Explaining the Postgres Query Optimizer

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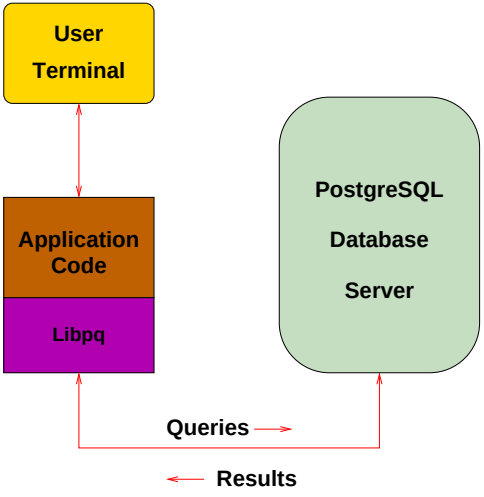
The optimizer is the "brain" of the database, interpreting SQL queries and determining the fastest method of execution. This talk uses the EXPLAIN command to show how the optimizer interprets queries and determines optimal execution.

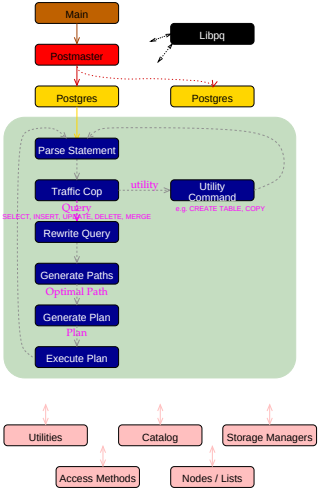
https://momjian.us/presentations

Last updated: August 2025

Postgres Query Execution

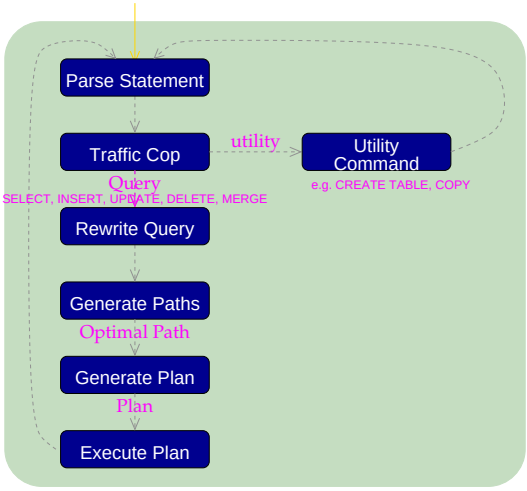


Postgres Query Execution



https://momjian.us/main/presentations/internals.html#internal_pics

Postgres Query Execution



https://www.highgo.ca/2024/01/26/a-comprehensive-overview-of-postgresql-query-processing-stages/

The Optimizer Is the Brain

https://www.flickr.com/photos/dierkschaefer/

What Decisions Does the Optimizer Have to Make?

- Scan Method
- Join Method
- Join Order

These blog posts have great descriptions of optimizer internals:

- https://www.highgo.ca/2024/03/22/understand-postgresqls-planner-simple-scan-paths-vs-plans/
- https://dev.to/ashenblade/postgresql-planner-development-and-debugging-47mc

Which Scan Method?

- Sequential Scan
- Bitmap Index Scan
- Index Scan

A Simple Example Using *pg_class.relname*

```
SELECT relname
FROM pg_class
ORDER BY 1
LIMIT 8;
               relname
-----------------------------------
 _pg_foreign_data_wrappers
 _pg_foreign_servers
 _pg_foreign_table_columns
 _pg_foreign_tables
 _pg_user_mappings
 administrable_role_authorizations
 applicable_roles
 attributes
```

Let's Use Just the First Letter of *pg_class.relname*

```
SELECT substring(relname, 1, 1)
FROM pg_class
ORDER BY 1
LIMIT 8;
 substring
-----------

 _
 _
 _
 _
 _
 a
 a
 a
```

Create a Temporary Table with an Index

```
CREATE TEMPORARY TABLE sample (letter, junk) AS
        SELECT substring(relname, 1, 1), repeat('x', 250)
        FROM pg_class
        ORDER BY random();  -- add rows in random order

CREATE INDEX i_sample on sample (letter);
```

All queries used in this presentation are available at https://momjian.us/main/writings/pgsql/optimizer.sql.

Create an EXPLAIN Function

```
CREATE OR REPLACE FUNCTION lookup_letter(text) RETURNS SETOF text AS $$
BEGIN
RETURN QUERY EXECUTE '
        EXPLAIN SELECT letter
        FROM sample
        WHERE letter = ''' || $1 || '''';
END
$$ LANGUAGE plpgsql;
```

What is the Distribution of the *sample* Table?

```
WITH letters (letter, count) AS (
        SELECT  letter, COUNT(*)
        FROM sample
        GROUP BY 1
)
SELECT letter, count, (count * 100.0 / (SUM(count) OVER ()))::numeric(4,1) AS "%"
FROM letters
ORDER BY 2 DESC;
```

What is the Distribution of the *sample* Table?

letter	count	%
p	342	83.4
c	13	3.2
r	12	2.9
f	6	1.5
s	6	1.5
t	6	1.5
u	5	1.2
_	5	1.2
d	4	1.0
v	4	1.0
a	3	0.7
e	2	0.5
k	1	0.2
i	1	0.2

Is the Distribution Important?

```
EXPLAIN SELECT letter
FROM sample
WHERE letter = 'p';
                                QUERY PLAN
-------------------------------------------------------------------------
 Bitmap Heap Scan on sample  (cost=4.16..10.07 rows=2 width=32)
   Recheck Cond: (letter = 'p'::text)
   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.16 rows=2 width=0)
         Index Cond: (letter = 'p'::text)
```

Is the Distribution Important?

```
EXPLAIN SELECT letter
FROM sample
WHERE letter = 'd';
                                QUERY PLAN
-------------------------------------------------------------------------
 Bitmap Heap Scan on sample  (cost=4.16..10.07 rows=2 width=32)
   Recheck Cond: (letter = 'd'::text)
   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.16 rows=2 width=0)
         Index Cond: (letter = 'd'::text)
```

Is the Distribution Important?

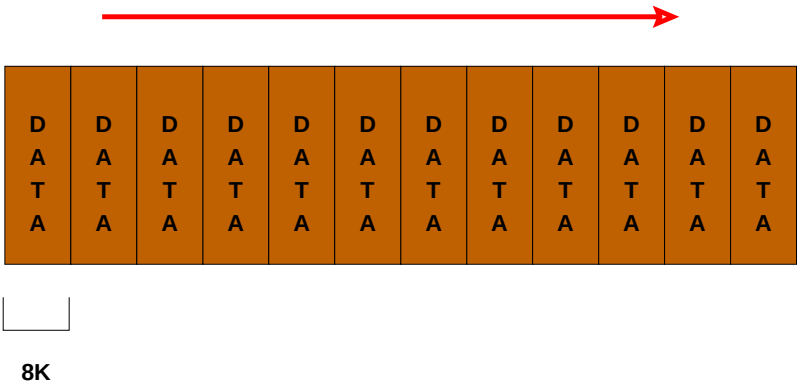
```
EXPLAIN SELECT letter
FROM sample
WHERE letter = 'i';
                                QUERY PLAN
-------------------------------------------------------------------------
 Bitmap Heap Scan on sample  (cost=4.16..10.07 rows=2 width=32)
   Recheck Cond: (letter = 'i'::text)
   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.16 rows=2 width=0)
         Index Cond: (letter = 'i'::text)
```

Running ANALYZE Causes a Sequential Scan for a Common Value

```
ANALYZE sample;

EXPLAIN SELECT letter
FROM sample
WHERE letter = 'p';
                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on sample  (cost=0.00..21.12 rows=342 width=2)
   Filter: (letter = 'p'::text)
```

Autovacuum cannot ANALYZE (or VACUUM) temporary tables because these tables are only visible to the creating session.

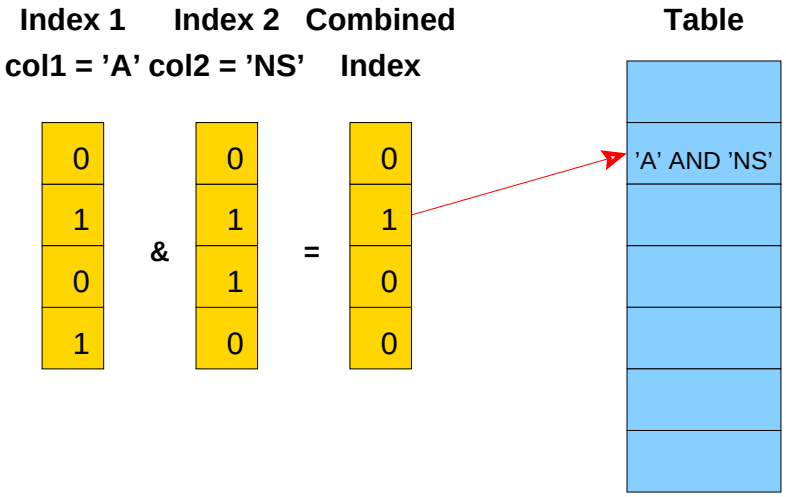
Heap


DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
8K

A Less Common Value Causes a Bitmap Index Scan

```
EXPLAIN SELECT letter
FROM sample
WHERE letter = 'd';
                                QUERY PLAN
-------------------------------------------------------------------------
 Bitmap Heap Scan on sample  (cost=4.18..14.23 rows=4 width=2)
   Recheck Cond: (letter = 'd'::text)
   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.18 rows=4 width=0)
         Index Cond: (letter = 'd'::text)
```

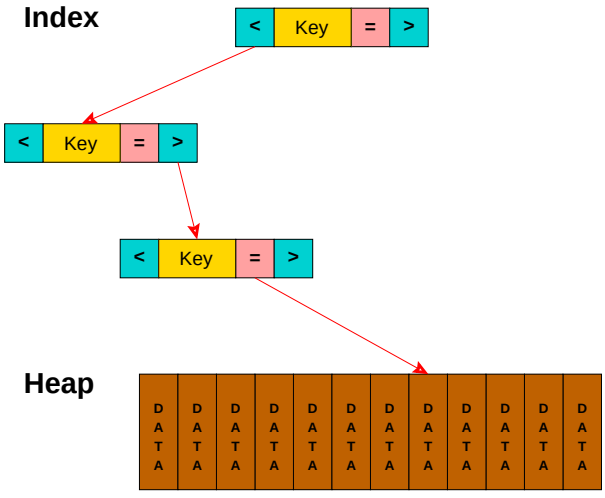
Bitmap Index Scan

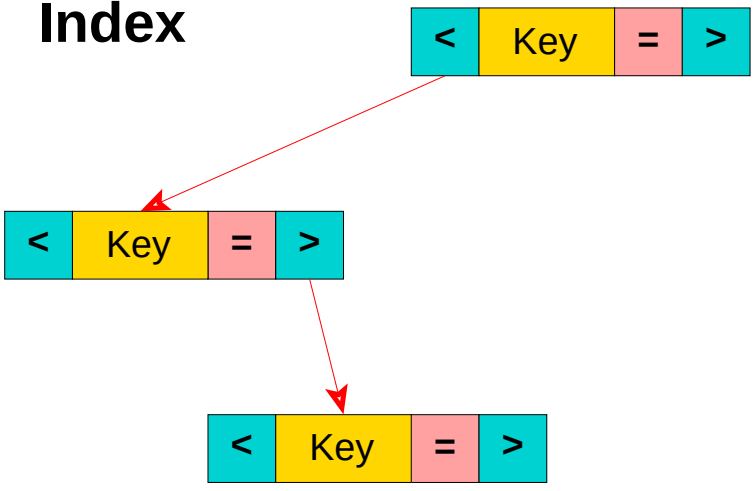


An Even Rarer Value Causes an Index Scan

```
EXPLAIN SELECT letter
FROM sample
WHERE letter = 'i';
                                  QUERY PLAN
------------------------------------------------------------------------------
 Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
   Index Cond: (letter = 'i'::text)
```

Index Scan


Index
< Key = >
< Key = >
< Key = >
Heap
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA


Index
< Key = >
< Key = >
< Key = >

Let's Look at All Values and their Effects

```
WITH letter (letter, count) AS (
        SELECT letter, COUNT(*)
        FROM sample
        GROUP BY 1
)
SELECT letter AS l, count, lookup_letter(letter)
FROM letter
ORDER BY 2 DESC;
 l | count |                                lookup_letter
---+-------+-------------------------------------------------------------------------
 p |   342 | Seq Scan on sample  (cost=0.00..21.12 rows=342 width=2)
 p |   342 |   Filter: (letter = 'p'::text)
 c |    13 | Bitmap Heap Scan on sample  (cost=4.25..20.69 rows=13 width=2)
 c |    13 |   Recheck Cond: (letter = 'c'::text)
 c |    13 |   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.25 rows=13 width=0)
 c |    13 |         Index Cond: (letter = 'c'::text)
 r |    12 | Bitmap Heap Scan on sample  (cost=4.24..20.14 rows=12 width=2)
 r |    12 |   Recheck Cond: (letter = 'r'::text)
 r |    12 |   ->  Bitmap Index Scan on i_sample  (cost=0.00..4.24 rows=12 width=0)
 r |    12 |         Index Cond: (letter = 'r'::text)
```

OK, Just the First Lines

```
WITH letter (letter, count) AS (
        SELECT letter, COUNT(*)
        FROM sample
        GROUP BY 1
)
SELECT letter AS l, count,
        (SELECT *
         FROM lookup_letter(letter) AS l2
         LIMIT 1) AS lookup_letter
FROM letter
ORDER BY 2 DESC;
```

Just the First EXPLAIN Lines

```
 l | count |                                  lookup_letter
---+-------+-------------------------------------------------------------------------------
 p |   342 | Seq Scan on sample  (cost=0.00..21.12 rows=342 width=2)
 c |    13 | Bitmap Heap Scan on sample  (cost=4.25..20.69 rows=13 width=2)
 r |    12 | Bitmap Heap Scan on sample  (cost=4.24..20.14 rows=12 width=2)
 f |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 t |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 s |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 u |     5 | Bitmap Heap Scan on sample  (cost=4.19..15.86 rows=5 width=2)
 _ |     5 | Bitmap Heap Scan on sample  (cost=4.19..15.86 rows=5 width=2)
 d |     4 | Bitmap Heap Scan on sample  (cost=4.18..14.23 rows=4 width=2)
 v |     4 | Bitmap Heap Scan on sample  (cost=4.18..14.23 rows=4 width=2)
 a |     3 | Bitmap Heap Scan on sample  (cost=4.17..12.31 rows=3 width=2)
 e |     2 | Bitmap Heap Scan on sample  (cost=4.16..10.07 rows=2 width=2)
 k |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
 i |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
```

Results will vary based on the clustering of values in heap pages.

We Can Force an Index Scan

```
SET enable_seqscan = false;

SET enable_bitmapscan = false;

WITH letter (letter, count) AS (
        SELECT letter, COUNT(*)
        FROM sample
        GROUP BY 1
)
SELECT letter AS l, count,
        (SELECT *
         FROM lookup_letter(letter) AS l2
         LIMIT 1) AS lookup_letter
FROM letter
ORDER BY 2 DESC;
```

Notice the High Cost for Common Values

```
 l | count |                                  lookup_letter
---+-------+-------------------------------------------------------------------------------
 p |   342 | Index Only Scan using i_sample on sample  (cost=0.15..56.35 rows=342 width=2)
 c |    13 | Index Only Scan using i_sample on sample  (cost=0.15..27.69 rows=13 width=2)
 r |    12 | Index Only Scan using i_sample on sample  (cost=0.15..25.53 rows=12 width=2)
 s |     6 | Index Only Scan using i_sample on sample  (cost=0.15..18.98 rows=6 width=2)
 f |     6 | Index Only Scan using i_sample on sample  (cost=0.15..18.98 rows=6 width=2)
 t |     6 | Index Only Scan using i_sample on sample  (cost=0.15..18.98 rows=6 width=2)
 u |     5 | Index Only Scan using i_sample on sample  (cost=0.15..16.82 rows=5 width=2)
 _ |     5 | Index Only Scan using i_sample on sample  (cost=0.15..16.82 rows=5 width=2)
 v |     4 | Index Only Scan using i_sample on sample  (cost=0.15..14.66 rows=4 width=2)
 d |     4 | Index Only Scan using i_sample on sample  (cost=0.15..14.66 rows=4 width=2)
 a |     3 | Index Only Scan using i_sample on sample  (cost=0.15..12.49 rows=3 width=2)
 e |     2 | Index Only Scan using i_sample on sample  (cost=0.15..10.33 rows=2 width=2)
 k |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
 i |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
```

```
RESET ALL;
```

This Was the Optimizer's Preference

```
 l | count |                                  lookup_letter
---+-------+-------------------------------------------------------------------------------
 p |   342 | Seq Scan on sample  (cost=0.00..21.12 rows=342 width=2)
 c |    13 | Bitmap Heap Scan on sample  (cost=4.25..20.69 rows=13 width=2)
 r |    12 | Bitmap Heap Scan on sample  (cost=4.24..20.14 rows=12 width=2)
 f |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 t |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 s |     6 | Bitmap Heap Scan on sample  (cost=4.19..17.25 rows=6 width=2)
 u |     5 | Bitmap Heap Scan on sample  (cost=4.19..15.86 rows=5 width=2)
 _ |     5 | Bitmap Heap Scan on sample  (cost=4.19..15.86 rows=5 width=2)
 d |     4 | Bitmap Heap Scan on sample  (cost=4.18..14.23 rows=4 width=2)
 v |     4 | Bitmap Heap Scan on sample  (cost=4.18..14.23 rows=4 width=2)
 a |     3 | Bitmap Heap Scan on sample  (cost=4.17..12.31 rows=3 width=2)
 e |     2 | Bitmap Heap Scan on sample  (cost=4.16..10.07 rows=2 width=2)
 k |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
 i |     1 | Index Only Scan using i_sample on sample  (cost=0.15..8.17 rows=1 width=2)
```

Which Join Method?

- Nested Loop
  - With Inner Sequential Scan
  - With Inner Index Scan
- Hash Join
- Merge Join

What Is in *pg_proc.oid*?

```
SELECT oid
FROM pg_proc
ORDER BY 1
LIMIT 8;
 oid
-----
   3
  31
  33
  34
  35
  38
  39
  40
```

Create Temporary Tables from *pg_proc* and *pg_class*

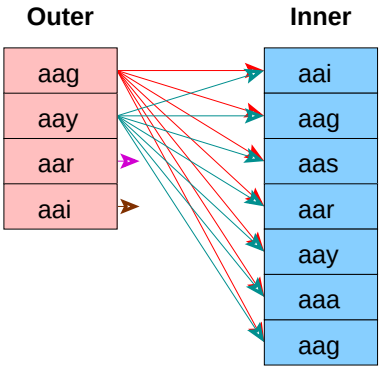
```
CREATE TEMPORARY TABLE sample1 (id, junk) AS
        SELECT oid, repeat('x', 250)
        FROM pg_proc
        ORDER BY random();  -- add rows in random order

CREATE TEMPORARY TABLE sample2 (id, junk) AS
        SELECT oid, repeat('x', 250)
        FROM pg_class
        ORDER BY random();  -- add rows in random order
```

These tables have no optimizer statistics and no indexes.

Join the Two Tables with a Tight Restriction

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
WHERE sample1.id = 33;
                                QUERY PLAN
-------------------------------------------------------------------------
 Nested Loop  (cost=0.00..364.14 rows=770 width=32)
   ->  Seq Scan on sample1  (cost=0.00..313.09 rows=77 width=4)
         Filter: (id = '33'::oid)
   ->  Materialize  (cost=0.00..41.45 rows=10 width=36)
         ->  Seq Scan on sample2  (cost=0.00..41.40 rows=10 width=36)
               Filter: (id = '33'::oid)
```

Nested Loop Join with Inner Sequential Scan



No Setup Required

Used For Small Tables

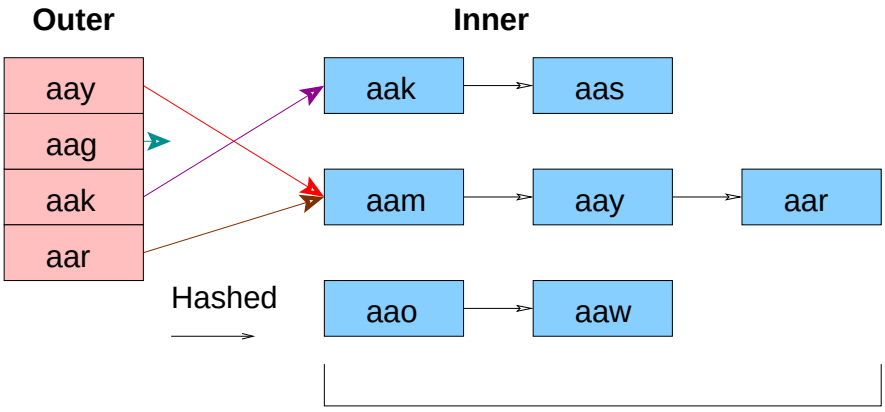
Pseudocode for Nested Loop Join with Inner Sequential Scan

```
for (i = 0; i < length(outer); i++)
  for (j = 0; j < length(inner); j++)
    if (outer[i] == inner[j])
      output(outer[i], inner[j]);
```

Join the Two Tables with a Looser Restriction

```
EXPLAIN SELECT sample1.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
WHERE sample2.id > 33;
                                QUERY PLAN
-------------------------------------------------------------------------
 Hash Join  (cost=49.86..2189.32 rows=52017 width=32)
   Hash Cond: (sample1.id = sample2.id)
   ->  Seq Scan on sample1  (cost=0.00..274.67 rows=15367 width=36)
   ->  Hash  (cost=41.40..41.40 rows=677 width=4)
         ->  Seq Scan on sample2  (cost=0.00..41.40 rows=677 width=4)
               Filter: (id > '33'::oid)
```

Hash Join



https://stormatics.tech/blogs/understanding-hash-aggregates-and-hash-joins-in-postgresql

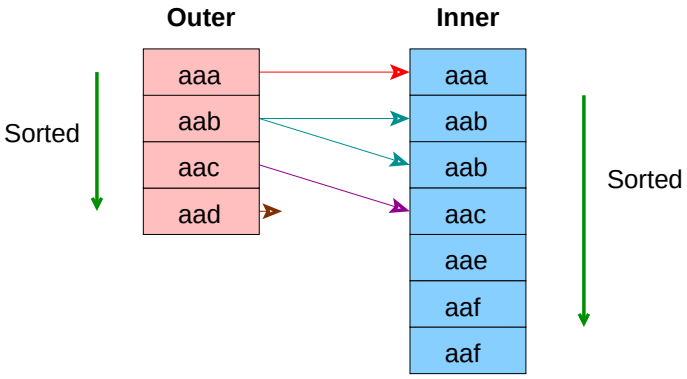
Pseudocode for Hash Join

```
for (j = 0; j < length(inner); j++)
  hash_key = hash(inner[j]);
  append(hash_store[hash_key], inner[j]);
for (i = 0; i < length(outer); i++)
  hash_key = hash(outer[i]);
  for (j = 0; j < length(hash_store[hash_key]); j++)
    if (outer[i] == hash_store[hash_key][j])
      output(outer[i], inner[j]);
```

Join the Two Tables with No Restriction

```
EXPLAIN SELECT sample1.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id);
                                QUERY PLAN
-------------------------------------------------------------------------
 Merge Join  (cost=1491.22..3843.32 rows=156129 width=32)
   Merge Cond: (sample2.id = sample1.id)
   ->  Sort  (cost=147.97..153.05 rows=2032 width=4)
         Sort Key: sample2.id
         ->  Seq Scan on sample2  (cost=0.00..36.32 rows=2032 width=4)
   ->  Sort  (cost=1343.26..1381.67 rows=15367 width=36)
         Sort Key: sample1.id
         ->  Seq Scan on sample1  (cost=0.00..274.67 rows=15367 width=36)
```

Merge Join



Ideal for Large Tables

An Index Can Be Used to Eliminate the Sort

Pseudocode for Merge Join

```
sort(outer);
sort(inner);
i = 0;
j = 0;
save_j = 0;
while (i < length(outer))
  if (outer[i] == inner[j])
    output(outer[i], inner[j]);
  if (outer[i] >= inner[j] && j < length(inner))
    j++;
    if (outer[i] > inner[j])
      save_j = j;
  else
    i++;
    j = save_j;
```

Order of Joined Relations Is Insignificant

```
EXPLAIN SELECT sample2.junk
FROM sample2 JOIN sample1 ON (sample2.id = sample1.id);
                                QUERY PLAN
-------------------------------------------------------------------------
 Merge Join  (cost=1491.22..3843.32 rows=156129 width=32)
   Merge Cond: (sample2.id = sample1.id)
   ->  Sort  (cost=147.97..153.05 rows=2032 width=36)
         Sort Key: sample2.id
         ->  Seq Scan on sample2  (cost=0.00..36.32 rows=2032 width=36)
   ->  Sort  (cost=1343.26..1381.67 rows=15367 width=4)
         Sort Key: sample1.id
         ->  Seq Scan on sample1  (cost=0.00..274.67 rows=15367 width=4)
```

The most restrictive relation, e.g., *sample2,* is always on the outer side of merge joins. All previous merge joins also had *sample2* in outer position.

Add Optimizer Statistics

```
ANALYZE sample1;

ANALYZE sample2;
```

This Was a Merge Join without Optimizer Statistics

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id);
                                QUERY PLAN
-------------------------------------------------------------------------
 Hash Join  (cost=25.38..195.17 rows=417 width=254)
   Hash Cond: (sample1.id = sample2.id)
   ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=4)
   ->  Hash  (cost=20.17..20.17 rows=417 width=258)
         ->  Seq Scan on sample2  (cost=0.00..20.17 rows=417 width=258)
```

Outer Joins Can Affect Optimizer Join Usage

```
EXPLAIN SELECT sample1.junk
FROM sample1 RIGHT OUTER JOIN sample2 ON (sample1.id = sample2.id);
                              QUERY PLAN
-----------------------------------------------------------------------
 Hash Right Join  (cost=25.38..195.17 rows=417 width=254)
   Hash Cond: (sample1.id = sample2.id)
   ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=258)
   ->  Hash  (cost=20.17..20.17 rows=417 width=4)
         ->  Seq Scan on sample2  (cost=0.00..20.17 rows=417 width=4)
```

Cross Joins Are Nested Loop Joins without Join Restriction

```
EXPLAIN SELECT sample1.junk
FROM sample1 CROSS JOIN sample2;
                                QUERY PLAN
-------------------------------------------------------------------------
 Nested Loop  (cost=0.00..17089.22 rows=1353165 width=254)
   ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=254)
   ->  Materialize  (cost=0.00..22.26 rows=417 width=0)
         ->  Seq Scan on sample2  (cost=0.00..20.17 rows=417 width=0)
```

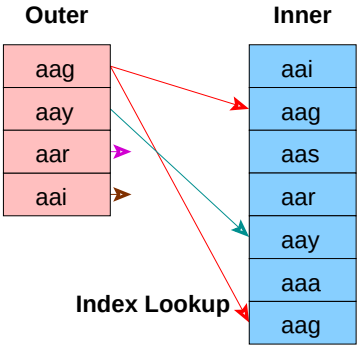
Create Indexes

```
CREATE INDEX i_sample1 on sample1 (id);

CREATE INDEX i_sample2 on sample2 (id);
```

Nested Loop with Inner Index Scan Now Possible

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
WHERE sample1.id = 33;
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Nested Loop  (cost=0.55..16.60 rows=1 width=254)
   ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..8.30 rows=1 width=4)
         Index Cond: (id = '33'::oid)
   ->  Index Scan using i_sample2 on sample2  (cost=0.27..8.29 rows=1 width=258)
         Index Cond: (id = '33'::oid)
```

Nested Loop Join with Inner Index Scan



No Setup Required

Index Must Already Exist

Pseudocode for Nested Loop Join with Inner Index Scan

```
for (i = 0; i < length(outer); i++)
  index_entry = get_first_match(outer[j])
  while (index_entry)
    output(outer[i], inner[index_entry]);
    index_entry = get_next_match(index_entry);
```

Query Restrictions Affect Join Usage

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
WHERE sample2.junk ~ '^aaa';
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Nested Loop  (cost=0.28..29.52 rows=1 width=254)
   ->  Seq Scan on sample2  (cost=0.00..21.21 rows=1 width=258)
         Filter: (junk ~ '^aaa'::text)
   ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..8.30 rows=1 width=4)
         Index Cond: (id = sample2.id)
```

No *junk* rows begin with 'aaa'.

All 'junk' Columns Begin with 'xxx'

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
WHERE sample2.junk ~ '^xxx';
                                QUERY PLAN
-------------------------------------------------------------------------
 Hash Join  (cost=26.42..196.21 rows=417 width=254)
   Hash Cond: (sample1.id = sample2.id)
   ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=4)
   ->  Hash  (cost=21.21..21.21 rows=417 width=258)
         ->  Seq Scan on sample2  (cost=0.00..21.21 rows=417 width=258)
               Filter: (junk ~ '^xxx'::text)
```

Hash join was chosen because many more rows are expected. The smaller table, e.g., *sample2,* is always hashed.

Without LIMIT, Hash Is Used for this Unrestricted Join

```
EXPLAIN SELECT sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1;
                                    QUERY PLAN
-------------------------------------------------------------------------------
 Sort  (cost=213.32..214.36 rows=417 width=254)
   Sort Key: sample2.junk
   ->  Hash Join  (cost=25.38..195.17 rows=417 width=254)
         Hash Cond: (sample1.id = sample2.id)
         ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=4)
         ->  Hash  (cost=20.17..20.17 rows=417 width=258)
               ->  Seq Scan on sample2  (cost=0.00..20.17 rows=417 width=258)
```

LIMIT Can Affect Join Usage

```
EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1
LIMIT 1;
                                        QUERY PLAN
-------------------------------------------------------------------------------------
 Limit  (cost=0.55..2.33 rows=1 width=258)
   ->  Nested Loop  (cost=0.55..742.75 rows=417 width=258)
         ->  Index Scan using i_sample2 on sample2  (cost=0.27..86.52 rows=417 width
         ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..1.56 rows=1 wid
               Index Cond: (id = sample2.id)
```

Sort is unneeded since an index is being used on the outer side.

LIMIT 10

```
EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1
LIMIT 10;
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Limit  (cost=0.55..18.35 rows=10 width=258)
   ->  Nested Loop  (cost=0.55..742.75 rows=417 width=258)
         ->  Index Scan using i_sample2 on sample2  (cost=0.27..86.52 rows=417 width
         ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..1.56 rows=1 wid
               Index Cond: (id = sample2.id)
```

LIMIT 100 Switches to Merge Join

```
EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1
LIMIT 100;
                                                QUERY PLAN
-----------------------------------------------------------------------------------------
 Limit  (cost=11.00..170.51 rows=100 width=258)
   ->  Merge Join  (cost=11.00..676.13 rows=417 width=258)
         Merge Cond: (sample1.id = sample2.id)
         ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..576.91 rows=324
         ->  Index Scan using i_sample2 on sample2  (cost=0.27..86.52 rows=417 width
```

Merge join is normally used for large joins, but the indexes eliminate the need for sorting both sides band LIMIT reduces the number of index entries that need to be accessed.

LIMIT 1000 Switches Back to Hash Join

```
EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1
LIMIT 1000;
                                    QUERY PLAN
-------------------------------------------------------------------------------------
 Limit  (cost=213.32..214.36 rows=417 width=258)
   ->  Sort  (cost=213.32..214.36 rows=417 width=258)
         Sort Key: sample2.id
         ->  Hash Join  (cost=25.38..195.17 rows=417 width=258)
               Hash Cond: (sample1.id = sample2.id)
               ->  Seq Scan on sample1  (cost=0.00..153.45 rows=3245 width=4)
               ->  Hash  (cost=20.17..20.17 rows=417 width=258)
                     ->  Seq Scan on sample2  (cost=0.00..20.17 rows=417 width=258)
```

For LIMIT 1000, index lookups are considered to be too expensive to partially execute the join, so a hash join is fully executed, which is then sorted and the LIMIT applied.

VACUUM Causes Merge Join Again

```
-- updates the visibility map
VACUUM sample1, sample2;

EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1
LIMIT 1000;
                                        QUERY PLAN
-------------------------------------------------------------------------------------
 Limit  (cost=40.67..150.78 rows=420 width=258)
   ->  Merge Join  (cost=40.67..150.78 rows=420 width=258)
         Merge Cond: (sample1.id = sample2.id)
         ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..97.75 rows=3298
         ->  Sort  (cost=38.50..39.55 rows=420 width=258)
               Sort Key: sample2.id
               ->  Seq Scan on sample2  (cost=0.00..20.20 rows=420 width=258)
```

VACUUM reduces the cost of index-only scans by making heap access less likely.

No LIMIT Was a Hash Join

```
EXPLAIN SELECT sample2.id, sample2.junk
FROM sample1 JOIN sample2 ON (sample1.id = sample2.id)
ORDER BY 1;
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Merge Join  (cost=40.67..150.78 rows=420 width=258)
   Merge Cond: (sample1.id = sample2.id)
   ->  Index Only Scan using i_sample1 on sample1  (cost=0.28..97.75 rows=3298 width
   ->  Sort  (cost=38.50..39.55 rows=420 width=258)
         Sort Key: sample2.id
         ->  Seq Scan on sample2  (cost=0.00..20.20 rows=420 width=258)
```

Same Join, Different Plans

Query Modifier	Plan
No LIMIT	Hash join
LIMIT 1	Nested loop join with two index scans
LIMIT 10	“”
LIMIT 100	Merge join with two index scans
LIMIT 1000	Hash join
VACUUM, LIMIT 1000	Merge join with index-only scan and sort
No LIMIT	“”

The last two are different from previous matching lines because of VACUUM.

Further Study

My later talk, *Beyond Joins and Indexes,* covers the many other operations performed by the optimizer.

https://momjian.us/main/presentations/performance.html#beyond

Conclusion

https://momjian.us/presentations

https://www.flickr.com/photos/trevorklatko/