Flexible Indexing with Postgres

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Postgres offers a wide variety of indexing structures, and many index lookup methods with specialized capabilities. This talk explores the many Postgres indexing options.
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Outline

1. Traditional indexing
2. Expression indexes
3. Partial indexes
4. Benefits of bitmap index scans
5. Non-B-tree index types
6. Data type support for index types
7. Index usage summary

1. Traditional Indexing

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B-Tree

- Ideal for looking up unique values and maintaining unique indexes
- High concurrency implementation
- Index is key/row-pointer, key/row-pointer
- Supply ordered data for queries
  - ORDER BY clauses (and LIMIT)
  - Merge joins
  - Nested loop with index scans

But I Want More!

- Index expressions/functions
- Row control
- Small, light-weight indexes
- Index non-linear data
- Closest-match searches
- Index data with many duplicates
- Index multi-valued fields

2. Expression Indexes

```
SELECT * FROM customer WHERE lower(name) = 'andy';

CREATE INDEX i_customer_name ON customer (name); ×

CREATE INDEX i_customer_lower ON customer (lower(name));
```

Let's Test It

```
CREATE TABLE customer (name) AS
SELECT 'cust' || i
FROM generate_series(1, 1000) AS g(i);

CREATE INDEX i_customer_name ON customer (name);

EXPLAIN SELECT * FROM customer WHERE name = 'cust999';
                                            QUERY PLAN
------------------------------------------------------------------------------------
 Index Only Scan using i_customer_name on customer  (cost=0.28..8.29 rows=1 width=7)
   Index Cond: (name = 'cust999'::text)

EXPLAIN SELECT * FROM customer WHERE lower(name) = 'cust999';
                              QUERY PLAN
--------------------------------------------------------
 Seq Scan on customer  (cost=0.00..20.00 rows=5 width=7)
   Filter: (lower(name) = 'cust999'::text)
```

Create an Expression Index

```
CREATE INDEX i_customer_lower ON customer (lower(name));

EXPLAIN SELECT * FROM customer WHERE lower(name) = 'cust999';
                                  QUERY PLAN
------------------------------------------------------------------------------
 Bitmap Heap Scan on customer  (cost=4.31..9.66 rows=5 width=7)
   Recheck Cond: (lower(name) = 'cust999'::text)
   ->  Bitmap Index Scan on i_customer_lower  (cost=0.00..4.31 rows=5 width=0)
         Index Cond: (lower(name) = 'cust999'::text)
```

Other Expression Index Options

- User-defined functions
- Concatenation of columns
- Math expressions
- Only IMMUTABLE functions can be used
- Consider casting when matching WHERE clause expressions to the indexed expression

3. Partial Indexes: Index Row Control

- Why index every row if you are only going to look up some of them?
- Smaller index on disk and in memory
- More shallow index
- Less INSERT/UPDATE index overhead
- Sequential scan still possible

Partial Index Creation

```
ALTER TABLE customer ADD COLUMN state CHAR(2);

UPDATE customer SET state = 'AZ'
WHERE name LIKE 'cust9__';

CREATE INDEX i_customer_state_az ON customer (state) WHERE state = 'AZ';
```

Test the Partial Index

```
EXPLAIN SELECT * FROM customer WHERE state = 'PA';
                        QUERY PLAN
----------------------------------------------------------
 Seq Scan on customer  (cost=0.00..17.50 rows=5 width=19)
   Filter: (state = 'PA'::bpchar)

EXPLAIN SELECT * FROM customer WHERE state = 'AZ';
                                    QUERY PLAN
----------------------------------------------------------------------------------
 Bitmap Heap Scan on customer  (cost=4.17..9.50 rows=5 width=19)
   Recheck Cond: (state = 'AZ'::bpchar)
   ->  Bitmap Index Scan on i_customer_state_az  (cost=0.00..4.17 rows=5 width=0)
```

Partial Index With Different Indexed Column

```
DROP INDEX i_customer_name;

CREATE INDEX i_customer_name_az ON customer (name) WHERE state = 'AZ';

EXPLAIN SELECT * FROM customer WHERE name = 'cust975';
                        QUERY PLAN
----------------------------------------------------------
 Seq Scan on customer  (cost=0.00..17.50 rows=1 width=19)
   Filter: (name = 'cust975'::text)
```

Partial Index With Different Indexed Column

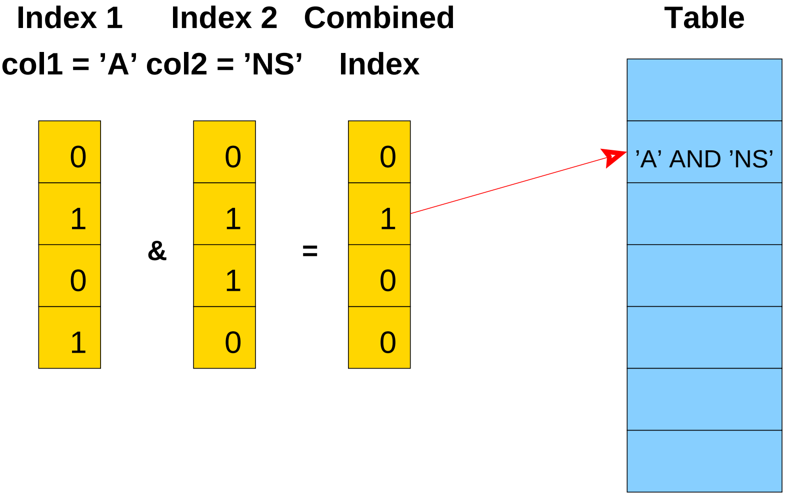
```
EXPLAIN SELECT * FROM customer
WHERE name = 'cust975' AND state = 'AZ';
                                     QUERY PLAN
-------------------------------------------------------------------------------------
 Index Scan using i_customer_name_az on customer  (cost=0.14..8.16 rows=1 width=19)
   Index Cond: (name = 'cust975'::text)

EXPLAIN SELECT * FROM customer
WHERE state = 'AZ';
                                   QUERY PLAN
----------------------------------------------------------------------------------
 Bitmap Heap Scan on customer  (cost=4.17..9.50 rows=5 width=19)
   Recheck Cond: (state = 'AZ'::bpchar)
   ->  Bitmap Index Scan on i_customer_name_az  (cost=0.00..4.17 rows=5 width=0)
```

4. Benefits of Bitmap Index Scans

- Used when:
  - an index lookup might generate multiple hits on the same heap (data) page
  - using multiple indexes for a single query is useful
- Creates a bitmap of matching entries in memory
- Row or block-level granularity
- Bitmap allows heap pages to be visited only once for multiple matches
- Bitmap can merge the results from several indexes with AND/OR filtering
- Automatically enabled by the optimizer

Bitmap Index Scan



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

Block-Range Index (BRIN)

- Tiny indexes designed for large tables
- Minimum/maximum values stored for a range of blocks (default 1MB, 128 8k pages)
- Allows skipping large sections of the table that cannot contain matching values
- Ideally for naturally-ordered tables, e.g., insert-only tables are chronologically ordered
- Index is 0.003% the size of the heap
- Indexes are inexpensive to update
- Index every column at little cost
- Slower lookups than B-tree

Generalized Inverted Index (GIN)

- Best for indexing values with many keys or values, e.g.,
  - text documents
  - JSON
  - multi-dimensional data, arrays
- Ideal for columns containing many duplicates
- Optimized for multi-row matches
- Key is stored only once
- Index is key/many-row-pointers
- Index updates are batched, though always checked for accuracy
- Compression of row pointer list
- Optimized multi-key filtering

Generalized Search Tree (GiST)

GiST is a general indexing framework designed to allow indexing of complex data types with minimal programming. Supported data types include

- geometric types
- range types
- hstore (key/value pairs)
- intarray (integer arrays)
- pg_trgm (trigrams)

Supports optional “distance” for nearest-neighbors/closest matches. (GIN is also generalized.)

Space-Partitioned Generalized Search Tree (SP-GIST)

- Similar to GIST in that it is a generalized indexing framework
- Allows the key to be split apart (decomposed)
- Parts are indexed hierarchically into partitions
- Partitions are of different sizes
- Each child needs to store only the child-unique portion of the original value because each entry in the partition shares the same parent value.

Hash Indexes

- Equality, non-equality lookups; no range lookups
- Crash-safe starting in Postgres 10
- Replicated starting in Postgres 10

I Am Not Making This Up

```
SELECT amname, obj_description(oid, 'pg_am')
FROM pg_am ORDER BY 1;

 amname |             obj_description
--------+----------------------------------------
 brin   | block range index (BRIN) access method
 btree  | b-tree index access method
 gin    | GIN index access method
 gist   | GiST index access method
 hash   | hash index access method
 spgist | SP-GiST index access method
```

Index Type Summary

- B-tree is ideal for unique values
- BRIN is ideal for the indexing of many columns
- GIN is ideal for indexes with many duplicates
- SP-GIST is ideal for indexes whose keys have many duplicate prefixes
- GIST for everything else

6. Data Type Support for Index Types

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Finding Supported Data Types - B-Tree

```
SELECT opfname FROM pg_opfamily, pg_am
WHERE opfmethod = pg_am.oid AND amname = 'btree'
ORDER BY 1;
```

```
abstime_ops            jsonb_ops              text_ops
array_ops              macaddr_ops            text_pattern_ops
bit_ops                money_ops              tid_ops
bool_ops               name_ops               time_ops
bpchar_ops             network_ops            timetz_ops
bpchar_pattern_ops     numeric_ops            tinterval_ops
bytea_ops              oid_ops                tsquery_ops
char_ops               oidvector_ops          tsvector_ops
datetime_ops           pg_lsn_ops             uuid_ops
enum_ops               range_ops              varbit_ops
float_ops              record_image_ops
integer_ops            record_ops
interval_ops           reltime_ops
```

These data types are mostly single-value and easily ordered. B-tree support for multi-valued types like tsvector is only for complete-field equality comparisons.

Finding Supported Data Types - BRIN

```
SELECT opfname FROM pg_opfamily, pg_am
WHERE opfmethod = pg_am.oid AND amname = 'brin'
ORDER BY 1;
```

```
abstime_minmax_ops      interval_minmax_ops      reltime_minmax_ops
bit_minmax_ops          macaddr_minmax_ops       text_minmax_ops
box_inclusion_ops       name_minmax_ops          tid_minmax_ops
bpchar_minmax_ops       network_inclusion_ops    time_minmax_ops
bytea_minmax_ops        network_minmax_ops       timetz_minmax_ops
char_minmax_ops         numeric_minmax_ops       uuid_minmax_ops
datetime_minmax_ops     oid_minmax_ops           varbit_minmax_ops
float_minmax_ops        pg_lsn_minmax_ops
integer_minmax_ops      range_inclusion_ops
```

Finding Supported Data Types - GIN

```
SELECT opfname FROM pg_opfamily, pg_am
WHERE opfmethod = pg_am.oid AND amname = 'gin'
ORDER BY 1;

    opfname
----------------
 array_ops
 jsonb_ops
 jsonb_path_ops
 tsvector_ops
```

These date types are multi-value, where each value is independent.

Finding Supported Data Types - GiST

```
SELECT opfname FROM pg_opfamily, pg_am
WHERE opfmethod = pg_am.oid AND amname = 'gist'
ORDER BY 1;

   opfname
--------------
 box_ops
 circle_ops
 jsonb_ops
 network_ops
 point_ops
 poly_ops
 range_ops
 tsquery_ops
 tsvector_ops
```

These data types are multi-value — some have independent values (JSON, tsvector), others have dependent values (point, box).

Finding Supported Data Types - SP-GiST

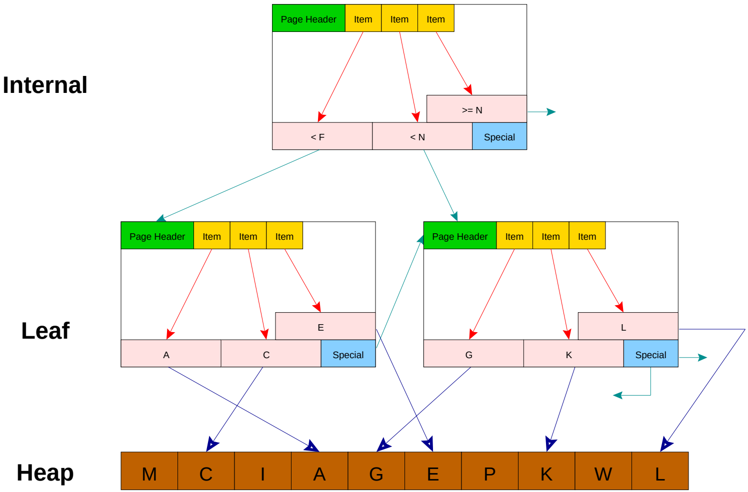
```
SELECT opfname FROM pg_opfamily, pg_am
WHERE opfmethod = pg_am.oid AND amname = 'spgist'
ORDER BY 1;

    opfname
----------------
 kd_point_ops
 quad_point_ops
 range_ops
 text_ops
```

For text, this is useful when the keys are long.

Index Type Examples

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

B-Tree


Internal
Page Header
Item
Item
Item
>= N
< F
< N
Special
Leaf
Page Header
Item
Item
Item
E
A
C
Special
Page Header
Item
Item
Item
L
G
K
Special
Heap
M
C
I
A
G
E
P
K
W
L

BRIN Example

```
CREATE TABLE brin_example AS
SELECT generate_series(1,100000000) AS id;

CREATE INDEX btree_index ON brin_example(id);
CREATE INDEX brin_index ON brin_example USING brin(id);

SELECT relname, pg_size_pretty(pg_relation_size(oid))
FROM pg_class
WHERE relname LIKE 'brin_%' OR relname = 'btree_index'
ORDER BY relname;
   relname     | pg_size_pretty
---------------+----------------
 brin_example  | 3457 MB
 btree_index   | 2142 MB
 brin_index    | 104 kB
```

GIN Example Using tsvector_ops

```
CREATE TABLE articles (doc TSVECTOR);

INSERT INTO articles VALUES ('The fox is sick');

INSERT INTO articles VALUES ('How sick is this');

SELECT ctid, * FROM articles ORDER BY 1;
 ctid  |            doc
-------+---------------------------
 (0,1) | 'The' 'fox' 'is' 'sick'
 (0,2) | 'How' 'is' 'sick' 'this'
```

GIN Example Using tsvector_ops

```
SELECT ctid, * FROM articles ORDER BY 1;
 ctid  |               doc
-------+---------------------------
 (0,1) | 'The' 'fox' 'is' 'sick'
 (0,2) | 'How' 'is' 'sick' 'this'

fox     (0,1)
is      (0,1), (0,2)
sick    (0,1), (0,2)
this    (0,2)
How     (0,2)
The     (0,1)
```

Integer arrays are indexed similarly.

GIN Example Using JSON

```
CREATE TABLE webapp (doc JSONB);

INSERT INTO webapp VALUES
('{"name": "Bill", "active": true}');

INSERT INTO webapp VALUES
('{"name": "Jack", "active": true}');

SELECT ctid, * FROM webapp ORDER BY 1;
 ctid  |                doc
-------+----------------------------------
 (0,1) | {"name": "Bill", "active": true}
 (0,2) | {"name": "Jack", "active": true}
```

GIN Example Using `jsonb_ops` (default)

```
(0,1) | {"name": "Bill", "active": true}
(0,2) | {"name": "Jack", "active": true}

CREATE INDEX i_webapp_yc ON webapp
USING gin (doc /* jsonb_ops */);

active (0,1), (0,2)
name   (0,1), (0,2)
true   (0,1), (0,2)
Bill   (0,1)
Jack   (0,2)
```

GIN Example Using jsonb_path_ops

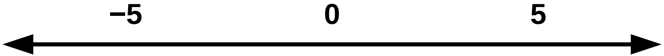
```
(0,1) | {"name": "Bill", "active": true}
(0,2) | {"name": "Jack", "active": true}

CREATE INDEX i_webapp_doc_path ON webapp
USING gin (doc jsonb_path_ops);

hash(active, true) (0,1), (0,2)
hash(name, Bill)   (0,1)
hash(name, Jack)   (0,2)
```

Nested keys have their parent keys (paths) prepended before hashing.

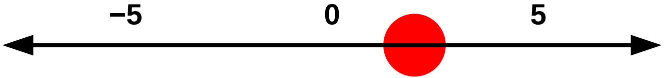
GiST

- Supports data types with loosely-coupled values, like tsvector, JSONB
- Uniquely supports data types with tightly-coupled values
  - multi-dimensional types (geographic)
  - range types
  - IP network data type

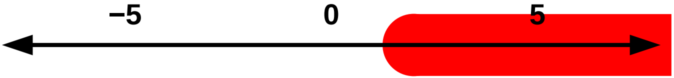
Linear Indexing



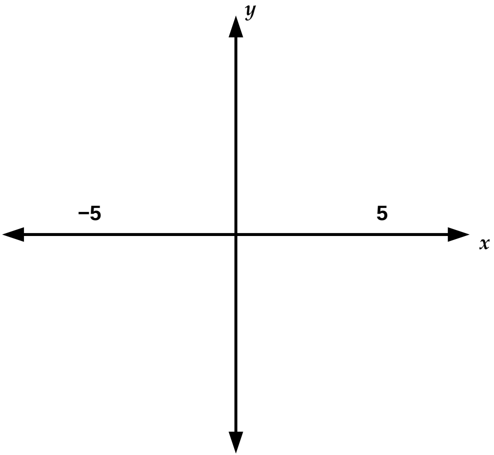
= 2

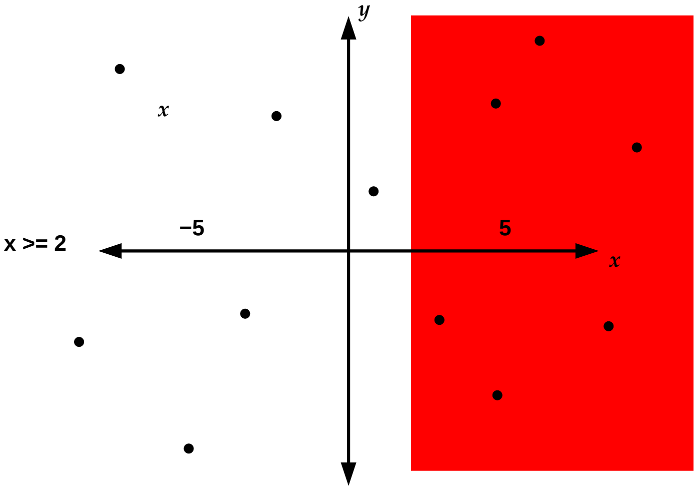


>= 2

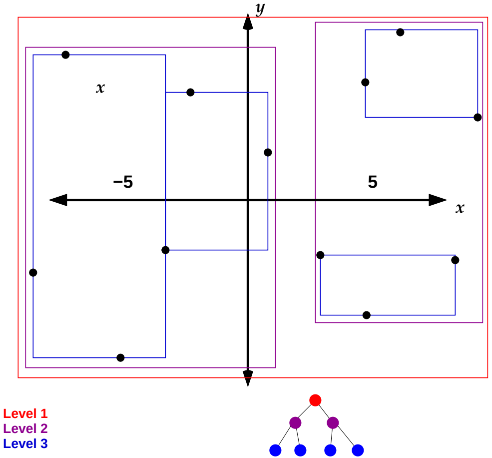


Multi-Dimensional




y
x
−5
5
x >= 2
x

R-Tree Indexes Bounding Boxes



Geographic objects (lines, polygons) also can appear in R-tree indexes. based on their own bounding boxes.

GiST Two-Dimensional Ops

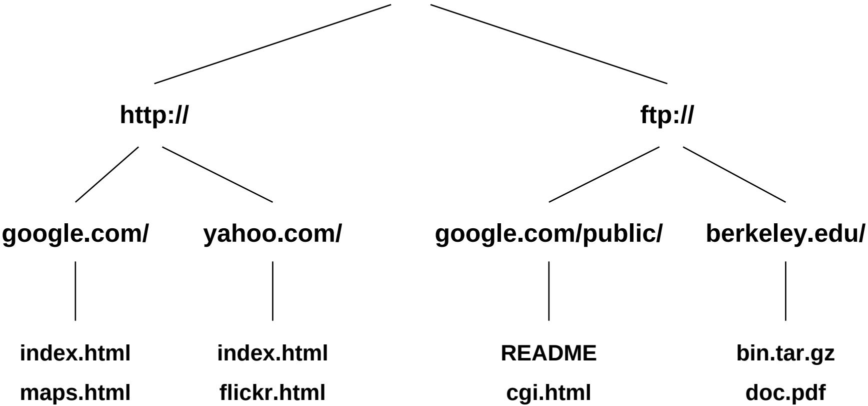
```
box_ops
circle_ops
point_ops
poly_ops
```

PostGIS also uses this indexing method.

Range Indexing With GIST

GIST range-type indexing uses large ranges at the top level of the index, with ranges decreasing in size at lower levels, just like how R-tree bounding boxes are indexed.

SP-GiST TEXT_OPS Example (Suffix Tree)



Internally split by character. B-trees use range partitioning, e.g., A–C, rather than common prefix partitioning, so a B-tree key must store the full key value.

Other SP-GiST Index Examples

- quad_point_ops uses four corner points in square partitions of decreasing size
- kd_point_ops splits on only one dimension

Extension Index Support

- btree_gin (GIN)
- btree_gist (GIST)
- cube (GIST)
- hstore (GIST, GIN)
- intarray (GIST, GIN)
- ltree (GIST)
- pg_trgm (GIST, GIN)
- PostGIS
- seg

7. Index Usage Summary

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

When To Create Indexes

- pg_stat_user_tables.seq_scan is high
- Check frequently-executed queries with EXPLAIN (find via pg_stat_statements or pgbadger)
- Sequential scans are not always bad
- If pg_stat_user_indexes.idx_scan is low, the index might be unnecessary
- Unnecessary indexes use storage space and slow down INSERTs and some UPDATEs

Evaluating Index Types

- Index build time
- Index storage size
- INSERT/UPDATE overhead
- Access speed
- Operator lookup flexibility

Conclusion

https://momjian.us/presentations

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