Termini PostgreSQL di Deep Dee Intu

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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
-------------------------------------------------------------------------
Seq Scan on bar  (cost=0.00..163693.05 rows=9999905 width=11
```

Make sense?

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

Why?

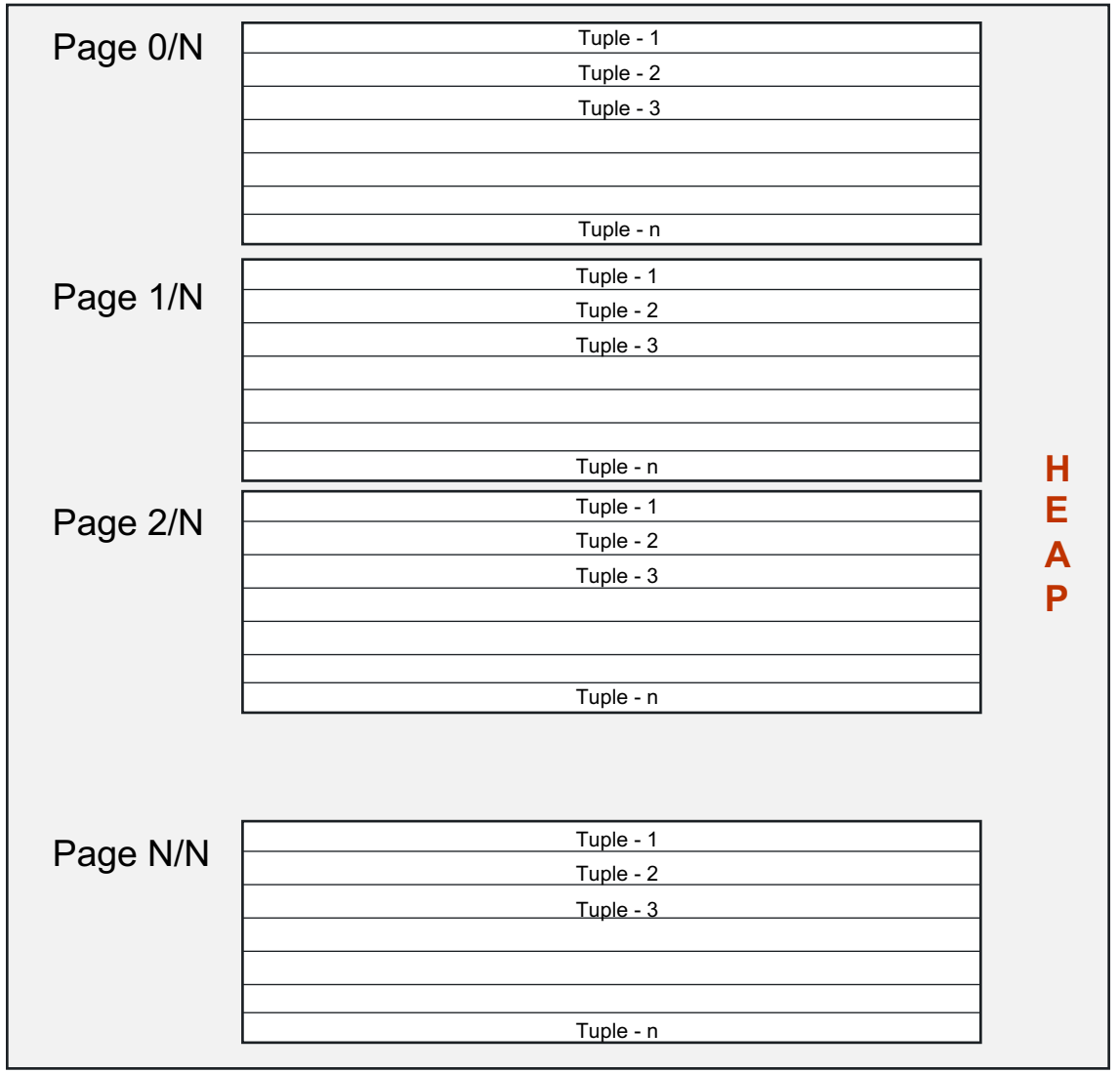
Selecting Data from HEAP

```
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?



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
```

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)
```

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

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

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

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
                 Index Cond: (id < 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.

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)
```

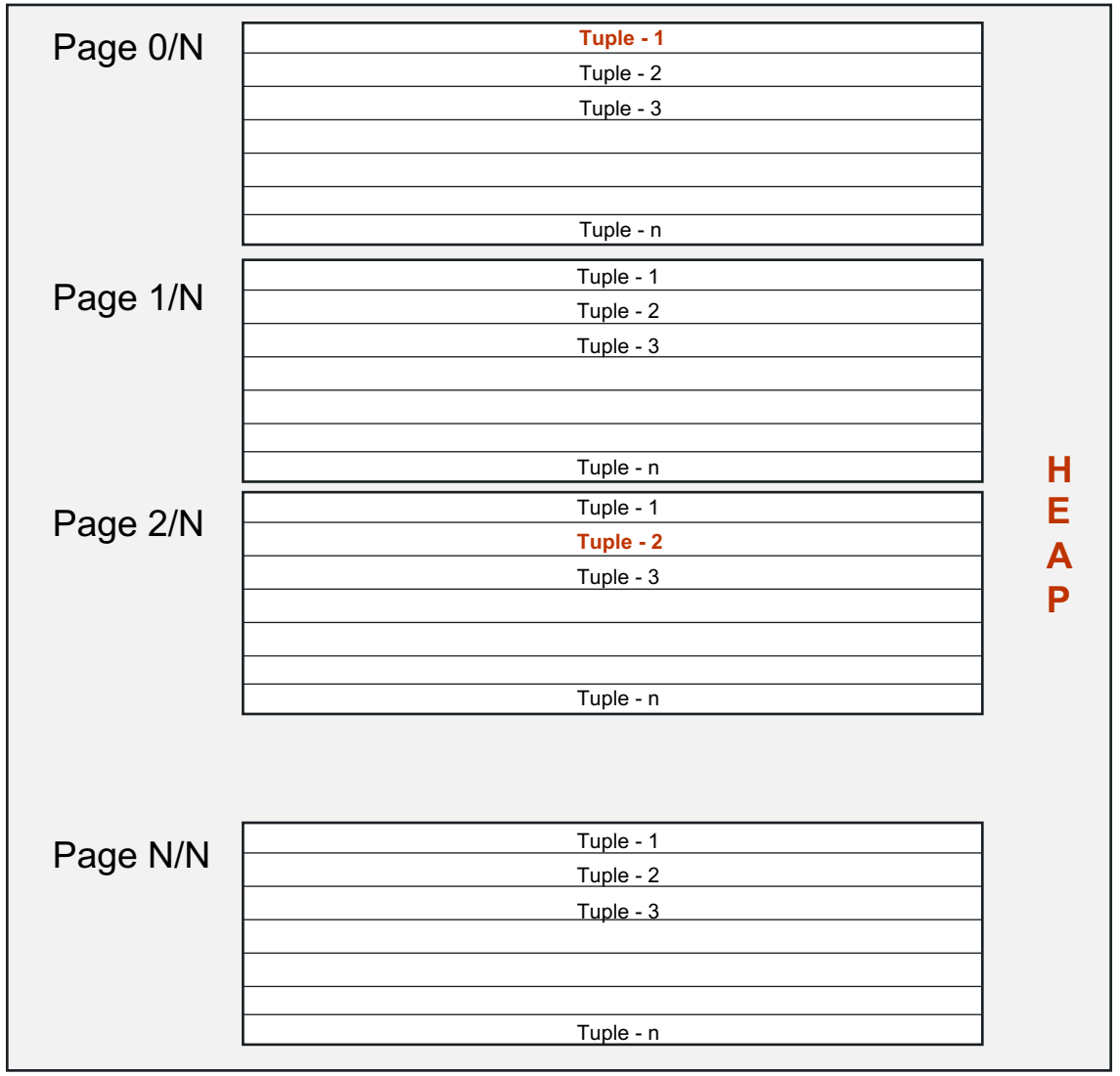
B-Tree Index 2/2

```
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
```



HASH Index

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

```
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)
```

```
CREATE INDEX idx_hash ON bar USING HASH (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

- 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

Like date, date of city have logical group

BRIN Index 2/3

Sequential Scan

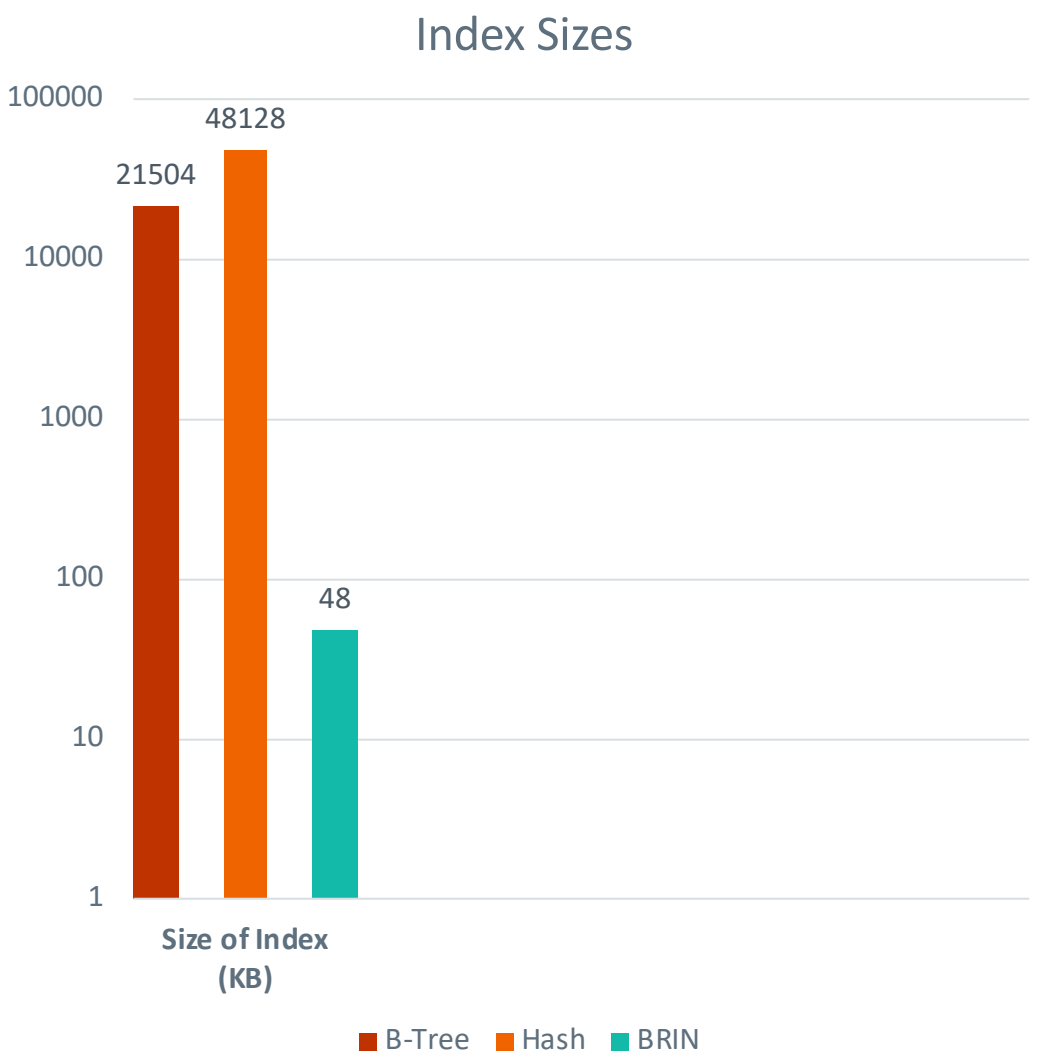
```
postgres=# EXPLAIN ANALYZE SELECT *
           FROM bar
           WHERE dt > '2022-09-28'
           AND   dt < '2022-10-28';
                          QUERY PLAN
-----------------------------------------------------
Seq Scan on bar (cost=0.00..2235285.00 rows=1
                 width=27)
                (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
```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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)
```