Information Systems
(Informationssysteme)

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Part VI

SQL: Structured Query Language

Basic SQL Query

We already saw the "Hello World!" example of SQL:

$$
\begin{array}{rl}
\texttt{SELECT} & A_1\texttt{,}\ \texttt{...,}\ A_n \\
\texttt{FROM} & R_1\texttt{,}\ \texttt{...,}\ R_m \\
\texttt{WHERE} & C
\end{array}
$$

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 ($* \equiv$ all attributes that occur in $R_1, \ldots, R_m$).

Tuple Variables

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**:

```
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 `*`.

Joins

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 $\langle \mathtt{s}, \mathtt{c} \rangle$ from the **Cartesian product** *Suppliers* × *ContactPersons* (the number of pairs may be huge).
- Among all pairs $\langle \mathtt{s}, \mathtt{c} \rangle$, select only those that satisfy the **join condition** `s.SuppID = c.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.

Joins

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):

```
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.

Duplicates

✎ **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 104).

→ 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

Indicators for non-monotonic behavior (in natural language):

- "there is no", "does not exist", etc.

  $\rightarrow$ **existential quantification**

- "for all", "the minimum/maximum"

  $\rightarrow$ **universal quantification**

  $\rightarrow$ $\forall r \in R : C(r) \;\Leftrightarrow\; \nexists r' \in R : \neg C(r')$

In an equivalent SQL formulation of such queries, this ultimately leads to a test whether a certain **query yields a (non-)empty result**.

IN / NOT IN

Such tests can be expressed with help of the `IN` ($\in$) and `NOT IN` ($\notin$) keywords in SQL:

```
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 )
```

The `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.

IN / NOT IN

The existence of a value in a subquery does not depend on multiplicity.

→ The previous query may equivalently be written as:

```
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.

IN vs. Join

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
```

IN / NOT IN

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.*:

```
⋮
WHERE (A, B) NOT IN (SELECT C, D FROM ...)
```

EXISTS / NOT EXISTS

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.
  - $\rightarrow$ Again, the DBMS is free to choose a more efficient evaluation strategy that returns the same result ($\leadsto$ “query unnesting”)

Correlation can be used with `IN`/`NOT IN`, too.

$\rightarrow$ Typically, this yields complicated query formulations (bad style).

Queries with `EXISTS`/`NOT EXISTS` can be non-correlated.

$\rightarrow$ The `WHERE` predicate then becomes **independent** of the outer tuple.

$\rightarrow$ 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:

```
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.

"For All"

Mathematical logic knows **two quantifiers**:

- $\exists x : \phi$ **existential quantifier**
  There is an x that satisfies formula ϕ.
- $\forall x : \phi$ **universal quantifier**
  For all x, formula ϕ is satisfied.

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

Universal quantification can be expressed due to the equivalence

$$\forall x : \phi \Leftrightarrow \neg\exists x : \neg\phi \ .$$

"For All" in SQL

✎ **State the query "Which is the most expensive cocktail?"**

(*I.e.*, the cocktail that is at least as expensive as all other cocktails.)

ALL, ANY, SOME

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).

```
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.

ALL, ANY, SOME

ANY can be used instead of ALL if one match should be enough to satisfy the overall predicate.

```
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.*,

$$\begin{array}{c} A\ \texttt{< ANY (SELECT}\ B\ \texttt{FROM}\ \cdots\ \texttt{WHERE}\ \cdots\texttt{)} \\ \equiv \\ \texttt{EXISTS (SELECT * FROM}\ \cdots\ \texttt{WHERE}\ \cdots\ \texttt{AND}\ A < B\,\texttt{)} \end{array}$$

- x `IN` S is equivalent to x `= 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
```

View Declarations

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 20 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.*,

$$\min\{42, 57, 5, 13, 27\} = 5 \quad .$$

- SQL defines five main aggregation functions:

  `COUNT`, `SUM`, `AVG`, `MAX`, `MIN` .

  (Some implementations might provide further aggregation functions: `STDDEV`, `VARIANCE`, ...)

- Example:

```
SELECT MAX (Price)
  FROM Ingredients
 WHERE Alcohol = 0
```

Aggregations and Duplicates

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!

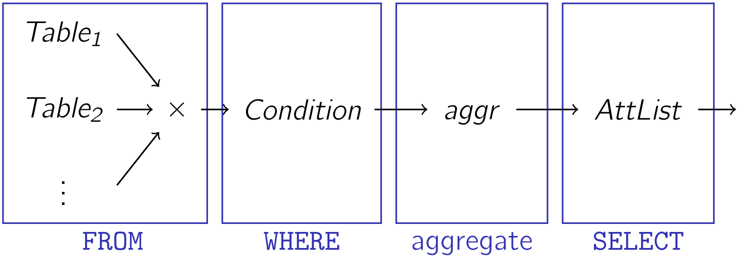
Evaluation of Aggregation Functions

Conceptually, queries with aggregation are evaluated as follows:[10]

1. Evaluate the `FROM` clause
   → Form a **Cartesian product** of all referenced tables/subqueries (see also slide 38).
2. Apply **predicates** of the `WHERE` clause.
   → Discard all rows that do not satisfy the `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).

[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.

GROUP BY

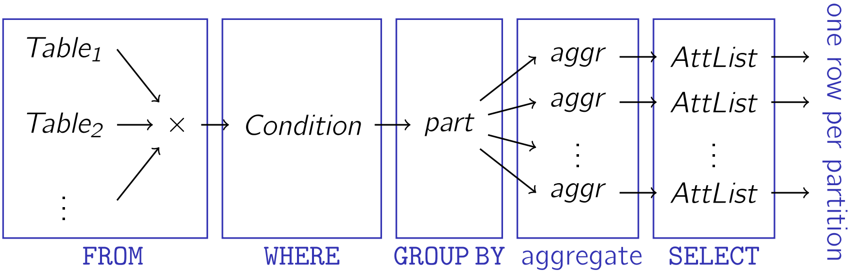
- The `GROUP BY` clause **partitions** the tuples of a table into **disjoint groups**.
- Aggregation functions are then applied **for each tuple group** separately.

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

GlassID	cnt
7	12
3	19
4	8

→ The tuple group with $GlassID = 7$ counts 12 rows, etc.

Evaluation with GROUP BY



- 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
```

Year	Month	Amt
2008	Jan	115154.86
2008	Jul	116348.82
2008	Jun	114418.37
2009	Jan	113908.68
2009	Jul	108407.65
2009	Jun	113489.23

✎ **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.

wrong!

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

Solution: Group by CocktailID **and** Name.

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

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

✔

Conditions over Aggregates

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?**

HAVING

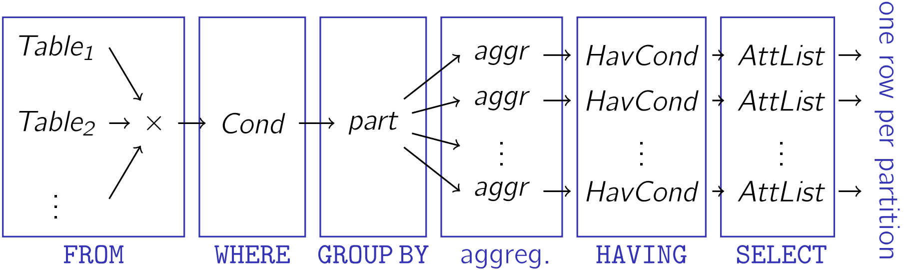
The SQL HAVING clause is a convenient means to describe exactly such types of queries.

```
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.

Evaluation with GROUP BY and HAVING

The `HAVING` clause is applied **after** grouping and aggregation (`WHERE` is applied before).



→ Conditions that **only** refer to `GROUP BY` columns may be put into `WHERE` or `HAVING`.

UNION

The SQL keyword UNION allows to collect results from multiple queries into a single output relation ($\rightsquigarrow$ algebra operator $\cup$).

```
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.

SQL Set Operators

- 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 $-$ (`MINUS` 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 ···
```

Order

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
```

ORDER BY

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.
  ($\rightsquigarrow \cdots$ `ORDER BY Year DESC, SUM(Amount) DESC`)

SQL Keyword JOIN

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

$$\textit{Table}_1 \texttt{ JOIN } \textit{Table}_2 \texttt{ ON } \textit{JoinCondition}$$

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:

$$(\textit{Table}_1 \texttt{ JOIN } \textit{Table}_2 \texttt{ ON } \textit{JoinCond}_1) \texttt{ JOIN } \textit{Table}_3 \texttt{ ON } \textit{JoinCond}_2$$

Outer Joins

The `JOIN` syntax also allows to specify **outer joins**:

```
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 80).

- `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`)

```
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.,
  $\rightarrow$ **data definition language**
- add, delete, or modify rows in the database,
  $\rightarrow$ **data manipulation language**
- define access rights on data.
  $\rightarrow$ **data control language**

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

$\rightarrow$ physical schema management (index creation), backup, etc.

Table Creation

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**:

```
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))
```

Dropping or Altering Tables

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)
```

Views

CREATE VIEW is also a data definition statement (since it changes the database schema; ↗ slide 175):

```
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:

```
DROP VIEW ConsistsOfIngr
```

Inserting Rows

Insert new rows into a table using the `INSERT` statement:

```
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,` $\cdots$`)` 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:

```
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.

```
INSERT INTO Budget (Project, Year, Amount)
  SELECT Project, 2012, AVG(Amount) * 1.10
    FROM Budget
   GROUP BY Project
```

Changing Values in Existing Rows

Values in existing rows can be changed with `UPDATE`:

```
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

UPDATE

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:

```
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 $\leftrightarrow$ Programming Language

SQL is **not** a complete programming language.

$\rightarrow$ It is not even meant to provide such expressiveness ($\nearrow$ slide 147)

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 $\leftrightarrow$ Object-oriented concepts
- declarative, set-oriented $\leftrightarrow$ imperative, record-oriented
- concurrency models, exception handling

SQL $\leftrightarrow$ Programming Language

Various forms of **SQL $\leftrightarrow$ 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 $\leftrightarrow$ C types.
  - → Reference C variables in SQL code using `:`*varname*.
  - → Extended SQL syntax to interact with C variables, *e.g.*, `SELECT` $\cdots$ `INTO` *VarList* `FROM` $\cdots$.
- To **iterate** over result sets, use **cursors**.
  - → `OPEN`, `FETCH`, ..., `FETCH`, `CLOSE`
  - → Make sure you properly close cursors; the database may release **locks** then.