project can employ more than two employees who are assigned to work more than 48 months.

```
CREATE TABLE Works
   (Eno       CHAR(3),
    Pno       CHAR(3),
    Resp      CHAR(15),
    Dur       INT,
PRIMARY KEY (Eno,Pno),
FOREIGN KEY (Eno) REFERENCES Emp(Eno)
    ON DELETE SET NULL
    ON UPDATE CASCADE,
FOREIGN KEY (Pno) REFERENCES Project(Pno),
CHECK(3 > ALL
   (SELECT   COUNT(Eno)
    FROM     Works
    WHERE    Dur > 48
    GROUP BY Pno));
```

Assertions

- Global constraints that apply to multiple relations.
- General form
  - **CREATE ASSERTION** name **CHECK** (condition)
- Example: The total salaries of employees who work on project P5 cannot exceed $500,000.

```
CREATE ASSERTION salary-control CHECK
  ((SELECT      SUM(Salary)
      FROM      Emp E, Pay P, Works W
      WHERE     W.Pno = 'P5'
      AND       W.Eno = E.Eno
      AND       E.Title = P.Title) <= 500000);
```

Triggers

- A trigger is a procedure that is automatically invoked by the DBMS in response to changes to the database.
- Three parts:
  - Event
    - Change to the database that activates the trigger
  - Condition
    - A test or a query that needs to be checked when the trigger is activated
    - For queries, condition is *true* if the query returns any result
  - Action
    - The procedure that is executed when the trigger is activated and the condition is *true*

Trigger Issues

- With respect to invoking statement
  - Execution before or after
  - Execution in place of
  - At the end of the transaction within which the trigger is activated (deferred)
  - Asynchronously within the context of a separate transaction
- How many times executed?
  - Statement-level: once per invoking statement
  - Row-level: once per modified tuple