Deep Dive Into PostgreSQL Indexes

Learn PostgreSQL index

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Heap vs Index

Tables (Heap)

“Tuple” and “Rows” are synonym

- Rows / Tuples stored in a table
- Every table in PostgreSQL has physical disk file(s)

“Relfilenode” is table file name of that table

“pg_class” is system table to contain table information

```
postgres=# CREATE TABLE foo(id int, name text);
postgres=# SELECT relfilenode FROM pg_class WHERE relname LIKE 'foo’;
         relfilenode
         -------------
          16384
```

“16384” is table filename

$PGDATA is Data Directory

- The physical files on disk can be seen in the PostgreSQL $PGDATA directory.

```
$ ls -lrt $PGDATA/base/13680/16384
-rw------- 1 vagrant vagrant 0 Apr 29 11:48 $PGDATA/base/13680/16384
```

- Tuple stored in a table does not have any order

Tables (Heap)

- Select whole table, must be a sequential scan.
- Select table’s rows where id is 5432, it should not be a sequential scan.

```
EXPLAIN SELECT name FROM bar;
                              QUERY PLAN
         Make sense?
--------------------------------------------------------------------------
Seq Scan on bar  (cost=0.00..163693.05 rows=9999905 width=11
```

```
EXPLAIN SELECT name FROM bar WHERE id = 5432;
                                QUERY PLAN
--------------------------------------------------------------------------
Gather  (cost=1000.00..116776.94 rows=1 width=11)
Workers Planned: 2                       Why?
      ->  Parallel Seq Scan on bar  (cost=0.00..115776.84 rows=1 width=11)
             Filter: (id = 5432)
```

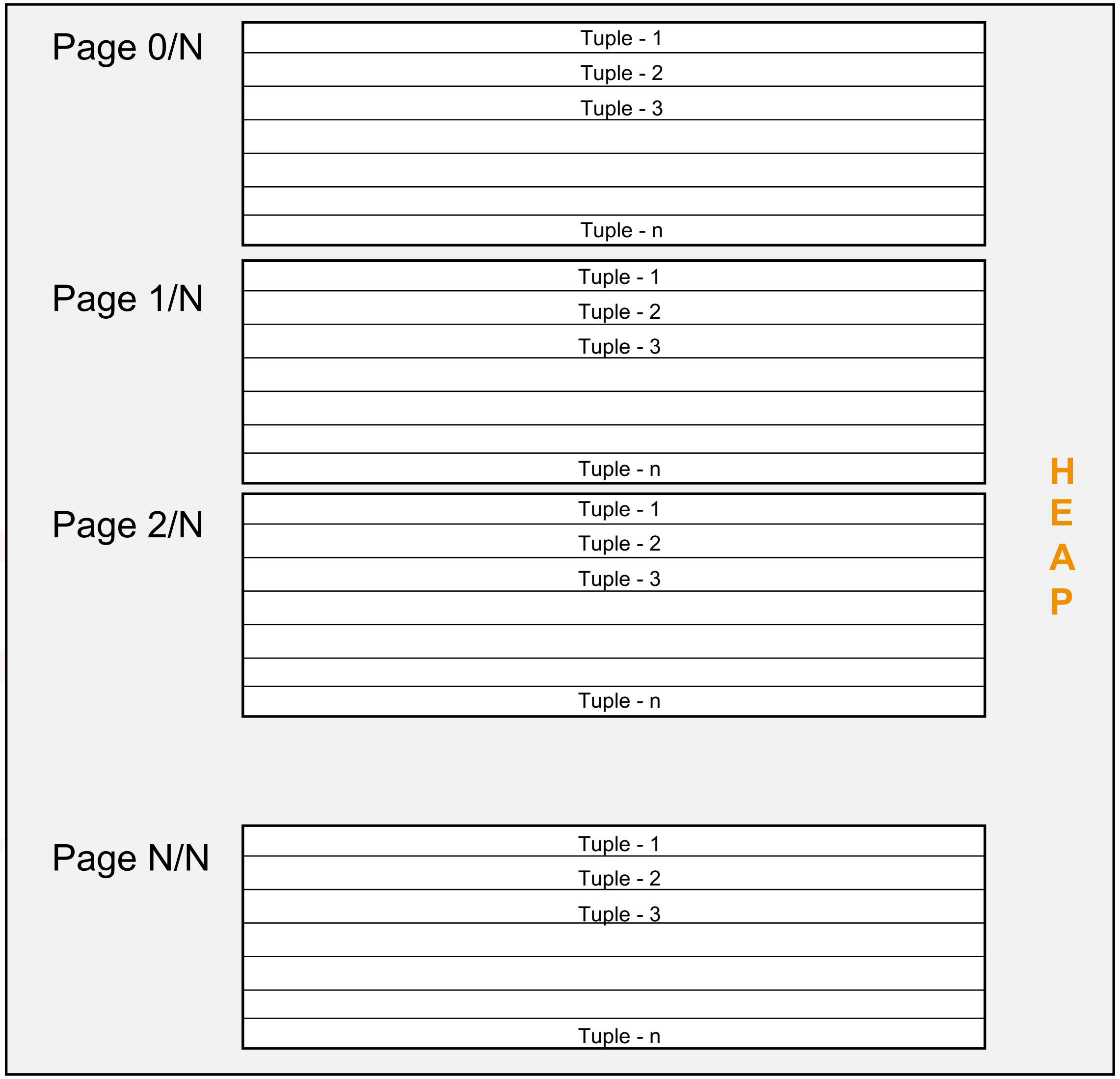
Selecting Data from HEAP

```
CREATE TABLE foo(id INTEGER, name TEXT);
INSERT INTO foo VALUES(1, 'Alex');
INSERT INTO foo VALUES(2, 'Bob');
```

```
SELECT ctid, * FROM foo;
 ctid   | id | name
-------+----+-------
 (0,1) |  1 | Alex
 (0,2) |  2 | Bob
(2 rows)
```

- How to select the data from the HEAP?
- Need to scan each and every page and look for the tuple in the page

Cost?



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PostgreSQL Indexes

https://www.postgresql.org/docs/current/indexes.html

Why Index?

- Indexes are entry points for tables
- Index used to locate the tuples in the table
- The sole reason to have an index is performance
- Index is stored separately from the table’s main storage (PostgreSQL Heap)
- More storage required to store the index along with original table

```
postgres=# EXPLAIN SELECT name FROM bar WHERE id = 5432;
                              Cost of the query  QUERY PLAN
----------------------------------------------------------------------------
Seq Scan on bar  (cost=0.00..159235.00 rows=38216 width=32)
Filter: (id = 5432)
```

```
postgres=# CREATE INDEX bar_idx ON bar(id);
```

```
postgres=# EXPLAIN SELECT name FROM bar WHERE id = 5432;
                                         QUERY PLAN  64313/159235 * 100 = 40%
----------------------------------------------------------------------------
Bitmap Heap Scan on bar  (cost=939.93..64313.02 rows=50000 width=32)
Recheck Cond: (id = 5432)
        ->  Bitmap Index Scan on bar_idx  (cost=0.00..927.43 rows=50000 width=0)
                Index Cond: (id = 5432)
```

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Index

- PostgreSQL standard way to create a index (https://www.postgresql.org/docs/current/sql-createindex.html)

```
postgres=# CREATE INDEX idx_btree ON bar(id);
```

PostgreSQL's Catalog for relations/index

```
postgres=# SELECT relfilenode FROM pg_class WHERE relname LIKE 'idx_btree';
       relfilenode
       -------------
        16425
```

Physical file name of the index

- PostgreSQL index has its own file on disk.

The physical file on disk can be seen in the PostgreSQL $PGDATA directory.

```
$ ls -lrt $PGDATA/13680/16425
-rw-------1 vagrant vagrant 1073741824 Apr 29 13:05 $PGDATA/base/13680/16425
```

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Creating Index 1/2

- Index based on single column of the table

"bar" is a table and "id" is column

```
postgres=# CREATE INDEX bar_idx ON bar(id);
```

```
postgres=# EXPLAIN SELECT name FROM bar WHERE id = 5432;
                                     QUERY PLAN
----------------------------------------------------------------------
Bitmap Heap Scan on bar (cost=939.93..64313.02 rows=50000 width=32)
   Recheck Cond: (id = 5432)
   ->  Bitmap Index Scan on bar_idx (cost=0.00..927.43 rows=50000 width=0)
         Index Cond: (id = 5432)
```

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Creating Index 2/2

- PostgreSQL locks the table when creating index

```
CREATE INDEX idx_btree ON bar USING BTREE(id);
CREATE INDEX
Time: 12303.172 ms (00:12.303)
```

- CONCURRENTLY option creates the index without locking the table

```
CREATE INDEX CONCURRENTLY idx_btree ON bar USING BTREE(id);
CREATE INDEX
Time: 23025.372 ms (00:23.025)
```

Expression Index 1/2

```
EXPLAIN SELECT * FROM bar WHERE lower(name) LIKE 'Text1';
                          QUERY PLAN
--------------------------------------------------------------
 Seq Scan on bar  (cost=0.00..213694.00 rows=50000 width=40)
   Filter: (lower((name)::text) ~~ 'Text1'::text)
```

```
CREATE INDEX idx_exp ON bar (lower(name));
```

```
EXPLAIN SELECT * FROM bar WHERE lower(name) LIKE 'Text1';
                                  QUERY PLAN
------------------------------------------------------------------------------
 Bitmap Heap Scan on bar  (cost=1159.93..64658.02 rows=50000 width=40)
   Filter: (lower((name)::text) ~~ 'Text1'::text)
   ->  Bitmap Index Scan on idx_exp  (cost=0.00..1147.43 rows=50000 width=0)
         Index Cond: (lower((name)::text) = 'Text1'::text)
```

Expression Index 2/2

```
postgres=# EXPLAIN SELECT * FROM bar WHERE (dt + (INTERVAL '2 days'))  < now();
                          QUERY PLAN
---------------------------------------------------------------
 Seq Scan on bar  (cost=0.00..238694.00 rows=3333333 width=40)
   Filter: ((dt + '2 days'::interval) < now())
```

```
postgres=# CREATE INDEX idx_math_exp ON bar((dt + (INTERVAL '2 days')));
```

```
postgres=# EXPLAIN SELECT * FROM bar WHERE (dt + (INTERVAL '2 days'))  < now();
                                     QUERY PLAN
-------------------------------------------------------------------------------------
 Bitmap Heap Scan on bar  (cost=62449.77..184477.10 rows=3333333 width=40)
   Recheck Cond: ((dt + '2 days'::interval) < now())
   ->  Bitmap Index Scan on idx_math_exp  (cost=0.00..61616.43 rows=3333333 width=0)
         Index Cond: ((dt + '2 days'::interval) < now())
```

Partial Index

Index

```
CREATE INDEX idx_full ON bar(id);

EXPLAIN SELECT * FROM bar
                 WHERE id  < 1000
                 AND name LIKE 'text1000';
                                          QUERY PLAN
------------------------------------------------------------------------
--
 Bitmap Heap Scan on bar  (cost=61568.60..175262.59 rows=16667 width=40)
   Recheck Cond: (id < 1000)
   Filter: ((name)::text ~~ 'text1000'::text)
   ->  Bitmap Index Scan on idx_full  (cost=0.00..61
width=0)
         Index Cond: (id < 1000)


SELECT pg_size_pretty(pg_total_relation_size('idx_full'));
 pg_size_pretty
----------------
 214 MB
(1 row)
```

Look at the size of the index

Partial Index

```
CREATE INDEX idx_part ON bar(id) where id < 1000;

EXPLAIN SELECT * FROM bar
           WHERE id  < 1000
           AND name LIKE 'text1000';
                                   QUERY PLAN
-----------------------------------------------------------------------
 Bitmap Heap Scan on bar  (cost=199.44..113893.44 rows=16667 width=40)
   Recheck Cond: (id < 1000)
                                       ~~ 'text1000'::text)
                                      on idx_part  (cost=0.00..195.28 rows=3333333

                                            < 1000)


SELECT pg_size_pretty(pg_total_relation_size('idx_part'));
 pg_size_pretty
----------------
 240 kB
(1 row)
```

Index where id < 1000 only

Why create full index if we don't need that.

Q: What will happen when we query where id >1000?

A: Answer is simple, this index won't selected.

Index Types

https://www.postgresql.org/docs/current/indexes-types.html

B-Tree Index 1/2

- What is a B-Tree index?
- Supported Operators
  - Less than <
  - Less than equal to <=
  - Equal =
  - Greater than equal to >=
  - Greater than >

Wikipedia: (https://en.wikipedia.org/wiki/Self-balancing_binary_search_tree)
In computer science, a self-balancing (or height-balanced) binary search tree is any node-based binary search tree that automatically keeps its height small in the face of arbitrary item insertions and deletions.

```
CREATE INDEX idx_btree ON foo USING BTREE (name);
```

```
postgres=# EXPLAIN ANALYZE SELECT * FROM foo WHERE name = 'text%';
                                        QUERY PLAN
-----------------------------------------------------------------------------------------------------
 Index Scan using idx_btree on foo  (cost=0.43..8.45 rows=1 width=19) (actual time=0.015..0.015 rows=0 loops=1)
   Index Cond: ((name)::text = 'text%'::text)
 Planning Time: 0.105 ms
 Execution Time: 0.031 ms
(4 rows)
```

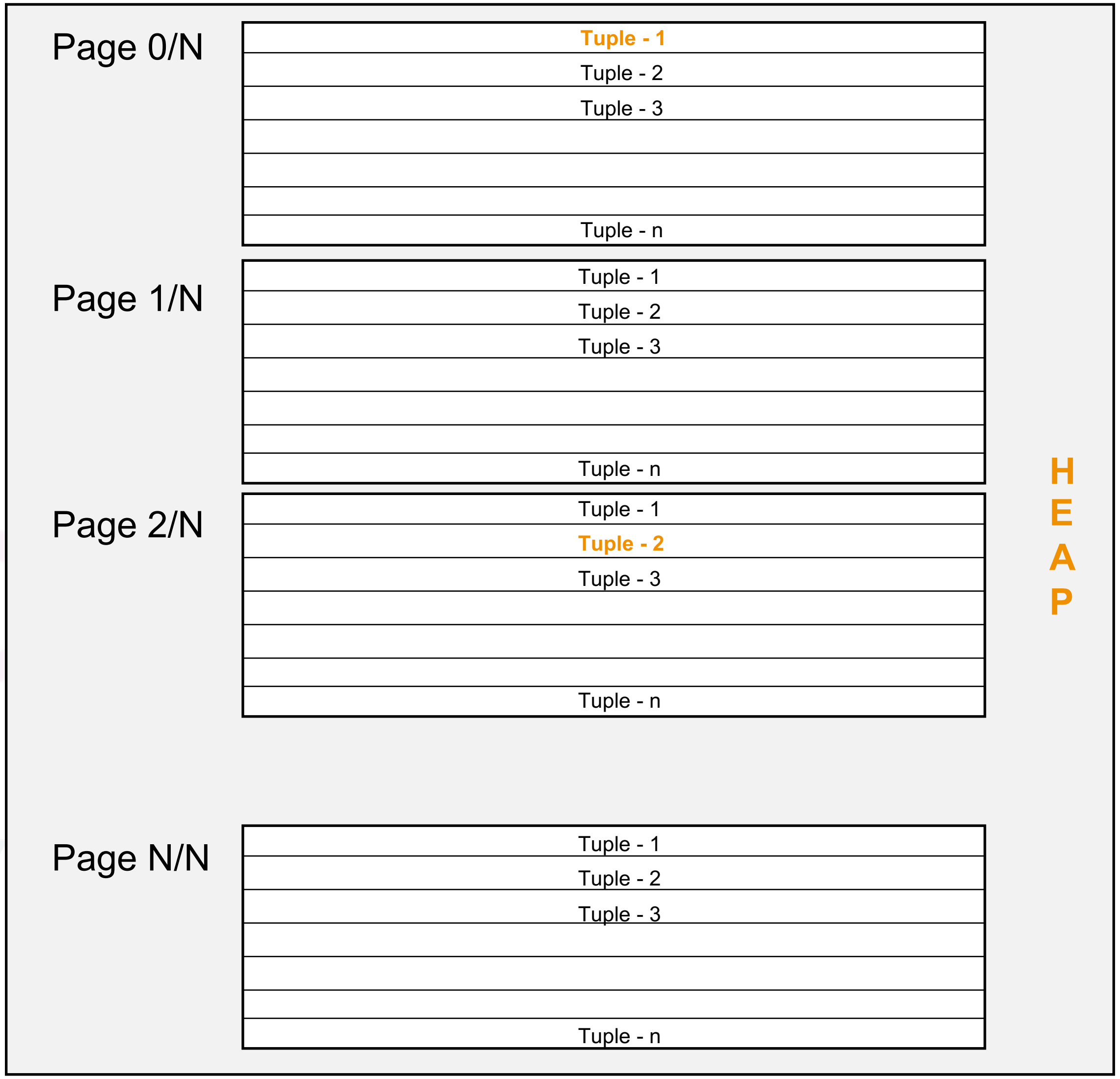
B-Tree Index 2/2

```
CREATE TABLE foo(id INTEGER, name TEXT, … );
INSERT INTO foo VALUES(1, 'Alex’, …);
INSERT INTO foo VALUES(2, ‘Bob, …
```

```
SELECT ctid, * FROM foo;
 ctid   | id | name  …
-------+----+-------
 (0,1) |  1 | Alex  …
 (0,2) |  2 | Bob
```

Index have the key and the location of the tuple.

```
ctid   | name
-------+------
 (0,1) | Alex
 (0,2) | Bob
```



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Page N/N
Tuple - 1
Tuple - 2
Tuple - 3
Tuple - n

HEAP

HASH Index

- What is a Hash index?
- Hash indexes only handles equality operators
- Hash function is used to locate the tuples

```
CREATE INDEX idx_hash ON bar USING HASH (name);
```

```
postgres=# \d bar
                     Table "public.bar"
 Column |        Type         | Collation | Nullable | Default
--------+---------------------+-----------+----------+---------
 id     | integer             |           |          |
 name   | character varying   |           |          |
 dt     | date                |           |          |
Indexes:
    "idx_btree" btree (name)
    "idx_hash" btree (name)
```

```
EXPLAIN ANALYZE SELECT * FROM bar WHERE name = 'text%';
                         QUERY PLAN
Index Scan using idx_hash on bar  (cost=0.43..8.45 rows=1 width=19) (actual time=0.023..0.023
rows=0 loops=1)
   Index Cond: ((name)::text = 'text%'::text)
 Planning Time: 0.080 ms
 Execution Time: 0.041 ms
(4 rows)
```

BRIN Index 1/3

Like date, date of city have logical group

- BRIN is a “Block Range Index”
- Used when columns have some correlation with their physical location in the table
- Space optimized because BRIN index contains only three items
  - Page number
  - Min value of column
  - Max value of column

BRIN Index 2/3

Sequential Scan

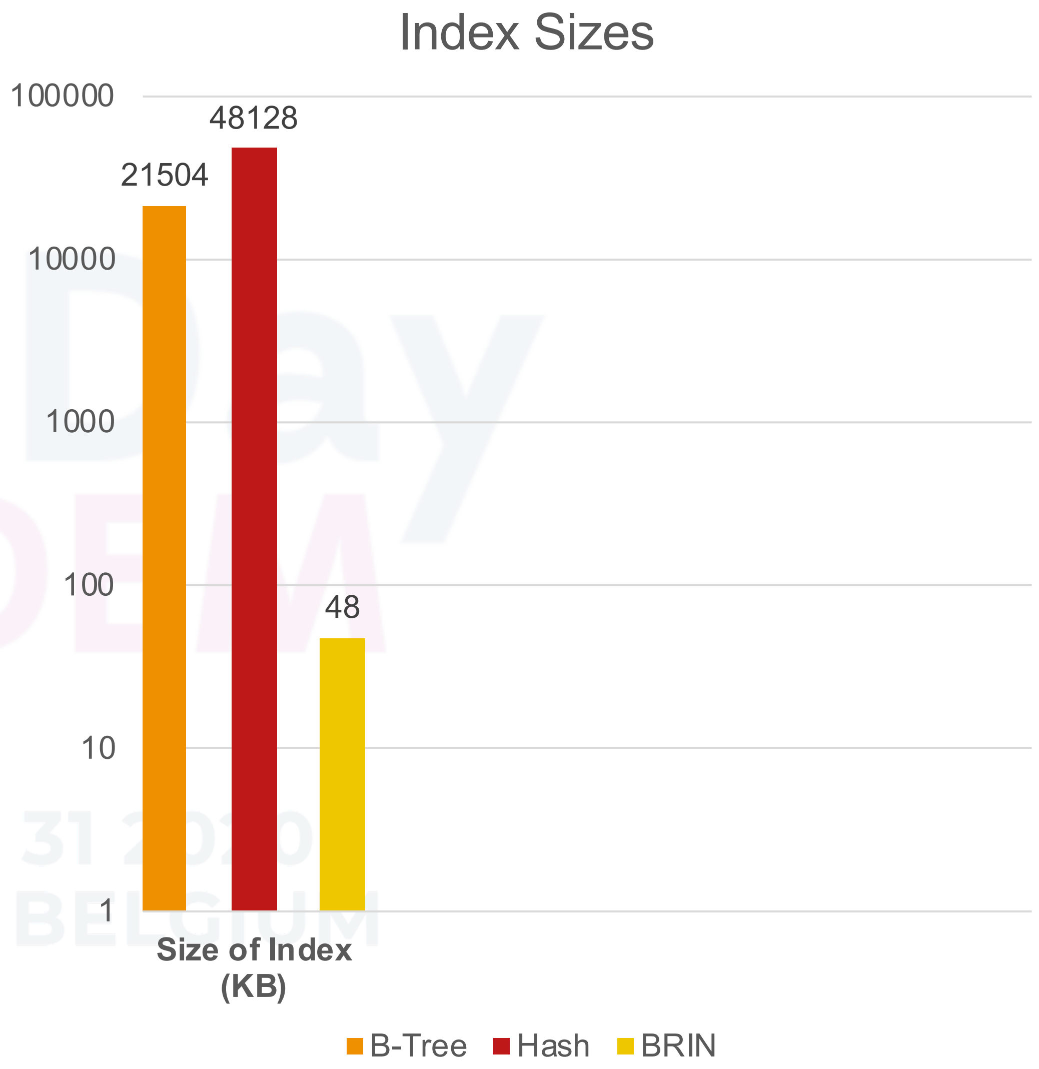
```
postgres=# EXPLAIN ANALYZE SELECT *
           FROM bar
           WHERE dt > '2022-09-28’
           AND   dt < '2022-10-28';
                         QUERY PLAN
-----------------------------------------------------
Seq Scan on bar (cost=0.00..2235285.00 rows=1
                 width=27)
                (actual time=0.139..7397.090 rows=29
                loops=1)
   Filter: ((dt > '2022-09-28 00:00:00)
       AND (dt < '2022-10-28 00:00:00))
   Rows Removed by Filter: 99999971
 Planning Time: 0.114 ms
 Execution Time: 7397.107 ms
(5 rows)
```

BRIN Index

```
postgres=# EXPLAIN ANALYZE SELECT *
           FROM bar
           WHERE dt > '2022-09-28’
           AND dt < '2022-10-28';
                         QUERY PLAN
-----------------------------------------------------
Bitmap Heap Scan on bar (cost=92.03..61271.08 rows=1
  width=27) (actual time=1.720..4.186 rows=29 loops=1)
   Recheck Cond: ((dt > '2022-09-28 00:00:00’)
             AND (dt < '2022-10-28 00:00:00'))
   Rows Removed by Index Recheck: 18716
   Heap Blocks: lossy=128
   ->  Bitmap Index Scan on idx_brin
         (cost=0.00..92.03 rows=17406 width=0)
         (actual time=1.456..1.456 rows=1280 loops=1)
         Index Cond: ((dt > '2022-09-28 00:00:00’)
                 AND (dt < '2022-10-28 00:00:00'))
 Planning Time: 0.130 ms
 Execution Time: 4.233 ms
(8 rows)
```

BRIN Index 3/3

- `CREATE INDEX idx_btree ON bar USING BTREE (date);`
- `CREATE INDEX idx_hash ON bar USING HASH (date);`
- `CREATE INDEX idx_brin ON bar USING BRIN (date);`



GIN Index 1/2

- Generalized Inverted Index
- GIN is to handle where we need to index composite values
- Slow while creating the index because it needs to scan the document up front

```
postgres=# \d bar
                Table "public.bar"
 Column |  Type   | Collation | Nullable | Default
--------+---------+-----------+----------+---------
 id     | integer |           |          |
 name   | jsonb   |           |          |
 dt     | date    |           |          |
```

```
postgres=# SELECT DISTINCT name, dt FROM bar LIMIT 5;
                                  name                                   |     dt
-------------------------------------------------------------------------+------------
 {"name": "Alex", "phone": ["333-333-333", "222-222-222", "111-111-111"]}  | 2019-05-13
 {"name": "Bob", "phone": ["333-333-444", "222-222-444", "111-111-444"]}   | 2019-05-14
 {"name": "John", "phone": ["333-3333", "777-7777", "555-5555"]}           | 2019-05-15
 {"name": "David", "phone": ["333-333-555", "222-222-555", "111-111-555"]} | 2019-05-16
(4 rows)
```

GIN Index 2/2

- Generalized Inverted Index
- GIN is to handle where we need to index composite values
- Slow while creating index because it needs to scan the document up front

```
CREATE INDEX idx_gin ON bar USING GIN (name);
```

```
postgres=# EXPLAIN ANALYZE SELECT * FROM bar
            WHERE name @> '{"name": "Alex"}’;
                     QUERY PLAN
-----------------------------------------------------
Seq Scan on bar  (cost=0.00..108309.34 rows=3499
width=96) (actual time=396.019..1050.143 rows=1000000
loops=1)
   Filter: (name @> '{"name": "Alex"}'::jsonb)
   Rows Removed by Filter: 3000000
 Planning Time: 0.107 ms
 Execution Time: 1079.861 ms
```

```
postgres=# EXPLAIN ANALYZE SELECT * FROM bar
           WHERE name @> '{"name": "Alex"}';
                     QUERY PLAN
-----------------------------------------------------
Bitmap Heap Scan on bar  (cost=679.00..13395.57
rows=4000 width=96) (actual time=91.110..445.112
rows=1000000 loops=1)
   Recheck Cond: (name @> '{"name": "Alex"}'::jsonb)
   Heap Blocks: exact=16394
   ->  Bitmap Index Scan on
idx_gin  (cost=0.00..678.00 rows=4000 width=0)
(actual time=89.033..89.033 rows=1000000 loops=1)
         Index Cond: (name @> '{"name":
"Alex"}'::jsonb)
 Planning Time: 0.168 ms
 Execution Time: 475.447 ms
```

GiST Index

- Generalized Search Tree
- It is Tree-structured access method
- It is a indexing framework used for indexing of complex data types.
  - Used to find the point within box
  - Used for full text search
  - Intarray

Where and What?

- B-Tree: Use this index for most of the queries and different data types
- Hash: Used for equality operators
- BRIN: For really large sequentially lineup datasets
- GIN: Used for documents and arrays
- GiST: Used for full text search

Index Only Scans

In PostgreSQL term

- Index is stored separately from the table’s main storage (PostgreSQL Heap)

- Query needs to scan both the index and the heap

- Index Only Scans only used when all the columns in the query part of the index

- In this case PostgreSQL fetches data from index only

Index Only Scans

```
CREATE INDEX idx_btree_ios ON bar (id, name);
```

```
EXPLAIN SELECT id, name, dt FROM bar WHERE id > 100000 AND id <100010;
                                   QUERY PLAN
Index Scan using idx_btree_ios on bar  (cost=0.56..99.20 rows=25 width=19)
   Index Cond: ((id > 100000) AND (id < 100010))
(2 rows)
```

```
EXPLAIN SELECT id, name FROM bar WHERE id > 100000 AND id <100010;
                                   QUERY PLAN
Index Only Scan using idx_btree_ios on bar  (cost=0.56..99.20 rows=25 width=15)
   Index Cond: ((id > 100000) AND (id < 100010))
(2 rows)
```

Duplicate Indexes

```
SELECT indrelid::regclass relname,
        indexrelid::regclass indexname, indkey
FROM pg_index
GROUP BY relname,indexname,indkey;
         relname          |                   indexname                   | indkey
--------------------------+-----------------------------------------------+----------
 pg_index                 | pg_index_indexrelid_index                     | 1
 pg_toast.pg_toast_2615   | pg_toast.pg_toast_2615_index                  | 1 2
 pg_constraint            | pg_constraint_conparentid_index               | 11
```

```
SELECT indrelid::regclass relname, indkey, amname
FROM pg_index i, pg_opclass o, pg_am a
WHERE o.oid = ALL (indclass)
AND a.oid = o.opcmethod
GROUP BY relname, indclass, amname, indkey
HAVING count(*) > 1;
 relname | indkey | amname
---------+--------+--------
 bar     |      2 | btree
(1 row)
```

Supported Data Types For A Particular Indexes

```
SELECT amname, opfname FROM pg_opfamily, pg_am WHERE opfmethod = pg_am.oid AND amname = ‘gin';
 amname |    opfname
--------+----------------
 gin    | array_ops
 gin    | tsvector_ops
 gin    | jsonb_ops
 gin    | jsonb_path_ops

SELECT amname, opfname FROM pg_opfamily, pg_am WHERE opfmethod = pg_am.oid AND amname = ‘gist';
 amname |   opfname
--------+--------------
 gist   | network_ops
 gist   | box_ops
 gist   | poly_ops
 gist   | circle_ops
 gist   | point_ops
 gist   | tsvector_ops
 gist   | tsquery_ops
 gist   | range_ops
 gist   | jsonb_ops
```

Index Stats (pg_stat_user_indexes, pg_stat_statement)

```
postgres=# \d pg_stat_user_indexes;
         View "pg_catalog.pg_stat_user_indexes"
    Column     |  Type  | Collation | Nullable | Default
---------------+--------+-----------+----------+---------
 relid         | oid    |           |          |
 indexrelid    | oid    |           |          |
 schemaname    | name   |           |          |
 relname       | name   |           |          |
 indexrelname  | name   |           |          |
 idx_scan      | bigint |           |          |
 idx_tup_read  | bigint |           |          |
 idx_tup_fetch | bigint |           |          |
```

Unused Indexes

```
SELECT relname, indexrelname, idx_scan
FROM  pg_catalog.pg_stat_user_indexes;

 relname | indexrelname  | idx_scan
---------+---------------+----------
 foo     | idx_foo_date  |        0
 bar     | idx_btree     |        0
 bar     | idx_btree_id  |        0
 bar     | idx_btree_name|        6
 bar     | idx_brin_brin |        4
(7 rows)
```

?

“Poor leaders rarely ask questions of themselves or others. Good leaders, on the other hand, ask many questions. Great leaders ask the great questions.”

Michael Marquardt author of
Leading with Questions

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