Structured Query Language (SQL)

- Data Definition Language (DDL)
  - CREATE, DROP, ALTER
- Data Manipulation Language (DML)
  - SELECT, INSERT, DELETE, UPDATE
- Data Control Language (DCL)
  - GRANT, REVOKE
  - COMMIT, ROLLBACK, SAVEPOINT

About SQL Dialects ...

- Each DBMS has its own SQL dialect
- Basic syntax is mostly the same in all dialects
- Different in two major aspects
  - Advanced SQL features, e.g. various types of subqueries, recursive queries
  - Non-standardized features, e.g. most functions, procedural languages, FTS

... About SQL Dialects

- Generally speaking, anything can be done in any dialect, just in different ways
- Stick to standard when possible, use dialect when necessary

SQL Script

- A text file contains SQL statements and comments
  - Statements: select, insert, create ...
  - Comments: lines started with --
- Usually uses the .sql suffix

Access PostgreSQL Server

- GUI client pgAdmin
- Command line client psql
- Web client phpPgAdmin
PostgreSQL Documentation

Examples: Create Tables

- Create the following tables:
  1. `students(id, name, email)
  2. `courses(id, name)
  3. `sections(id, course_id, year)
  4. `enrollment(id, section_id, student_id, grade)

Naming Conventions

- Use plural form for table names
- Use singular form for column names
- Use underscore to concatenate multiple words, e.g. `course_id
  - Do not use mixed cases in names (e.g. `CourseId) because many DBMS treat names as case-insensitive

Data Type

- Determines the storage required for a field
- Common data types
  - String types
  - Numeric types
  - Date and time types
  - Other types

String Types

- `char(n)
  - Fixed-length strings
  - Max length n
- `varchar(n)
  - Variable-length strings
  - Max length n
- `text
  - For articles, essays, ...

Numeric Types

- Integer types
  - `integer, `int
  - Variations: `smallint, `bigint, `long...
  - Auto increment
    - `AUTO_INCREMENT
    - Serial
- `Boolean
  - `boolean, `bool
- Floating-point types
  - `real
  - Variations: `float, `double...
- Arbitrary precision number
  - `decimal(m,n)
  - `numeric(m,n)
Date and Time Types

- **date** – YYYY-MM-DD
- **time** – HH:MM:SS
- **datetime** – YYYY-MM-DD HH:MM:SS
- **timestamp** – YYYY-MM-DD HH:MM:SS

Data Integrity Constraints

- **Not NULL**
- **Default**
- **Unique**
- **Primary key**
  - Unique + Not NULL
  - Only one primary key per table
- **Foreign key**
- **Check**

Constraint Syntax

- Column constraint
- Table constraint
- Named constraint

Examples: Modify Tables

- **Add grade point to grades**
  - 5. Create grades table
  - 6. Drop the the grade column in the enrollment table
  - 7. Add a grade_id column to the enrollment table
  - 8. Add a foreign key constraint to the grade_id column

About ALTER TABLE

- Modify tables
  - Name
  - Schema
- Modify constraints
  - Add, remove

- Modify columns
  - Add, remove
  - Name
  - Type

Exactly what operations are supported depend on the DBMS.

Delete Table

```
drop table table_name;
```
Examples: Populate Tables

- Populate the tables we created so far
- Insert a record in each table
- Create all sections for 2009

SQL Literals

- Number: 10, 30.2
- String: ‘CPU’, ‘John’s Kitchen’
- Date: ‘2007-06-01’
- Time: ‘12:00:00’
- Boolean: ‘t’, ‘f’, 1, 0
- NULL

Sample Database: University

departments

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
</tr>
</thead>
</table>

faculty

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>department_id</th>
</tr>
</thead>
</table>

students

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>graduation_date</th>
<th>major_id</th>
</tr>
</thead>
</table>

grades

<table>
<thead>
<tr>
<th>id</th>
<th>letter</th>
<th>value</th>
</tr>
</thead>
</table>

courses

<table>
<thead>
<tr>
<th>id</th>
<th>title</th>
<th>department_id</th>
</tr>
</thead>
</table>

sections

<table>
<thead>
<tr>
<th>id</th>
<th>course_id</th>
<th>instructor_id</th>
<th>year</th>
</tr>
</thead>
</table>

enrollment

<table>
<thead>
<tr>
<th>id</th>
<th>student_id</th>
<th>section_id</th>
<th>grade_id</th>
</tr>
</thead>
</table>

Examples: Simple Selection

- Find the sections taught by instructor #1 in 2004
- List the names of the students whose names start with “A” in alphabetic order
- List the id’s of the courses that were offered before 2009

SQL Operators

- Arithmetic
  - +, -, *, /, %
- Comparison
  - <, >, <=, >=, =, !=, <>, between
- Logical
  - and, or, not
- String
  - like
  - ||
- Other
  - is null
  - in
  - distinct
  - order by

LIKE

- Simple pattern matching
  - %: any zero or more characters
  - _: any single character
Example: Functions

14. Find the students who graduated in June
15. Find the students who graduated in the last six months

Functions in PostgreSQL

http://www.postgresql.org/docs/current/interactive/functions.html

Common Functions in Databases

- Numerical functions
- String functions
- Date and time functions
- NULL related functions
- Aggregation functions

Most functions are DBMS specific.

Numerical functions

- Precision functions
- Power and square root
- Logarithmic functions
- Trigonometric functions
- Random number generator

String Functions

- String length
- Concatenation
- Locate/extract substring
- Trim white spaces
- Change cases
- Format numbers or dates

Date and Time Functions

- Extract date or time field
- Add or subtract a time interval
- Get current date or time
- Convert string to date or time
NULL Related Functions

- If NULL then something
- If something then NULL

Examples: Joins

- 16. Find the names of the departments that offer the course “Databases”
- 17. Find the names of the faculty who taught the course “Databases”
- 18. Find the courses that have never been offered

Join Syntax

- Equi-join syntax
- Inner join syntax

Cross Join

- A.K.A. Cartesian Product
- The results are all possible combinations of the rows from Table 1 with the rows from Table 2

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_1</td>
<td>b_1</td>
<td>c_1</td>
<td>d_1</td>
</tr>
<tr>
<td>a_2</td>
<td>b_2</td>
<td>c_2</td>
<td>d_2</td>
</tr>
<tr>
<td>a_3</td>
<td>b_3</td>
<td>c_3</td>
<td>d_3</td>
</tr>
</tbody>
</table>

Problem of Cross Join

- Suppose Table 1 has 1000 rows, Table 2 has 1000 rows, how many rows does the result of Table 1 cross join Table 2 have??

Equi-Join

- Cross join with additional conditions

```
select ... from T1, T2 where ... ...
```

```sql
  cross join additional conditions
```
**Inner Join**

- a.k.a Join
- Combine two rows (one from each table) if they meet the join condition
- In other words, the results include the *matching rows* from the two tables

---

**Inner Join Example**

<table>
<thead>
<tr>
<th>table1</th>
<th>table2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Outer Joins**

- Include the results of an Inner Join and the unmatched rows from *one or both join tables*

---

**Left Outer Join**

- a.k.a. Left Join

<table>
<thead>
<tr>
<th>table1</th>
<th>table2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Right Outer Join**

- a.k.a. Right Join

<table>
<thead>
<tr>
<th>table1</th>
<th>table2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Full Outer Join**

- a.k.a. Full Join
Examples: Subqueries

19. Find the student with the earliest graduation date
20. Find the departments that offered classes in 2007
21. Find the faculty who taught classes in 2007

Query Results

Query results are either a table or a value
- E.g. `select * from products` or `select count(*) from products`

Query results can be used in places where a table/value can be used

* A value can also be considered as a table with only one row and one column

Correlated Subquery

The inner query uses column(s) from the outer query
- For example:

  ```sql
  select * from faculty f where exists
  ( select * from sections
    where year = 2001
    and instructor_id = f.id );
  ```

How Correlated Subqueries Work

Examples: Set Operations

22. List all the names of the students and the faculty
23. List the names that appear in both the students table and the faculty table
24. List the names that appear in the students table but not in the faculty table

Set Operations

- Union
  - `{1,2,3} ∪ {2,3,4} = {1,2,3,4}`
- Intersect
  - `{1,2,3} ∩ {2,3,4} = {2,3}`
- Difference
  - `{1,2,3} − {2,3,4} = {1}`
Set Operations in Databases

- UNION
- INTERSECT
- EXCEPT

About UNION

- Combine result tables of SELECT statements
- The result tables must have the same number of columns
- The corresponding columns must have the same (or at least "compatible") type
- Duplicates in union results
  - UNION = automatically remove duplicates
  - UNION ALL = keep duplicates

INTERSECT and EXCEPT

- Same syntax as UNION
- Some databases do not support INTERSECT and EXCEPT, but the operations can be done in different ways
  - How??

Example: Aggregation Functions

- 25. Find the earliest graduation date
- 26. Find the number of courses offered by the Computer Science Department

Aggregation Functions

- Operate on multiple rows and return a single result
  - sum
  - avg
  - count
  - max and min

Be Careful with NULL

```
<table>
<thead>
<tr>
<th>product_id</th>
<th>upc</th>
<th>quantity</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1020301</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>1342193</td>
<td>null</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>null</td>
<td>100</td>
<td>null</td>
</tr>
</tbody>
</table>
```

max(price)?? min(price)?? avg(price)??
count(upc)?? count(*)??
sum(quantity) ??
Example: Aggregation Queries

1. List the number of students in each section
2. List the number courses offered by department
3. List the number of students graduated by year
4. Find the years in which there were more than 2 students graduated

Understand GROUP BY ...

Without aggregation/GROUP BY

```
SELECT section_id, student_id FROM enrollment;
```

<table>
<thead>
<tr>
<th>section_id</th>
<th>student_id</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>53</td>
<td>4</td>
</tr>
<tr>
<td>53</td>
<td>6</td>
</tr>
</tbody>
</table>

... Understand GROUP BY

With aggregation/GROUP BY

```
SELECT section_id, count(student_id) FROM enrollment GROUP BY section_id;
```

<table>
<thead>
<tr>
<th>section_id</th>
<th>student_id</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>43</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>43</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>33</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>53</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>53</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

How GROUP BY Works

1. Calculate the results without aggregation/GROUP BY
2. Divide the result rows into groups that share the same value in the grouping attribute(s)
3. Apply the aggregation function(s) to the aggregation attribute(s) for each group

The result attributes must be either a group attribute or a aggregation attribute.

HAVING vs. WHERE

1. Calculate the results without aggregation/GROUP BY
2. Divide the result rows into groups that share the same value in the grouping attribute(s)
3. Apply the aggregation function(s) to the aggregation attribute(s) for each group

WHERE conditions

4. Final results

HAVING conditions

Example: Top N Queries

1. Find the top 2 sections with the most students
2. Find the names of the top 3 faculty who taught the most number of sections
Top N Queries in PostgreSQL

Example: Using ORDER BY, LIMIT and OFFSET

```sql
select * from students
order by graduation_date asc
limit 3
offset 2;
```

What if there is a tie??

Examples: Update and Delete

33. Change the name and department_id of faculty #5 to “John” and 10, respectively
34. Delete all the enrollment records of the Elocution class in 2001
35. Change all the B+ grades in the Calculus class in 2001 to A-

Update and Delete

```sql
delete from table [where condition(s)];

update table set field=value [, …] [where condition(s)];
```

Need for Transactions ...

Not all operations can be done with a single, atomic SQL statement, e.g. transferring money from one bank account to another:

1. Check the balance of account #1
   ```sql
   select balance from accounts where id = 1;
   ```

2. Withdraw $100 from account #1
   ```sql
   update accounts set balance = balance - 100 where id = 1;
   ```

3. Deposit $100 to account #2
   ```sql
   update accounts set balance = balance + 100 where id = 2;
   ```

Bad things could happen due to concurrent access and/or system failure

1. My wife checks the balances of both accounts and notices that $100 is missing
2. My wife withdraws all the money in account #1
3. My wife checks the balance of account #1

Need for Transactions ...

Bad things could happen due to concurrent access and/or system failure

1. Check the balance of account #1
2. Withdraw $100 from account #1
3. Deposit $100 to account #2
... Need for Transactions

- Bad things could happen due to concurrent access and/or system failure

  -- 1. Check the balance of account #1
  select balance from accounts where id = 1;

  -- 2. Withdraw $100 from account #1
  update accounts set balance = balance - 100
  where id = 1;

  -- 3. Deposit $100 to account #2
  update accounts set balance = balance + 100
  where id = 2;

Transaction

- A transaction is a group of SQL statements treated by the DBMS as a single unit of work

Transaction Statements

- Start a transaction
  - BEGIN, START TRANSACTION

- End a transaction
  - COMMIT
  - ROLLBACK

- Nested transaction
  - SAVEPOINT
  - ROLLBACK TO SAVEPOINT

Example: Transactions

- Use a transaction to add two records to the faculty table
  - 36. Abort the transaction
  - 37. Commit the transaction

What happens if another transaction access the faculty table at the same time??

ACID Properties

- Database transactions are expected to have ACID properties
  - Atomic
  - Consistent
  - Isolated
  - Durable

Atomicity

- A transaction completes or fails as a whole, i.e. either all operations in the transaction are performed or none of them are.
Consistency

- Transaction should preserve database constraints.

Durability

- The changes made by committed transactions are guaranteed to be permanent, despite possible system failures.

Isolation

- Databases are often accessed by many users at the same time.
- Multiple transactions running concurrently should not interfere with each other, i.e. it should appear to the user that each transaction is executed in isolation.

SQL Isolation Levels

- Read uncommitted
- Read committed
- Repeatable read
- Serializable

Isolation Example

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>milk</td>
<td>2.99</td>
</tr>
<tr>
<td>2</td>
<td>beer</td>
<td>6.99</td>
</tr>
</tbody>
</table>

Transaction #1:
-- MIN
select name, price from items where price = (select min(price) from items);
-- MAX
select name, price from items where price = (select max(price) from items);
-- COUNT
select count(*) from items;

Read Uncommitted

- A transaction may read data written by another transaction that has not committed
Dirty Read

Transaction #2:

-- UPDATE
update items set price = 7.99 where name = 'beer';
-- ABORT
rollback;

Consider the interleaving of T1 and T2:
MIN, UPDATE, MAX, COUNT, ABORT

Read Committed

A transaction reads only committed data.

Non-repeatable Read

Transaction #2:

-- UPDATE
update items set price = 7.99 where name = 'milk';
-- COMMIT
commit;

Consider the interleaving of T1 and T2:
MIN, UPDATE, COMMIT, MAX, COUNT

Repeatable Read

A transaction reads only committed data, and, everything seen the first time will be seen the second time.

Phantom Read

Transaction #2:

-- INSERT
insert into items values (3, 'wine', 10.99);
-- COMMIT
commit;

Consider the interleaving of T1 and T2:
MIN, MAX, INSERT, COMMIT, COUNT

Serializable

It appears to the user that the transactions are executed one at a time.
Isolation Levels in PostgreSQL

- Read committed (default)
- Serializable

About Concurrent Transactions

- Concurrency is needed to maximize performance
- Concurrent transactions can lead to problems due to aborted operations and interleaving operations
- 4 isolation levels
- 3 problems

Example: Indexes and Views

- 38. Create an index on the name column of the students table
- 39. Create a view showing the id, course name, instructor’s name, and the number of students in each section
- 40. Remove the view

Search with an Index

About Indexes

- Indexes make query execution more efficient
- Many DBMS automatically create indexes for primary key and unique columns
- There are many different types of indexes designed for different types of data and operations
  - E.g. B-tree, R-tree, Hash Index

About Views

- A view can be used as a table in SQL statements
- Most views cannot be updated
- The data in a view is dynamically computed, i.e. changes to base tables are automatically reflected in the view
Why Views

- Present the data in a user friendly way while keeping the base tables normalized
- Simplify SQL queries
- Security reasons
  - Views can be access controlled just like tables
  - Expose only part of the data to certain type of users

Summary

- Create and maintain database schema
- Query and update data
- Transactions and ACID
- Indexes and views