Part VI

SQL: Structured Query Language
We already saw the “Hello World!” example of SQL:

```
SELECT A_1, \ldots, A_n 
FROM R_1, \ldots, R_m 
WHERE C
```

Semantics:

- All relations $R_1, \ldots, R_m$ listed in the `FROM` clause are combined into a **Cartesian product** $R_1 \times \cdots \times R_m$.
- The `WHERE` clause **filters** all rows according to the condition $C$. (Absence of the `WHERE` clause is equivalent to $C \equiv \text{true}$.)
- The `SELECT` clause specifies the **attributes** $A_1, \ldots, A_n$ to report in the result ($\ast \equiv \text{all attributes that occur in } R_1, \ldots, R_m$).
SQL adopted the notion of **tuple variables**:

```
SELECT i.Name, i.InStock, s.Supplier, s.Price
FROM Ingredients AS i, SoldBy AS s
WHERE i.Name = s.Ingredient
AND s.Price < i.Price
```

Tuple variables **range over tuples**; e.g., `i` represents a **single row** in `Ingredients`.

- If **no tuple variable** is given explicitly, a variable will **automatically be created** with the **name of the table**:

  `FROM Foo`  
  =  
  `FROM Foo AS Foo`  

  (If a variable is given in the query, the implicit variable is **not** declared.)

- The keyword **AS** is optional.
Attribute References

Attributes can be referenced in the form

\[ v.A, \]

where \( v \) is a tuple variable and \( A \) an attribute name.

If attribute name \( A \) is **unambiguous**, the tuple variable may be **omitted**:

```sql
SELECT Name, InStock, Supplier, s.Price
FROM Ingredients AS i, SoldBy AS s
WHERE Name = Ingredient
AND s.Price < i.Price
```

**Personal recommendation:**
- Fully qualify all attribute names (except for trivial queries).
- Avoid using \( * \).
Consider a query with two tables in the FROM clause:

```
SELECT s.Name, c.Name AS Contact, c.Phone
FROM Suppliers AS s, ContactPersons AS c
WHERE s.SuppID = c.SuppID
```

The semantics of this query can be understood as follows:

- Enumerate all pairs of tuples \( \langle s, c \rangle \) from the Cartesian product \( \text{Suppliers} \times \text{ContactPersons} \) (the number of pairs may be huge).
- Among all pairs \( \langle s, c \rangle \), select only those that satisfy the join condition \( s.\text{SuppID} = c.\text{SuppID} \).

Most likely, your system will choose a better evaluation strategy.
- E.g., using indexes or efficient join algorithms.
- But the output is the same as if obtained by full enumeration.
The **join condition** must be specified explicitly in the **WHERE** clause (otherwise, the system will assume you want the Cartesian product).

It is almost always an **error** when two tuple variables are not linked by an explicit join predicate (this query most likely returns nonsense):

```sql
SELECT s.Name, c.Name AS Contact, c.Phone
FROM Suppliers AS s, ContactPersons AS c
WHERE s.Name = 'Shop Rite'
AND c.Phone LIKE '+49 351%'
```

→ In case of **composite keys** (that span multiple attributes), don’t forget to link tuple variables via **all** key columns.
What does the following query return?

```
SELECT c.CocktailID, c.Name
FROM Cocktails AS c, ConsistsOf AS co,
     Ingredients AS i
WHERE c.CocktailID = co.CocktailID
AND co.IngrID = i.IngrID
AND i.Alcohol > 0
```

To **eliminate duplicates** use the keyword `DISTINCT`:

```
SELECT DISTINCT c.CocktailID, c.Name
... ... ...
```
Unnecessary Joins

Do not join more tables than needed

→ Query might run slowly if the optimizer overlooks the redundancy.

```
SELECT c.Name, c.Phone
FROM Suppliers AS s, ContactPersons AS c
WHERE s.SuppID = c.SuppID
AND c.Phone LIKE '+49 351%'
```
Unnecessary joins might also lead to **unexpected results**.

What is wrong with these two queries?

1. Return all supplier names with an address in ‘Dresden’:

```
SELECT s.Name
FROM Suppliers AS s, ContactPersons AS c
WHERE s.SuppID = c.SuppID
AND s.Address LIKE '%Dresden%'
```

2. Return all cocktails with ‘Bacardi’ in their name:

```
SELECT c.Name
FROM Cocktails AS c, ConsistsOf AS co, Ingredients AS i
WHERE c.CocktailID = co.CocktailID
AND co.IngrID = i.IngrID
AND c.Name LIKE '%Bacardi%'
```
Non-Monotonic Behavior

SQL queries that use only the constructs introduced above are monotonic (↗ slide 105).

→ If further tuples are inserted to the database, the query result can only grow.

Some real-world queries, however, demand non-monotonic behavior.

- E.g., “Return all non-alcoholic cocktails (i.e., those without any alcoholic ingredient).”
  → Insertion of a new ConsistsOf tuple could “make” a cocktail alcoholic and thus invalidate a previously correct answer.

Such queries cannot be answered with the SQL subset we saw so far.
**Indicators** for non-monotonic behavior (in natural language):

- “there is no”, “does not exist”, etc.
  - **existential quantification**

- “for all”, “the minimum/maximum”
  - **universal quantification**
  - \( \forall r \in R : C(r) \iff \nexists r' \in R : \neg C(r') \)

In an equivalent SQL formulation of such queries, this ultimately leads to a test whether a certain query yields a (non-)empty result.
Such tests can be expressed with help of the \texttt{IN ( ∈)} and \texttt{NOT IN (✓)} keywords in SQL:

\begin{verbatim}
SELECT c.Name
FROM Cocktails AS c
WHERE CocktailID NOT IN (SELECT co.CocktailID
FROM ConsistsOf AS co,
Ingredients AS i
WHERE i.IngrID = co.IngrID
AND i.Alcohol <> 0 )
\end{verbatim}

The \texttt{IN (NOT IN)} keyword tests whether an attribute value appears (does not appear) in a set of values computed by another SQL subquery.

→ At least conceptually, the subquery is evaluated before the main query starts.
The existence of a value in a subquery does not depend on multiplicity.

→ The previous query may equivalently be written as:

```sql
SELECT Name
FROM Cocktails
WHERE CocktailID NOT IN (SELECT DISTINCT CocktailID
FROM ConsistsOf AS co,
Ingredients AS i
WHERE i.IngrID = co.IngrID
AND i.Alcohol > 0 )
```

Whether/how this will affect query performance depends on the particular system and data.

→ The DBMS optimizer likely knows about this equivalence and decide on duplicate elimination/preservation itself.
Consider again the query for all alcoholic cocktails.

Do the following queries return the same result?

SELECT Name
    FROM Cocktails
WHERE CocktailID IN (SELECT DISTINCT CocktailID
    FROM ConsistsOf AS co,
    Ingredients AS i
    WHERE i.IngrID = co.IngrID
    AND i.Alcohol > 0 )

SELECT DISTINCT c.Name
    FROM Cocktails AS c, ConsistsOf AS co,
    Ingredients AS i
WHERE c.CocktailID = co.CocktailID
    AND co.IngrID = i.IngrID AND i.Alcohol > 0
Remarks:

- In earlier versions of SQL, the subquery must return only a single output column.
  - This ensures that the result of the subquery is a set of atomic values and not an arbitrary relation.
- Since SQL-92, comparisons were extended to the tuple level. It is thus valid to write, e.g.:

  ```sql
  WHERE (A, B) NOT IN (SELECT C, D FROM ...)
  ```
The construct NOT EXISTS enables the main (or outer) query to check whether the result of a subquery is empty.\(^9\)

- In the subquery, tuple variables declared in the FROM clause of the outer query may be referenced.

SELECT Name
FROM Cocktails AS c
WHERE NOT EXISTS (SELECT DISTINCT CocktailID
FROM ConsistsOf AS co,
Ingredients AS i
WHERE i.IngrID = co.IngrID
AND co.CocktailID = c.CocktailID
AND i.Alcohol > 0)

\(^9\)Likewise, EXISTS tests for non-emptiness.
Correlated Subqueries

The reference of an outer tuple makes the subquery **correlated**.

- The subquery is **parameterized** by the outer tuple variable.
- Conceptually, correlated subqueries have to be **re-evaluated** for every new binding of a tuple to the outer tuple variable.
  → Again, the DBMS is free to choose a more efficient evaluation strategy that returns the same result (〜“query unnesting”)

Correlation can be used with **IN/NOT IN**, too.
→ Typically, this yields complicated query formulations (bad style).

Queries with **EXISTS/NOT EXISTS** can be non-correlated.
→ The **WHERE** predicate then becomes **independent** of the outer tuple.
→ This is rarely desired and almost always an indication of an error.
Correlated Subqueries

Subqueries may reference tuple variables from the outer query.
The converse (referencing a tuple variable of the subquery in the outer query) is not allowed:

```sql
SELECT c.Name, i.Alcohol ← wrong!
FROM Cocktails AS c
WHERE EXISTS (SELECT DISTINCT CocktailID
FROM ConsistsOf AS co,
Ingredients AS i
WHERE i.IngrID = co.IngrID
AND co.CocktailID = c.cocktailID
AND i.Alcohol > 0 )
```

→ Compare this to variable scoping in block-structured programming languages (C, Java).
EXISTS/NOT EXISTS

- **EXISTS/NOT EXISTS** only tests for the **existence** of (at least) one row in the subquery result.

- The **actual tuple value** returned by the query is **immaterial** to the overall query result.

- It is good style to make this explicit in the subquery phrasing:
  - → ... EXISTS (SELECT * FROM ...)
  - → ... EXISTS (SELECT NULL FROM ...)
  - → ... EXISTS (SELECT 42 FROM ...)

- It is legal SQL syntax, though, to specify arbitrarily complex result tuples in the subquery’s SELECT clause.
Mathematical logic knows **two quantifiers**:

- $\exists x : \phi$  **existential quantifier**
  There is an $x$ that satisfies formula $\phi$.

- $\forall x : \phi$  **universal quantifier**
  For all $x$, formula $\phi$ is satisfied.

We saw an SQL notation to express **existential quantification**.

**Universal quantification** can be expressed due to the equivalence

\[
\forall x : \phi \iff \neg \exists x : \neg \phi .
\]
State the query “Which is the most expensive cocktail?” (I.e., the cocktail that is at least as expensive as all other cocktails.)
For a restricted form of quantification, SQL provides additional notation.

→ Comparison of a **single value** with the **values in a set** (that is computed by a subquery).

```sql
SELECT c1.Name 
FROM Cocktails AS c1 
WHERE c1.Price >= ALL ( SELECT c2.Price 
                           FROM Cocktails AS c2 )
```

- Prices of qualifying outer rows must be greater or equal than **all** prices returned by the subquery.
- Analogously: Comparisons =, <, etc.
ANY can be used instead of ALL if one match should be enough to satisfy the overall predicate.

```sql
SELECT c1.Name
FROM Cocktails AS c1
WHERE NOT c1.Price < ANY (SELECT c2.Price
FROM Cocktails AS c2)
```

- SOME can be used as a synonym for ANY.
Remarks

- **ANY/ALL** do **not** extend the expressiveness of SQL, since, e.g.,

\[
A < \text{ANY (SELECT } B \text{ FROM } \cdots \text{ WHERE } \cdots ) \equiv \text{EXISTS (SELECT } * \text{ FROM } \cdots \text{ WHERE } \cdots \text{ AND } A < B) \]

- \(x \text{ IN } S\) is equivalent to \(x = \text{ANY } S\).

- The subquery must yield a **single result column**.

- If none of the keywords **ALL**, **ANY**, or **SOME** are present, the subquery must yield **at most one row**.
  - → This is a **semantical property** of the query, which the query compiler cannot check for you.
  - → This is a common source of trouble (your query might run well when you test, but fail on real data).
Subqueries in the FROM Clause

Since the result of an SQL query is a table, it seems most natural to use a subquery result whenever a table might be specified, i.e., in the FROM clause.

```
SELECT c.Name AS CocktailName, x.IngrName
FROM (SELECT co.CocktailID, i.Name AS IngrName
      FROM ConsistsOf AS co, Ingredients AS i
      WHERE co.IngrID = i.IngrID) AS x,
     Cocktails AS c
WHERE c.CocktailID = x.CocktailID
```

- SQL is orthogonal in this sense. Earlier versions of SQL (up to SQL-86) were not orthogonal in this sense.
- Inside the subquery, tuple variables in the same FROM clause may not be referenced.
Subqueries in the FROM Clause

Subqueries in the FROM clause may occur implicitly because of view declarations, e.g.,

```
CREATE VIEW ConsistsOfIngr AS
    SELECT co.CocktailID, i.Name AS IngrName
    FROM ConsistsOf AS co, Ingredients AS i
    WHERE co.IngrID = i.IngrID
```

- This view declaration **permanently registers** the subquery under the name ConsistsOfIngr.
- After declaration, the view may be used in queries **just like a table.**

```
SELECT c.Name AS CocktailName, x.IngrName
FROM ConsistsOfIngr AS x, Cocktails AS c
WHERE c.CocktailID = x.CocktailID
```
Views are not only for convenience.

- They help to provide **logical data independence**.
  - *E.g.*, replace an actual table by a view declaration that computes the logical table content.
  - See slide 21 for an example.

- They can be used for **access control**.
  - *E.g.*, **deny** a certain user access to the base table(s), but **allow** access to a view over those tables. Access is now restricted to only those data generated by the view.
Aggregations

- **Aggregation functions** are functions from a multiset to a single value, e.g.,

\[
\min\{42, 57, 5, 13, 27\} = 5.
\]

- SQL defines five main aggregation functions:

  \[
  \text{COUNT}, \text{SUM}, \text{AVG}, \text{MAX}, \text{MIN}.
  \]

  (Some implementations might provide further aggregation functions: \text{STDDEV}, \text{VARIANCE}, ...)

- Example:

  ```sql
  SELECT MAX (Price)
  FROM Ingredients
  WHERE Alcohol = 0
  ```
Some aggregation functions are sensitive to duplicates. If so, SQL allows to explicitly request to ignore duplicates:

```
SELECT COUNT(DISTINCT City) 
    FROM Suppliers 
    WHERE ZipCode LIKE '0%'
```

If you are only interested in counting rows, use `COUNT(*)`:

```
SELECT COUNT(*) 
    FROM Ingredients 
    WHERE Alcohol > 0
```

There is a subtle difference between `COUNT(*)` and `COUNT(A)`. The former will count all rows; the latter only those where attribute A does not contain a null value. The latter might be much more expensive to evaluate!
Conceptually, queries with aggregation are evaluated as follows:\textsuperscript{10}

1. **Evaluate the** \texttt{FROM} **clause**
   - Form a **Cartesian product** of all referenced tables/subqueries
   (see also slide 39).

2. **Apply** \texttt{predicates} of the \texttt{WHERE} **clause**.
   - Discard all rows that do not satisfy the \texttt{WHERE} predicate.

3. **Add column values received from** 2 to sets/multisets that will be input to the aggregation functions.
   - Remove duplicates if requested by **DISTINCT** keyword within aggregation function(s).

4. **Compute aggregation result(s)** and print a **single row** of aggregated value(s).

\textsuperscript{10} As usual, the system is free to choose a more efficient execution strategy.
Evaluation of Aggregation Functions

Notes:

- Null values are ignored during aggregation. Exception: `COUNT (*)` also counts null values.
- If the aggregation input set is empty, aggregation functions return `NULL`. Exception: `COUNT` returns 0.
Evaluation of Aggregation Functions

Restrictions:

- Aggregations must not be nested (makes no sense).
- Aggregations must not be used in the WHERE clause.
  - Aggregation is performed only after the WHERE clause has been evaluated.
- The result of an aggregation query is a single output tuple.
- If aggregation is used, no attributes may appear in the SELECT clause.
  - Would make no sense, because aggregation yields a single output row.
  - But see GROUP BY clause below.
The `GROUP BY` clause partitions the tuples of a table into disjoint groups.

Aggregation functions are then applied for each tuple group separately.

```sql
SELECT GlassID, COUNT(*) AS cnt
FROM Cocktails
GROUP BY GlassID
```

<table>
<thead>
<tr>
<th>GlassID</th>
<th>cnt</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

→ The tuple group with `GlassID = 7` counts 12 rows, etc.
Query returns as many result rows as there are distinct values in the GROUP BY attribute(s).

Any attribute that appears in the GROUP BY clause may also be used in the SELECT clause.
GROUP BY Examples

The GROUP BY clause may contain more than one column:

```
SELECT Year, Month, 
    SUM(Amount) AS Amt 
FROM Sales 
WHERE Month LIKE 'J%' 
GROUP BY Year, Month 
```

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Amt</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Jan</td>
<td>115154.86</td>
</tr>
<tr>
<td>2008</td>
<td>Jul</td>
<td>116348.82</td>
</tr>
<tr>
<td>2008</td>
<td>Jun</td>
<td>114418.37</td>
</tr>
<tr>
<td>2009</td>
<td>Jan</td>
<td>113908.68</td>
</tr>
<tr>
<td>2009</td>
<td>Jul</td>
<td>108407.65</td>
</tr>
<tr>
<td>2009</td>
<td>Jun</td>
<td>113489.23</td>
</tr>
</tbody>
</table>

What is the result of this query?

```
SELECT Month 
FROM Sales 
WHERE Month LIKE 'J%' 
GROUP BY Month 
```

This one?

```
SELECT Month, SUM(Amount) 
FROM Sales 
WHERE Month LIKE 'J%' 
GROUP BY Year, Month 
```
GROUP BY: Columns in SELECT

Only columns (and aggregation functions) listed in the `GROUP BY` clause may appear in the `SELECT` part.

```sql
SELECT c.CocktailID, c.Name, COUNT(*)
FROM Cocktails AS c, ConsistsOf AS co
WHERE c.CocktailID = co.CocktailID
GROUP BY c.CocktailID
```

**Wrong!**

Solution: Group by CocktailID and Name.

→ Since CocktailID is a key, this will not actually affect grouping.

```sql
SELECT c.CocktailID, c.Name, COUNT(*)
FROM Cocktails AS c, ConsistsOf AS co
WHERE c.CocktailID = co.CocktailID
GROUP BY c.CocktailID, c.Name
```
Remember that aggregations must not be used in the `WHERE` clause.

- With `GROUP BY`, it makes sense to filter out entire groups, based on some aggregate group property.
- E.g., Report average sales amount per month only for those months where there were at least 5 transactions.

Can we express that with the SQL constructs we learned so far?
The SQL **HAVING** clause is a convenient means to describe exactly such types of queries.

```sql
SELECT Year, Month, AVG(Amount) AS Average
FROM Sales
GROUP BY Year, Month
HAVING COUNT(*) >= 5
```

- In the **HAVING** clause, the same types of expressions may be used as in the **SELECT** clause, i.e.,
  - aggregation functions,
  - columns listed in the **GROUP BY** clause.
The `HAVING` clause is applied after grouping and aggregation (where `WHERE` is applied before).

Conditions that **only** refer to `GROUP BY` columns may be put into `WHERE` or `HAVING`.
The SQL keyword `UNION` allows to collect results from multiple queries into a single output relation (∽ algebra operator ∪).

```
SELECT Name, Price
    FROM Ingredients
        WHERE Alcohol > 0
UNION
SELECT Name, Price
    FROM Cocktails
```

`UNION` is strictly needed (no other way in SQL to express such queries).

Typical use case:

→ Specializations of a general concept are stored in separate tables. They can be re-combined using `UNION`. 
Combined relations must be **schema-compatible**.
- But SQL is less strict than relational algebra.
- Both operands must have the same number of columns; columns of compatible types must be listed in same order. Column names, however, do not matter (need not be identical).

The **other set operators** are available in SQL, too:
- **UNION** implements $\cup$
- **EXCEPT** implements $- \ (\text{MINUS} \text{ is synonym})$
- **INTERSECT** implements $\cap$

All three operators remove duplicates.

To **keep duplicates**: combine with **ALL**

```
SELECT · · · FROM · · · WHERE · · ·
UNION ALL  (or: EXCEPT ALL, INTERSECT ALL)
SELECT · · · FROM · · · WHERE · · ·
```
All SQL queries return result rows in **arbitrary order**.

- You might observe that the system produces the same order when you run the same query multiple times. But there is **no guarantee**: the next run might already lead to a different order.

- This is **intentional**. The system might find a **better execution strategy** if it is allowed to produce results in any order.

Sometimes it is desirable to present the **overall result** of a query **in a particular order** to the user.

→ SQL keyword **ORDER BY**.

```
SELECT LastName, FirstName, Phone
FROM ContactPersons
ORDER BY LastName, FirstName
```
Conceptually, the ORDER BY specification is applied as the last operation, only to present results to the user.

→ May reference columns and aggregation functions just like the SELECT part.

→ ORDER BY does not make sense in subqueries and is thus forbidden there.

The ORDER BY clause is a list of ordering criteria.

→ lexicographic ordering according to this list

→ Append DESC to a sort key to sort in descending order.

(→ ... ORDER BY Year DESC, SUM(Amount) DESC)
Joins can be expressed in SQL by listing the relations in the `FROM` clause and constraining the Cartesian product in the `WHERE` clause.

```
SELECT s.Name, c.Name AS Contact, c.Phone
FROM Suppliers AS s, ContactPersons AS c
WHERE s.SuppID = c.SuppID
```

→ Don’t be afraid. The system will recognize the pattern and **not** build up the Cartesian product.

Alternatively, joins can be made explicit as follows:

```
SELECT s.Name, c.Name AS Contact, c.Phone
FROM Suppliers AS s JOIN ContactPersons AS c
  ON s.SuppID = c.SuppID
```
That is, you can write

\[ \text{Table}_1 \Join \text{Table}_2 \text{ ON JoinCondition} \]

in the FROM part of your query.

There are a number of restrictions on what can be used as a JoinCondition:

- The condition must **only** refer to columns of the two referenced tables.
- The condition **must not** contain any subqueries.

The JOIN clause can be nested:

\[(\text{Table}_1 \Join \text{Table}_2 \text{ ON JoinCond}_1) \Join \text{Table}_3 \text{ ON JoinCond}_2\]
The JOIN syntax also allows to specify outer joins:

```sql
SELECT s.Name, c.Name AS Contact, c.Phone
FROM Suppliers AS s
    LEFT OUTER JOIN ContactPersons AS c
    ON s.SuppID = c.SuppID
```

- Likewise: `RIGHT OUTER JOIN`, `FULL OUTER JOIN`.
- `JOIN` is synonym for `INNER JOIN`.

**Further syntactic sugar:**

- `Table_1 NATURAL JOIN Table_2`
- `Table_1 JOIN Table_2 USING (ColumnList)`
Null Values

SQL also uses **null values** and **three-valued logic** (↗ slide 81).

- **NULL** is the literal for the null value.
  (INSERT INTO Suppliers VALUES (42, 'Foo Inc.', NULL))
- **Test** for null values with **IS NULL** (or **IS NOT NULL**)

```sql
SELECT Name, www
FROM Suppliers AS s
WHERE www IS NOT NULL
```

Do **not** use = NULL in tests.

Comparisons =, <=, etc. with NULL **always** yield NULL
(i.e., “unknown”; also NULL = NULL → NULL).
Beyond Queries

So far we only looked at the **data retrieval language part** of SQL.

SQL also offers syntax to

- create or delete tables, to modify their schema, etc.,
  - **data definition language**
- add, delete, or modify rows in the database,
  - **data manipulation language**
- define access rights on data.
  - **data control language**

Systems also implement further commands, not strictly part of SQL:

- physical schema management (index creation), backup, etc.
To create a new table, use the `CREATE TABLE` statement:

```
CREATE TABLE Ingredients ( IngrID INTEGER NOT NULL,  
                          Name       CHAR(30),  
                          Alcohol    DECIMAL(3,1),  
                          Flavor     CHAR(20) )
```

Data types (somewhat system-dependent):

- `INTEGER`, `SMALLINT`, `BIGINT`
- `DECIMAL (m,n)`: `m` digits total, `n` of which are decimals
- `CHAR (n)`: fixed-length strings
- `VARCHAR (n)`: variable-length strings (up to length `n`)
- `DATE`, `TIME`, `DATETIME`, etc.
Table Creation

- Allow (**NULL**; default) or disallow (**NOT** **NULL**) **null values**.
- Specify **key constraints**:

```sql
CREATE TABLE Suppliers (SupplID INTEGER NOT NULL,
                        Name CHAR(30) NOT NULL,
                        www VARCHAR(200),
                        PRIMARY KEY (SupplID))

CREATE TABLE Contacts (ContactID INTEGER NOT NULL,
                        SupplID INTEGER NOT NULL,
                        Name CHAR(40),
                        Phone CHAR(20),
                        PRIMARY KEY (ContactID),
                        FOREIGN KEY (SupplID)
                        REFERENCES Suppliers(SupplID))
```
Deleting an entire table (including its schema definition):

```
DROP TABLE Suppliers
```

- All data in the table is irrecoverably lost.
- Many systems implicitly commit transactions upon DDL statements (see later).

Change the schema of existing tables using the `ALTER TABLE` statement, e.g.,

```
ALTER TABLE Contacts ADD COLUMN Email VARCHAR(30)
```
CREATE VIEW is also a data definition statement (since it changes the database schema; slide 176):

```sql
CREATE VIEW ConsistsOfIngr AS
    SELECT co.CocktailID, i.Name AS IngrName
    FROM ConsistsOf AS co, Ingredients AS i
    WHERE co.IngrID = i.IngrID
```

To remove a view declaration from the schema, use the DROP VIEW statement:

```sql
DROP VIEW ConsistsOfIngr
```
Inserting Rows

Insert new rows into a table using the INSERT statement:

```sql
INSERT INTO Suppliers (SupplID, Name, www)
VALUES (42, 'Seven Eleven', NULL)
```

- List tuple values in same order as list of column names.
- The list of column names (SupplID, · · · ) can be omitted (must then give values for all columns).
- You may choose to not specify all columns, but only if the missing columns allow null values or are declared with a default value.
Inserting Rows

The inserted row(s) may also be the result of an SQL query:

```sql
INSERT INTO SalesStat (Year, Month, Amount)
SELECT Year, Month, SUM(Amount)
FROM Sales
GROUP BY Year, Month
```

DML statements are executed with **snapshot semantics**.

→ Conceptually, new values are computed based on a **snapshot** of the database. **Then** the updates are applied.

→ The statement does not “see” its own effects.

```sql
INSERT INTO Budget (Project, Year, Amount)
SELECT Project, 2012, AVG(Amount) * 1.10
FROM Budget
GROUP BY Project
```
Values in existing rows can be changed with **UPDATE**:

```sql
UPDATE Employee
SET Salary = Salary * 1.05,
    Bonus = Bonus + 500
WHERE EmpType = 'Manager'
```

→ In the table listed in the **UPDATE** part, all rows that satisfy the **WHERE** clause are assigned new values as stated by the **SET** clause.

→ Without a **WHERE** clause, all rows are updated.

→ Again: snapshot semantics
New column values can be computed via `SELECT` statements:

```
UPDATE Sales AS s1
SET CumulativeAmount = (SELECT SUM(Amount)
                         FROM Sales s2
                         WHERE s2.Year <= s1.Year)
```

⚠️ The subquery must return at most one row!
Row Deletion

Tuples can be deleted with help of the `DELETE` statement:

```sql
DELETE FROM Customers
WHERE CustomerID = 42
```

- `DELETE` without a `WHERE` clause deletes all rows of the table. But the table itself remains existent.
  - Use `DROP TABLE` to remove the table.
SQL is not a complete programming language.
→ It is not even meant to provide such expressiveness (↗ slide 148)

Application programs typically use SQL to interact with the database.

- They generate SQL statements (e.g., based on user input), ship them to the DBMS, and present results to the user (e.g., via a GUI).

**Challenge:** Impedance mismatch

- Different **type systems**
- SQL ↔ Object-oriented concepts
- declarative, set-oriented ↔ imperative, record-oriented
- concurrency models, exception handling
Various forms of SQL ↔ programming language integration exist.

- Embedded SQL (e.g., for C): SQL used in PL with special markup
- SQL as a language subset (e.g., 4GL programming languages)
- PL constructs that are compiled into SQL code (e.g., Linq, ActiveRecords)
- Libraries for SQL interaction (e.g., JDBC, ODBC)

Example: Embedded SQL (for DB2 and C; next slide)
EXEC SQL INCLUDE SQLCA;

EXEC SQL BEGIN DECLARE SECTION;
short IngrID;
char Name[31];
EXEC SQL END DECLARE SECTION;

void main (void) {
    EXEC SQL CONNECT TO DEMO;

    EXEC SQL DECLARE IngrCursor CURSOR FOR
        SELECT IngrID, Name
        FROM Ingredients;

    EXEC SQL OPEN IngrCursor;

    while (1) {
        EXEC SQL FETCH IngrCursor into :IngrID, :Name;

        if (sqlca.sqlcode == 100)
            break;

        printf (" %8i | %30s\n", IngrID, Name);
    }

    EXEC SQL CLOSE IngrCursor;
}
Embedded SQL

- Instructions for **DB2 preprocessor** marked with `EXEC SQL`.
  - Preprocessor turns these into “real” C code, which is then compiled by a regular C compiler.

- **Variable declarations** marked, so preprocessor knows where to convert SQL types ↔ C types.
  - Reference C variables in SQL code using `:varname`.
  - Extended SQL syntax to interact with C variables, e.g.,
    ```sql
    SELECT · · · INTO VarList FROM · · ·
    ```

- To **iterate** over result sets, use **cursors**.
  - `OPEN`, `FETCH`, ..., `FETCH`, `CLOSE`
  - Make sure you properly close cursors; the database may release **locks** then.