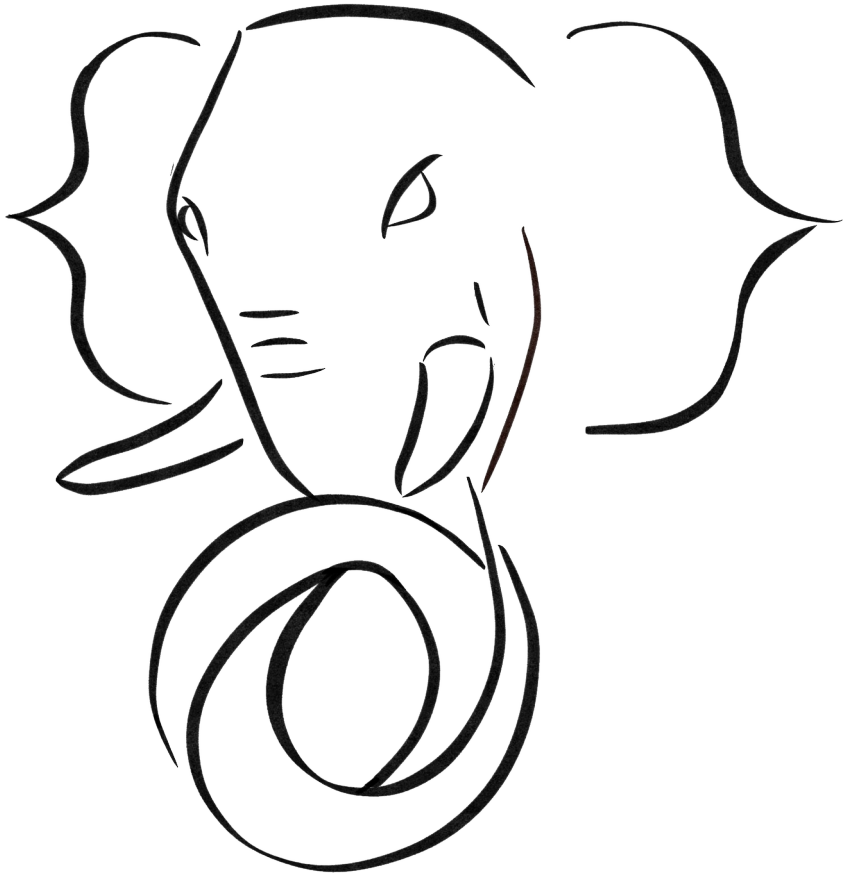
JSON[b] Roadmap



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PGCon 2020
VIRTUAL

Since Postgres95

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Nikita Glukhov

- Postgres Contributor
- Core developer @ Postgres Professional
- Principal developer of SQL/JSON
- Parameters for operator classes
- Contributed to GiST, GIN, SP-GiST
- Transforms for jsonb to PL/Perl

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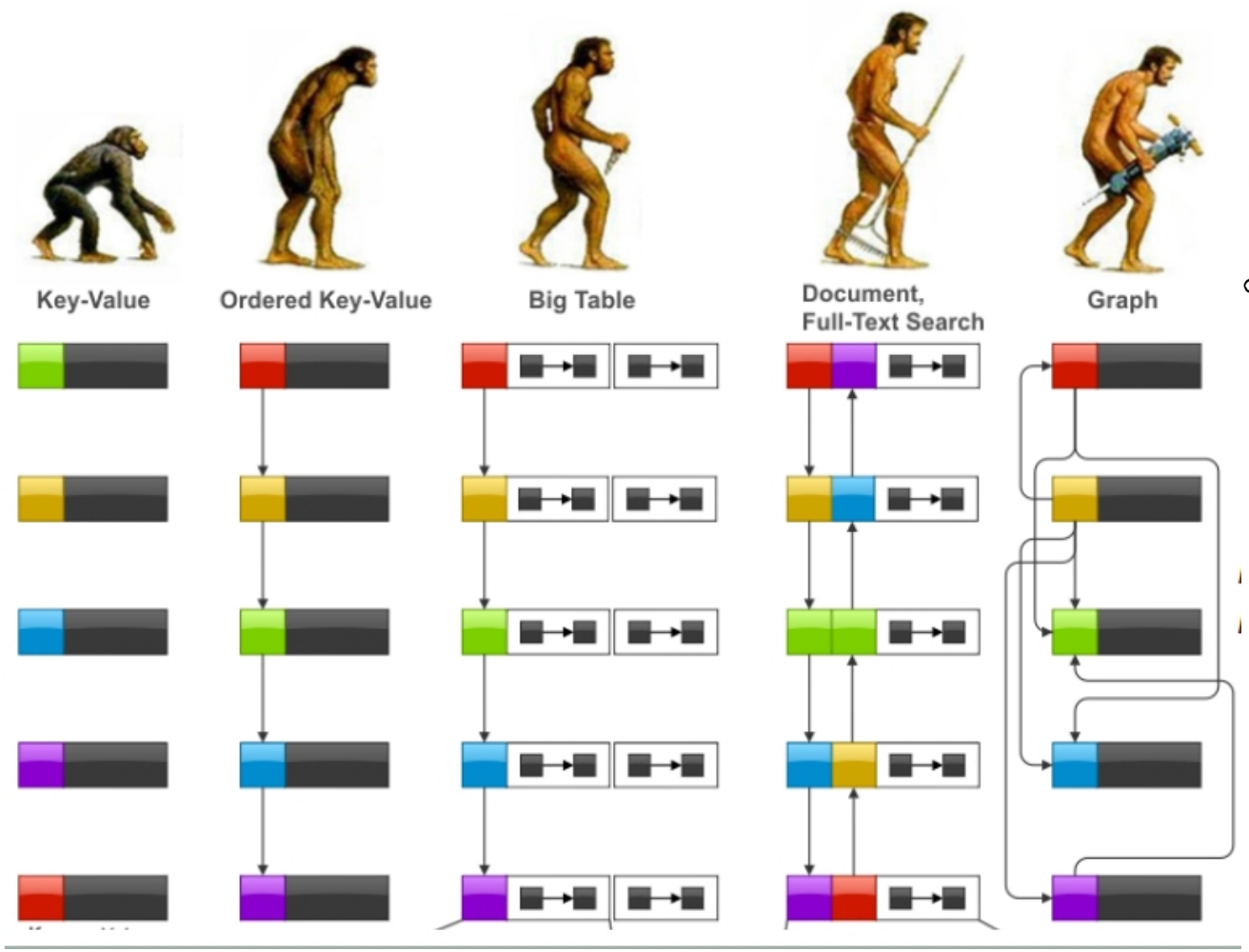
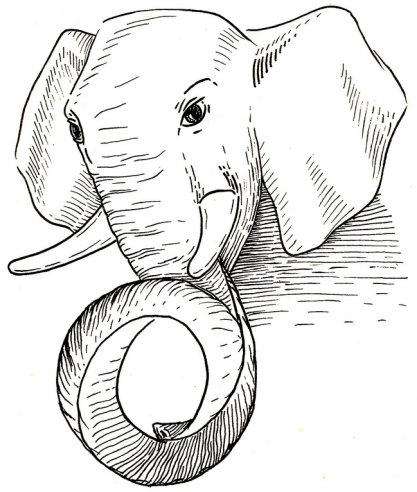
NOSQL POSTGRES IN SHORT





?

SQL/JSON — 202?
- Complete SQL/JSON
- Better indexing, syntax

JSONPATH - 2019
- SQL/JSON — 2016
- Indexing

JSONB - 2014
- Binary storage
- Nesting objects & arrays
- Indexing

JSON - 2012
- Textual storage
- JSON validation

HSTORE - 2003
- Perl-like hash storage
- No nesting, no arrays
- Indexing

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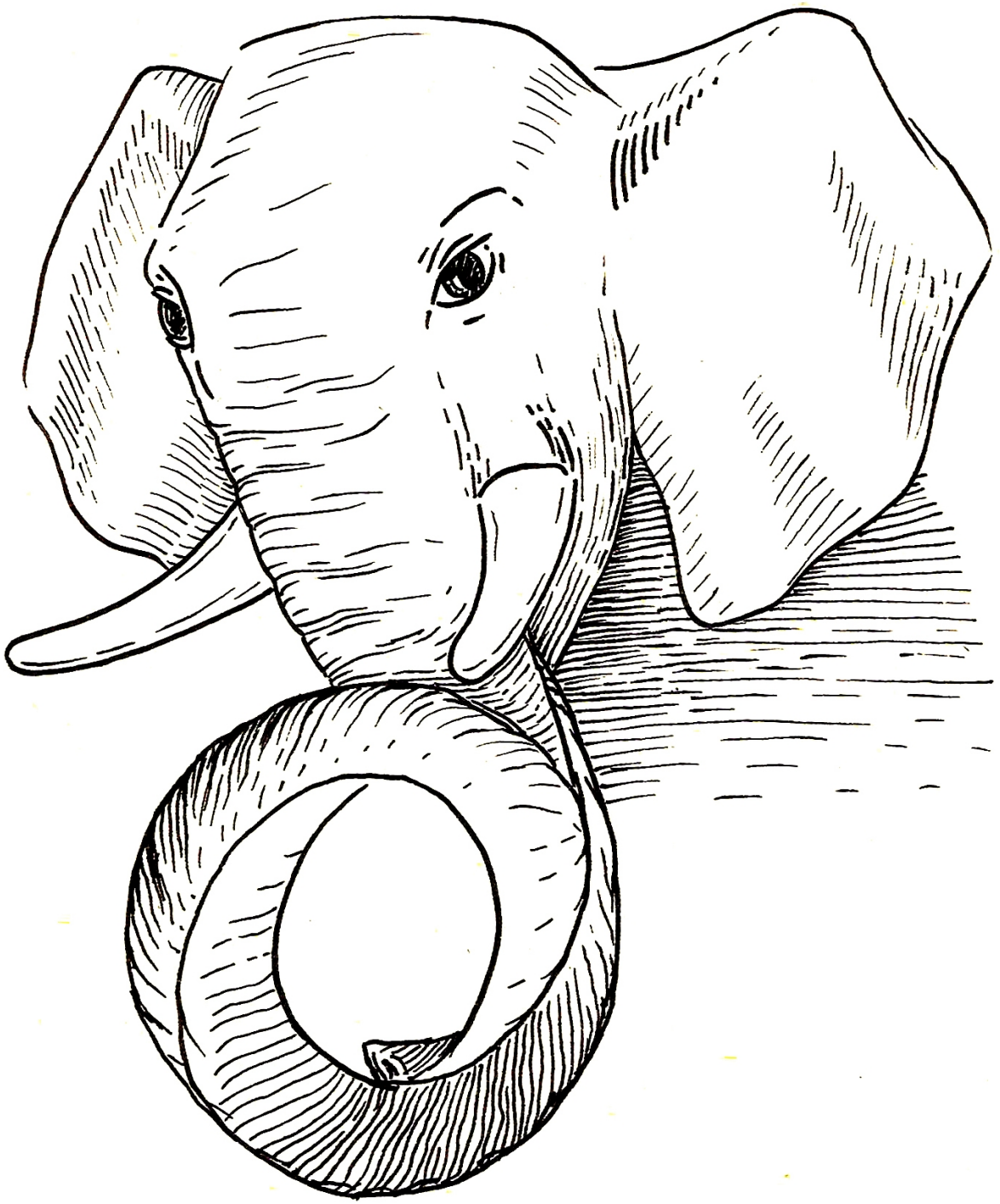
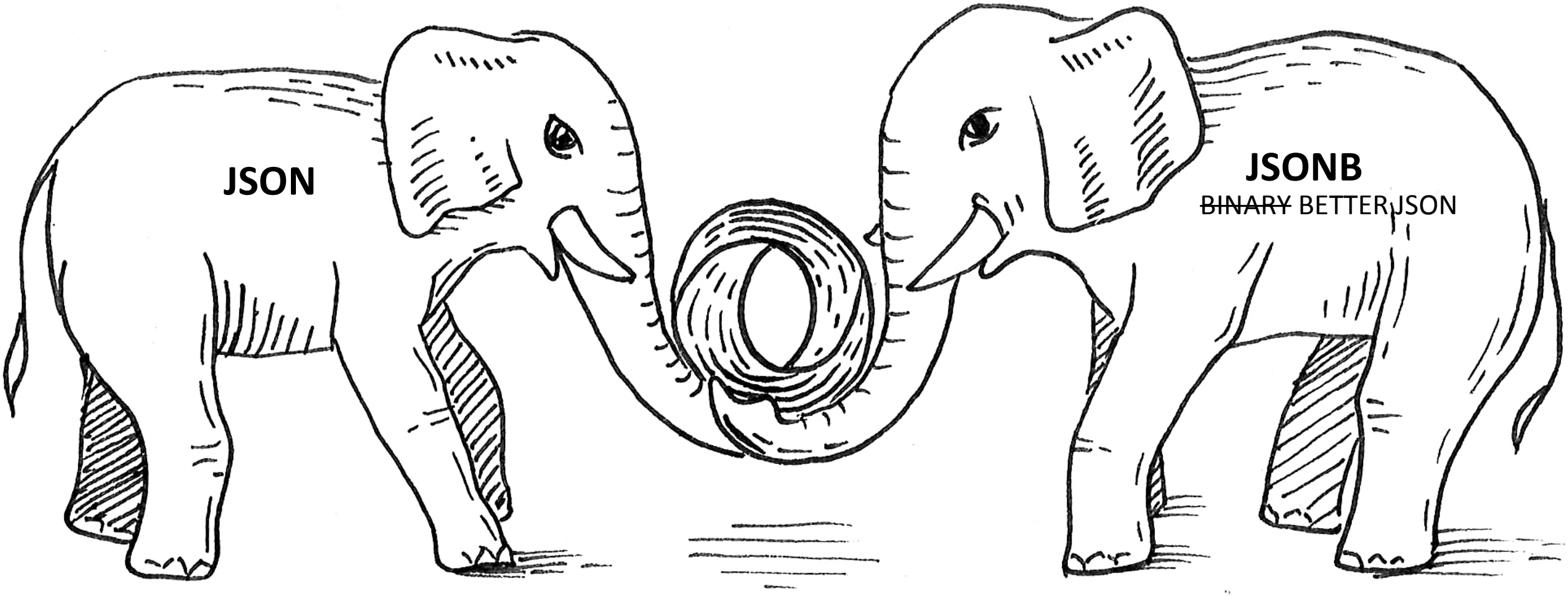


Json in PostgreSQL

(state of Art)

Two JSON data types !!!



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Jsonb vs Json

```
SELECT j::json AS json, j::jsonb AS jsonb FROM
(SELECT '{"cc":0, "aa":  2, "aa":1,"b":1}' AS j) AS foo;
                json                |           jsonb
------------------------------------+----------------------------
 {"cc":0, "aa":  2, "aa":1,"b":1} | {"b": 1, "aa": 1, "cc": 0}
```

- json: textual storage «as is»
- jsonb: binary storage, no need to parse, has index support
- jsonb: no whitespaces, no duplicated keys (last key win)
- jsonb: keys are sorted by (length, key)
- jsonb: a rich set of functions (\df jsonb*), "arrow" operators
- jsonb: great performance, thanks to indexes
- JsQuery ext. - json query language with GIN indexing support

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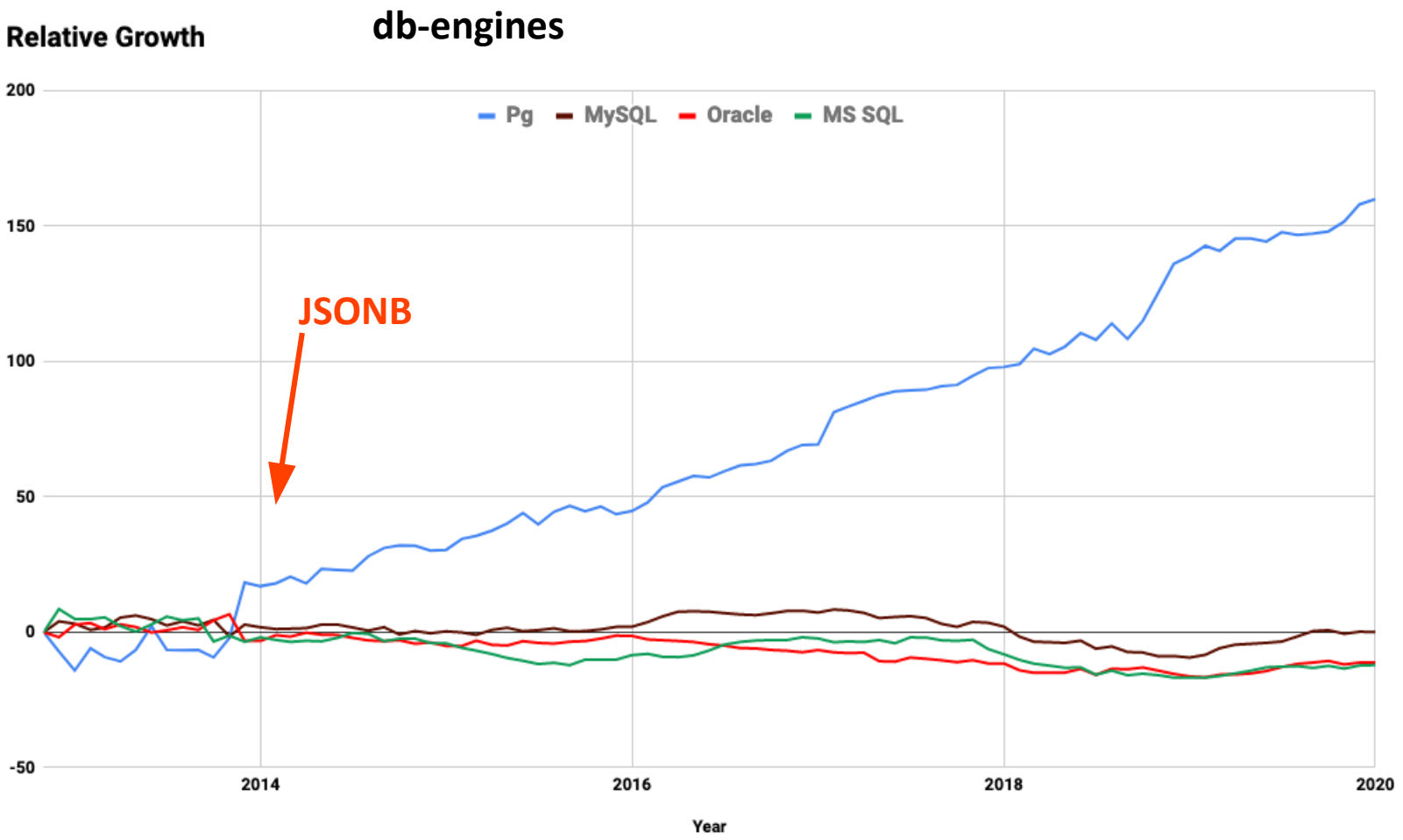
Postgres revolution: embracing relational databases

- NoSQL users attracted by the NoSQL Postgres features



Dec 18, 2014

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SQL/Foundation recognized JSON after the success of Postgres

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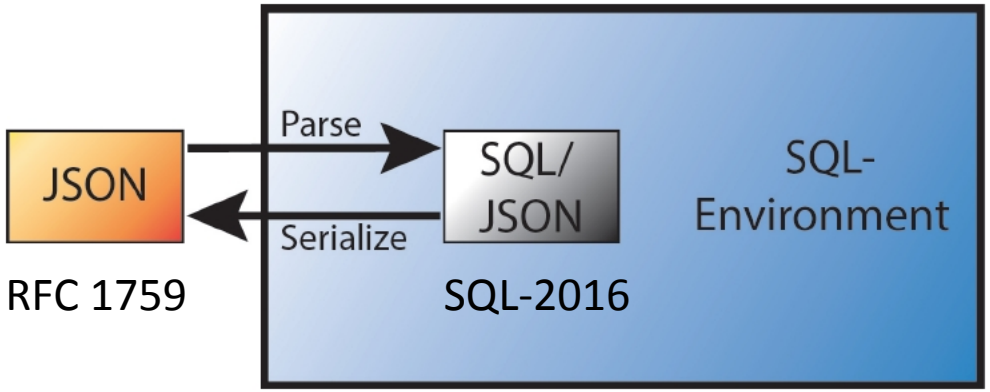
SQL/JSON in SQL-2016



- SQL/JSON data model
  - *A sequence of SQL/JSON items*, each item can be (recursively) any of:
    - SQL/JSON scalar — non-null value of SQL types: Unicode character string, numeric, Boolean or datetime
    - SQL/JSON *null,* value that is distinct from any value of any SQL type (not the same as NULL)
    - SQL/JSON arrays, ordered list of zero or more SQL/JSON items — SQL/JSON *elements*
    - SQL/JSON objects — unordered collections of zero or more SQL/JSON *members* (key, SQL/JSON item)
- JSON Path language
  - Describes a <projection> of JSON data to be used by SQL/JSON functions
- SQL/JSON functions (9)
  - Construction functions: values of SQL types to JSON values
  - Query functions: JSON values to SQL types
    JSON Path(JSON values) → SQL/JSON types -> converted to SQL types

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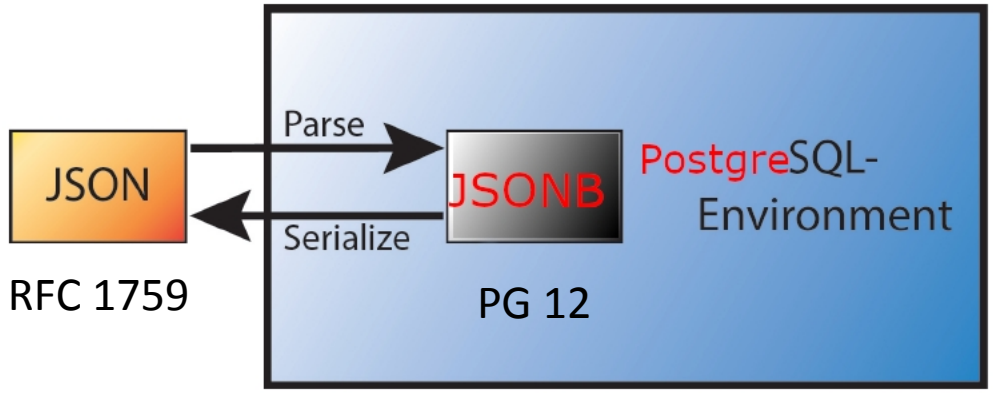
SQL/JSON in PostgreSQL



- SQL/JSON data model
  - **Jsonb is the (practical) subset of SQL/JSON data model**
    ORDERED and UNIQUE KEYS
- JSON Path language
  - Describes a <projection> of JSON data (to be used by SQL/JSON functions)
  - **Most important part of SQL/JSON - committed to PG12 !**
- SQL/JSON functions
  - Constructor functions: **json[b] construction functions**
  - Query functions: **need some functions/operators with jsonpath support**
- Indexes
  - **Use already existing indexes (built-in, jsquery)**
    Add support of jsonpath to the existing opclasses

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JSON Path query language

- **JSON Path** expression specify the parts of json. It is an optional path mode 'strict' or 'lax' (default), followed by a *path* or unary/binary expression on *paths*. *Path* is a sequence of path elements, started from path variable, path literal or expression in parentheses and zero or more operators (JSON accessors, filters, and item methods)

```
'lax $.floor[*].apt[*] ? (@.area > 40 && @.area < 90)'
```

  - Dot notation used for member access – '$.a.b.c'
    $ - the current context element
    [*], [0 to LAST] – array access (starts from zero!)
  - Filter(s) - '$.a.b.c ? (@.x > 10)'
    @ - current context in filter expression
  - Item methods - '$.a.b.c.x.type()'
    type(), size(), double(), ceiling(), floor(), abs(), keyvalue(), datetime()

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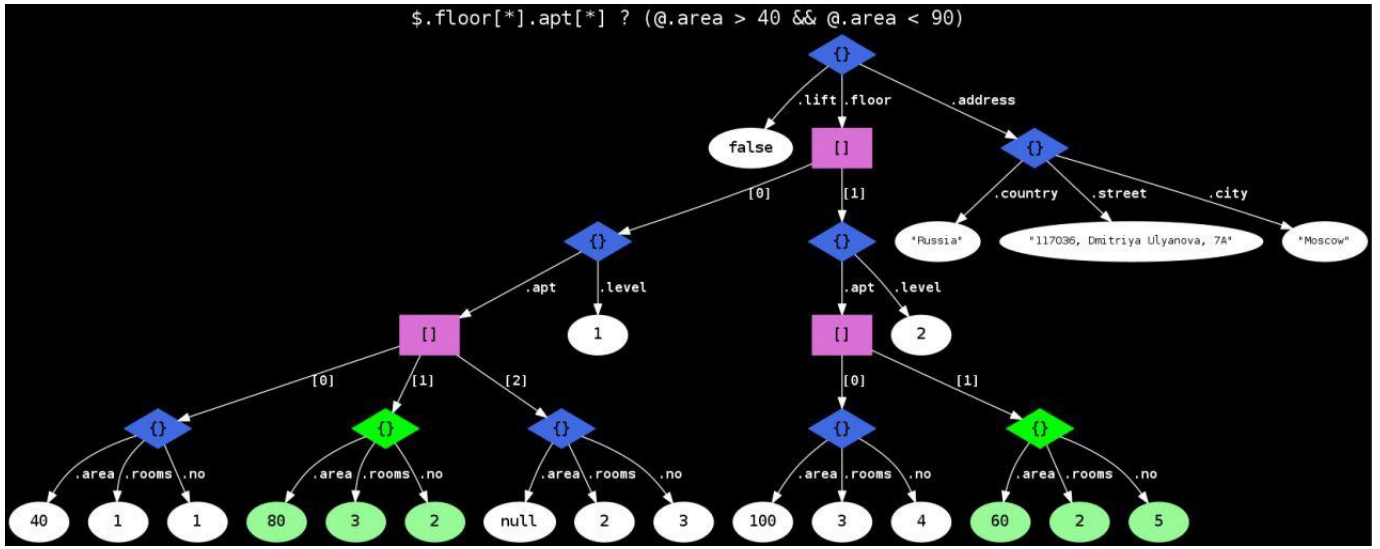
How path expression works

```
'$.floor[*].apt[*] ? (@.area > 40 && @.area < 90)'
```



1) $ - json itself
2) .floor — an array floor
3) [*] – an array of two floors
4) .apt — two arrays of objects (apartments on each floor)
5) [*] - SQL/JSON seq. of length 5, extracts five objects (apartments)
6) Each apartment filtered by (@.area > 40 && @.area < 90) expression

   The result is a sequence of two SQL/JSON items (green)

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SQL/JSON standard conformance

SQL/JSON feature	PostgreSQL 12	Oracle 18c	MySQL 8.0.4	SQL Server 2017
JSON PATH: 15	15/15	11/15	5/15	2/15

PostgreSQL 13 has **the best implementation** of JSON Path

More information: JSONPATH@PGCONF.EU-2019

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JSONB indexing: built-in opclasses

```
Sample jsonb: {"k1": "v1", "k2": ["v2", "v3"]}
```

- **`jsonb_ops`** (default GIN opclass for jsonb) extracts keys and values
  - "k1", "k2", "v1", "v2", "v3"
  - Supports top-level key-exists operators ?, ?& and ?| , contains @> operator
  - Overlapping of large postings might be slow
- **jsonb_hash_ops** extracts hashes of paths:
  - hash("k1"."v1"), hash("k2".#."v2"), hash("k2".#."v3")
  - Supports only contains @> operator
  - Much faster and smaller than default opclass (for @>)
- Indexes provides jsonb perfomance of NoSQL database

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Roadmap (ideas)

- Generic JSON API. The Grand Unification.
- Jsonb partial decompression
- SQL/JSON functions from SQL-2016 standard
- Planner support functions
- Jsonpath as parameter for jsonb opclasses
- Jsquery GIN opclasses to core
- Jsonpath syntax extension
- Simple Dot-Notation Access to JSON Data
- COPY …. (FORMAT json);

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Generic JSON (GSON) API

The Grand Unification.

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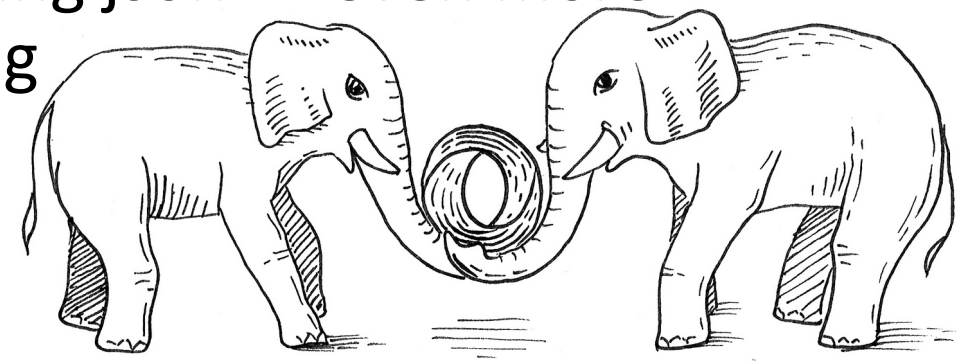
Why GSON ?

- JSON, JSONB — two implementations of users functions
- SQL/JSON currently supports only jsonb, adding json — even more overlapping



- Coming SQL standard will specify JSON data type
  - Oracle 20c (preview) introduced JSON data type, which stored in binary format OSON

```
[local]:5555 postgres@postgres=# \df json_
json_agg                 json_each_text           json_out
json_agg_finalfn         json_extract_path        json_populate_record
json_agg_transfn         json_extract_path_text   json_populate_recordset
json_array_element       json_in                  json_recv
json_array_element_text  json_object              json_send
json_array_elements      json_object_agg          json_strip_nulls
json_array_elements_text json_object_agg_finalfn  json_to_record
json_array_length        json_object_agg_transfn  json_to_recordset
json_build_array         json_object_field        json_to_tsvector
json_build_object        json_object_field_text   json_typeof
json_each                json_object_keys
[local]:5555 postgres@postgres=# \df jsonb_
jsonb_agg                 jsonb_extract_path         jsonb_path_match
jsonb_agg_finalfn         jsonb_extract_path_text    jsonb_path_match_opr
jsonb_agg_transfn         jsonb_ge                   jsonb_path_match_tz
jsonb_array_element       jsonb_gt                   jsonb_path_query
jsonb_array_element_text  jsonb_hash                 jsonb_path_query_array
jsonb_array_elements      jsonb_hash_extended        jsonb_path_query_array_tz
jsonb_array_elements_text jsonb_in                   jsonb_path_query_first
jsonb_array_length        jsonb_insert               jsonb_path_query_first_tz
jsonb_build_array         jsonb_le                   jsonb_path_query_tz
jsonb_build_object        jsonb_lt                   jsonb_populate_record
jsonb_cmp                 jsonb_ne                   jsonb_populate_recordset
jsonb_concat              jsonb_object               jsonb_pretty
jsonb_contained           jsonb_object_agg           jsonb_recv
jsonb_contains            jsonb_object_agg_finalfn   jsonb_send
jsonb_delete              jsonb_object_agg_transfn   jsonb_set
jsonb_delete_path         jsonb_object_field         jsonb_set_lax
jsonb_each                jsonb_object_field_text    jsonb_strip_nulls
jsonb_each_text           jsonb_object_keys          jsonb_to_record
jsonb_eq                  jsonb_out                  jsonb_to_recordset
jsonb_exists              jsonb_path_exists          jsonb_to_tsvector
jsonb_exists_all          jsonb_path_exists_opr      jsonb_typeof
jsonb_exists_any          jsonb_path_exists_tz
```

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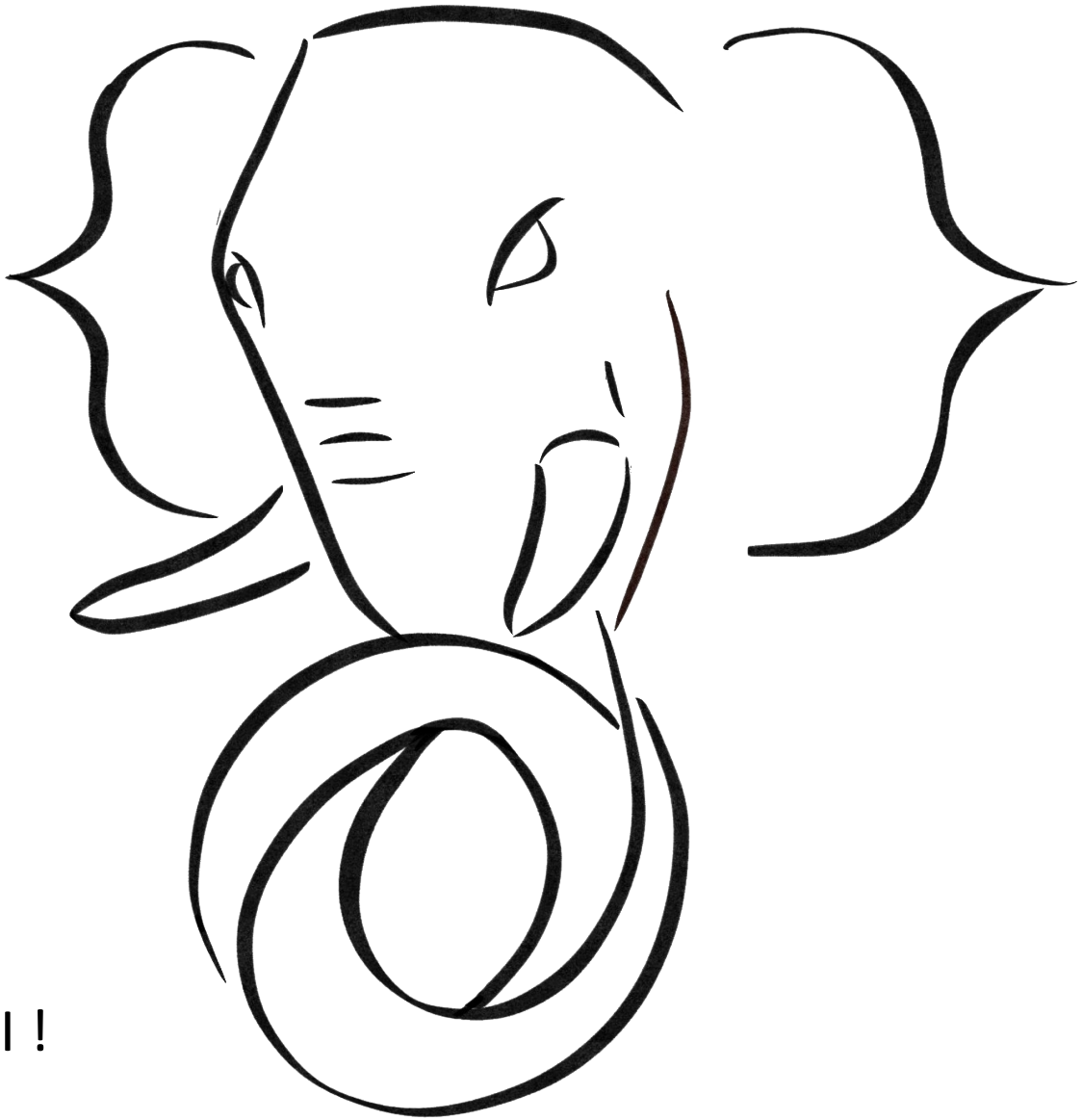
Why GSON ?

- For the sake of compatibility with SQL standard we need one JSON data type, which is internally
  - jsonb by default
  - Optionally behave as "old textual json"
  - Speculative syntax might looks:

```
CREATE TABLE TEST
(
    Jb JSON [binary]|text
);
```

  - "Here comes The" idea of Generic JSON API !



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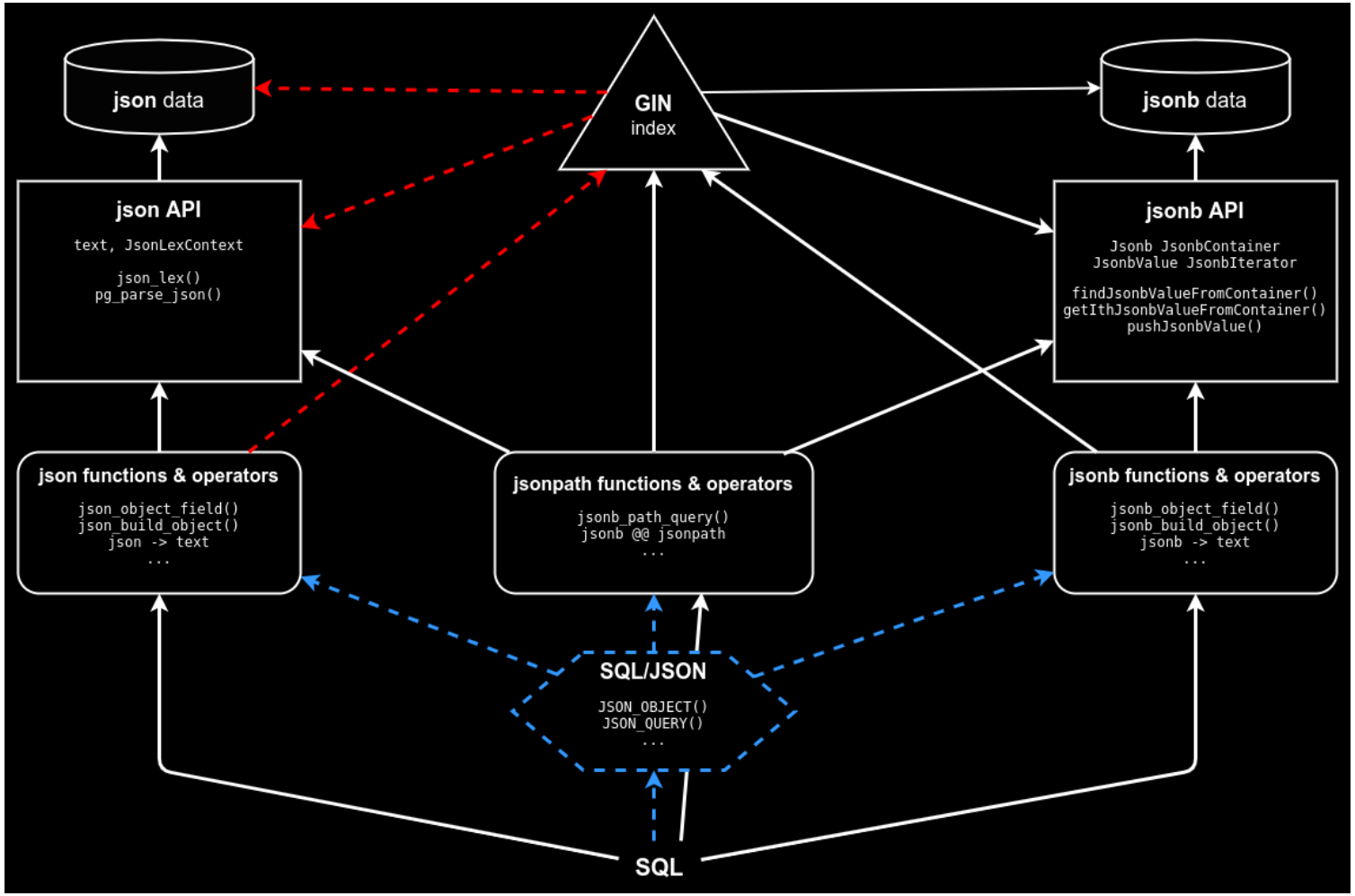
Generic JSON (GSON) — Current JSON[B] API

- Current JSON API is different for json and jsonb data types:
  - Json has lexer and parser with visitor interface
  - Jsonb uses Json lexer and parser for input, and several functions and iterators for access.
- This makes difficult to implement jsonpath functions for json (required by the SQL standard) and possibly GIN indexes for json.
- It is not easy to add new features like partial decompression/detoasting or slicing, different storage formats (jsonbc, bson, oson,…).



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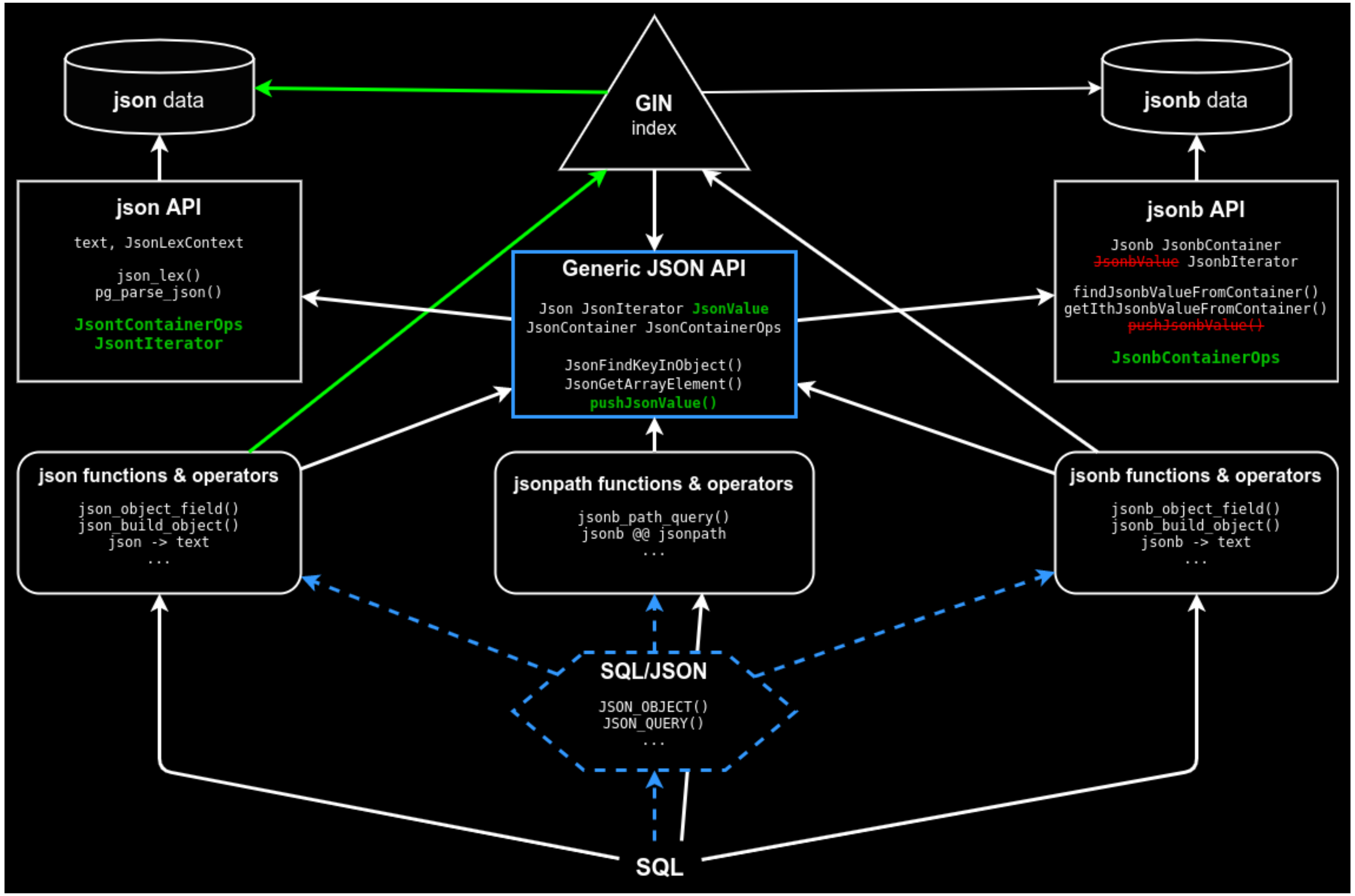
Generic JSON (GSON) — New API

- New generic JSON API is based on jsonb API:
  - JSON datums, containers, and iterators are wrapped into generic `Json`, `JsonContainer`, and `JsonIterator` structures.
  - `JsonbValue` and its builder function `pushJsonbValue()` are renamed and used as is.
- All container-specific functions are hidden into `JsonContainerOps`, which has three implementations:
  - `JsonbContainerOps` for jsonb
  - `JsontContainerOps` for json
  - `JsonvContainerOps` for in-memory tree-like `JsonValue` (not shown)
- For json only iterators need to be implemented, access functions are implemented using these iterators.
- Details available in Addendum



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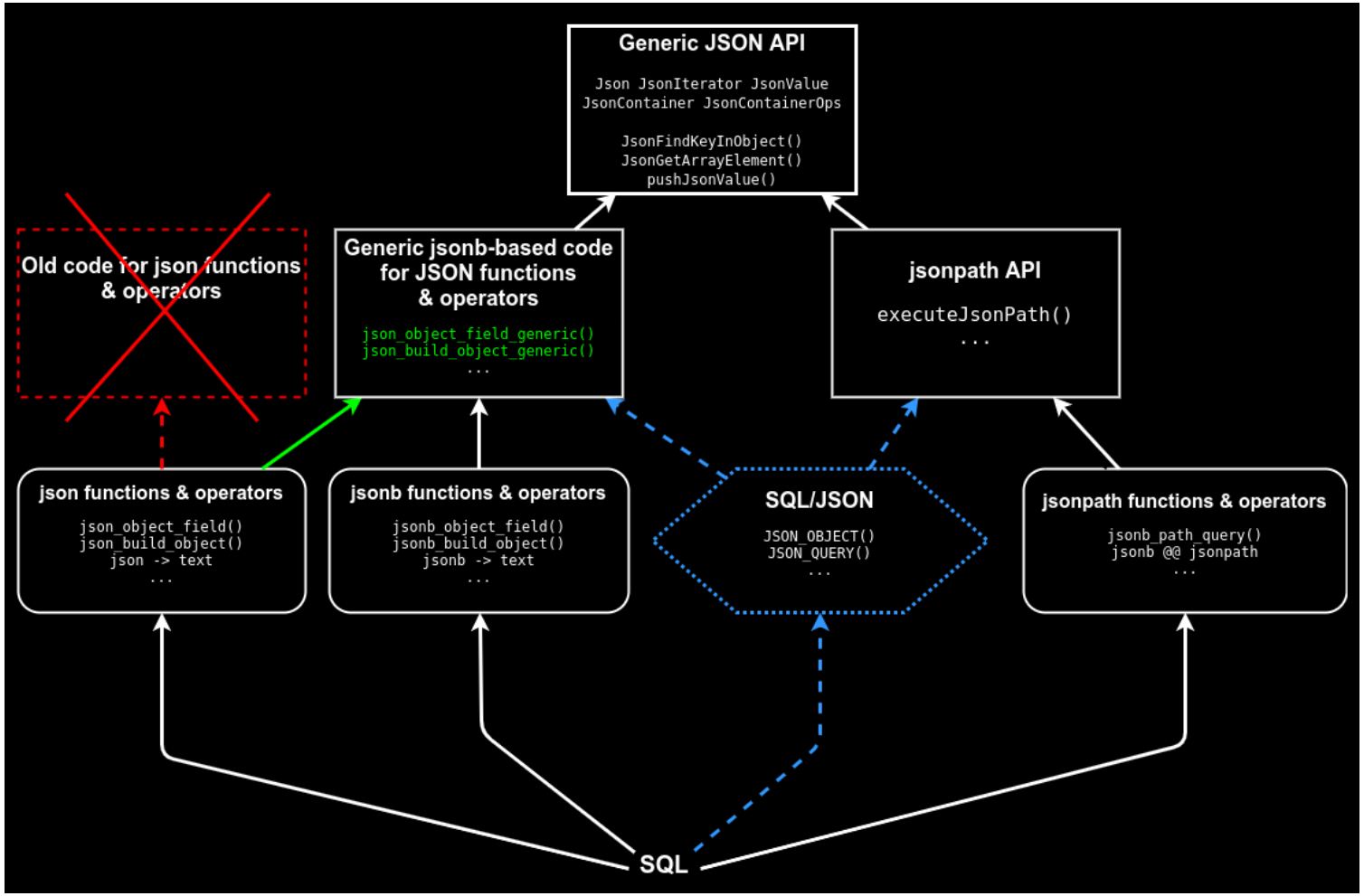
Generic JSON (GSON) — Duplicated code removal

- Generic JSON API allows reuse the code of jsonb user functions and operators for json data type.
- The old code of json functions and operators is almost completely removed.
- Json and jsonb user functions have only the separate entry in which input datums are wrapped into Json structures. But they share the same body by the calling generic subroutine.
- SQL/JSON uses these generic subroutines and generic jsonpath API.



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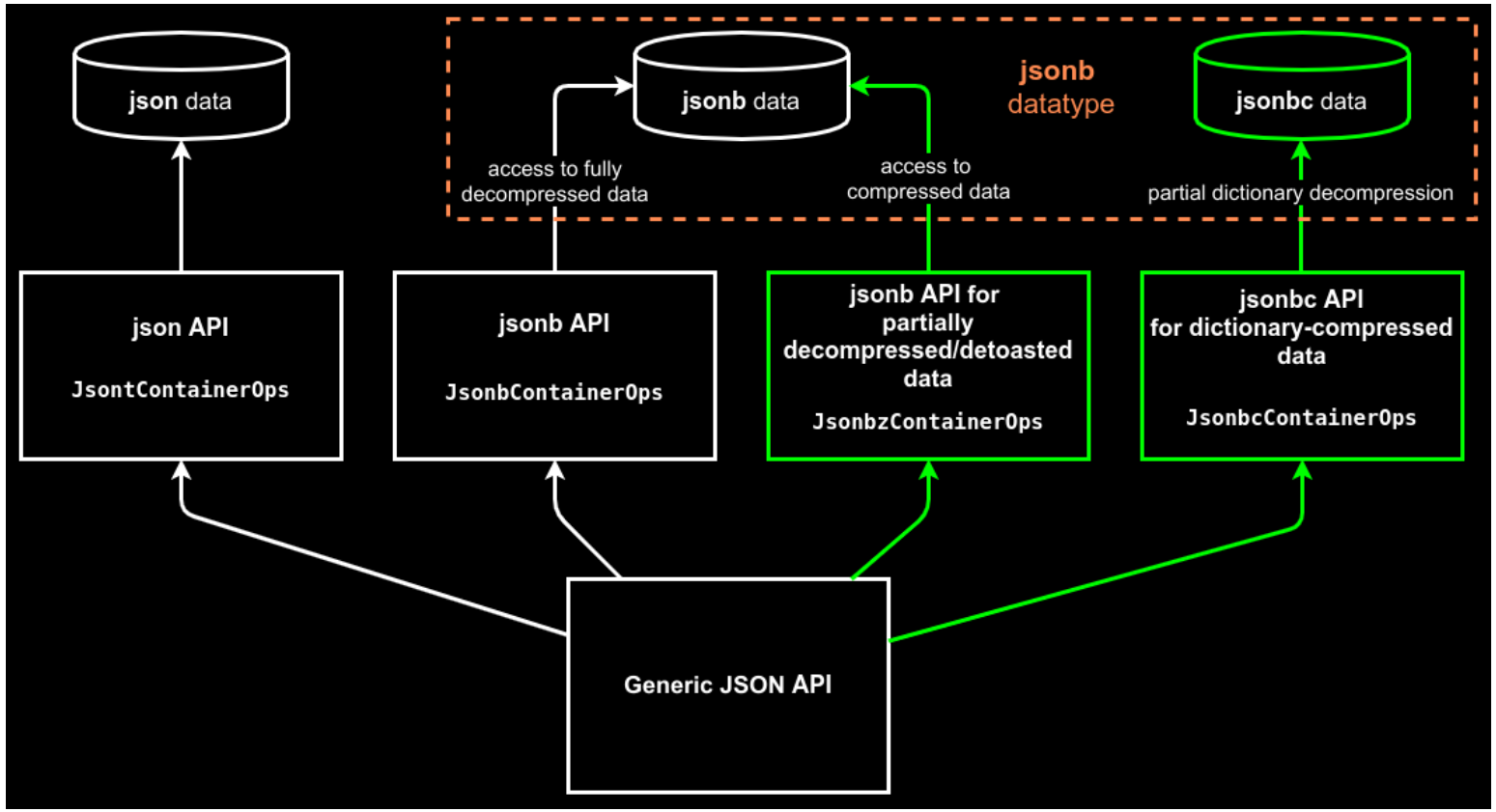
Generic JSON (GSON) — New features

- It is easy to add new features like partial decompression/detoasting or slicing, different storage formats (jsonbc, bson, oson,…).
- Need to implement ContainerOps interface:
  Two mandatory methods – `init`, `IteratorInit`
  (other methods could be used from default implementation)




```
struct JsonContainerOps
{
 int              dataSize; /* size of
JsonContainer.data[] */
 void           (*init)(JsonContainerData *cont,
Datum value);
 JsonIterator  *(*iteratorInit)(JsonContainer *cont);
 JsonValue     *(*findKeyInObject)(JsonContainer
*obj, const char *key, int len);
 JsonValue     *(*findValueInArray)(JsonContainer
*arr, const JsonValue *val);
 JsonValue     *(*getArrayElement)(JsonContainer
*arr, uint32 index);
 uint32         (*getArraySize)(JsonContainer *arr);
 char          *(*toString)(StringInfo out,
JsonContainer *, int estimatedlen);
 JsonContainer *(*copy)(JsonContainer *src);
};
```

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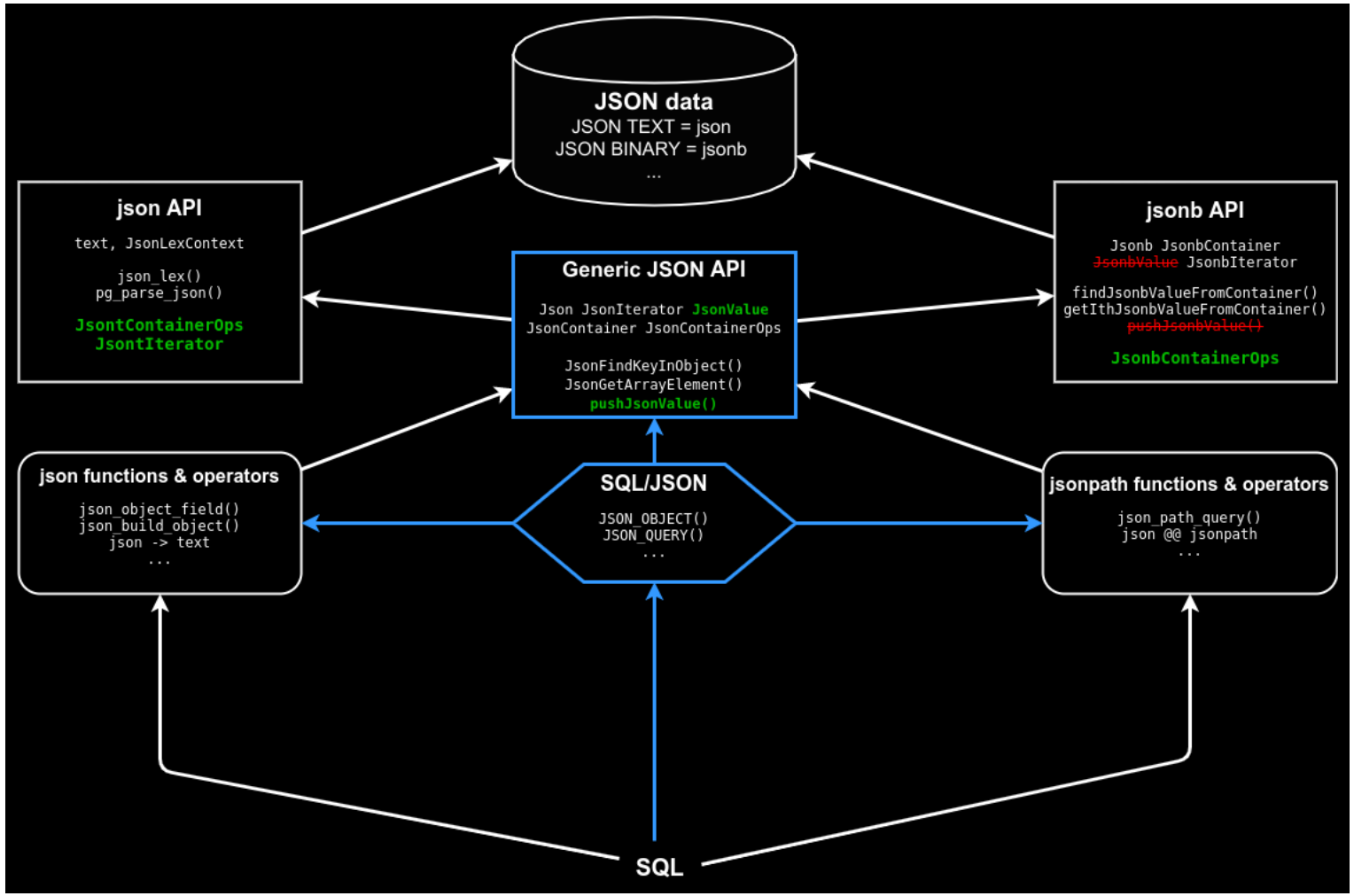
Generic JSON (GSON) — Unified JSON data type

- GSON is a step forward to Unified JSON data type, it unifies implementation of users functions.
- But it doesn't solve the problem of unified json data type as required by SQL Standard.
- We have three options:

1) Noop, json (as from standard) applications will be slow
2) SQL JSON as alias to jsonb
3) Implement pluggable storage method for data type. In case of JSON it means only **one** JSON data type and several storage formats: text, binary, compressed binary,…., and **one set** of functions !

- Possible variant of development: 1 → 2 → 3.



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Indexing JSON

- GSON allows to implement GIN opclass for indexing JSON

```
        Table "public.jtest"
 Column | Type  | Collation | Nullable | Default
--------+-------+-----------+----------+---------
 js     | json  |           |          |
 jb     | jsonb |           |          |
Indexes:
    "jtest_jb_idx" gin (jb jsonb_path_ops)
    "jtest_js_idx" gin (js json_path_ops)
```

Total: 1252973 bookmarks

```
SELECT count(*) FROM jtest WHERE js @> '{"tags":[{"term":"NYC"}]}';
 Aggregate (actual time=3.749..3.750 rows=1 loops=1)
   ->  Bitmap Heap Scan on jtest (actual time=0.223..3.718 rows=285 loops=1)
         Recheck Cond: (js @> '{"tags":[{"term":"NYC"}]}'::json)
         Heap Blocks: exact=285
         ->  Bitmap Index Scan on jtest_js_idx (actual time=0.126..0.126 rows=285 loops=1)
               Index Cond: (js @> '{"tags":[{"term":"NYC"}]}'::json)
 Planning Time: 1.813 ms
 Execution Time: 3.910 ms
(8 rows)
```

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Indexing JSON

- GSON allows to implement GIN opclass for indexing JSON. It's still slower than jsonb, but is much faster than sequential scan (2700x for bookmarks).

```
SELECT count(*) FROM jtest WHERE jb @> '{"tags":[{"term":"NYC"}]}';
                                 QUERY PLAN
-----------------------------------------------------------------------------------------
 Aggregate (actual time=0.863..0.863 rows=1 loops=1)
   ->  Bitmap Heap Scan on jtest (actual time=0.074..0.839 rows=285 loops=1)
         Recheck Cond: (jb @> '{"tags": [{"term": "NYC"}]}'::jsonb)
         Heap Blocks: exact=285
         ->  Bitmap Index Scan on jtest_jb_idx (actual time=0.042..0.042 rows=285 loops=1)
               Index Cond: (jb @> '{"tags": [{"term": "NYC"}]}'::jsonb)
 Planning Time: 0.217 ms
 Execution Time: 0.889 ms
(8 rows)
```

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JSONB as SQL JSON: compatibility solution

- Most people love `jsonb` and would be happy to use it as SQL JSON, some people still need "textual json", so we elaborate option 2 as follows below.
- We map PG `jsonb` type to the new standard SQL JSON type using special mode enabled by GUC **sql_json json|jsonb (`json` by default),also** `specified in postgresql.conf. If sql_json = jsonb`, then:
  - `jsonb` is alias for `"json"`
  - `json` is alias for `"json text"`
- Type names are rewritten in SQL parser and in `format_type_extended()` similar to `smallint`, `timestamp with timezone` etc.

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JSONB as SQL JSON: compatibility solution

- Example:

```
CREATE TABLE t1 (js json, jb jsonb);

\d t1
                Table "public.t1"
 Column |  Type | Collation | Nullable | Default
--------+-------+-----------+----------+---------
 js     | json  |           |          |
 jb     | jsonb |           |          |


SET sql_json = jsonb;

\d t1
                  Table "public.t1"
 Column |   Type    | Collation | Nullable | Default
--------+-----------+-----------+----------+---------
 js     | json text |           |          |
 jb     | json      |           |          |
```

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JSONB as SQL JSON: compatibility solution

- Example:

```
SET sql_json = jsonb;
CREATE TABLE t2 (js json, jb jsonb, jt json text);
\d t2
                    Table "public.t2"
 Column |   Type    | Collation | Nullable | Default
--------+-----------+-----------+----------+---------
 js     | json      |           |          |
 jb     | json      |           |          |
 jt     | json text |           |          |

SET sql_json = json;
\d t2
                   Table "public.t2"
 Column | Type  | Collation | Nullable | Default
--------+-------+-----------+----------+---------
 js     | jsonb |           |          |
 jb     | jsonb |           |          |
 jt     | json  |           |          |
```

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JSONB as SQL JSON: compatibility solution

- Example:

```
postgres=# SELECT j::json AS json, j::jsonb AS jsonb, j::json text AS "json text"
FROM (VALUES ('{"cc":0, "aa":  2, "aa":1,"b":1}')) AS foo(j);
                json                |           jsonb            |            json text
------------------------------------+----------------------------+---------------------------------
 {"cc":0, "aa":  2, "aa":1,"b":1} | {"b": 1, "aa": 1, "cc": 0} | {"cc":0, "aa":  2, "aa":1,"b":1}
(1 row)

postgres=# SET sql_json = jsonb;
SET

postgres=# SELECT j::json AS json, j::jsonb AS jsonb, j::json text AS "json text"
FROM (VALUES ('{"cc":0, "aa":  2, "aa":1,"b":1}')) AS foo(j);
             json              |           jsonb            |            json text
-------------------------------+----------------------------+---------------------------------
 {"b": 1, "aa": 1, "cc": 0} | {"b": 1, "aa": 1, "cc": 0} | {"cc":0, "aa":  2, "aa":1,"b":1}
(1 row)
```

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Jsonb partial decompression

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Jsonb partial decompression

- Current jsonb implementation works with fully decompressed binary jsonb data. `Jsonb` and `JsonbContainer` structures refers to plain binary data. So, it cannot benefit from partial pglz decompression.
- Generic JSON API interface allows easy implementation of partial pglz decompression (with resume support) for jsonb by implementing only new `JsonbzContainerOps` without modification of user functions.
- pglz code has modified to provide an ability to caller to preserve decompression state between successive calls of `pglz_decompress()`.
- Prototype currently supports only partial pglz decompression, but it is possible to use partial de-TOASTing.

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Jsonb partial decompression - Example

- Remember: keys in jsonb sorted by length,name
- Table with 100,000 128 KB jsonb compressed into 1.2KB (no TOAST):

```
-- { "key1": 2^6 "a", ... "key10": 2^16 "a" }
CREATE TABLE t AS SELECT (
    SELECT jsonb_object_agg('key' || i, repeat('a', pow(2, i + 6)::int)) jb
    FROM generate_series(1, 10) i
) FROM generate_series(1, 100000);
```

- Table with 100,000 1MB jsonb compressed into 12KB (with TOAST):

```
-- { "key1": 2^9 "a", ... "key10": 2^19 "a" }
CREATE TABLE t AS SELECT (
    SELECT jsonb_object_agg('key' || i, repeat('a', pow(2, i + 9)::int)) jb
    FROM generate_series(1, 10) i
) FROM generate_series(1, 100000);
```

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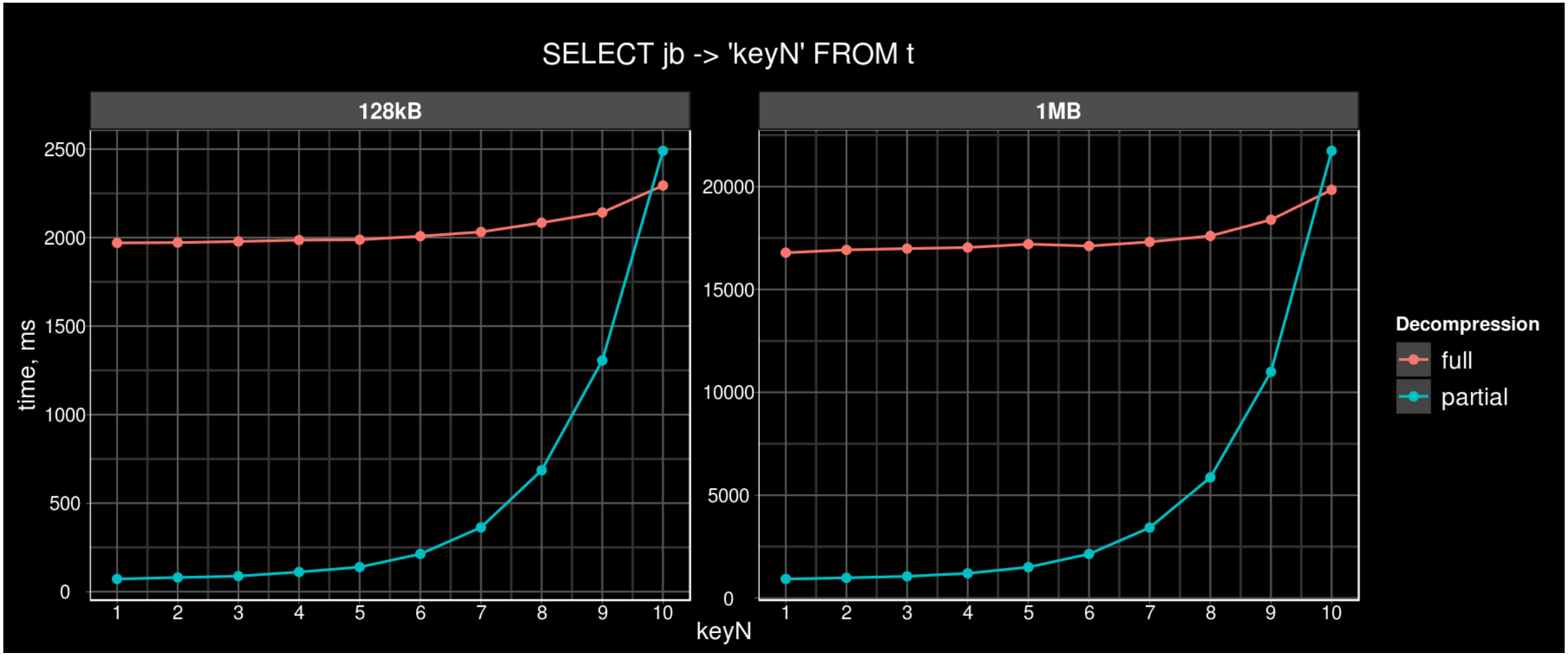
Jsonb partial decompression - Example



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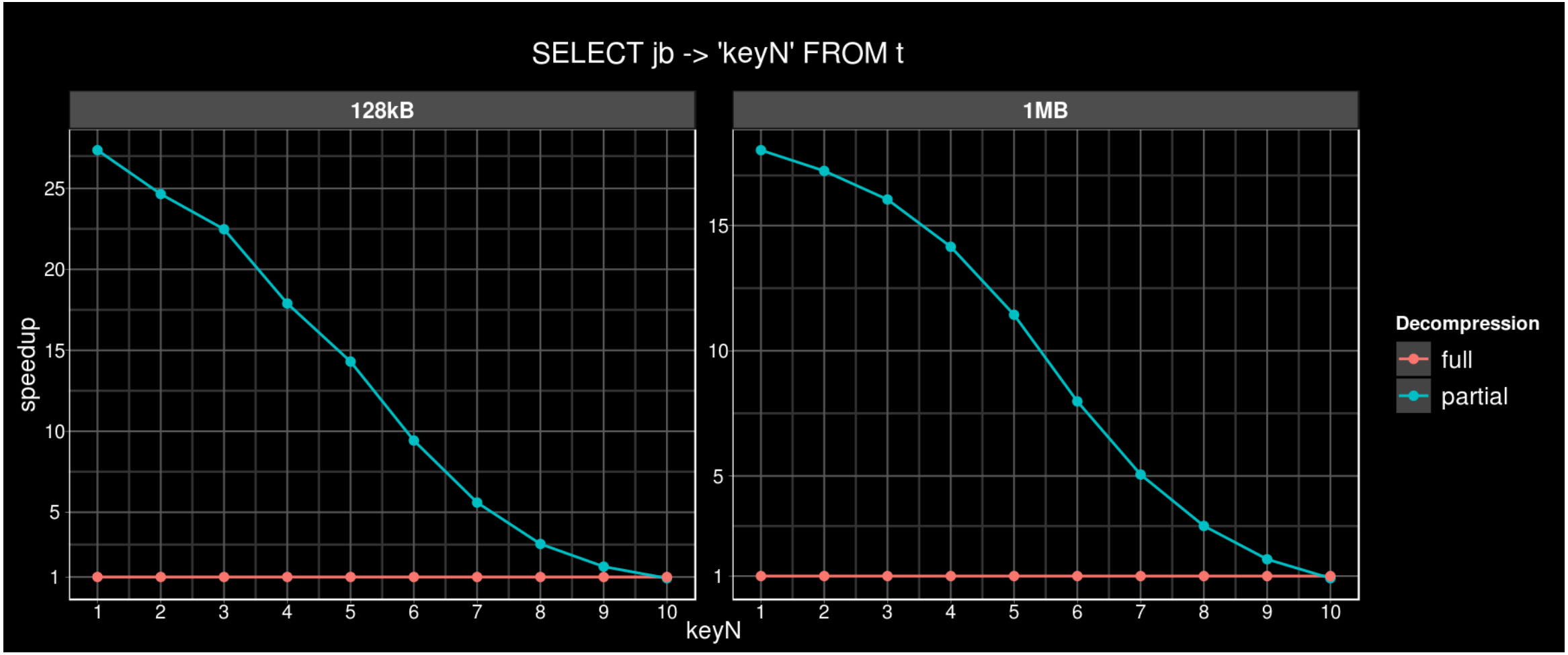
Jsonb partial decompression - Example



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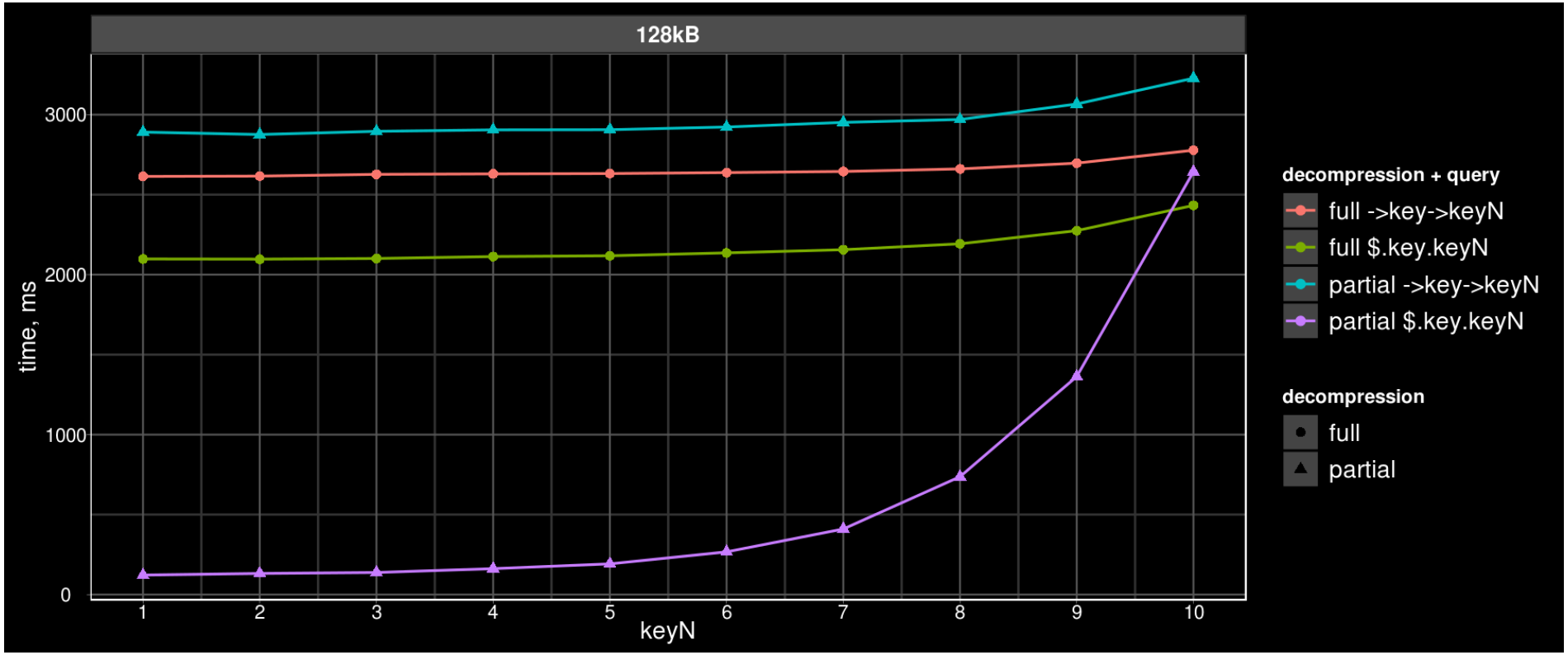
Jsonb partial decompression (jsonpath vs. ->)

- Table with 100,000 128 KB 2-level jsonb compressed into 1.2KB (no TOAST):

```
-- { "key": { "key1": 2^6 "a", ... "key10": 2^16 "a" } }
CREATE TABLE t AS SELECT (
  SELECT jsonb_build_object('key', jsonb_object_agg('key' || i, repeat('a', pow(2, i + 6)::int))) jb
    FROM generate_series(1, 10) i
) FROM generate_series(1, 100000);
```



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Jsonb partial decompression - Summary

- Access to data in the beginning of compressed JSONB is much faster (without any modification of users functions). JSON support could be added.
- Multilevel JSONPATH is much faster than chained arrow operators/functions for compressed JSONB, since JSONPATH functions benefit from pglz resume between levels.
- +Partial deToasting (prefix, sliced)
- Life Hack: keep "important" keys in the beginning !

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SQL/JSON FUNCTIONS

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SQL/JSON FUNCTIONS

- The SQL/JSON **construction** functions (json[b]_xxx() functions):
  - JSON_OBJECT - construct a JSON[b] object.
    - json[b]_build_object()
  - JSON_ARRAY - construct a JSON[b] array.
    - json[b]_build_array()
  - JSON_ARRAYAGG - aggregates values as JSON[b] array.
    - json[b]_agg()
  - JSON_OBJECTAGG - aggregates name/value pairs as JSON[b] object.
    - json[b]_object_agg()

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SQL/JSON in PostgreSQL

- The SQL/JSON **retrieval** functions:
  - JSON_VALUE - Extract an SQL value of a predefined type from a JSON value.
  - JSON_QUERY - Extract a JSON text from a JSON text using an SQL/JSON path expression.
  - JSON_TABLE - Query a JSON text and present it as a relational table.
  - IS [NOT] JSON - test whether a string value is a JSON text.
  - JSON_EXISTS - test whether a JSON path expression returns any SQL/JSON items

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JSON_TABLE — relational view of json

- Table with rooms from 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 | num_rooms
-------+----+------+-----------
     1 |  1 |   40 |         1
     1 |  2 |   80 |         3
     1 |  3 |   50 |         2
     2 |  4 |  100 |         3
     2 |  5 |   60 |         2
(5 rows)
```

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Parameters for Opclasses

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Parameters for opclasses

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

- AM (access method)
- Set of operators
- AM specific support function

Examples:

- CREATE INDEX .. USING btree (textcolumn **text_pattern_ops**)
- CREATE INDEX .. USING gin (jsoncolumn **jsonb_ops**)
- CREATE INDEX .. USING gin (jsoncolumn **jsonb_path_ops**)

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Extending Indexing infrastructure

- Opclasses have «hardcoded» constants (signature size)
  - Let user to define these constants for specific data — **PG13**
- Use different algorithms to index
  - Specify what to use depending on data
- Indexing of non-atomic data (arrays, json[b], tsvector,…)
  - Specify what part of column value to index unlike partial index
  - No need to use an exact expression in SQL as for functional index, since opclass knows what to index unlike functional index
- Talk @ PGCON-2018: Jsonb "smart" indexing. Parametrized opclasses.

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Parameters for opclasses: syntax

- Parenthized parameters added after column's opclass.

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

```
CREATE INDEX ON small_arrays USING gist (
      arr gist__intbig_ops(siglen=32),
      arr DEFAULT (num_ranges = 100)
);
CREATE INDEX bookmarks_selective_idx ON bookmarks USING
  gin(js jsonb_ops(projection='strict $.tags[*].term'));
```

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Parameters for opclasses: jsonb selective indexing

- Opclass parameters can be used in GIN jsonb opclasses for selective indexing of parts of jsonb documents. We implemented 'projection' parameter for in-core jsonb_ops and jsonb_path_ops, which specify what part(s) of JSONB to index using jsonpath expression.

  Example of creation selective index on `$.roles[*].role`:

```
CREATE INDEX names_role_prj_idx ON imdb.names USING gin
  (jb jsonb_path_ops (projection = '$.roles[*].role'));
```

- Using jsonpath extension for sequence constructions we can index multiple paths (branches of JSONB tree):

```
CREATE INDEX names_role_prj_idx ON imdb.names USING gin
  (jb jsonb_path_ops (projection = 'pg $.id, $.roles[*].role'));
```

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Parameters for opclasses: jsonb selective indexing

- Comparison of full, functional, and selective jsonb indexes on imdb titles:
  - full index:
    ```
    CREATE INDEX titles_full_idx ON titles USING gin (jb jsonb_path_ops);
    ```
  - functional index on `$.id, $.kind $.year[*]`:
    ```
    CREATE FUNCTION title_id_kind_year(title jsonb) RETURNS jsonb LANGUAGE sql AS
    $$ SELECT jsonb_path_query_first(title, 'pg {id: $.id, kind: $.kind, year: $.year}') $$;

    CREATE INDEX titles_func_idx ON titles USING gin (title_id_kind_year(jb) jsonb_path_ops);
    ```
  - selective index on `$.id, $.kind $.year[*]`:
    ```
    CREATE INDEX titles_prj_idx ON titles USING gin
      (jb jsonb_path_ops (projection = 'pg $.id, $.kind, $.year'));
    ```
- Resulting index size and build time:

```
titles_full_idx | 644 MB | 118 s
titles_func_idx | 219 MB |  29 s
titles_prj_idx  | 214 MB |  24 s
```

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Parameters for opclasses: jsonb selective indexing

Example: simple query contains only indexed paths

- The same query can be accellerated by full and selective indexes

```
SELECT * FROM imdb.titles WHERE jb @> '{"kind": "episode", "year": [2016]}';

 Bitmap Heap Scan on titles (actual rows=184431 loops=1)
   Recheck Cond: (jb @> '{"kind": "episode", "year": [2016]}'::jsonb)
   Heap Blocks: exact=42963
   ->  Bitmap Index Scan on titles_prj_idx (actual rows=184431 loops=1)
         Index Cond: (jb @> '{"kind": "episode", "year": [2016]}'::jsonb)
 Planning Time: 0.162 ms
 Execution Time: 386.052 ms
```

- Query should includes indexed condition for functional index

```
SELECT * FROM imdb.titles
WHERE title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016]}';

 Bitmap Heap Scan on titles (actual rows=184431 loops=1)
   Recheck Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016]}'::jsonb)
   Heap Blocks: exact=42963
   ->  Bitmap Index Scan on titles_fn_idx3 (actual rows=184431 loops=1)
         Index Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016]}'::jsonb)
 Planning Time: 0.174 ms
 Execution Time: 590.238 ms (more complex recheck)
```

PostgresPro

Parameters for opclasses: jsonb selective indexing

Example: simple query + non-indexable condition

- The same query can be accellerated by full and selective indexes

```
SELECT * FROM imdb.titles
WHERE jb @> '{ "kind": "episode", "year": [2016], "title": "Telediario" }';
```

```
 Bitmap Heap Scan on titles (actual rows=2 loops=1)
   Recheck Cond: (jb @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
   Rows Removed by Index Recheck: 184429
   Heap Blocks: exact=42963
   ->  Bitmap Index Scan on titles_prj_idx (actual rows=184431 loops=1)
         Index Cond: (jb @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
 Planning Time: 0.123 ms
 Execution Time: 382.264 ms
```

- functional index (not working) — wrong query

```
SELECT * FROM titles
WHERE title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016], "title": "Telediario" }';
```

```
Bitmap Heap Scan on titles (actual rows=0 loops=1)
   Recheck Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
   ->  Bitmap Index Scan on titles_fn_idx (actual rows=0 loops=1)
         Index Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
 Planning Time: 0.161 ms
 Execution Time: 0.141 ms
```

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Parameters for opclasses: jsonb selective indexing

Example: simple query + non-indexable condition

- The same query can be accellerated by full and selective indexes:

```
SELECT * FROM imdb.titles
WHERE jb @> '{ "kind": "episode", "year": [2016], "title": "Telediario" }';
```

```
 Bitmap Heap Scan on titles (actual rows=2 loops=1)
   Recheck Cond: (jb @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
   Rows Removed by Index Recheck: 184429
   Heap Blocks: exact=42963
   ->  Bitmap Index Scan on titles_prj_idx (actual rows=184431 loops=1)
         Index Cond: (jb @> '{"kind": "episode", "year": [2016], "title": "Telediario"}'::jsonb)
 Planning Time: 0.123 ms
 Execution Time: 382.264 ms
```

- functional index - correct query:

```
SELECT * FROM titles
WHERE title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016] }'
  AND jb @> '{"title": "Telediario"}';
```

```
Bitmap Heap Scan on titles (actual rows=2 loops=1)
   Recheck Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016]}'::jsonb)
   Filter: (jb @> '{"title": "Telediario"}'::jsonb)
   Rows Removed by Filter: 184429
   Heap Blocks: exact=42963
   ->  Bitmap Index Scan on titles_fn_idx (actual rows=184431 loops=1)
         Index Cond: (title_id_kind_year(jb) @> '{"kind": "episode", "year": [2016]}'::jsonb)
 Planning Time: 0.186 ms
 Execution Time: 651.831 ms
```

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Parameters for opclasses: jsonb selective indexing

Selective jsonb opclasses support:

- Various user operators:
```
jb @@ '$.kind == "series" && $.year[*] == 2020'
jb @? '$ ? (@.kind == "series" && @.year[*] == 2020)'
jb @> '{ "kind": "series", "year":  [ 2020 ] }'
```
- Arbitrary additonal non-indexed conditions logically ANDed :
```
jb @@ '$.kind == "series" && $.id starts with "Foo"';
jb @@ '$ ? (@.id starts with "Foo").kind == "series"';
jb @> '{ "kind": "series", "release_dates": [{ "country": "USA"}] }'
```
- Array subscipts matching:
```
jb @@ '$.year[0 to 2] == 2020';
```
- Strict/lax indexed/query paths combinations

Not supported:

- Filters in indexed paths (predicate implication proving is needed)
- Expressions (for example, $.a + $.b)
- Item methods (like `.type()`, `.datetime()`)

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JsQuery indexes to core

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JSONB indexing: Jsquery extension

- jsonb_path_value_ops
  - (hash(full_path);value)
  - exact and range queries on values, exact path searches
- jsonb_laxpath_value_ops (branch sqljson)
  - The same as above, but array path items are ignored, which greatly simplifies extraction of ***lax*** JSON path queries.
- jsonb_value_path_ops
  - (value; bloom(path_1) | bloom(path_2) | … bloom(path_N))
  - Exact value search and wildcard path queries.
- Also, jsquery provides debugging and query optimizer with hints.

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Jsquery_laxpath_value_ops

- jsonb_path_value_ops is slow for long lax paths:

```
CREATE TABLE t AS SELECT '{}'::jsonb jb FROM generate_series(1, 1000000) i;

CREATE INDEX t_path_ops_idx ON t USING gin (jb jsonb_path_value_ops);

SELECT * FROM t WHERE jb @@ '$.k1.k2.k3.k4.k5.k6.k7.k8.k9 == 1'::jsonpath;

 Planning Time: 0.574 ms
 Execution Time: 3.026 ms
```

- For this jsonpath jsonb_path_value_ops extracts 2^10 (1024) entries:

```
SELECT gin_debug_jsonpath_path_value('$.k1.k2.k3.k4.k5.k6.k7.k8.k9 == 1');

                   gin_debug_jsonpath_path_value
-----------------------------------------------------------------
 OR
   #.k1.#.k2.#.k3.#.k4.#.k5.#.k6.#.k7.#.k8.#.k9 = 1 , entry 0   +
   #.k1.#.k2.#.k3.#.k4.#.k5.#.k6.#.k7.#.k8.#.k9.# = 1 , entry 1 +
   …
   k1.k2.k3.k4.k5.k6.k7.k8.k9 = 1 , entry 1022                  +
   k1.k2.k3.k4.k5.k6.k7.k8.k9.# = 1 , entry 1023                +

(1 row)
```

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jsquery_laxpath_value_ops

- jsonb_laxpath_value_ops does not accounts arrays in paths and:

```
CREATE INDEX t_laxpath_ops_idx ON t USING gin (jb jsonb_laxpath_value_ops);

SELECT * FROM t WHERE jb @@ '$.k1.k2.k3.k4.k5.k6.k7.k8.k9 == 1'::jsonpath;

 Planning Time: 0.059 ms          (was 0.574 ms, 10x  speedup)
 Execution Time: 0.025 ms         (was 3.026 ms, 120x speedup)
```

- For this jsonpath jsonb_laxpath_value_ops extracts only 1 entry as expected:

```
SELECT gin_debug_jsonpath_laxpath_value('$.k1.k2.k3.k4.k5.k6.k7.k8.k9 == 1');

                  gin_debug_jsonpath_laxpath_value
-----------------------------------------------------------------
  k1.k2.k3.k4.k5.k6.k7.k8.k9 = 1 , entry 0 +

(1 row)
```

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Planner support for jsonpath

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Planner support function for jsonpath functions

- PG12+: API for planner support functions allows transform functions to operator expression, which can be accelerated by index.

```
CREATE [OR REPLACE] FUNCTION
  name ([[argmode] [argname] argtype [{DEFAULT|=} default_expr] [,…]])
{
  .........
  | SUPPORT support_function
  .........
} ...
```

- `jsonb_path_match()` transforms to *`jsonb @@ jsonpath`* (uses index !) and pass variables (impossible for operators) !

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Planner support function for jsonpath functions

- PG12+: API for planner support functions allows transform functions to operator expression, which can be accelerated by index.

```
SELECT * FROM t t1, t t2 WHERE
jsonb_path_match(t1.js, '$.a == $a', vars => t2.js, silent => true);
            index                          QUERY PLAN
-----------------------------------------------------------------------
 Nested Loop
   ->  Seq Scan on t t2
   ->  Bitmap Heap Scan n t t1
         Filter: jsonb_path_match(js, '($."a" == $"a")'::jsonpath,
t2.js, true)
         ->  Bitmap Index Scan on t_js_idx
               Index Cond: (js @@ jsonpath_embed_vars('($."a" ==
$"a")'::jsonpath, t2.js))
(6 rows)
```

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Jsonpath syntax extensions

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Jsonpath syntax extensions

- Array construction syntax:

```
SELECT jsonb_path_query('[1,2,3]', '[0, $[*], 4]');
 [0, 1, 2, 3, 4]
```

- Object construction syntax:

```
SELECT jsonb_path_query('[1,2,3]','{a: $, "s": $.size()}');
 {"a": [1, 2, 3], "s": 3}
```

- Sequence construction syntax:

```
SELECT jsonb_path_query('[1,2,3]', '0, $[*], 4');
 0
 1
 2
 3
 4
```

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Jsonpath syntax extensions (constructors)

- Sequence construction syntax is useful for selective jsonb indexing (see "Opclass parameters"):

```
CREATE INDEX titles_prj_idx ON titles USING gin
  (jb jsonb_path_ops(projection = 'pg $.id, $.kind, $.year[*]'));
```

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Jsonpath syntax extensions (constructors)

- Object and array construction syntax is useful for constructing derived objects:

```
SELECT jsonb_path_query(jb, 'pg {id: $.id,
                                 company_names: [$.companies[*].name]}')
FROM imdb.titles;
Execution Time: 13569.575 ms
```

- Without constructors query becomes much more complex and more slow (especially variant without jsonpath):

```
SELECT jsonb_build_object(
  'id', jb -> 'id',
  'company_names', jsonb_path_query_array(jb, '$.companies[*].name')
) FROM imdb.titles;
Execution Time: 17228,896 ms

SELECT jsonb_build_object(
  'id', jb -> 'id',
  'company_names', (SELECT jsonb_agg(company -> 'name')
                    FROM jsonb_array_elements(jb -> 'companies') company)
) FROM imdb.titles;
Execution Time: 29716,909 ms
```

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Jsonpath syntax extensions (IN simplification)

- Array and sequence construction syntax can be useful for set-inclusion queries (like SQL IN predicate):

```
SELECT count(*) FROM imdb.names
WHERE jb @@ 'pg $.roles[*].role == ("editor", "producer", "director")';
 Execution Time: 20622.929 ms

SELECT count(*) FROM imdb.names
WHERE jb @@ 'pg $.roles[*].role == ["editor", "producer", "director"]'; -- unwrapped in lax
 Execution Time: 21508.483 ms
```

- Currently, one should use a sequence of AND conditions that even works slower:

```
SELECT count(*) FROM imdb.names
WHERE jb @? 'pg $.roles[*].role ?
              (@ == "editor" || @ == "producer" || @ == "director")';
 Execution Time: 29490.021 ms
```

- Such IN expressions with constants can be speed up with GIN indexes.

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Jsonpath syntax extensions

- Object subscripting:

```
SELECT jsonb_path_query('{"a": 1}', '$["a"]');
 1


SELECT jsonb_path_query('{"a": 1, "b": "ccc"}', '$["a","b"])';
 1
 "ccc"


SELECT jsonb_path_query('{"a": 1}', 'lax $["a", "b"]');
 1

SELECT jsonb_path_query('{"a": 1}', 'strict $["a", "b"]');
 ERROR:  JSON object does not contain key "b"
```

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Jsonpath syntax extensions

- Array item methods with lambda expressions (ECMAScript 6 style):

```
SELECT jsonb_path_query('[1,2,3]', '$.map(x => x + 10)');
 [11, 12, 13]


SELECT jsonb_path_query('[1,2,3]', '$.reduce((x,y) => x + y)');
 6

SELECT jsonb_path_query('[1,2,3]', '$.fold((x,y) => x + y, 10)');
 16

SELECT jsonb_path_query('[1,2,3]', '$.max()');
 3
```

- Alternative syntax for lambdas: `'$.fold($1 + $2, 10)'`

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Jsonpath syntax extensions

- Sequence functions with lambda expressions:

```
SELECT jsonb_path_query('[1,2,3]', 'map($[*], x => x + 10)');
 11
 12
 13    -- sequence is returned, not array


SELECT jsonb_path_query('[1,2,3]', 'reduce($[*], (x,y) => x+y)');
 6

SELECT jsonb_path_query('[1,2,3]', 'fold($[*], (x,y)=>x+y, 10)');
 16

SELECT jsonb_path_query('[1,2,3]', 'max($[*])');
 3
```

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Simple Dot-Notation Access To JSON Data

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Simple.Dot.Notation.Access.To.JSON.Data

- Simple dot-notation is handy for simple queries than arrow operators and functions
  - `j.key1.key2` instead of:
    - `j -> 'key1' -> 'key2'`
    - `JSON_QUERY(j, '$.key1.key2')`
  - `j.key1[1]` instead of:
    - `j -> 1`
    - `JSON_QUERY(j, '$.key1[1]')`
  - `j.key1[*]` instead of:
    - `json_array_elements(j -> 'key1')` SRF ???
    - `JSON_QUERY(j, '$.key1[*]') WITH ARRAY WRAPPER` ???

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COPY … (FORMAT json)

- Currently it's impossible to load data from JSON without temporary table
- COPY [TO|FROM] ... (FORMAT json)
- It's possible to load only selected data from JSON using jsonpath
  - Example:
    Load array of json: [{"a": ..., "b": ..., "c": ... }, ...]
  - COPY target_table FROM 'path/to/data.json' (FORMAT json, JSONPATH '$[*]');

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Jsonb Roadmap for Postgres Community

- PG14?: Generic JSON API + Unification + json_path_ops - Generic JSON API @ Github
  The Grand Unification (option 2) - JSON as JSONB @ Github
- PG14?: Jsonb partial decompression - Jsonb partial decompression @ Github
- PG14: SQL/JSON functions from SQL-2016 standard - SQL/JSON @ Github
- PG14?: Planner support functions - Jsonb planner support functions @ Github
- PG14: Jsonpath as parameter for jsonb opclasses - Jsonb selective opclasses @ Github
- PG14: Jsquery GIN opclasses to core - Jsquery GIN opclasses
- PG14: Jsonpath syntax extension - Jsonpath syntax extensions @ Github
- Simple Dot-Notation Access to JSON Data
- COPY with support of jsonpath (idea)
- Contact obartunov@postgrespro.ru, n.gluhov@postgrespro.ru for collaboration.
  Together we can do anything !

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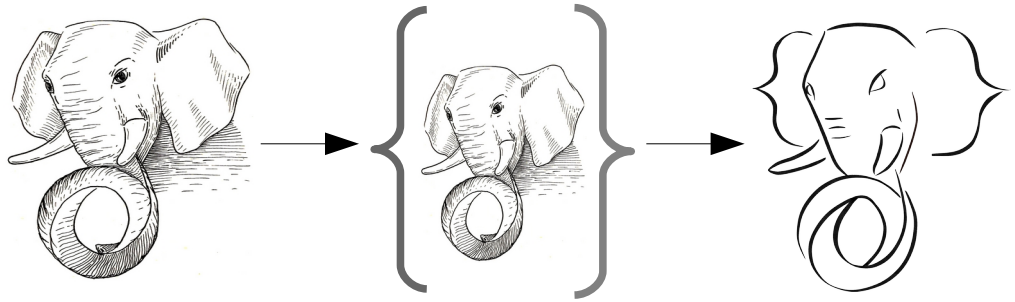
References

1)This talk:
http://www.sai.msu.su/~megera/postgres/talks/jsonb-roadmap-pgcon-2020.pdf
2)Technical Report (SQL/JSON) - available for free
http://standards.iso.org/i/PubliclyAvailableStandards/c067367_ISO_IEC_TR_19075-6_2017.zip
3)Gentle introduction to JSON Path in PostgreSQL
https://github.com/obartunov/sqljsondoc/blob/master/jsonpath.md
4)Jsquery extension: https://github.com/postgrespro/jsquery/tree/sqljson
http://www.sai.msu.su/~megera/postgres/talks/pgconfeu-2014-jsquery.pdf
5)Parameters for opclasses
http://www.sai.msu.su/~megera/postgres/talks/opclass_pgconf.ru-2018.pdf
6)IMDB tables: http://www.sai.msu.su/~megera/postgres/files/imdb/imdb/



Original idea by Oleg Bartunov,
final implementation by Denis Rosa

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ADDENDUM

Generic JSON API

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JSON API

- Json (replacement of Jsonb)

```
typedef struct Json
{
    CompressedDatum   datum; /* original datum */
    JsonContainerData root;  /* root container (like Jsonb.root) */
} Json;
```

- JsonContainer (replacement of JsonbContainer)

```
typedef struct JsonContainerData
{
    JsonContainerOps *ops;   /* container vtable */

    /* fields extracted from container by its init() method */
    int               size;  /* number of object fields or array elements */
    JsonValueType     type;  /* array, object or scalar */

    /* container-specific data (binary jsonb, json text, JsonValue *) */
    void             *data[FLEXIBLE_ARRAY_MEMBER];
} JsonContainer;
```

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JSON API — Container methods

- JSON container methods

```
struct JsonContainerOps
{
 int             dataSize; /* size of JsonContainer.data[] */
 void           (*init)(JsonContainerData *cont, Datum value);
 JsonIterator  *(*iteratorInit)(JsonContainer *cont);
 JsonValue     *(*findKeyInObject)(JsonContainer *obj, const char *key, int len);
 JsonValue     *(*findValueInArray)(JsonContainer *arr, const JsonValue *val);
 JsonValue     *(*getArrayElement)(JsonContainer *arr, uint32 index);
 uint32         (*getArraySize)(JsonContainer *arr);
 char          *(*toString)(StringInfo out, JsonContainer *, int estimatedlen);
 JsonContainer *(*copy)(JsonContainer *src);
};
```

- Three implementations:

`jsonbContainerOps` – for `jsonb` datatype
`jsontContainerOps` – for `json` datatype
`jsonvContainerOps` – for in-memory tree-like `JsonValue`

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JSON API - Container methods

- `void` **`init`**`(JsonContainerData *cont, Datum value)`
  Initialize `JsonContainerData.data` from datum, filling `size` and `type` fields.

- `JsonIterator *`**`iteratorInit`**`(JsonContainer *cont)`
  Initialize `JsonIterator` for container (`JsonbIteratorInit()`)

- `JsonValue *`**`findKeyInObject`**`(JsonContainer *obj, const char *key, int len)`
  Find key in object (`findJsonbValueFromContainer()`)

- `JsonValue *`**`findValueInArray`**`(JsonContainer *arr, const JsonValue *val)`
  Find element in array (`findJsonbValueFromContainer()`)

- `JsonValue *`**`getArrayElement(`**`JsonContainer *arr, uint32 index`**`)`**
  Extract array element by index (`getIthJsonbValueFromContainer()`)

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JSON API - Container methods

- `uint32 **getArraySize**(JsonContainer *arr)`

  Fetch array size if it is unkown (`JsonContainer.size == -1`). Used only for text JSONs.

- `char ***toString**(StringInfo out, JsonContainer *, int estimatedlen)`

  Convert JSON to text representation.

  `jsonb, jsonv:` called `JsonbToCString()` which iterates through JSON
  `jsont:` simply return text as is

- `JsonContainer ***copy**(JsonContainer *src)`

  Copy container data.

  `jsont, jsonb` — copy underlying flat binary data
  `jsonv` — copy `JsonValue` tree

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JSON API — Convenient macros

JSON container methods are called through a set of convenient macros:

```
JsonIteratorInit(js)
JsonFindKeyInObject(js, key)
JsonFindValueInArray(js, val)
JsonGetArrayElement(js, index)
JsonGetArraySize(js)
JsonCopy(js)
JsonToString(js, out)
```

Their definitions are trivial:

```
#define  JsonFindKeyInObject(js, key) \
 ((js)->ops->findKeyInObject(js, key))
```

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JSON API - Iterators

- Iterator API is absolutely similar to JsonbIterators

```
/* analogue of JsonbIteratorNext() */
typedef JsonIteratorToken (*JsonIteratorNextFunc)(JsonIterator **iterator,
                                                  JsonValue *value,
                                                  bool skipNested);


/* analogue of JsonbIterator */
struct JsonIteratorData
{
    JsonIterator         *parent;
    JsonContainer        *container;
    JsonIteratorNextFunc  next;
};

#define JsonIteratorNext(it, value, skipNested) \
            ((*it)->next(it, value, skipNested))
```

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JSON API — Wrapping and unwrapping

- Wrapping json[b] datums is done inside DatumGetJsonX() macros:

```
#define DatumGetJsonbP(datum) DatumGetJson(datum, &jsonbContainerOps)
#define DatumGetJsontP(datum) DatumGetJson(datum, &jsontContainerOps)
```

`DatumGetJson()` calls `init()` method.

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JSON API — Wrapping and unwrapping

- Unwrapping and encoding into target datatype is done inside JsonXGetDatum() macros (typically right before returning from user functions):

```
#define PG_RETURN_JSONB_P(js) PG_RETURN_DATUM(JsonbPGetDatum(js))
#define PG_RETURN_JSONT_P(js) PG_RETURN_DATUM(JsontPGetDatum(js))

#define JsonbPGetDatum(js) JsonFlatten(JsonUniquify(js), JsonbEncode, \
                                       &jsonbContainerOps)()

#define JsontPGetDatum(js) CStringGetTextDatum(JsonToCString(&js->root, NULL))

void JsonbEncode(StringInfoData *buffer, const JsonbValue *val);
```

`JsonFlatten()` calls the specified encoder function in the separate `MemoryContext`, passing initialized `StringInfo`.

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JSON API — User functions

- Old json functions are almost completely removed, jsonb querying and building code is reused. Typical pair of user functions now look like this:

```
Datum
jsonb_object_field(PG_FUNCTION_ARGS)
{
  PG_RETURN_JSONB_P(json_object_field_internal(PG_GETARG_JSONB_PC(0),
                                               PG_GETARG_TEXT_PP(1)));
}


Datum
json_object_field(PG_FUNCTION_ARGS)
{
  PG_RETURN_JSONT_P(json_object_field_internal(PG_GETARG_JSONT_P(0),
                                               PG_GETARG_TEXT_PP(1)));
}

static Json *
json_object_field_internal(Json *js, text *key) { ... }
```

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JSON API — Uniquification of JSON objects

- Reusing jsonb code for JSON building, it is important to conditionally disable uniquification of object keys for json type that is done in `pushJsonbValue(WJB_END_OBJECT)`.
- Added **`uniquified`** flag to `JsonValue.val.object`, which is set in constructors after `pushJsonbValue(WJB_BEGIN_OBJECT)`.
- Also added several **`uniquified`** flags to `JsonValue.val.array`, `JsonValue.val.object`, `JsonValue.val.binary` structures, which determines key uniqueness of all their underlying subobjects.
- `JsonUniquify()` checks these flags and recursively uniquifyes subobjects if necessary.

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JSON API — Preserving formatting of text JSONs

- Reusing jsonb code for JSON building, it also is important to preserve differences in formatting of json/jsonb:

```
SELECT json_build_object ('a', 'b', 'c', ' [ 1]'::json);
{"a" : "b", "c" :  [ 1]}

SELECT jsonb_build_object('a', 'b', 'c', ' [ 1]'::json);
{"a": "b", "c": [1]}
```

  Json preserves formatting of its json parts, json object constructors add space before colon, json_agg() uses newline as array element separator.

- Several separator char fields added to `JsonValue.val.array` and `JsonValue.val.object`. They are initialized in builder functions and used in `JsonToCString()`.
- `pushJsonbValue()` now does not unpack binary jsons to preserve their formatting.

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