Jsonb «smart» indexing.

Parametrized opclasses

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Indexes !

- Index is a search structure with finally tuple (or page) pointers
- Index has no visibility information (MVCC !)
- Indexes used only for accelerations
- Index scan should produce the same results as sequence scan with filtering
- Indexes can be: **partial** (where price > 0.0), **functional** (to_tsvector(text)), **multicolumn** (timestamp, tsvector)
- Indexes not always useful !
  - Low selectivity
  - Maintainance overhead

Index Encyclopaedia

- B-tree
- HASH
- GiST
- GIN
- SP-GiST
- BRIN
- Bloom (contrib)
- RUM (https://github.com/postgrespro/rum)
- In progress: OUZO, VODKA (more liqueurs?)

Concept: opclass

Operator class is a «glue» or named collection of:

- AM
- Set of operators
- AM specific support function

Example:

- B-tree, </<=/=/>=/>, btint4cmp()
- CREATE INDEX .. USING btree (textcolumn **text_pattern_ops**)

Extending Indexing infrastructure

- Opclasses have «hardcoded» constants (signature size)
  - Let user to define these constants for specific data
- Indexing of non-atomic data (arrays, json[b], tsvector,…)
  - Specify what to index — partial index only filters rows
- Use different algorithms to index
  - Specify what to use depending on data

Opclass parameters: syntax

- Parenthized parameters added after column's opclass. Default opclass can be specified with DEFAULT keyword:

```
CREATE INDEX idx ON tab USING am (
    {expr {DEFAULT | opclass} ({name=value} [,…])} [,…]
) …
```

```
CREATE INDEX ON small_arrays USING gist (
      arr gist__intbig_ops(siglen=32),
      arr DEFAULT (num_ranges = 100)
);
```

Opclass parameters: implementation

- Parameters are stored in `text[]` column `indoptions` of `pg_catalog.pg_index`
- i-th element of `indoptions[]` is a `text` array (in a text form) of parameters of i-th index column serialized into a string.
- Each parameter is stored as 'name=value' text string.

Opclass parameters: implementation

- Parameters are stored in `text[]` column `indoptions` of `pg_catalog.pg_index`

```
SELECT (
      SELECT array_agg(opcname) opclasses
      FROM unnest(indclass::int[]) opcid, pg_opclass opc
      WHERE opc.oid=opcid), indoptions
FROM pg_index
WHERE indoptions IS NOT NULL;
             opclasses                |              indoptions
--------------------------------------+--------------------------------------
 {jsonb_path_ops}                     | {"{paths=$.tags[*].term}"}
 {gist__intbig_ops,gist__int_ops}     | {"{siglen=32}","{num_ranges=100}"}
(3 rows)
```

Opclass parameters: implementation

Each access method supporting opclass parameters specifies `amopclassoptions` routine for transformation of `text[]` parameters datum into a binary `bytea` structure which will be cached in `RelationData` and `IndexOptInfo` structures:

```
typedef bytea *(*amopclassoptions_function) (
    Relation index, AttrNumber colnum,
    Datum indoptions, bool validate
);
```

Opclass parameters: implementation

- Access method which wants simply to delegate parameters processing to one of column opclass's support functions can use `index_opclass_options_generic()` subroutine in its `amopclassoptions` implementation.

```
bytea *index_opclass_options_generic(
    Relation relation, AttrNumber attnum,
    uint16 procnum, Datum indoptions, bool validate);
```

- This support functions must have the following signature:

```
internal function(options internal, validate bool)
```

Opclass options passed as a `text[]` datum.

Returned pointer to `bytea`.

Opclass parameters: implementation

- Example: contrib/intarray

```
CREATE FUNCTION g_intbig_options(internal, boolean)
RETURNS internal
AS 'MODULE_PATHNAME', 'g_intbig_options'
LANGUAGE C IMMUTABLE STRICT PARALLEL SAFE;

ALTER OPERATOR FAMILY gist__intbig_ops USING gist
ADD FUNCTION 10 (_int4) g_intbig_options (internal, boolean);
```

PostgreSQL extendability

It is imperative that a user be able to construct new access methods to provide efficient access to instances of nontraditional base types

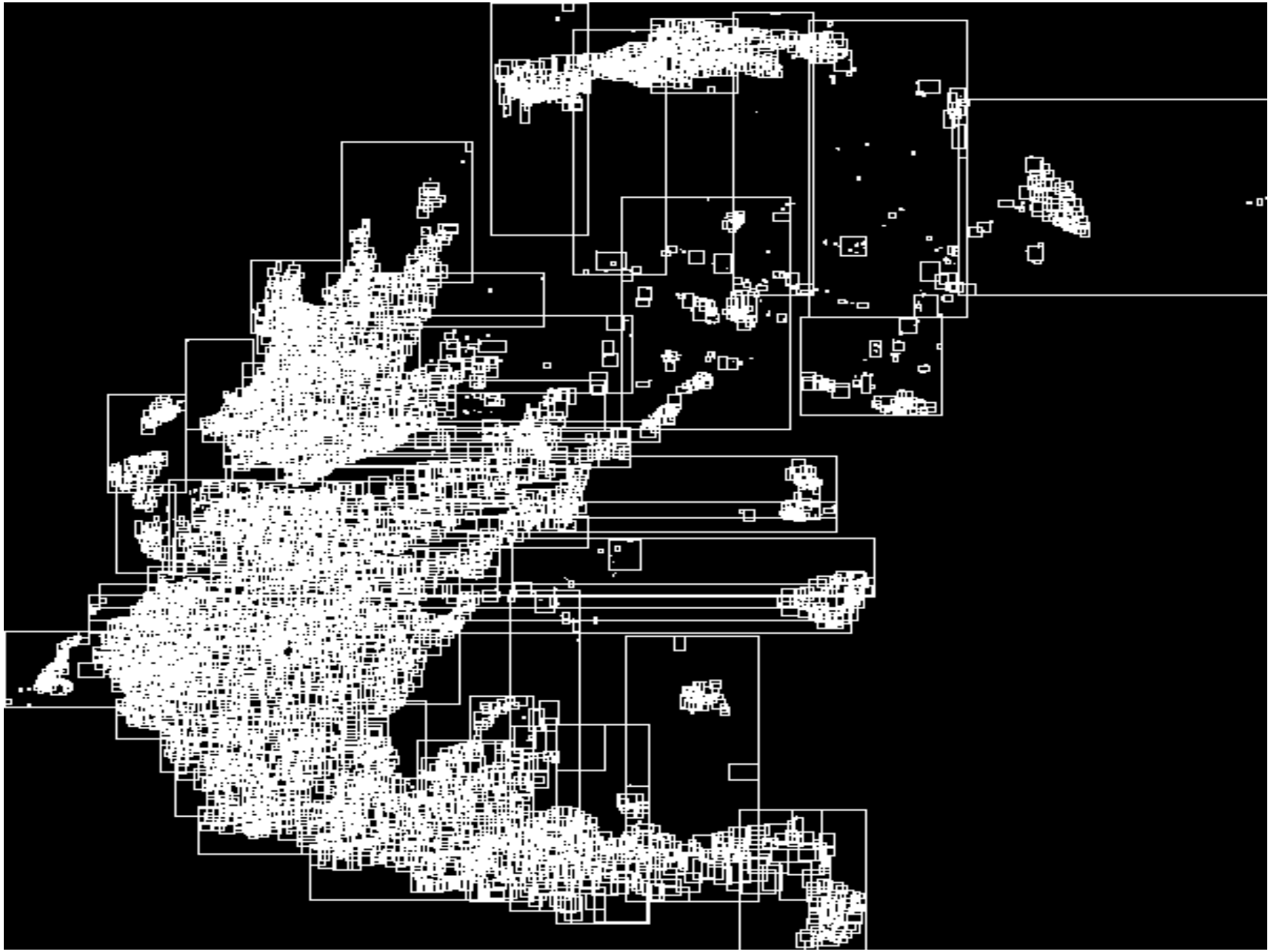
Michael Stonebraker, Jeff Anton, Michael Hirohama.

Extendability in POSTGRES , IEEE Data Eng. Bull. 10 (2) pp.16-23, 1987

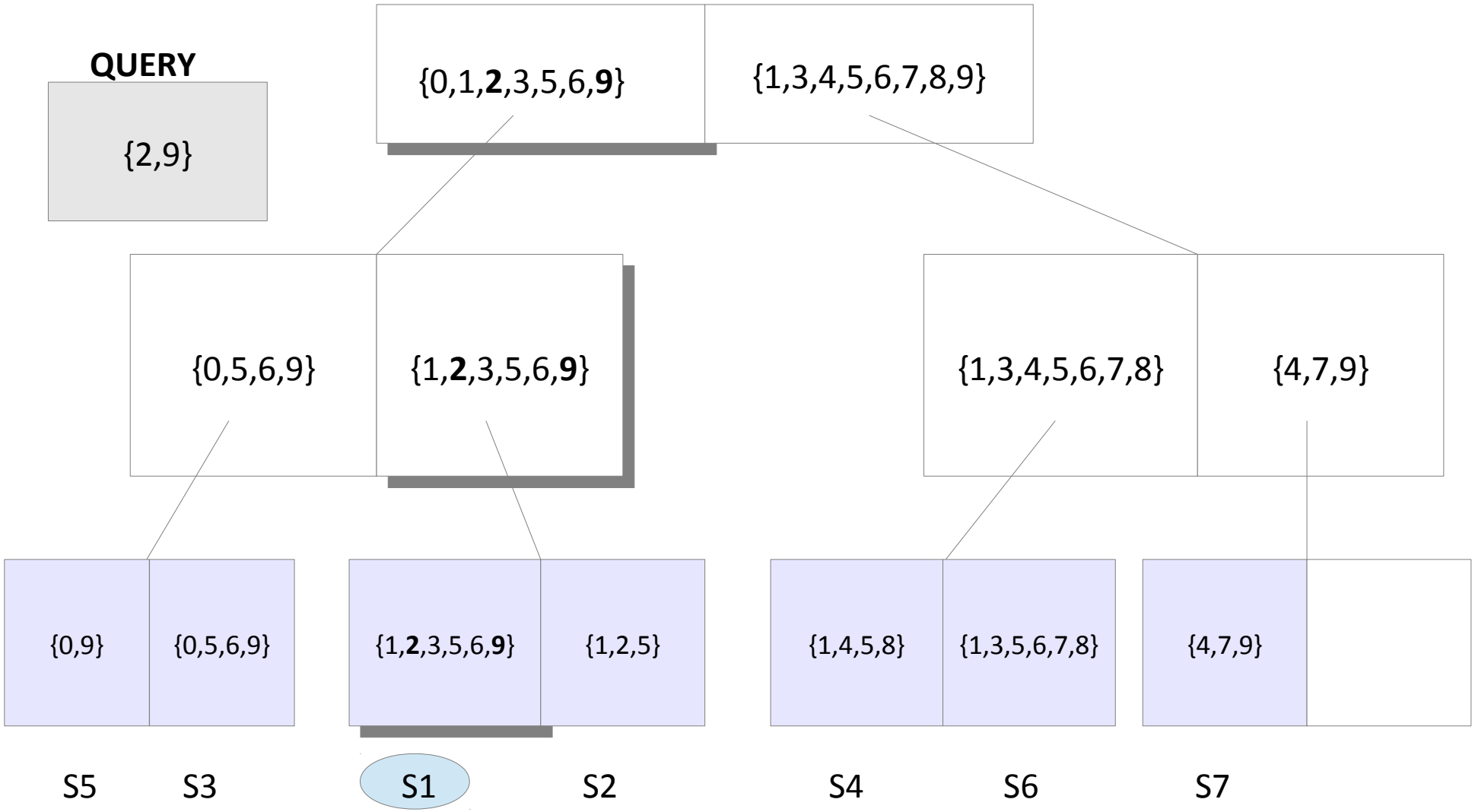
Extensibility PostgreSQL: GiST

- Generalized Search Tree (GiST)
  J. M. Hellerstein, J. F. Naughton, and Avi Pfeffer. "Generalized search trees for database systems.", VLDB 21, 1995
  - AM is considered as predicate hierarchy, where each predicate is a some union of all keys in subtree (bounding box of subtree)
  - Framework for implementation search trees, which semantic is close to R-tree.
- GiST provides
  - Navigation on tree (search, insert, KNN-search)
  - Consistency/Concurrency/Recovery

GiST — Rtree example (Greece)



RD-Tree


QUERY
{2,9}
{0,1,2,3,5,6,9}
{1,3,4,5,6,7,8,9}
{0,5,6,9}
{1,2,3,5,6,9}
{1,3,4,5,6,7,8}
{4,7,9}
{0,9}
{0,5,6,9}
{1,2,3,5,6,9}
{1,2,5}
{1,4,5,8}
{1,3,5,6,7,8}
{4,7,9}
S5
S3
S1
S2
S4
S6
S7

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"THE RD-TREE: AN INDEX STRUCTURE FOR SETS", Joseph M. Hellerstein

FTS Index (GiST): RD-Tree

- Word signature — words hashed to the specific position of '1'

  w1 -> S1: 01000000 Document: w1 w2 w3

  w2 -> S2: 00010000

  w3 -> S3: 10000000

- Document (query) signature — superposition (bit-wise OR) of signatures

  S: 11010000

- Bloom filter

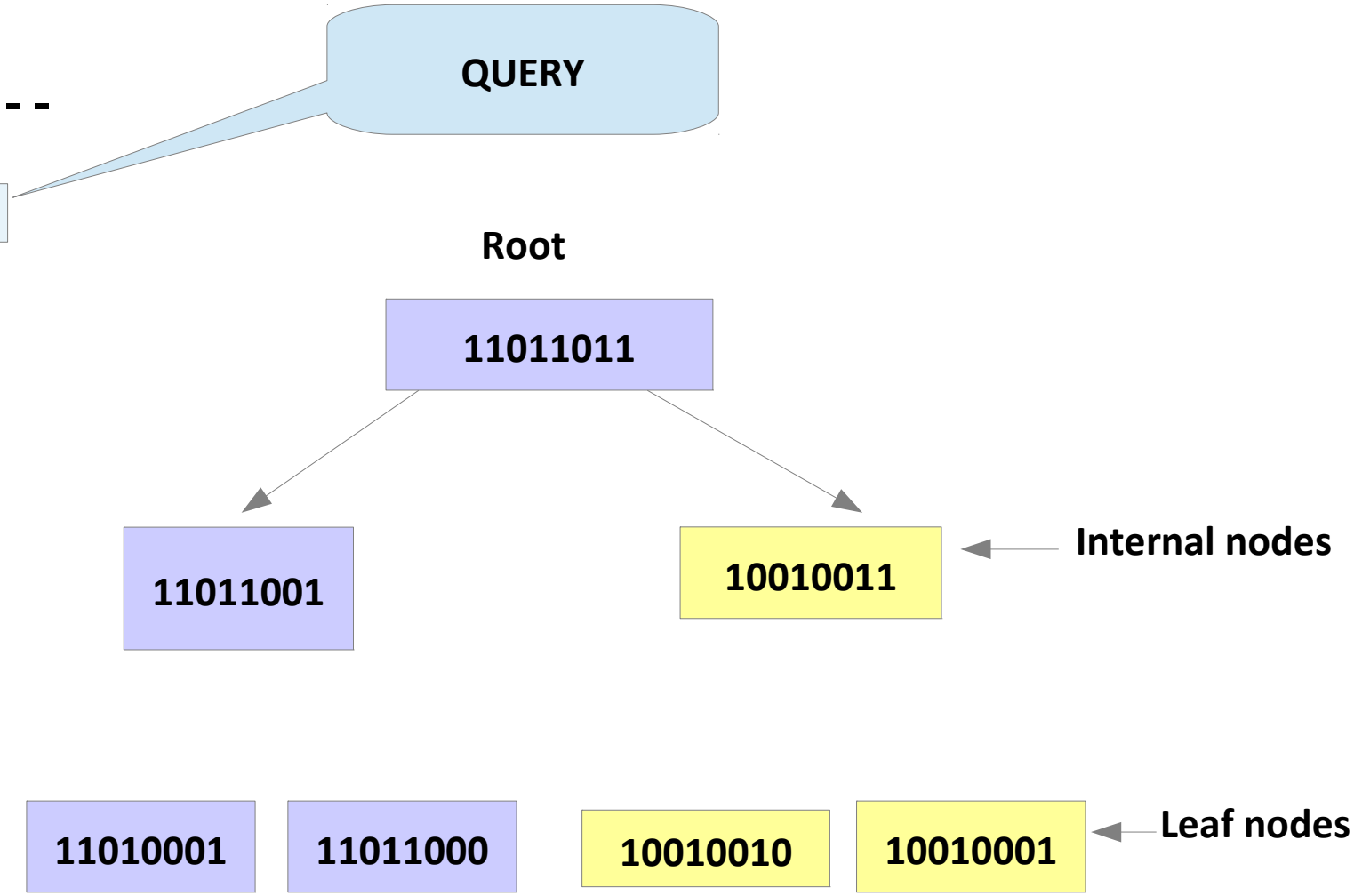
  Q1: 00000001 – exact not

  Q2: 01010000 - may be contained in the document, **false drop**

- Signature is a lossy representation of document
  - + fixed length, compact, + fast bit operations
  - - lossy (false drops), - saturation with #words grows

FTS Index (GiST): RD-Tree

word	signature
ac	00000011
ars	**11000000**
brevis	00001010
generis	01000100
humani	00110000
jus	00010001
longa	00100100
necis	01001000
nostra	10000001
vita	01000001
vitae	00011000



Opclass parameters: intarray

- contrib/intarray — NULL-free one-dimensional arrays of integers (https://www.postgresql.org/docs/current/static/intarray.html)

  Example:

  Int[] && int[] - overlap

- Indexes

```
gist__int_ops(num_ranges) - default (do not use it
                        if you do not know what you do)
gist__intbig_ops(siglen)  - use it!.
```

Opclass parameters: GiST examples

- core:
  tsvector_ops(siglen)
- contrib/intarray:
  gist__int_ops(num_ranges)

  gist__intbig_ops(siglen)
- contrib/ltree:

  gist_ltree_ops(siglen)

  gist__ltree_ops(siglen)
- contrib/pg_trgm:

  gist_trgm_ops(siglen)

Opclass parameters: GiST

- Parametrized GiST opclass should specify optional 10th (`GIST_OPCLASSOPT_PROC`) support function with signature:

```
internal function (options internal, validate bool)
```

- Returned parsed bytea * with parameters will be passed in all support functions in the last argument.

Opclass parameters: intarray

```
SELECT i AS id,
(select  array_agg(round(random() * (100 - 1)) + 1)::int[]
FROM generate_series (0,  (random()*100 + i * 0)::int))
AS arr INTO arrays FROM generate_series(1,1000000) i;
```

```
                Table "public.arrays"  – 255MB size
 Column |   Type    | Collation | Nullable | Default
--------+-----------+-----------+----------+---------
 id     | integer   |           |          |
 arr    | integer[] |           |          |
Indexes:
    "arrays_arr_idx" gist (arr gist__intbig_ops)  -- siglen = 252
    "arrays_arr_idx1" gist (arr gist__intbig_ops (siglen='64'))
    "arrays_arr_idx2" gist (arr gist__intbig_ops (siglen='32'))
```

Opclass parameters: intarray

```
                                List of relations
 Schema |       Name         | create |  Size   | Q1  | Q2
--------+--------------------+--------+---------+-----+-----
 public | arrays_arr_idx     | 28  sec| 451 MB  | 641 | 387
 public | arrays_arr_idx1    | 17  sec| 143 MB  | 535 | 164
 public | arrays_arr_idx2    | 15  sec| 86 MB   | 527 |  73
(3 rows)

Q1: SELECT count(*) FROM arrays WHERE arr @> '{1,2,3}';
Q1: SELECT count(*) FROM arrays WHERE arr <@ '{1,2,3}';
```

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GIN
Generalized Inverted Index

PROFESSIONAL Postgres

GIN

Report Index

A

B

D

E

PROFESSIONAL Postgres

GIN

Report Index

A

B

QUERY: compensation accelerometers

INDEX: accelerometers 5,10,25,28,**30**,36,58,59,61,73,74 compensation **30**,68

RESULT: **30**

E

GIN

- Internal structure is basically just a B-tree
  - Optimized for storing a lot of duplicate keys
  - Duplicates are ordered by heap TID
- Interface supports indexing more than one key per indexed value
  - Full text search: “foo bar” → “foo”, “bar”
- Bitmap scans only

Opclass parameters: GIN

- Parametrized GIN opclass should specify optional 7th (`GIN_OPCLASSOPTIONS_PROC`) support function with signature:

```
internal function (options internal, validate bool)
```

- Returned parsed bytea * with parameters will be passed in all support functions in the last argument.

GIN jsonb opclasses: jsonb_ops, jsonb_path_ops

sample: {"k1": "v1", "k2": ["v2", "v3"]}

- **jsonb_ops** extracts keys and values separately:

  "k1", "k2", "v1", "v2", "v3"

  overlapping of large postings, might be slow

- **jsonb_path_ops** extracts hashes of paths:

  hash("k1"."v1"), hash("k2".#."v2"), hash("k2".#."v3")

  fast search for particular paths, but can't search for separate keys and values

Opclass parameters: GIN examples

- core:
  tsvector_ops(weights)

- core (used jsonpath type from SQL/JSON branch):
  jsonb_ops(projection)
  jsonb_path_ops(projection)

SQL/JSON in PostgreSQL

- SQL-2016 path language specifies the parts (the projection) of JSON data to be retrieved by path engine for SQL/JSON functions.
- **Jsonpath —** the binary data type for SQL/JSON path expression to effective query JSON data.

```
SELECT JSON_QUERY(js,
   '$.floor[*] ? (@.level >1).apt[*] ? (@.area>$min && @.area < $max).no'
                    PASSING 40 AS min, 90 AS max )
FROM house;
```

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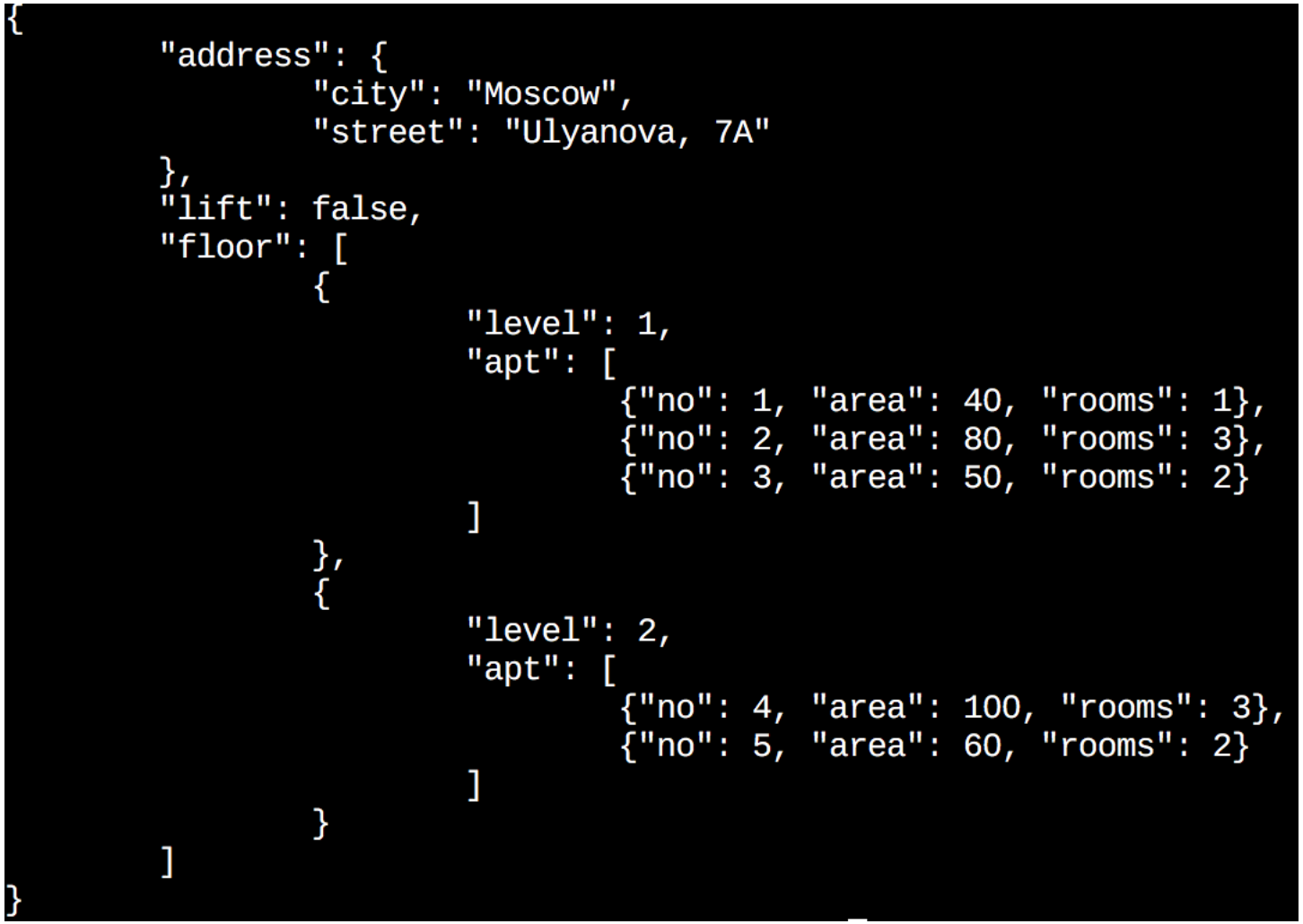
Visual guide on jsonpath



$.floor[0, 1].apt[1 to last]

```
SELECT JSON_QUERY(js, '$.floor[0, 1].apt[1 to last]' WITH WRAPPER) FROM house;
                                                  ?column?
-----------------------------------------------------------------------------
 [{"no": 2, "area": 80, "rooms": 3}, {"no": 3, "area": 50, "rooms": 2},
  {"no": 5, "area": 60, "rooms": 2}]
(1 row)
```

JSON_TABLE — relational view of json

```
SELECT  apt.*
FROM
  house,
  JSON_TABLE(js, '$.floor[0, 1]' COLUMNS (
    level int,
    NESTED PATH '$.apt[1 to last]' COLUMNS (
      no int,
      area int,
      rooms int
    )
  )) apt;
 level | no | area | rooms
-------+----+------+-------
     1 |  2 |   80 |     3
     1 |  3 |   50 |     2
     2 |  5 |   60 |     2
(3 rows)
```

Opclass parameters: jsonb

- Added `projection` parameter to GIN `jsonb_ops` and `jsonb_path_ops` for specification of indexed fragments of JSON document.
- `projection` parameter is a string in standard SQL/JSON path format. We use our jsonpath syntax extension for joining path expressions into sequences with comma symbol:
  `jsonpath '$.a[*], $.b, $.c[*].d'`
- Each indexed path must start with `$` and only the following path elements are supported now:
  `.key .* .**{1,3}`
  `[*]`
  `[3, 5 to 7]` (constant indices only)

Opclass parameters: jsonb

- Indexed path specifications can be strict or lax (default).
  The following projections are equivalent due to automatic array wrapping/unwrapping in lax mode:

```
projection='lax $.a[*].b'
projection='strict $.a.b, $[*].a.b, $.a[*].b, $[*].a[*].b,
            $.a.b[*], $[*].a.b[*], $.a[*].b[*], $[*].a[*].b[*]'
```

- Sequential scan is used if the query does not emit any indexed entries or contains not-indexed path in OR-ed predicate:
  `projection='$.a'`

  `js @~ '$.b == 1'` => sequential scan
  `js @~ '$.a == 1 || $.b == 2'` => sequential scan
  `js @~ '$.a == 1 && $.b == 2'` => index scan of `$.a` with recheck which filters `$.b`

Opclass parameters: jsonb bookmarks examples

- JSON document structure: {


```
 "id": "http://delicious.com/url/b5b3cbf9a9176fe43c27d7b4af94a422#mcasas1",
 "author": "mcasas1",
 "title": "TheaterMania",
 "updated": "Tue, 08 Sep 2009 23:28:55 +0000",
 "tags": [
   {"term": "NYC", "scheme": "http://delicious.com/mcasas1/", "label": null}
 ],
 "link": "http://www.theatermania.com/broadway/",
 "links": [{"href": "http://www.theatermania.com/broadway/",
            "type": "text/html", "rel": "alternate"}],
 "comments": "http://delicious.com/url/b5b3cbf9a9176fe43c27d7b4af94a422",
 "guidislink": false,
 "title_detail": {
    "base": "http://feeds.delicious.com/v2/rss/recent?min=1&count=100",
    "type": "text/plain", "language": null, "value": "TheaterMania"
 },
 "source": {},
 "wfw_commentrss": "http://feeds.delicious.com/v2/rss/url/b5b3cbf9a9176fe43c27d7b4af94a422"
}
```

Opclass parameters: jsonb bookmarks examples

- We want to find bookmarks by tag terms
- Full and selective jsonb indices:

```
CREATE INDEX bookmarks_full_idx ON bookmarks USING
  gin(js jsonb_ops);

CREATE INDEX bookmarks_full_path_idx ON bookmarks USING
  gin(js jsonb_path_ops);

CREATE INDEX bookmarks_selective_idx ON bookmarks USING
  gin(js jsonb_ops(projection='strict $.tags[*].term'));

CREATE INDEX bookmarks_selective_path_idx ON bookmarks USING
  gin(js jsonb_path_ops(projection='strict $.tags[*].term'));
```

Opclass parameters: jsonb bookmarks examples

- Functional indices on SQL/JSON functions and operators:

```
CREATE INDEX bookmarks_oper_idx ON bookmarks USING
  gin((js @# '$.tags.term'));

CREATE INDEX bookmarks_oper_path_idx ON bookmarks USING
  gin((js @# '$.tags.term') jsonb_path_ops);

CREATE INDEX bookmarks_json_query_jsonb_idx ON bookmarks USING
  gin(JSON_QUERY(js, '$.tags.term' WITH WRAPPER));

CREATE INDEX bookmarks_json_query_jsonb_path_idx ON bookmarks USING
  gin(JSON_QUERY(js, '$.tags.term' WITH WRAPPER) jsonb_path_ops);

CREATE INDEX bookmarks_json_query_texta_idx ON bookmarks USING
  gin(JSON_QUERY(js, '$.tags.term' RETURNING text[] WITH WRAPPER)
COLLATE "C");
```

Opclass parameters: jsonb bookmarks examples

- Functional indices on plain jsonb functions:

```
CREATE FUNCTION bookmark_tags(bookmark jsonb) RETURNS jsonb
  AS $$ SELECT jsonb_agg(tag->'term')
        FROM jsonb_array_elements($1->'tags') tag(tag)
  $$ LANGUAGE sql IMMUTABLE;

CREATE FUNCTION bookmark_tags_text(bookmark jsonb) RETURNS text[]
  AS $$ SELECT array_agg(tag->>'term')
        FROM jsonb_array_elements($1->'tags') tag(tag)
  $$ LANGUAGE sql IMMUTABLE;


CREATE INDEX bookmarks_func_jsonb_idx ON bookmarks USING
  gin(bookmark_tags(js));
CREATE INDEX bookmarks_func_jsonb_path_idx ON bookmarks USING
  gin(bookmark_tags(js) jsonb_path_ops);
CREATE INDEX bookmarks_func_texta_idx ON bookmarks USING
  gin(bookmark_tags_text(js) COLLATE "C");
```

Opclass parameters: jsonb bookmarks examples

Index	Size	Build time
bookmarks_full_idx	629 MB	183.1 s
bookmarks_full_path_idx	300 MB	98.5 s
bookmarks_selective_idx	32 MB	8.0 s
bookmarks_selective_path_idx	33 MB	4.5 s
bookmarks_oper_idx	35 MB	6.5 s
bookmarks_oper_path_idx	33 MB	4.5 s
bookmarks_json_query_jsonb_idx	35 MB	7.3 s
bookmarks_json_query_jsonb_path_idx	33 MB	5.4 s
bookmarks_json_query_texta_idx	34 MB	7.5 s
bookmarks_func_jsonb_idx	35 MB	18.8 s
bookmarks_func_jsonb_path_idx	33 MB	17.2 s
bookmarks_func_texta_idx	34 MB	15.1 s

How to debug indexes usage?

- Many indexes, long creation. Let hide unneeded indexes from planner
- Plantuner - http://www.sai.msu.su/~megera/wiki/plantuner

  Example: https://obartunov.livejournal.com/197604.html

Opclass parameters: jsonb bookmarks examples

Queries for full or selective index (performance is the same for them):

- `SELECT COUNT(*) FROM bookmarks WHERE js @> '{"tags": [{"term": "NYC"}]}';`
  0.664 ms jsonb_path_ops
  7.399 ms jsonb_ops

- `SELECT COUNT(*) FROM bookmarks WHERE js @~ '$.tags.term == "NYC"';`
  0.722 ms jsonb_path_ops
  7.500 ms jsonb_ops

- `SELECT COUNT(*) FROM bookmarks WHERE js @~ 'strict $.tags[*].term == "NYC"';`
  0.719 ms jsonb_path_ops
  7.414 ms jsonb_ops

- `SELECT COUNT(*) FROM bookmarks WHERE js @? '$.tags ? (@.term == "NYC")';`
  0.685 ms jsonb_path_ops
  14.978 ms jsonb_ops

Opclass parameters: jsonb bookmarks examples

Queries for functional indices:

- `SELECT COUNT(*) FROM bookmarks WHERE **js @# '$.tags.term' @> '"NYC"'**;`
- `SELECT COUNT(*) FROM bookmarks WHERE **JSON_QUERY(js, '$.tags.term' WITH WRAPPER) @> '"NYC"'**;`
- `SELECT COUNT(*) FROM bookmarks WHERE **JSON_QUERY(js, '$.tags.term' RETURNING text[] WITH WRAPPER) @> '{NYC}' COLLATE "C"**;`
- `SELECT COUNT(*) FROM bookmarks WHERE **bookmark_tags_jsonb(js) @> '"NYC"'**;`
- `SELECT COUNT(*) FROM bookmarks WHERE **bookmark_tags_text(js) @> '{NYC}' COLLATE "C"**;`

Results are the same because only 1 entry is scanned:

```
0.812 ms jsonb_path_ops
0.787 ms jsonb_ops

0.829 ms jsonb_path_ops
0.793 ms jsonb_ops

0.176 ms (no recheck)

3.771 ms (expensive recheck)

0.175 ms (no recheck)
```

Opclass parameters: jsonb results

- Index size and build time of selective indices are significaly lower than for the full ones, but they are same as for the functional indices on SQL/JSON functions or operators.
- Selective indexes allow more flexible queries
- Searches by functional **jsonb_ops** indices are faster than by full or selective ones because fewer index entries are scanned.
- Functional jsonb indices with subqueries in expressions are slow on both search and update.
- Searches by text[] indices are the fastest due to absence recheck.

Opclass parameters: roadmap

GIN jsonb_ops and jsonb_path_ops:

- Filters for indexed paths:
  ```
  projection='$[*] ? (@ < 5)'
  ```
  Predicate implication proving is needed here.

- Expression indexing (like ordinary functional indices):
  ```
  projection='$.a + $.b'
  ```

- .datetime() support:
  ```
  projection='$.datetime()'
  js @~ '$.datetime() < "2018-02-06".datetime()'
  ```

- .type() support:
  ```
  js @~ '$.type() == "object"'
  ```

Opclass parameters: roadmap

JsQuery GIN support:

- indexed paths can be specified with new jsquery extension that allows us to extract fragments of jsonb:

```
SELECT jsonb '[{"a":1,"b":2},{"a":3,"b":4}]' ~~ '#.a';
[1, 3]
```

-
```
CREATE INDEX ON t USING gin
  (jb jsonb_value_path_ops(projection='#.a, b.c.#'));
```

- JsQuery indexes can be queried with jsquery operator @@ or with jsonpath operators @? and @~:

```
SELECT * FROM t WHERE jb @@ '#.a = 1 and b.c.# > 2';
SELECT * FROM t WHERE jb @~ '$[*].a == 1 && $.b.c[*] > 2';
```

Catalog «jsonb-fication»

- Indoptions — first candidate
- *options (rel, att, col, srv, ft, fdw and so on)
- ACLs
- Extconfig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