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**Advanced sql joinS**

**Thinking in Sets**

**ADVANCED SQL PUZZLES**

**Welcome**

**The SQL statements and diagrams from this document can be found in following Git repository.**

[**https://github.com/smpetersgithub/AdvancedSQLPuzzles/tree/main/Database%20Writings**](https://github.com/smpetersgithub/AdvancedSQLPuzzles/tree/main/Database%20Writings)

**The examples are based on Microsoft’s SQL Server. The provided SQL statements can be modified easily to fit any dialect of SQL.**

**I welcome any corrections, new tricks, new techniques, dead links, misspellings, bugs, and especially any new puzzles that would be a great fit for this document.**

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**c**

The most essential concept of understanding SQL is how joins operate. Any SQL statement that combines rows from two or more tables, views, table functions, must make use of a join. The ANSI-standard specifies three types of joins:

* INNER JOIN
* OUTER JOIN
* CROSS JOIN

Even before we begin looking into these types of joins, it is best to understand table operators and how they interact with the different logical query-processing phases. SQL does not process the query in the order in which it is written, as the SELECT statement is processed almost last.

The correct processing order is:

1. FROM
2. WHERE
3. GROUP BY
4. HAVING
5. SELECT
6. ORDER BY

Once a query first enters the FROM statement, there are four types of table operators that can be performed, and each of these operators has a series of subphases.

1. JOIN
2. APPLY
3. PIVOT
4. UNPIVOT

The APPLY operator might be unfamiliar to some people, as this operator is used when you want to join a table to a table-valued function. For more information on the APPLY, PVIOT, and UNPIVOT operators, a quick internet search will fill in the gaps. Our focus will be on the JOIN operator.

The sub-phases involved in the join operator are:

1. Create a cartesian product
2. Process the ON predicate logic
3. Add the outer rows if an OUTER JOIN was specified

And then repeat for each table specified in the FROM clause.

I have also included this diagram in Appendix A to provide a larger view. You can also download this from the provided Git repository.

Diagram

Description automatically generated

Figure 1

From this diagram we must take note that there is only one true type of table join, the cartesian product. INNER and OUTER JOINS should be considered restricted cartesian products, where the ON predicate specifies the restriction. If you are unfamiliar with a cartesian product, a quick internet search will fill in the gaps.

The below query is an example of a restricted cartesian product, where the restriction is the value in the Customer ID field must match.

SELECT \*

FROM Customers emp INNER JOIN

Orders ord ON emp.CustomerID = ord.CustomerID;

If we modify the above query to use an OUTER JOIN, the query performs an additional step by adding the outer rows.

The biggest difference between INNER and OUTER JOINS, is that for INNER joins the join logic acts as a filter where both columns need to equate to each other, thus restricting the output to only the records that have these matching column values. For OUTER JOINS, the join logic acts as a matching criterion, where the record count output is not affected by this join logic as it will display the results from the preserved table. For the OUTER JOINS, additional logic is needed in the WHERE clause to add filtering logic to the result set.

For INNER and OUTER JOINS, these types of joins require a comparison operator to equate rows from the participating tables based on a common field in both the tables. These comparison operators are described as equi-joins or non-equi joins (sometimes referred to as theta joins).

Equi-joins look for equality between the joining columns in the tables, and non-equi joins look for anything other than equality between the joining columns, such as greater than or inequality.

Many of these types of joins are rooted in relational algebra. Introduced by Edgar F. Codd in 1970, relational algebra uses algebraic structures with a well-founded semantics for modeling data and defining queries on it. If you are unfamiliar with relational algebra and Edgar F. Codd, I recommend picking up a college level textbook on the subject.

There are also set operators. The difference between a join and set operation, while both concepts can be used to combine data from multiple tables, a join combines columns from separate tables which are often of different types, whereas set operations combine rows from separate relations, which are of the same type. When defining type, we must think of similarity between datasets. A table of customers and a table of orders are of two different types, as one consists of customer information and the other consists of order information. If we were to compare relations containing only the Customer ID field from the Customers table to only the Customer ID of the Orders table, then we have identical types, Customer ID types.

The different set operators are:

1. UNION
2. UNION ALL
3. INTERSECT
4. MINUS

We will discuss set operators more in a bit.

Lastly, there are also join algorithms. SQL is a declarative language; we tell the database what to do, not how to do it. When an SQL statement is executed, a query optimizer will try and retrieve the data in the most efficient way possible. During this query processing, a join algorithm is chosen based upon the available indexes, statistics, and size of the tables (or views, table valued function, etc.…).

Three fundamental algorithms exist for performing a join operation:

1. Nested loop join
2. Sort-merge
3. Hash join

The **nested loop join** is a logical structure in which one loop resides inside another loop. This join typically occurs when one table is smaller than the other table by a considerable size. The larger this difference between the number of rows in the inputs, the more benefit this operator will provide. The inner loop executes for each outer row and searches for matching rows in the inner input table.

The **merge join** requires both the inputs to be sorted on keys and requires a minimum of one equality expression between the matching columns. The algorithm reads a row for each input and compares them using a join key. When a match is detected, both rows in the sets are returned. If a match is not detected, the row with the smaller value is discarded. Because there is a sort key, the algorithm can efficiently transverse the input tables.

A **hash join** is used when large tables are joined, often where an index is not available. The hash join builds a hash table in memory and then scans for matches. It is the least efficient of the joins.

Nested loops are the only algorithm that supports non-equi joins. Merge and hast joins require an equi-join predicate in the queries logic.

**join diagramS**

Traditionally, Venn diagrams are used to show a visual explanation of SQL joins. Joins are relatively easy to understand and using Venn diagrams works for pedagogical reasons. But using Venn diagrams to describe joins is using a wrong comparison, as Venn diagrams are intended to show set operations and not join operations. A good example of the limitation in Venn diagrams is that it is not able to show the CROSS JOIN properly.

Although not as user-friendly as Venn diagrams, join diagrams are a more proper way of demonstrating joins. Here we have a simple join diagram showing the CROSS, INNER, LEFT, and FULL JOIN. I have purposely left out the RIGHT JOIN, as it is simply a reversal of the LEFT JOIN.

Graphical user interface, application

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Figure 2

Now that we understand the different joins and their processing order, let’s move into some specific examples.

In this demonstration, I quickly move through the different types of joins and give an overview of each. I hope this document works as a quick reminder in the nuances of join theory, and I try to keep things on the advanced level by adding NULL markers to the example tables.

**Given the following tables, determine the output of each SQL statement.**

For the following examples you will need to understand the behavior of NULL markers. I’ve provided some rather simple tables with minimal records. In some statements, the example data may not be sufficient, and in these cases feel free to add your own data and experiment.

Here is the example data will be using. As we will discover in the following statements, NULL markers are neither equal nor not equal to each other, they are unknown.

The DDL statements to create these tables can be found in the [GitHub repository located here](https://github.com/smpetersgithub/AdvancedSQLPuzzles/tree/main/Database%20Writings).

**Table A Table B**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **ID** | **Fruit** | **Quantity** |  | **ID** | **Fruit** | **Quantity** |
| 1 | Apple | 17 |  | 1 | Apple | 17 |
| 2 | Peach | 20 |  | 2 | Peach | 25 |
| 3 | Mango | 11 |  | 3 | Kiwi | 20 |
| 4 | <NULL> | 5 |  | 4 | <NULL> | <NULL> |

**INNER JOINS**

The INNER JOIN selects records from two tables given a join condition. This type of join requires a comparison operator to combine rows from the participating tables based on a common field(s) in both the tables. This comparison operator acts as a filter.

We can use both equi-join and non-equi join operators between the joining fields, as we will demonstrate below.

To start, here is the most common join you will use, an INNER JOIN between two tables.

A join between two tables is called a binary relationship. In this example, we use an equi-join as we are looking for equality between the two fields. Note the output does not contain any NULL markers, as NULL markers are neither equal to nor not equal to each other, they are unknown. The below statement represents the SQL-89 syntax.

--1.1

SELECT a.Fruit,

b.Fruit

FROM ##TableA a INNER JOIN

##TableB b ON a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |

We can also specific the matching criteria in the WHERE clause with the SQL-89 syntax.

--1.2

SELECT a.Fruit,

b.Fruit

FROM ##TableA a,

##TableB b

WHERE a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |

Remembering that all types of joins are restricted cartesian products, the following query produces the same results as 1.1 and 1.2.

--1.3

SELECT a.Fruit,

b.Fruit

FROM ##TableA a CROSS JOIN

##TableB b

WHERE a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |

This next statement incorporates an INNER JOIN with a non-equi join, which looks for inequality between two fields. Normally you will combine a non-equi join with an equi-join when creating predicate logic (although not always the case). This statement uses both an equi-join and a non-equi join to find fruits which exist in both tables but have different quantities.

--1.4

SELECT a.Fruit,

b.Fruit

FROM ##TableA a INNER JOIN

##TableB b ON a.Fruit = b.Fruit AND a.Quantity <> b.Quantity;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Peach | Peach |

This query uses both an equi-join and a non-equi join, and functions similar to a CROSS JOIN, but because we have NULL markers in the table, they are eradicated as NULL markers are neither equal nor not equal to each other, they are unknown.

--1.5

SELECT a.Fruit,

b.Fruit

FROM ##TableA a INNER JOIN

##TableB b ON a.Fruit <> b.Fruit OR a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Apple |
| Mango | Apple |
| Apple | Peach |
| Peach | Peach |
| Mango | Peach |
| Apple | Kiwi |
| Peach | Kiwi |
| Mango | Kiwi |

A CROSS JOIN creates all possible permutations of the two tables and will include the NULL markers.

--1.6

SELECT a.Fruit,

b.Fruit

FROM ##TableA a CROSS JOIN

##TableB b;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Apple |
| Mango | Apple |
| <NULL> | Apple |
| Apple | Peach |
| Peach | Peach |
| Mango | Peach |
| <NULL> | Peach |
| Apple | Kiwi |
| Peach | Kiwi |
| Mango | Kiwi |
| <NULL> | Kiwi |
| Apple | <NULL> |
| Peach | <NULL> |
| Mango | <NULL> |
| <NULL> | <NULL> |

Here are some other examples of INNER JOINS using non-equi joins.

--1.7

SELECT \*

FROM ##TableA a INNER JOIN

##TableB b ON a.Quantity >= b.Quantity;

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ID** | **Fruit** | **Quantity** | **ID** | **Fruit** | **Quantity** |
| 1 | Apple | 17 | 1 | Apple | 17 |
| 2 | Peach | 20 | 1 | Apple | 17 |
| 2 | Peach | 20 | 3 | Kiwi | 20 |

--1.8

SELECT \*

FROM ##TableA a INNER JOIN

##TableB b ON a.Fruit = b.Fruit AND a.Quantity BETWEEN 10 AND 20;

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ID** | **Fruit** | **Quantity** | **ID** | **Fruit** | **Quantity** |
| 1 | Apple | 17 | 1 | Apple | 17 |
| 2 | Peach | 20 | 2 | Peach | 25 |

Functions can be used in the join condition as well. Assigning the empty string to a NULL value via the ISNULL function causes the NULLs to now equate to each other. Note, the empty string does not have an ASCII value assigned to it. As demonstrated below, the CHAR function will return an empty set.

--1.9

SELECT a.Fruit,

b.Fruit

FROM ##TableA a INNER JOIN

##TableB b ON ISNULL(a.Fruit,'') = ISNULL(b.Fruit,'');

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |
| <NULL> | <NULL> |

OUTER JOINS

OUTER JOINS consist of LEFT, RIGHT, and FULL OUTER JOIN.

LEFT OUTER JOIN and RIGHT OUTER JOIN function the same; the LEFT OUTER JOIN returns all records from the left table, and the RIGHT OUTER JOIN returns all records from the right table.

It is best practice to use the LEFT OUTER JOIN over the RIGHT OUTER JOIN, as we naturally read from left to right. I will only demonstrate the LEFT OUTER JOIN for this reason.

**LEFT OUTER JOIN**

The most widely used case for the LEFT OUTER JOIN is when we want all values in Table A, regardless of their presence in Table B. A join condition in an OUTER JOIN acts as a matching criterion and not as a filtering mechanism.

--2.1

SELECT a.Fruit,

b.Fruit

FROM ##TableA a LEFT OUTER JOIN

##TableB b ON a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |
| Mango | <NULL> |
| <NULL> | <NULL> |

A LEFT OUTER JOIN is one of several methods to determine records in Table A that do not exist in Table B. The following statement returns all values in Table A that do not exist in Table B. There are other (and possibly better) ways of writing this query which we will cover later.

--2.2

SELECT a.Fruit

FROM ##TableA a LEFT OUTER JOIN

##TableB b ON a.Fruit = b.Fruit

WHERE b.Fruit IS NULL;

|  |
| --- |
| **Fruit** |
| Mango |
| <NULL> |

Predicate logic placed in the ON clause behaves differently than predicate logic in the WHERE clause. Notice the difference in output between the following queries.

--2.3

SELECT a.Fruit,

b.Fruit

FROM ##TableA a LEFT OUTER JOIN

##TableB b ON a.Fruit = b.Fruit AND b.Fruit = 'Apple';

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | <NULL> |
| Mango | <NULL> |
| <NULL> | <NULL> |

Compare the following output to the previous query where the predicate logic was placed in the ON clause. Placing a predicate on the outer joined table in the WHERE clause causes this to function as an INNER JOIN.

--2.4

SELECT a.Fruit,

b.Fruit

FROM ##TableA a LEFT OUTER JOIN

##TableB b ON a.Fruit = b.Fruit

WHERE b.Fruit = 'Apple';

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |

You can also have nested SELECT statements which act as OUTER JOINS, as demonstrated below. The result of this query is the same as 2.1.

--2.5

SELECT a.Fruit,

(SELECT b.Fruit FROM ##TableB b WHERE a.Fruit = b.Fruit) AS Fruit

FROM ##TableA a;

**FULL OUTER JOIN**

The FULL OUTER JOIN is an often-underutilized join as it has a more specific use case than the other joins. This join is best used to compare two similar tables as shown below. Remember to use this type of join when you want to compare two shopping baskets.

The following shows the contents of fruits in both Table A and Table B.

--3.1

SELECT a.Fruit,

b.Fruit

FROM ##TableA a FULL OUTER JOIN

##TableB b ON a.Fruit = b.Fruit;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |
| Mango | <NULL> |
| <NULL> | <NULL> |
| <NULL> | Kiwi |
| <NULL> | <NULL> |

This FULL OUTER JOIN will list the items that do not exist in either of the two tables. The results are Mango and Kiwi, along with two NULL records, as NULL markers are not equal.

--3.2

SELECT a.Fruit,

b.Fruit

FROM ##TableA a FULL OUTER JOIN

##TableB b ON a.Fruit = b.Fruit

WHERE a.Fruit IS NULL OR b.Fruit IS NULL;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Mango | <NULL> |
| <NULL> | <NULL> |
| <NULL> | Kiwi |
| <NULL> | <NULL> |

**NATURAL JOIN**

Some database systems support the NATURAL JOIN construct. It is simplified way of specifying a join where two tables have commonly named column names. SQL Server currently does not support natural joins.

Here are some examples of the NATURAL JOIN syntax from the Oracle documentation. The benefit of natural joins is that the output does not contain duplicate fields as the commonly named columns between the tables will be condensed into one field.

--4.1

SELECT \*

FROM Countries NATURAL JOIN

Cities;

--4.2

SELECT \*

FROM Countries NATURAL JOIN Cities

USING (Country, Country\_ISO\_Code);

--4.3

SELECT \*

FROM Countries NATURAL LEFT JOIN

Cities;

**CROSS JOINS**

A CROSS JOIN creates all permutations (i.e., a cartesian product) of the two joining tables. It will produce a result set which is the number of rows in the first table multiplied by the number of rows in the second table.

Here is a simplest form of the CROSS JOIN.

--5.1

SELECT a.Fruit,

b.Fruit

FROM ##TableA a CROSS JOIN

##TableB b;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Apple |
| Mango | Apple |
| <NULL> | Apple |
| Apple | Peach |
| Peach | Peach |
| Mango | Peach |
| <NULL> | Peach |
| Apple | Kiwi |
| Peach | Kiwi |
| Mango | Kiwi |
| <NULL> | Kiwi |
| Apple | <NULL> |
| Peach | <NULL> |
| Mango | <NULL> |
| <NULL> | <NULL> |

Placing the join condition in the WHERE clause of a CROSS JOIN creates an INNER JOIN. Functions such as a CASE statement can be incorporated into the predicate logic as well.

--5.2

SELECT a.Fruit,

b.Fruit

FROM ##TableA a CROSS JOIN

##TableB b

WHERE (CASE a.Fruit WHEN 'Orange' THEN 'Tangerine' ELSE a.Fruit END) = b.Fruit;

|  |  |
| --- | --- |
| **F+ruit** | **Fruit** |
| Apple | Apple |
| Peach | Peach |

You can also add complicated join logic like the following.

--5.3

SELECT a.Fruit,

b.Fruit

FROM ##TableA a,

##TableB b

WHERE (CASE WHEN a.Quantity > 15 THEN a.Quantity ELSE a.ID END) = b.Quantity;

|  |  |
| --- | --- |
| **Fruit** | **Fruit** |
| Apple | Apple |
| Peach | Kiwi |

**SEMI AND ANTI JOINS**

Semi-joins and anti-joins are two closely related join methods. The semi-join and anti-join are types of joins between two tables where rows from the outer query are returned based upon the presence or absence of a matching row in the joined table.

Anti-joins use the NOT IN or NOT EXISTS operators. Semi-joins use the IN or EXISTS operators.

There are several benefits of using anti-joins and semi-joins over INNER joins:

1. Semi-joins and anti-joins remove the risk of returning duplicate rows.
2. Semi-joins and anti-joins increase readability as the result set can only contain the columns from the outer semi-joined table.

There are several key differences between semi-joins and anti-joins:

1. The NOT IN operator will return an empty set if the anti-join contains a NULL marker. The NOT EXISTS will return a dataset that contains a NULL marker if the anti-join contains a NULL marker.
2. The IN and EXIST operators will return a dataset if the semi-join contains a NULL marker.
3. The NOT EXISTS and EXIST operators can join on multiple columns between the outer and inner SQL statements. The NOT IN or IN operators join on only one single field.

If you are performing an anti-join to a NULLable column, consider using the NOT EXISTS operator over the NOT operator.

This statement returns an empty dataset as the NOT IN operator will return an empty set if the anti-join contains a NULL marker.

--6.1

SELECT Fruit

FROM ##TableA

WHERE Fruit NOT IN (SELECT Fruit FROM ##TableB);

|  |
| --- |
| **Fruit** |

<Empty Data Set>

Adding an ISNULL function to the inner query is one way to alleviate the issue of NULL markers.

--6.2

SELECT Fruit

FROM ##TableA

WHERE Fruit NOT IN (SELECT ISNULL(Fruit,'') FROM ##TableB);

|  |
| --- |
| **Fruit** |
| Mango |

A better practice is to place predicate logic in the WHERE clause to eradicate the NULL markers.

--6.3

SELECT Fruit

FROM ##TableA

WHERE Fruit NOT IN (SELECT Fruit FROM ##TableB WHERE Fruit IS NOT NULL);

|  |
| --- |
| **Fruit** |
| Mango |

The opposite of anti-joins are semi-joins. Using the IN operator, this query will return results and we do not need any special logic to handle NULL markers.

--6.4

SELECT Fruit

FROM ##TableA

WHERE Fruit IN (SELECT Fruit FROM ##TableB);

|  |
| --- |
| **Fruit** |
| Apple |
| Peach |

The IN and NOT IN operators can also take a hard coded list of values as its input. For this example, we use the IN operator. Even though we include a NULL marker in the inner query, the results do not include a NULL marker.

--6.5

SELECT Fruit

FROM ##TableA

WHERE Fruit IN ('Apple','Kiwi',NULL);

|  |
| --- |
| **Fruit** |
| Apple |

EXISTS is much the same as IN. But with EXISTS you must specify a query and you can specify multiple join conditions.

--6.6

SELECT Fruit

FROM ##TableA a

WHERE EXISTS (SELECT 1 FROM ##TableB b WHERE a.Fruit = b.Fruit AND

a.Quantity = b.Quantity);

|  |
| --- |
| **Fruit** |
| Apple |

Here is the usage of the NOT EXISTS.

--6.6

SELECT Fruit

FROM ##TableA a

WHERE NOT EXISTS (SELECT 1 FROM ##TableB b WHERE a.Fruit = b.Fruit AND

a.Quantity = b.Quantity);

|  |
| --- |
| Fruit |
| Peach |
| Mango |
| <NULL> |

**BEHAVIOR OF NULLS**

Up to this point we have used temporary tables to arrive at our conclusions concerning NULL markers. However, we can simply forgo the tables and simply use predicate logic to determine how NULL markers react to the different SQL constructs.

The following SQL statements equate to UNKNOWN and result an empty set.

--7.1

SELECT 1 WHERE NULL = NULL;

SELECT 1 WHERE 1 = NULL;

SELECT 1 WHERE NULL <> NULL;

SELECT 1 WHERE NULL = NULL;

SELECT 1 WHERE 1 = NULL;

SELECT 1 WHERE NULL <> NULL;

SELECT 1 WHERE 1 <> NULL;

SELECT 1 WHERE NULL > NULL;

SELECT 1 WHERE 1 > NULL;

The following SQL statements equate to TRUE.

--7.2

SELECT 1 WHERE NULL IS NULL;

SELECT 1 WHERE 1 IS NOT NULL;

SELECT 1 WHERE 1 = 1;

The following SQL statements equate to FALSE.

--7.3

SELECT 1 WHERE 1 IS NULL;

SELECT 1 WHERE NULL IS NOT NULL;

SELECT 1 WHERE 1 <> 1;

**VALUES KEYWORD**

Specific to SQL Server, we can also use the VALUES constructor to easily create data. It’s not often used in this manner, but it is worth noting the use.

The VALUES constructor specifies a set of row value expressions to be constructed into a table and allows multiple rows of data to be specified in a single DML statement. Normally we use the VALUES constructor to specify the data to insert into a table, as we initially did with our test data, but it can also be used as a derived table in an SQL statement.

Here is a basic example of using the VALUES constructor.

--8.1

SELECT a, b

FROM (VALUES (1, 2), (3, 4), (5, 6), (7, 8), (9, 10)) AS MyTable(a, b);

|  |  |
| --- | --- |
| **a** | **b** |
| 1 | 2 |
| 3 | 4 |
| 5 | 6 |
| 7 | 8 |
| 9 | 10 |

Here is a more elaborate example where the VALUES constructor specifies the values to return.

--8.2

SELECT a.Fruit

FROM ##TableA a INNER JOIN

(VALUES ('Kiwi'), ('Apple')) AS b(Fruit) ON a.Fruit = b.Fruit;

|  |
| --- |
| **Fruit** |
| Apple |

You can also place functions into the VALUES constructor.

--8.3

SELECT a.Fruit,

b.ID

FROM ##TableA a CROSS JOIN

(VALUES (NEWID())) AS b(ID);

|  |  |
| --- | --- |
| **Fruit** | **New\_ID** |
| Apple | 72A95D25-1224-405E-8879-295C2DD0891A |
| Peach | 3767AF47-17B1-4D92-9FBA-632E07A7D10D |
| Mango | 60B37D3D-2FB4-4F24-B486-2CBCD2C09A6B |
| <NULL> | 6466B482-C607-497D-A355-0A9A97E61711 |

**SET OPERATORS**

Now let’s move our attention away from join theory and focus on set operators. The difference between a join and set operation, is that although both concepts are used to combine data from multiple tables, a join combines columns from separate relations, whereas set operations combine rows.

Earlier we showed that Venn diagrams are good for set theory, but not optimal for join theory. Venn diagrams are for showing differences between sets, which in traditional set theory there are 5 basic operations, which are depicted in the following figure.

A picture containing diagram

Description automatically generated

Figure 3

SQL only supports the intersection, union, and relative complement in set theory (with the constructs INTERSECT, UNION, and MINUS/DIFFERENCE). SQL does not have constructs for the symmetric difference or the absolute complement. Also, none of these properly show a LEFT JOIN or a RIGHT JOIN, which is another example of how Venn diagrams should be used for set and not join theory.

The SQL standard for SET OPERATORS does not use the term *EQUAL TO* or *NOT EQUAL TO* when describing their behavior. Instead, it uses the terminology of *IS [NOT] DISTINCT FROM* and the following expressions are TRUE when using SET OPERATORS.

* NULL is not distinct from NULL
* NULL is distinct from “Apples”.

The phrase “Null is not distinct from NULL” may seem difficult to understand at first, but this simply means that NULLS are treated as equalities in the context of SET OPERATORS. In the following examples, we see the SET OPERATORS treat the NULL markers differently than the JOIN syntax.

Here are some examples of set operators in SQL and how they interact with the NULL markers in our example tables.

UNION will return all rows without duplication. Here the UNION interprets the NULLS as similar and combines the record into one. The UNION operator demonstrates that NULL is not distinct from NULL.

--9.1

SELECT Fruit FROM ##TableA

UNION

SELECT Fruit FROM ##TableB;

|  |
| --- |
| **Fruit** |
| <NULL> |
| Apple |
| Kiwi |
| Mango |
| Peach |

The UNION ALL operator returns all values including each NULL marker.

--9.2

SELECT Fruit FROM ##TableA

UNION ALL

SELECT Fruit FROM ##TableB;

|  |
| --- |
| **Fruit** |
| Apple |
| Peach |
| Mango |
| <NULL> |
| Apple |
| Peach |
| Kiwi |
| <NULL> |

INTERSECT will return matching rows and the NULL marker is included in the output.

--9.3

SELECT Fruit FROM ##TableA

INTERSECT

SELECT Fruit FROM ##TableB;

|  |
| --- |
| **Fruit** |
| <NULL> |
| Apple |
| Peach |

EXCEPT will return the records in the table in the first statement that do not exist in the second statement below it. Some SQL languages use MINUS or DIFFERENCE instead of EXCEPT.

--9.4

SELECT Fruit FROM ##TableA

EXCEPT

SELECT Fruit FROM ##TableB;

|  |
| --- |
| **Fruit** |
| Mango |

**SELF JOINS**

Now that we have discussed both joins and set operations (and how they interact with NULL markers) with our example tables, let us move into more specific examples. We will start with self joins, which are joins where the table is joined to itself. Self joins are also called unary relationships.

**Example 1**

The most common example used to demonstrate a self-join is the Manager and Employee hierarchical relationship. In this relationship, the table contains both a foreign key (Manager ID), which relates to its primary key (Employee ID).

Here is an example of such a hierarchy.

|  |  |  |  |
| --- | --- | --- | --- |
| **Employee ID** | **Name** | **Title** | **Manager ID** |
| 1 | Ramirez | President | <NULL> |
| 2 | Baers | Vice President | 1 |
| 3 | Santana | Vice President | 1 |
| 4 | Perkins | Director | 2 |
| 5 | Mercer | Director | 3 |

We can use the following self-join to determine each employee's manager.

--10.1

SELECT a.EmployeeID,

a.Name,

a.Title ,

a.ManagerID,

b.Name AS ManagerName,

b.Title

FROM #Employees a INNER JOIN

#Employees b ON a.ManagerID = b.EmployeeID;

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Employee ID** | **Name** | **Title** | **Manager ID** | **Manager Name** | **Title** |
| 2 | Baers | Vice President | 1 | Ramirez | President |
| 3 | Santana | Vice President | 1 | Ramirez | President |
| 4 | Perkins | Director | 2 | Baers | Vice President |
| 5 | Mercer | Director | 3 | Santana | Vice President |

It is worth mentioning that the above problem lends itself to using a self-referencing common table expression to determine the level of depth each employee has from the highest tier.

In the below example, the common table expression cte\_Recursion references itself in the UNION ALL statement.

--10.2

WITH cte\_Recursion AS

(

SELECT EmployeeID,

Name,

Title,

ManagerID,

0 AS Depth

FROM #Employees

WHERE ManagerID IS NULL

UNION ALL

SELECT b.EmployeeID,

b.Name,

b.Title,

b.ManagerID,

a.Depth + 1 AS Depth

FROM cte\_Recursion a INNER JOIN

#Employees b on a.EmployeeID = b.ManagerID

)

SELECT a.EmployeeID,

a.Name,

a.Title,

a.ManagerID,

b.Name AS ManagerName,

b.Title AS ManagerTitle,

a.Depth

FROM cte\_Recursion a LEFT JOIN

#Employees b ON a.ManagerID = b.EmployeeID

ORDER BY 1;

The above query returns the following dataset.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Employee ID** | **Name** | **Title** | **Manager ID** | **Manager Name** | **Manager Title** | **Depth** |
| 1 | Ramirez | President | <NULL> | <NULL> | <NULL> | 0 |
| 2 | Baers | Vice President | 1 | Ramirez | President | 1 |
| 3 | Santana | Vice President | 1 | Ramirez | President | 1 |
| 4 | Perkins | Director | 2 | Baers | Vice President | 2 |
| 5 | Mercer | Director | 3 | Santana | Vice President | 2 |

**Example 2**

Here is another example problem that can be solved with a self-join. Unlike the above problem, this table does not have a foreign key that references its primary key.

List all cities that have more than one customer along with the customer details.

|  |  |  |
| --- | --- | --- |
| **ID** | **Name** | **City** |
| 1 | Smith | Milwaukee |
| 2 | Harshaw | Detroit |
| 3 | Brown | Dallas |
| 4 | Williams | Detroit |

The syntax to solve this puzzle with a self-join is shown below.

--10.3

SELECT a.ID,

a.Name,

a.City

FROM #Customer a INNER JOIN

#Customer b ON a.City = b.City AND a.Name <> b.Name;

The above query uses a self-join and returns the following result set.

|  |  |  |
| --- | --- | --- |
| **ID** | **Name** | **City** |
| 2 | Harshaw | Detroit |
| 4 | Williams | Detroit |

Because the Customer table does not have a foreign key relationship, the above query could (and most probably should) be written using the following syntax. This statement is slightly more verbose, but the intent of the statement becomes a bit more obvious.

--10.4

WITH cte\_CountCity AS

(

SELECT City

FROM #Customer

GROUP BY City

HAVING COUNT(City) > 1

)

SELECT b.\*

FROM cte\_CountCity a INNER JOIN

#Customer b on a.City = b.City;

**Example 3**

Often, if you need to use a self-join there are options you can use (such as window functions) to avoid the use of a self-join. Let’s look at an example.

Given the below dataset consisting of the weight of various animals, create a cumulative total column summing the current row plus all previous rows.

|  |  |  |
| --- | --- | --- |
| **ID** | **Animal** | **Weight** |
| 1 | Elephant | 13000 |
| 2 | Rhinoceros | 8000 |
| 3 | Hippopotamus | 3000 |
| 4 | Giraffe | 2000 |
| 5 | Water Buffalo | 2000 |

This can be accomplished via the following self-join. Notice the use of a CROSS JOIN and a non-equi join.

--10.5

SELECT a.ID,

a.Animal,

SUM(b.Weight) AS Cummulative\_Weight

FROM #Animals a CROSS JOIN

#Animals b

WHERE a.ID >= b. ID

GROUP BY a.ID, a.Animal;

|  |  |  |
| --- | --- | --- |
| **ID** | **Animal** | **Cummulative Weight** |
| 1 | Elephant | 13000 |
| 4 | Giraffe | 26000 |
| 3 | Hippopotamus | 24000 |
| 2 | Rhinoceros | 21000 |
| 5 | Water Buffalo | 28000 |

However, a better way to write this statement is by using a windowing function.

--10.6

SELECT ID,

Animal,

SUM(Weight)

OVER (ORDER BY ID ROWS BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW)

AS Cummulative\_Weight

FROM #Animals;

|  |  |  |
| --- | --- | --- |
| **ID** | **Animal** | **Cummulative Weight** |
| 1 | Elephant | 13000 |
| 4 | Giraffe | 26000 |
| 3 | Hippopotamus | 24000 |
| 2 | Rhinoceros | 21000 |
| 5 | Water Buffalo | 28000 |

I recommend going through the full feature list of windowing techniques. Functions such as MIN, MAX, COUNT, AVG, SUM, RANK, DENSE\_RANK, ROW\_NUMBER, NTILE, CUME\_DIST, LAG, and LEAD all have windowing capabilities.

**POSITIVE BALANCES**

Earlier we used two tables containing fruits and their quantities to show the various ways we can write SQL joins. The fruit table example works for pedagogical reasons but isn’t the best real-world scenario.

A good puzzle to showcase the multitude of ways a problem can be solved with SQL is the following:

Given the below table, write as many different SQL statements as possible that returns all accounts who never had a positive balance. The result set should only include account 45643, as this is the only account who never had a positive balance.

|  |  |
| --- | --- |
| **ID** | **Balance** |
| 45643 | -123 |
| 45643 | -343 |
| 45643 | -34 |
| 18797 | -45 |
| 18797 | -56 |
| 18797 | 67 |
| 18797 | 78 |
| 87765 | 12 |
| 87765 | 567 |
| 87765 | 343 |

There are 5 different constructs we can use to create the desired output.

1. HAVING
2. OUTER JOIN
3. EXCEPT
4. NOT IN
5. NOT EXISTS

Going through each of the possible solutions, we arrive at the following. Each of the SQL statements will output account 45643.

**EXCEPT Set Operator**

--11.1

SELECT DISTINCT ID FROM #AccountBalances WHERE Balance < 0

EXCEPT

SELECT DISTINCT ID FROM #AccountBalances WHERE Balance > 0;

|  |
| --- |
| **ID** |
| 45643 |

**HAVING with MAX**

--11.2

SELECT ID

FROM #AccountBalances

GROUP BY ID

HAVING MAX(Balance) < 0;

|  |
| --- |
| **ID** |
| 45643 |

**NOT IN**

--11.3

SELECT DISTINCT

ID

FROM #AccountBalances

WHERE ID NOT IN (SELECT ID FROM #AccountBalances WHERE Balance > 0);

|  |
| --- |
| **ID** |
| 45643 |

**NOT EXISTS**

--11.4

SELECT DISTINCT ID

FROM #AccountBalances a

WHERE NOT EXISTS (SELECT 1 FROM #AccountBalances b WHERE Balance > 0 AND

a.ID = b.ID);

|  |
| --- |
| **ID** |
| 45643 |

**LEFT OUTER JOIN**

--11.5

SELECT DISTINCT

a.ID

FROM #AccountBalances a LEFT OUTER JOIN

#AccountBalances b ON a.ID = b.ID AND b.Balance > 0

WHERE b.ID IS NULL;

|  |
| --- |
| **ID** |
| 45643 |

As you can see, we have a multitude of ways to write this query. In the real world, I would test each of these different syntaxes to see which statement gives the most optimized execution plan. Performing such analysis here is out of scope, and I will reserve this for a later time.

**THINKING IN SETS**

Ultimately SQL is an extension of your ability to solve set based problems. Now that we have worked through examples of the different joins, let’s work through an example problem that demonstrates how to think in sets.

The following puzzle is more suited for solving with a graph-based database system rather than a relational database system, but ultimately it gives the best example. The solution to this problem requires multiple steps and some unique ways of joining the tables to arrive at the desired output.

**Mutual Friends Puzzle**

Given the following connections, determine the number of mutual connections between the friends.

|  |  |
| --- | --- |
| **Friend 1** | **Friend 2** |
| Jason | Mary |
| Mike | Mary |
| Mike | Jason |
| Susan | Jason |
| John | Mary |
| Susan | Mary |

Here is the desired output.

|  |  |  |
| --- | --- | --- |
| **Friend 1** | **Friend 2** | **Mutual Friends** |
| Jason | Mary | 2 |
| John | Mary | 0 |
| Jason | Mike | 1 |
| Mary | Mike | 1 |
| Jason | Susan | 1 |
| Mary | Susan | 1 |

* Jason and Mary have 2 mutual friends: Mike and Susan.
* John and Mary have 0 mutual friends.
* Jason and Mike have 1 mutual friend: Mary
* And so forth…......

Now, let’s break this down into the needed sets to solve this puzzle.

**Step 1**

First, create a list of reciprocals where each friendship exists twice.

For example, the friendship between Jason and Mary will exist as Jason and Mary and its reciprocal, Mary and Jason.

We now have 12 records from our original 6 records.

|  |  |
| --- | --- |
| **Friend 1** | **Friend 2** |
| Jason | Mary |
| Jason | Mike |
| Jason | Susan |
| John | Mary |
| Mary | Jason |
| Mary | John |
| Mary | Mike |
| Mary | Susan |
| Mike | Jason |
| Mike | Mary |
| Susan | Jason |
| Susan | Mary |

**Step 2**

Here is where it gets a bit tricky....

Second, we are going to build off our first dataset and construct a set of individuals that we check to determine if they are a friend.

This is best described by example.

Jason and Mary are friends.

Jason is also friends with Mike and Susan.  
Mary is also friends with John, Mike, and Susan.

For the friendship reciprocal of Jason and Mary, we need to check Jason for friendships with John, Mike, and Susan (Mary's friends).

For the friendship reciprocal of Mary and Jason, we need to check Mary for friendships with Mike and Susan (Jason's friends).

|  |  |  |
| --- | --- | --- |
| **Friend 1** | **Friend 2** | **Mutual Friend** |
| Jason | Mary | John |
| Jason | Mary | Mike |
| Jason | Mary | Susan |
| Jason | Mike | Mary |
| Jason | Susan | Mary |
| John | Mary | Jason |
| John | Mary | Mike |
| John | Mary | Susan |
| Mary | Jason | Mike |
| Mary | Jason | Susan |
| Mary | Mike | Jason |
| Mary | Susan | Jason |
| Mike | Jason | Mary |
| Mike | Jason | Susan |
| Mike | Mary | Jason |
| Mike | Mary | John |
| Mike | Mary | Susan |
| Susan | Jason | Mary |
| Susan | Jason | Mike |
| Susan | Mary | Jason |
| Susan | Mary | John |
| Susan | Mary | Mike |

**Step 3**

Next, given the above dataset, we create reciprocals of the Friend1 and Friend2 columns and place the values in alphabetical order.

For example, Jason and Mary will remain as Jason and Mary, but the reciprocal of Mary and Jason becomes Jason and Mary. This will give us duplicate rows for us to determine who the mutual friends are.

|  |  |  |
| --- | --- | --- |
| **Friend 1** | **Friend 2** | **Mutual Friend Check** |
| Jason | Mike | Mary |
| Jason | Mike | Mary |
| Jason | Mike | Susan |
| Jason | Susan | Mary |
| Jason | Susan | Mary |
| Jason | Susan | Mike |
| John | Mary | Jason |
| John | Mary | Mike |
| John | Mary | Susan |
| Mary | Mike | Jason |
| Mary | Mike | Jason |
| Mary | Mike | John |
| Mary | Mike | Susan |
| Mary | Susan | Jason |
| Mary | Susan | Jason |
| Mary | Susan | John |
| Mary | Susan | Mike |

**Step 4**

Next, we are going to group and count the above dataset.

|  |  |  |  |
| --- | --- | --- | --- |
| **Friend 1** | **Friend 2** | **Mutual Friend Check** | **Grouping Count** |
| Jason | Mary | John | 1 |
| Jason | Mary | Mike | 2 |
| Jason | Mary | Susan | 2 |
| Jason | Mike | Mary | 2 |
| Jason | Mike | Susan | 1 |
| Jason | Susan | Mary | 2 |
| Jason | Susan | Mike | 1 |
| John | Mary | Jason | 1 |
| John | Mary | Mike | 1 |
| John | Mary | Susan | 1 |
| Mary | Mike | Jason | 2 |
| Mary | Mike | John | 1 |
| Mary | Mike | Susan | 1 |
| Mary | Susan | Jason | 2 |
| Mary | Susan | John | 1 |
| Mary | Susan | Mike | 1 |

**Step 5**

Next, we review the Grouping Count column in the previous dataset. If the Grouping Count is 2, then the Mutual Friend Check column is indeed a mutual friend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Friend 1** | **Friend 2** | **Mutual Friend Check** | **Friend Count** |
| Jason | Mary | John | 0 |
| Jason | Mary | Mike | 1 |
| Jason | Mary | Susan | 1 |
| Jason | Mike | Mary | 1 |
| Jason | Mike | Susan | 0 |
| Jason | Susan | Mary | 1 |
| Jason | Susan | Mike | 0 |
| John | Mary | Jason | 0 |
| John | Mary | Mike | 0 |
| John | Mary | Susan | 0 |
| Mary | Mike | Jason | 1 |
| Mary | Mike | John | 0 |
| Mary | Mike | Susan | 0 |
| Mary | Susan | Jason | 1 |
| Mary | Susan | John | 0 |
| Mary | Susan | Mike | 0 |

**Step 6**

And then finally sum the results.

|  |  |  |
| --- | --- | --- |
| **Friend 1** | **Friend 2** | **Total Mutual Friends** |
| Jason | Mike | 1 |
| Jason | Susan | 1 |
| John | Mary | 0 |
| Mary | Mike | 1 |
| Mary | Susan | 1 |

Breaking down each of the above steps into the needed SQL statements, we get the following.

**Step 1**

First, we are going to create a set of duplicates using the UNION statement, but we create a list of all pairings where each friendship exists twice. Notice in the second UNION we reverse the order, and Friend 2 is before Friend 1 in the SELECT statement.

--Step 1

--12.1

WITH cte\_Reciprocal\_Friends AS

(

SELECT Friend1,

Friend2

FROM #Friends

UNION

SELECT Friend2,

Friend1

FROM #Friends

)

SELECT \*

INTO #Distinct\_Friends\_Full\_1

FROM cte\_Reciprocal\_Friends;

ORDER BY 1,2;

**Step 2**

Step 2 is the tricky part where we need to create a validation list for each set of friends. We use an INNER JOIN with a non-equi join to arrive at our results.

--Step 2

--12.2

SELECT a.\*,

b.Friend2 AS Mutual\_Friend\_Check

INTO #Mutual\_Friend\_Check\_2

FROM #Distinct\_Friends\_Full\_1 a INNER JOIN

#Distinct\_Friends\_Full\_1 b ON a.Friend2 = b.Friend1

WHERE a.Friend1 <> b.Friend2;

ORDER BY 1,2;

**Step 3**

For step 3 we create a list of reciprocals and place the Friend 1 and Friend 2 columns in alphabetical order. The result of this statement will create duplicates.

--Step 3

--12.3

SELECT (CASE WHEN Friend1 < Friend2 THEN Friend1 ELSE Friend2 END) AS Friend1,

(CASE WHEN Friend1 < Friend2 THEN Friend2 ELSE Friend1 END) AS Friend2,

Mutual\_Friend\_Check

INTO #Reciprocal\_Mutual\_Friend\_Check\_3

FROM #Mutual\_Friend\_Check\_2;

**Step 4**

Step 4 simply does a COUNT and GROUP BY.

--Step 4

--12.4

SELECT Friend1,

Friend2,

Mutual\_Friend\_Check,

COUNT(\*) AS Grouping\_Count

INTO #Reciprocal\_Mutual\_Friend\_Check\_Count\_4

FROM #Reciprocal\_Mutual\_Friend\_Check\_3

GROUP BY Friend1, Friend2, Mutual\_Friend\_Check;

**Step 5**

For step 5, we create a CASE statement to check if the column Grouping Count contains a 2 (a duplicate from the previous step 3). If the value is 2, then the field Mutual Friend Check is a mutual friend.

--Step 5

--12.5

SELECT Friend1,

Friend2,

Mutual\_Friend\_Check,

(CASE Grouping\_Count WHEN 1 THEN 0 WHEN 2 THEN 1 END) AS Friend\_Count

INTO #Reciprocal\_Mutual\_Friend\_Check\_Count\_Modified\_5

FROM #Reciprocal\_Mutual\_Friend\_Check\_Count\_4;

**Step 6**

And the last step is to simply sum the column Friend Count to arrive at our answer.

--Step 6

--12.6

SELECT Friend1,

Friend2,

SUM(Friend\_Count) AS Total\_Mutual\_Friends

FROM #Reciprocal\_Mutual\_Friend\_Check\_Count\_Modified\_5

GROUP BY Friend1, Friend2;

ORDER BY 1,2;

**CONCLUSION**

Within SQL, the word join can mean many things. There are the traditional joins of INNER, OUTER, and FULL. But the word join can also be used to describe equi-joins, non-equi joins, natural joins, self-joins, or the different join algorithms: nested loop joins, sort-merge, and hash joins.

SQL is a combination of both join and set theory and understanding the various nuances of these two is instrumental in understanding SQL. In join theory, all joins are restricted cartesian products. When a join table operation is initiated, a cartesian product is created, which is then restricted by the ON condition. If an OUTER JOIN is specified, then an additional step of adding the outer rows is needed. The main difference between an INNER and an OUTER JOIN, is that an INNER JOIN acts as a filter, whereas OUTER JOINS acts as a matching criterion.

We also discussed the different join operators and the processing order of SQL, which is different than its written order. I’ve included the diagram in Appendix A, and this should give insight into the internal workings of SQL. Although the SELECT clause is the first statement in an SQL statement, the FROM clause is executed first, and then the WHERE clause.

Set operations are also discussed and how Venn diagrams are the better construct to show set operations and not join operations. For join operations, I recommend using join diagrams to show example tables and the results. When performing set operations, the datasets need to be of the same type.

We also worked through example real world problems where self joins are needed to create the desired output. SQL is the language of databases, and there are multiple syntax options for solving set-based problems. The Positive Balances example problem is a perfect example in how many ways we can construct an SQL statement that arrives at the desired output. Ultimately, it is up to the developer to choose the best statement.

I hope this document has helped you understand the behavior of SQL joins. If you have any questions, bug fixes, or want to say hello, please contact me through my website at <https://advancedsqlpuzzles.com>.

**The End.**

Appendix A

Diagram

Description automatically generated

Figure 1