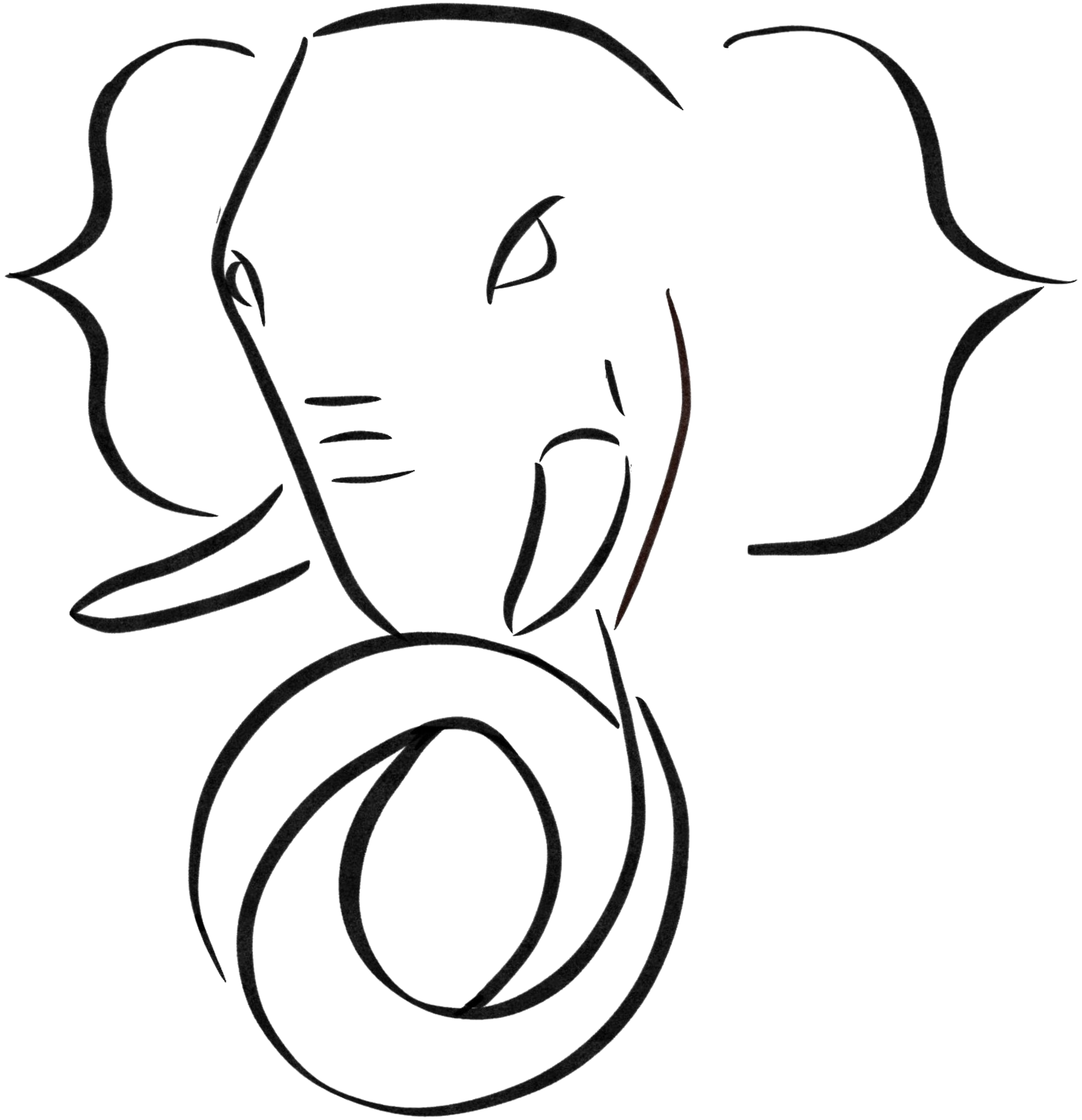


Scaling JSONB

Oleg Bartunov
Nikita Glukhov
Postgres PROFESSIONAL

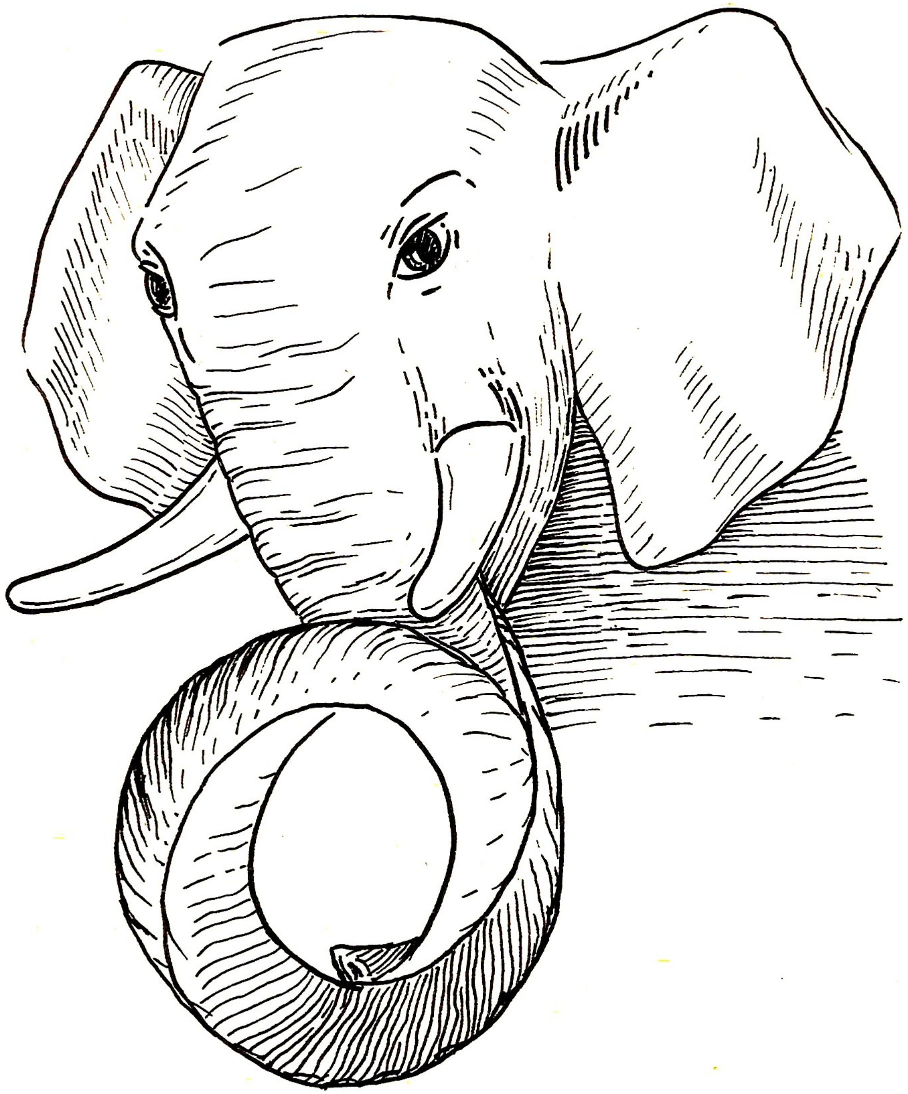
http://www.sai.msu.su/~megera/postgres/talks/jsonb-pgvision-2021.pdf

Since Postgres95

Research scientist @
Moscow University
CEO Postgres Professional
Major PostgreSQL contributor

PostgresPro

Nikita Glukhov



Senior developer @Postgres Professional
PostgreSQL contributor

Major CORE contributions:

- Jsonb improvements
- SQL/JSON (Jsonpath)
- KNN SP-GiST
- Opclass parameters

Current development:

- SQL/JSON functions
- Jsonb performance

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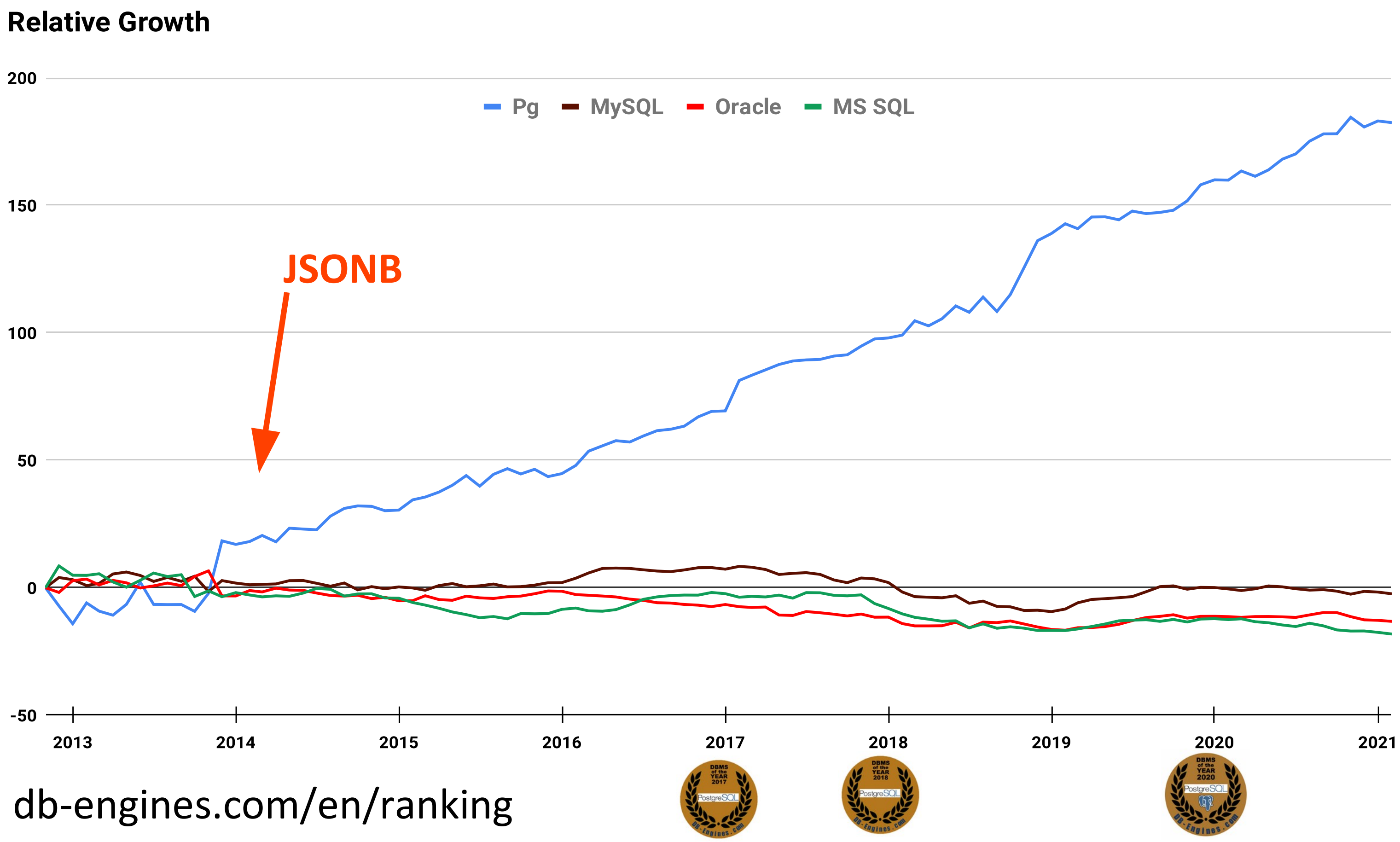
Postgres breathed a second life into relational databases

- Postgres innovation - the first relational database with NoSQL support
- NoSQL Postgres attracts the NoSQL users
- JSON became a part of SQL Standard 2016



db-engines.com/en/ranking

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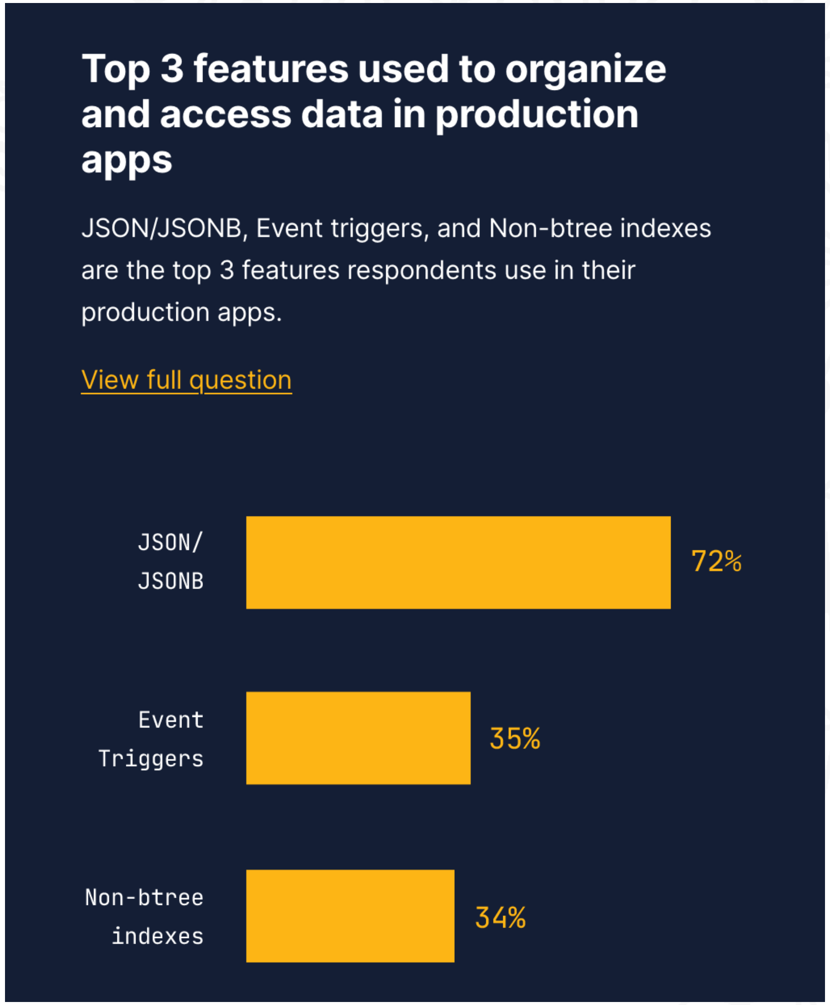
JSONB Popularity - CREATE TABLE qq (js JSONB)

State of PostgreSQL 2021 (Survey)

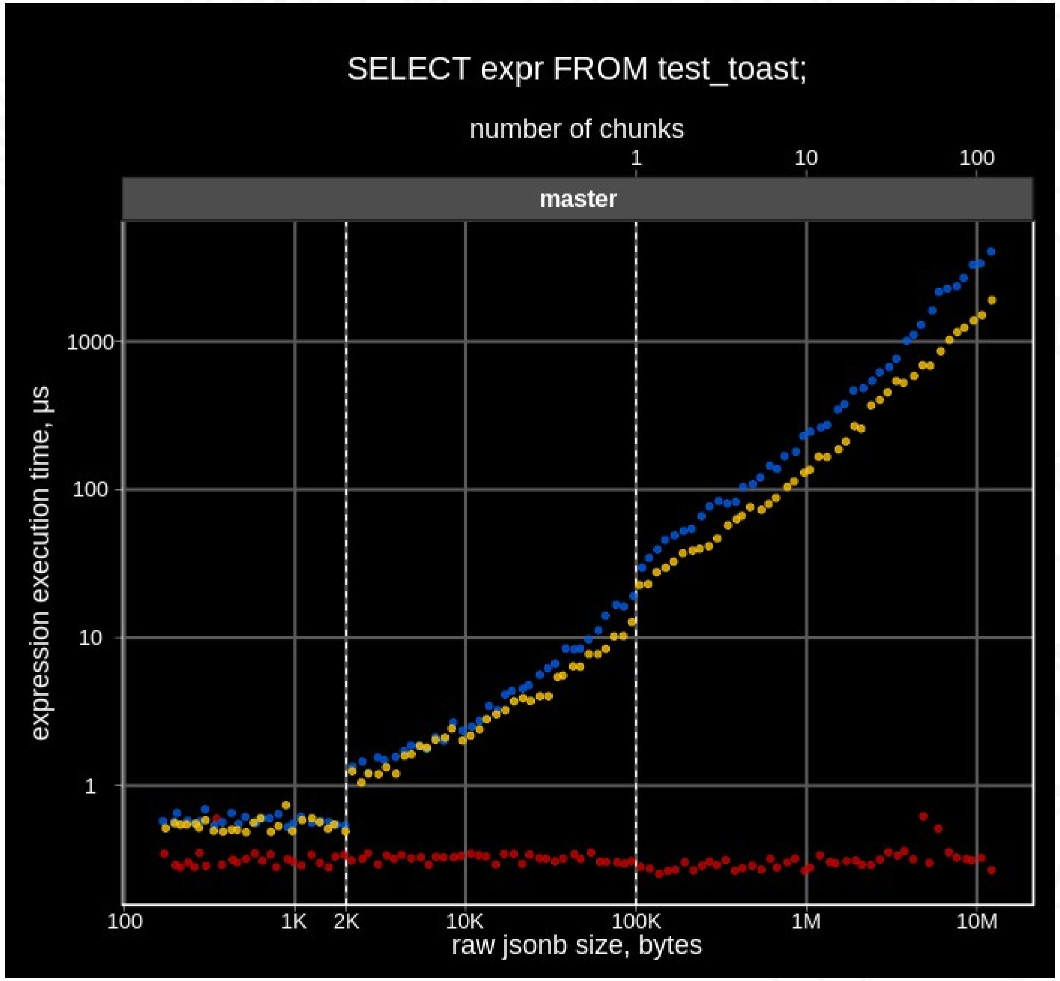


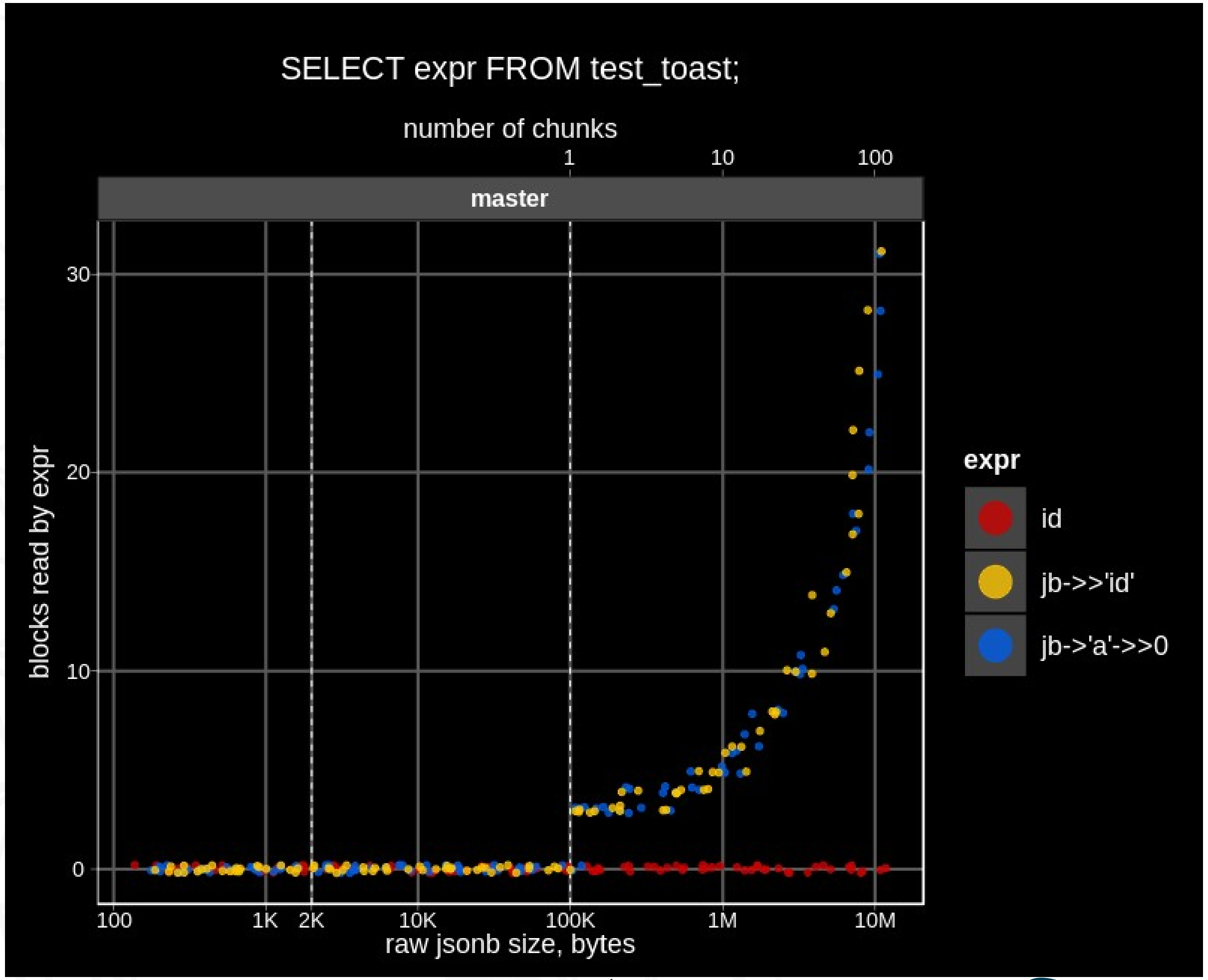
Pgsql telegram (6170) — 26.02.2021

- SELECT 8061/312083
- SQL 4473/144789
- JSON[B] 3116/88234
- TABLE 2997/129936
- JOIN 2345/108860
- INDEX 1519/74327
- BACKUP 1484/42618
- VACUUM 1470/53919
- REPLICA 707/31036

Popular mistake: CREATE TABLE qq (jsonb)

(id, {...}::jsonb) vs ({id,...}::jsonb)





Large jsonb is TOASTed !

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JSONB Projects: What we were working on

- SQL/JSON functions (SQL-2016) and JSON_TRANSFORM
- Generic JSON API (GSON). Jsonb as a SQL Standard JSON data type.
- *Better jsonb indexing (Jsquery GIN opclasses)*
- *Parameters for jsonb operators (planner support functions for Jsonb)*
- *JSONB selective indexing (Jsonpath as parameter for jsonb opclasses)*
- *Jsonpath syntax extension*
- *Simple Dot-Notation Access to JSON Data*

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Current TOP-priority project

- SQL/JSON functions (SQL-2016) and JSON_TRANSFORM
- Generic JSON API. Jsonb as a SQL Standard JSON data type.
- *Better jsonb indexing (Jsquery GIN opclasses)*
- *Parameters for jsonb operators (planner support functions for Jsonb)*
- *JSONB selective indexing (Jsonpath as parameter for jsonb opclasses)*
- *Jsonpath syntax extension*
- *Simple Dot-Notation Access to JSON Data*

- JSONB - 1st-class citizen in Postgres
  - Efficient storage,select, update, API

PostgresPro

Top-priority: JSONB - 1st-class citizen in Postgres

- Popularity of JSONB — it's mature data type, rich functionality
- Startups use Postgres and don't care about compatibilty to Oracle/MS SQL
  - Jsonpath is important and committed
  - There is rich user API to Jsonb, so SQL/JSON functions are not in top-priority list
- Not enough resources in community (developers, reviewers, committers)
  - SQL/JSON — 4 years, 55 versions
  - JSON/Table — 48 versions
- We concentrate on efficient storage, select, update (OLTP+OLAP)
  - Extendability of JSONB format
  - Extendability of TOAST — data type aware TOAST, TOAST for non-atomic attributes

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Motivational example (synthetic test)

- A table with 100 jsonbs of different sizes (130B-13MB, compressed to 130B-247KB):

```
CREATE TABLE test_toast AS
SELECT
 i id,
 jsonb_build_object(
  'key1', i,
  'key2', (select jsonb_agg(0) from
           generate_series(1, pow(10, 1 + 5.0 * i / 100.0)::int)),-- 10-100k elems
  'key3', i,
  'key4', (select jsonb_agg(0) from
           generate_series(1, pow(10, 0 + 5.0 * i / 100.0)::int)) -- 1-10k elems

 ) jb
FROM generate_series(1, 100) i;
```

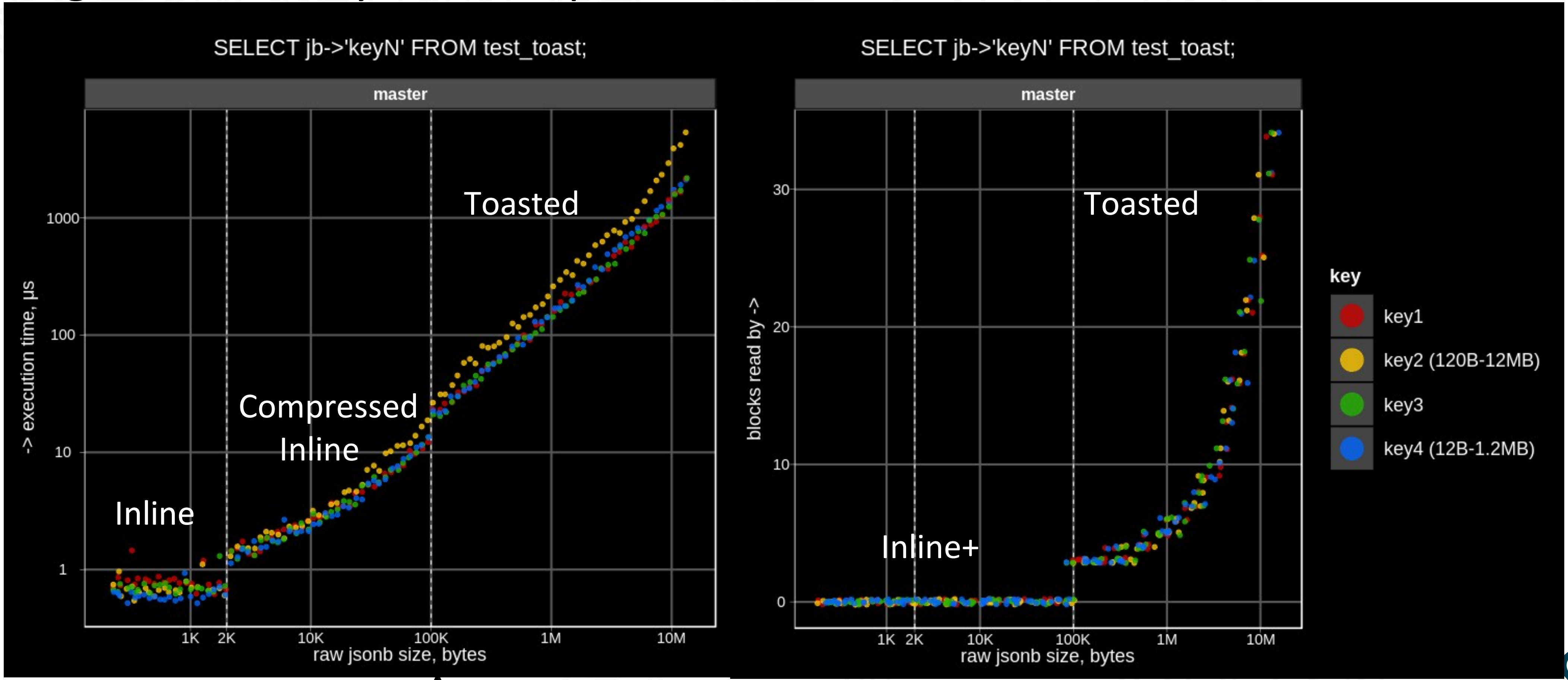
- Each jsonb looks like: `key1,` loooong `key2,` `key3,` long `key4.`
- We measure execution time of operator `->(jsonb, text)` for each row by repeating it 1000 times in the query:

```
SELECT jb -> 'keyN', jb -> 'keyN', … jb -> 'keyN' FROM test_toast WHERE id = ?;
```

PostgresPro

Motivational example (synthetic test)

Key access time for TOASTed jsonbs linearly increase with jsonb size, regardless of key size and position.



Large jsonb is TOASTed !

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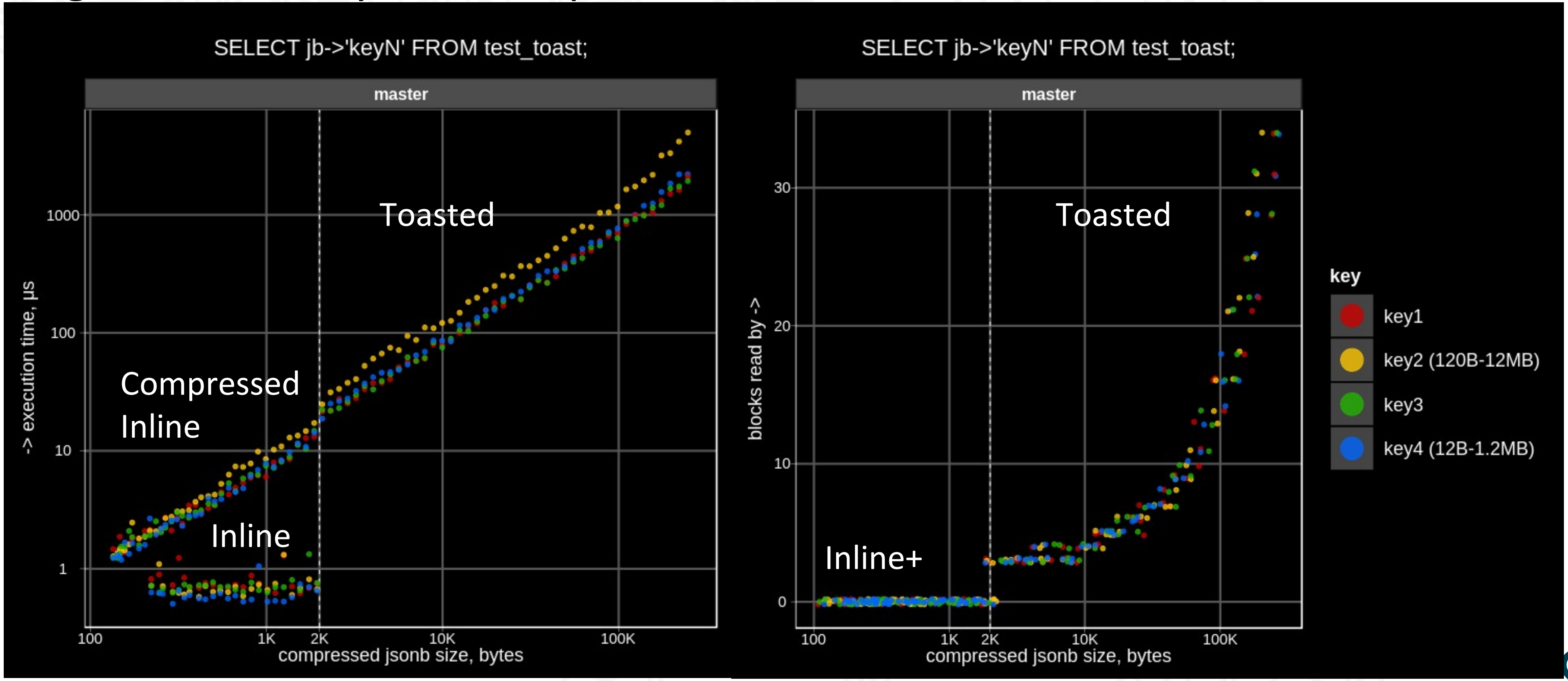
TOAST performance problems (synthetic test)

Key access time for TOASTed jsonbs linearly increase with jsonb size, regardless of key size and position.



Large jsonb is TOASTed !

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Motivational example (IMDB test)

- Real-world JSON data extracted from IMDB database (imdb-22-04-2018-json.dump.gz)
- Typical IMDB «name» document looks like:

```
{
    "id": "Connors, Steve (V)",
    "roles": [
         {
             "role": "actor",
             "title": "Copperhead Creek (????)"
         },
         {
             "role": "actor",
             "title": "Ride the Wanted Trail (????)"+
         }
     ],
     "imdb_id": 1234567
 }
```

- There are many other infrequent fields, but only `id`, `imdb_id` are mandatory, and `roles` array is the **biggest** and most frequent (see next slide).

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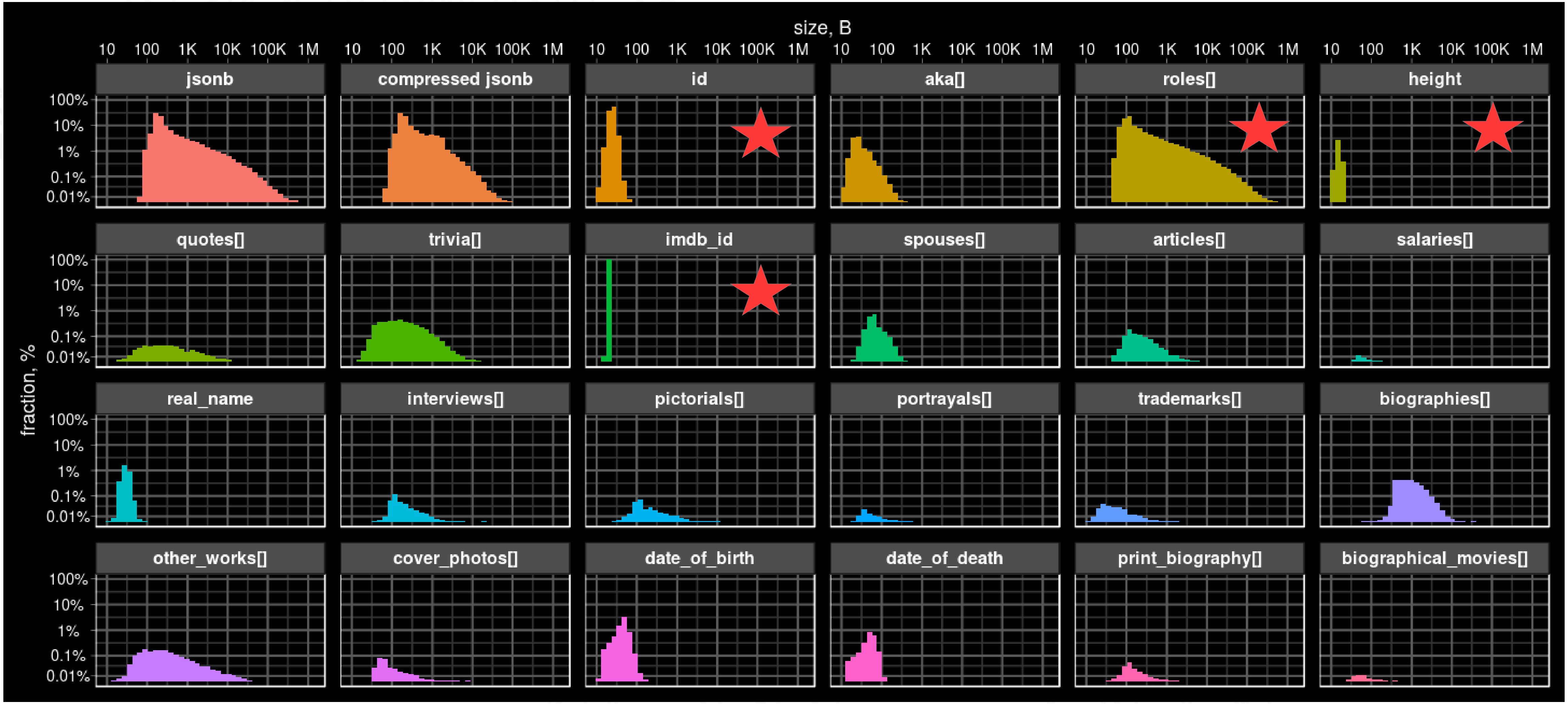
IMDB data set field statistics



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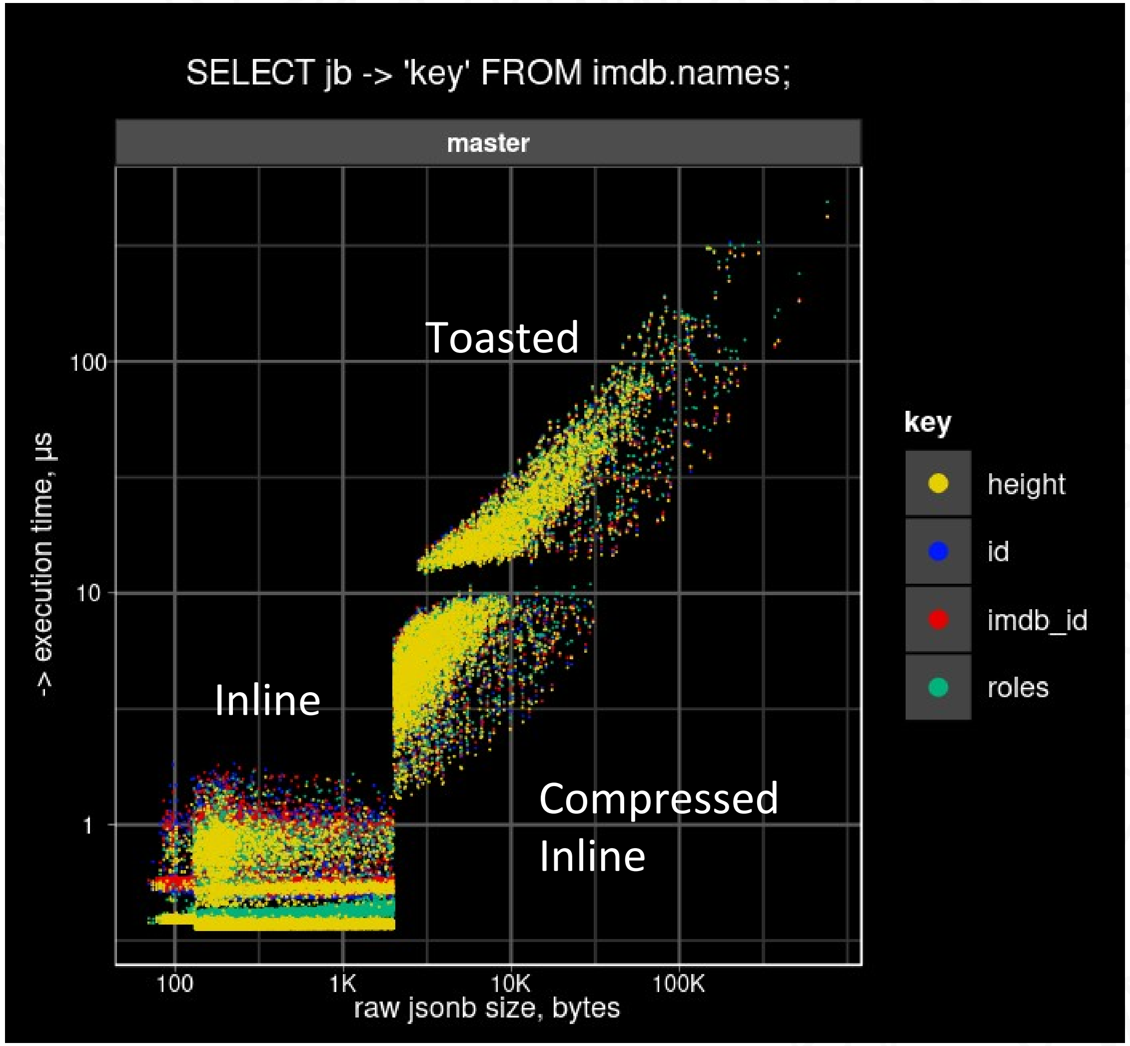
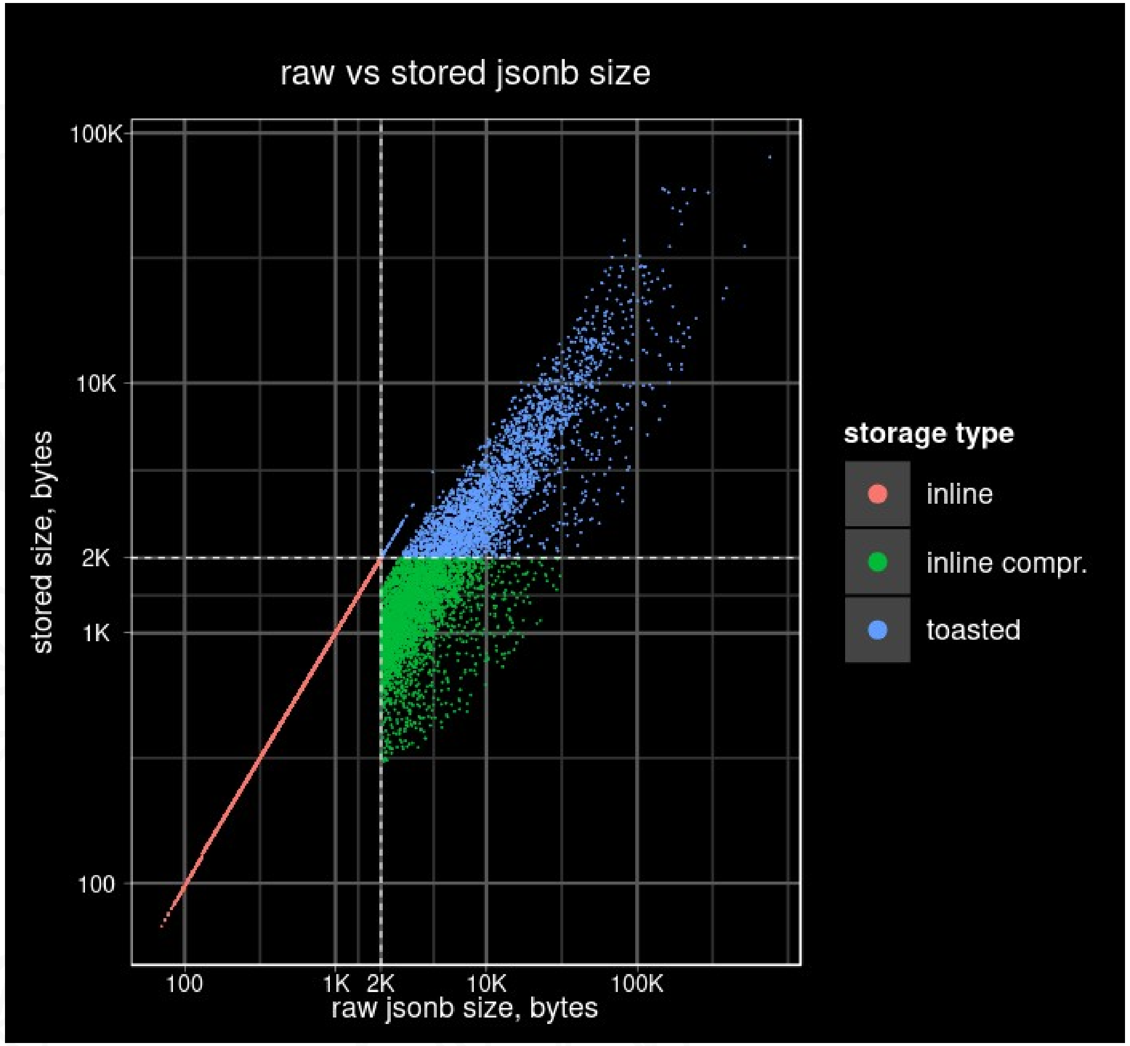
Motivational example (IMDB test)





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Motivation

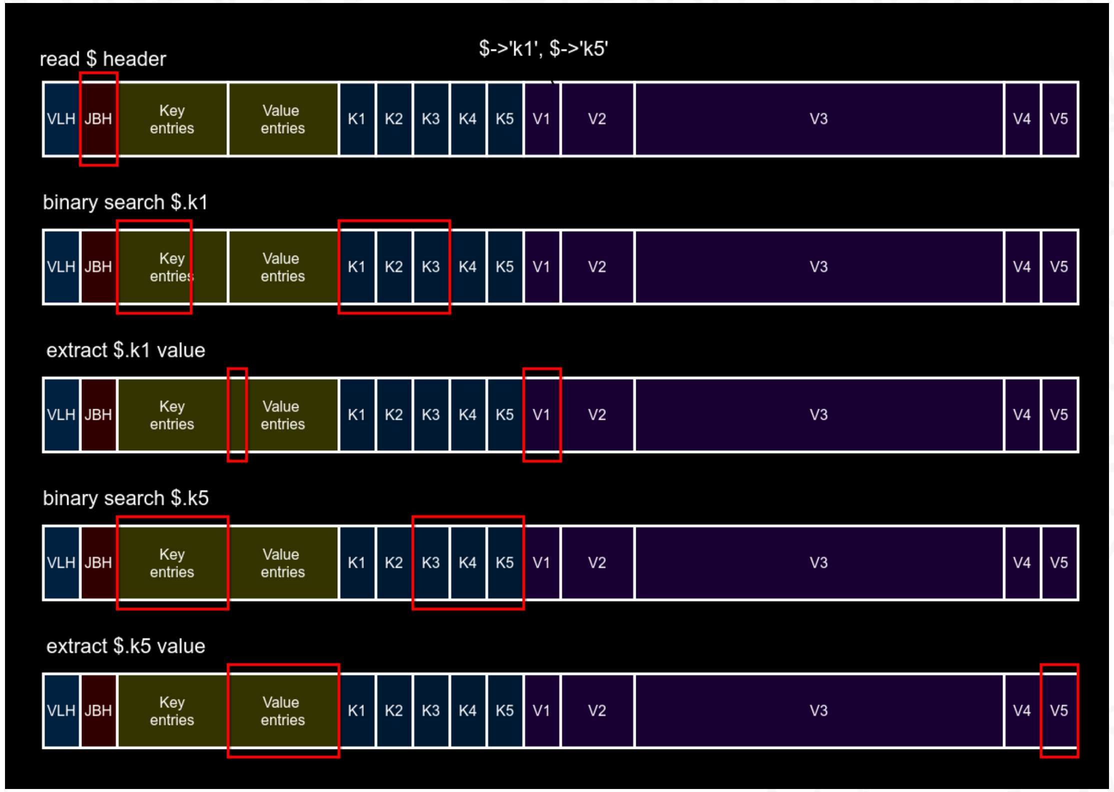
- Decompression is the biggest problem. Big overhead of decompression of the whole jsonb limits the applicability of jsonb as document storage with partial access.
  - Need partial decompression
- Toast introduces additional overhead - read too many block
  - Read only needed blocks — partial detoast

Jsonb deTOAST improvements

- Partial pglz decompression
- Sort jsonb object key by their length
- Partial deTOASTing using TOAST iterators
- Inline TOAST
- Shared TOAST
  - Access
  - Update
  - In-place update
- Bonus slides: Appendable bytea

Jsonb partial decompression

- Partial decompression eliminates overhead of pglz decompression of the whole jsonb.
- Jsonb is decompressed step by step: header, KV entries array, key name and key value. Only prefix of jsonb has to be decompressed to acccess a given key !



full decompression

partial decompression

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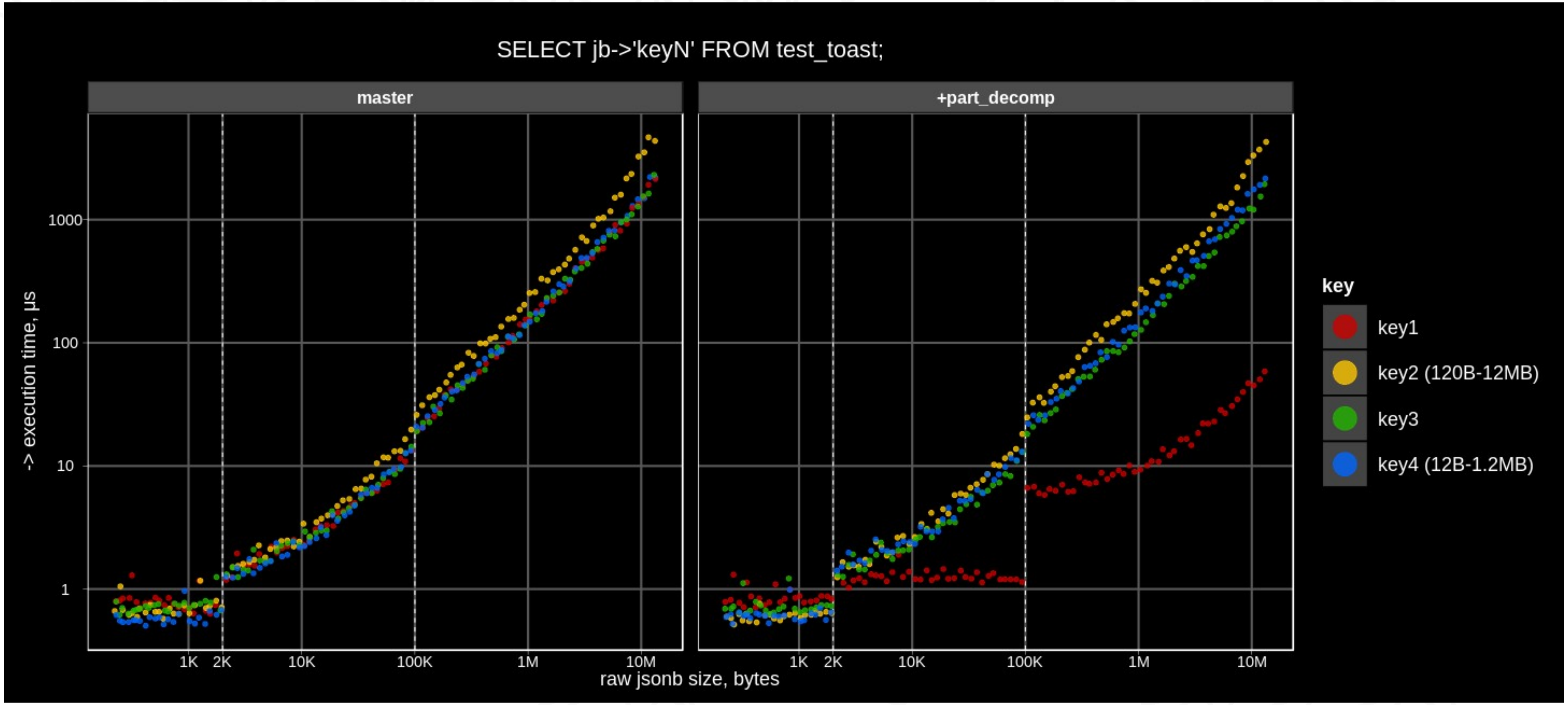
Jsonb partial decompression results (synthetic)

Access to key1 (red) in the prefix of jsonb was significantly improved:

- For inline compressed jsonb access time becomes constant
- For jsonb > 1MB acceleration is of order(s) of magnitude.



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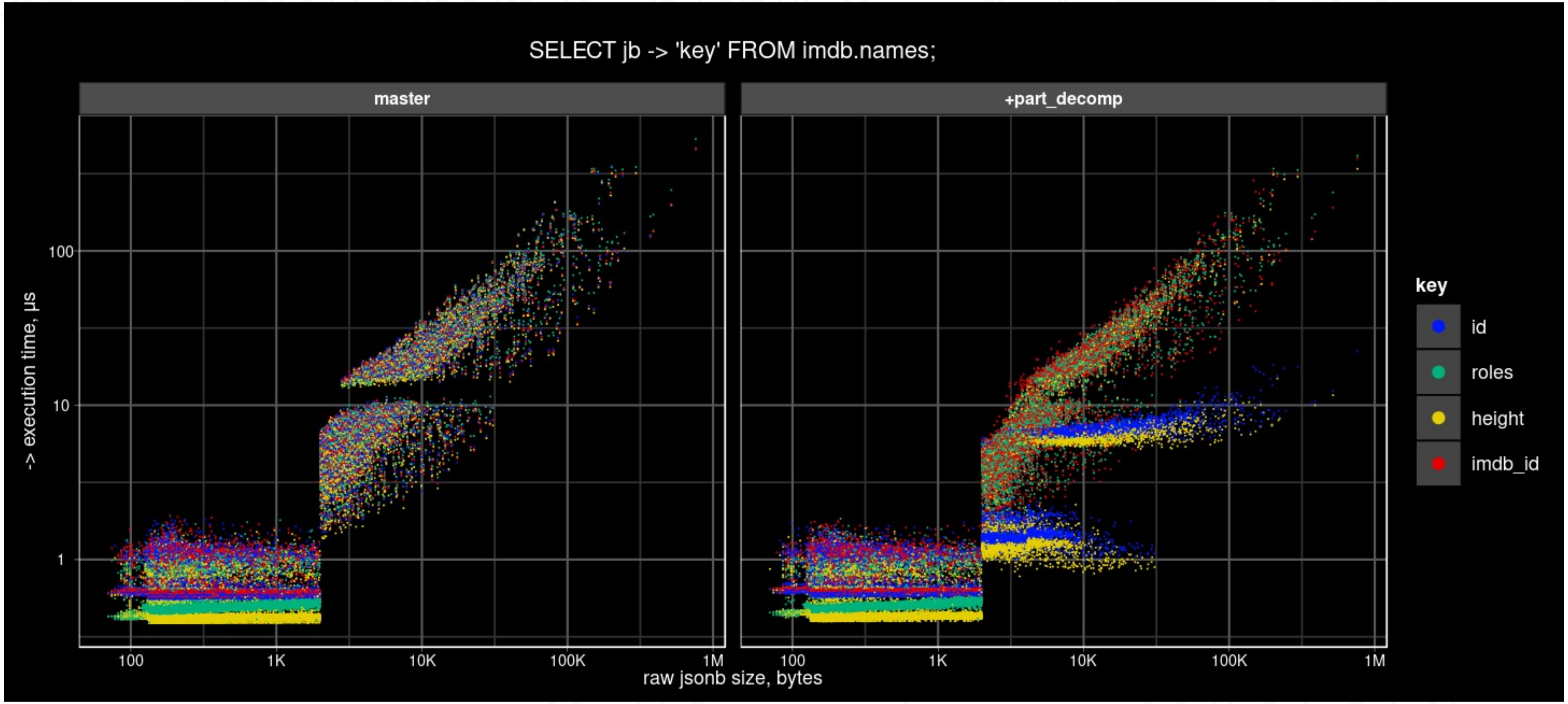
Jsonb partial decompression results (IMDB)

- Access to the first key «id» and rare key «height» was significantly improved.
- Access time to big key «roles» and short «imdb_id» remains mostly unchanged



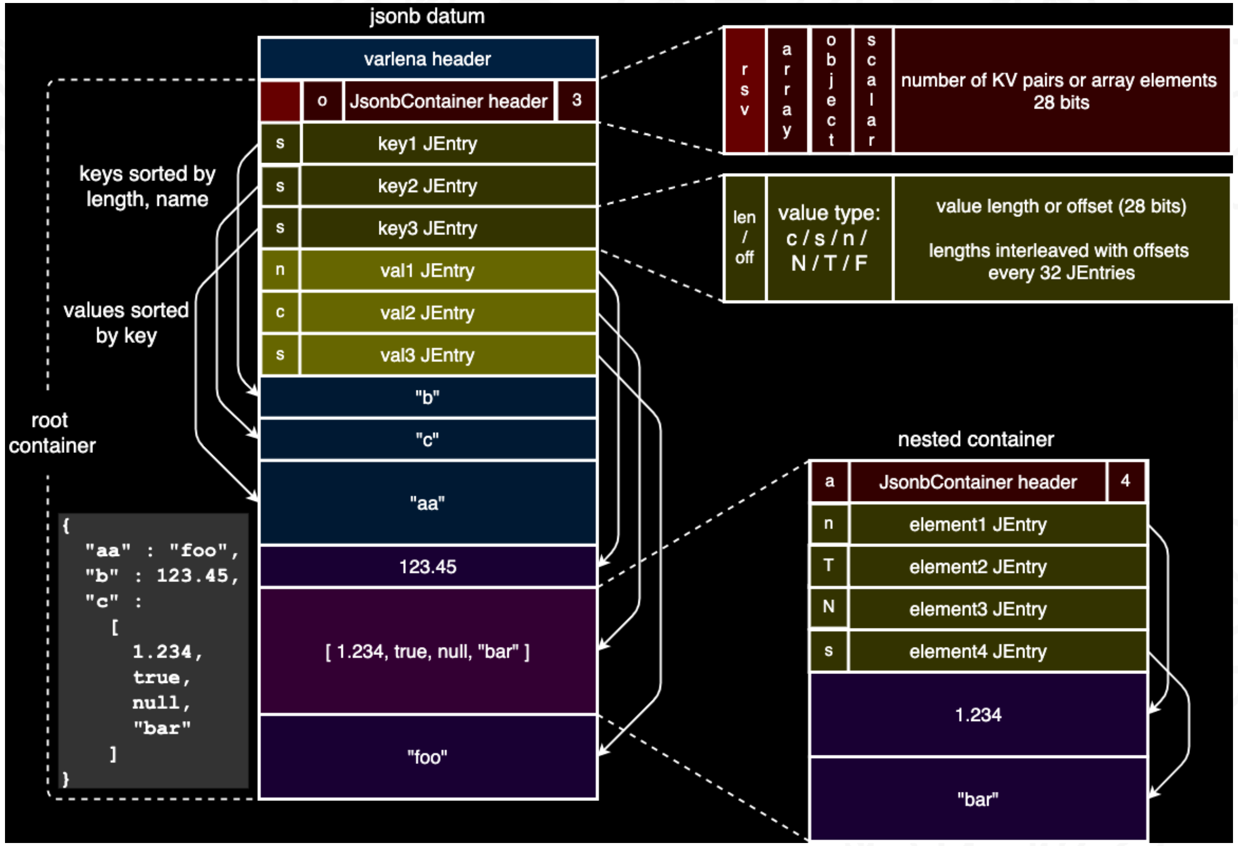
Sorting jsonb keys by length

In the original jsonb format object keys are sorted by (length,name), so the short keys with longer or alphabetically greater names are placed at the end and cannot benefit from the partial decompression. Sorting by length allows fast decompressions of the shortest keys (metadata).

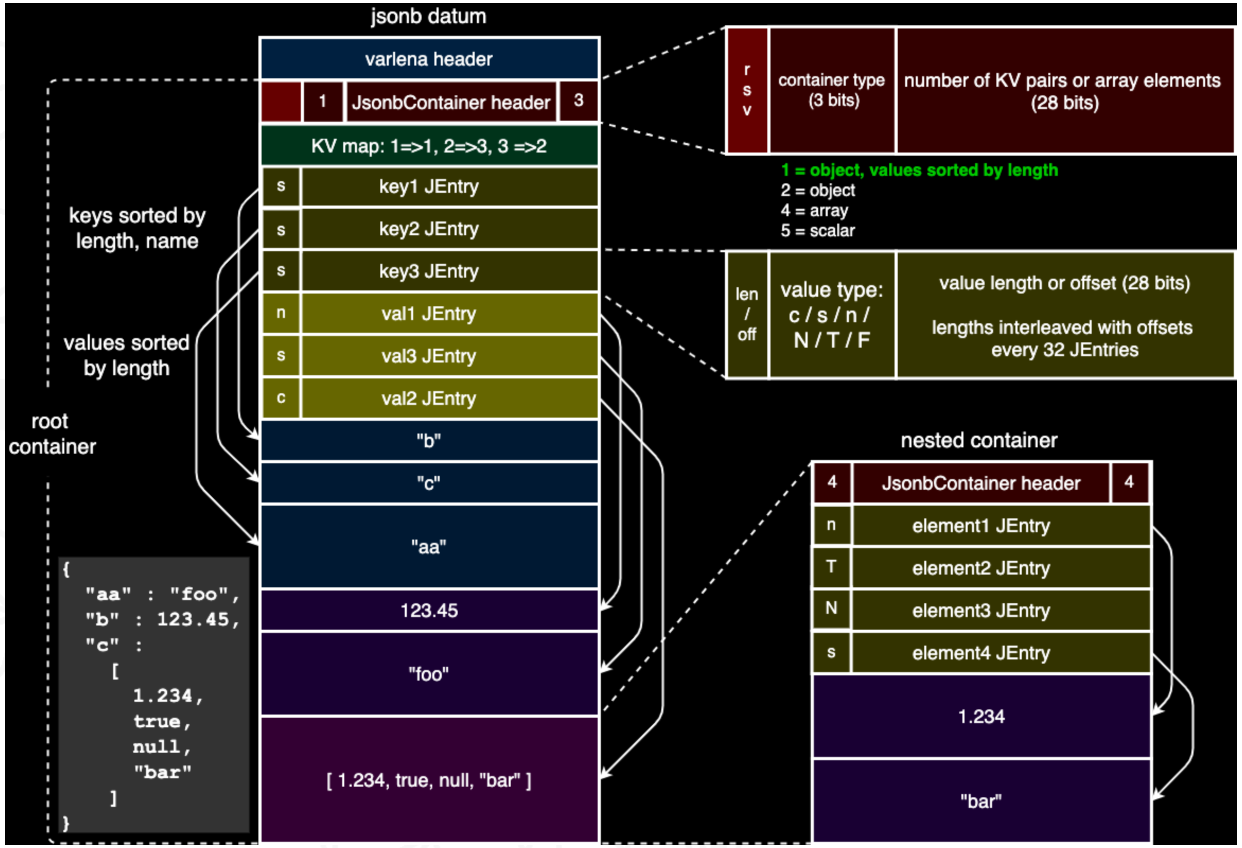
original: keys names and values sorted by key names

new: keys values sorted by their length

JSONB Binary Format (src/include/utils/jsonb.h)



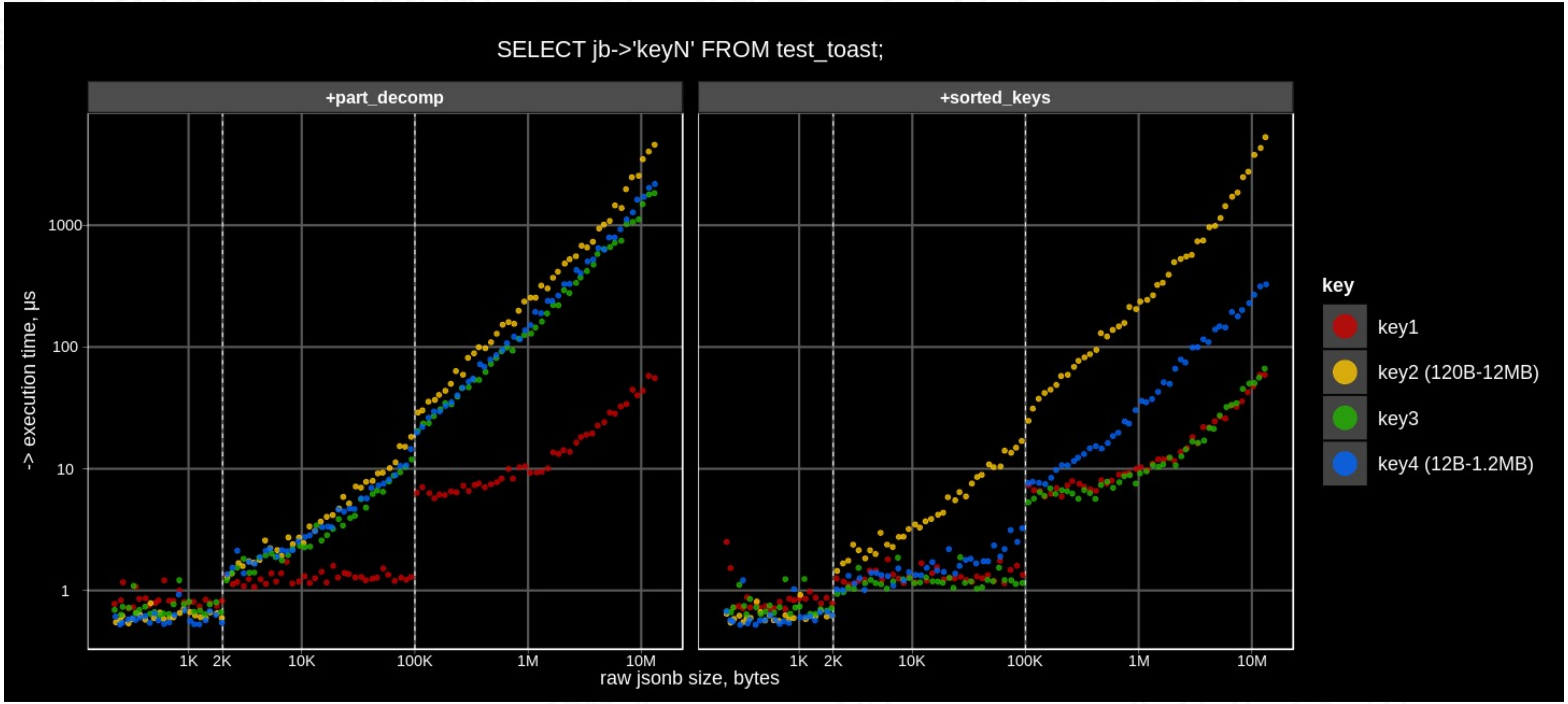
ORIGINAL: VALUES SORTED BY KEYS



VALUES SORTED BY THEIR LENGTH

Sorting jsonb keys by length results (synthetic)

Access time to the all short keys and medium-length key4 (excluding long key2, placed now at the end of jsonb) was significantly speed up:



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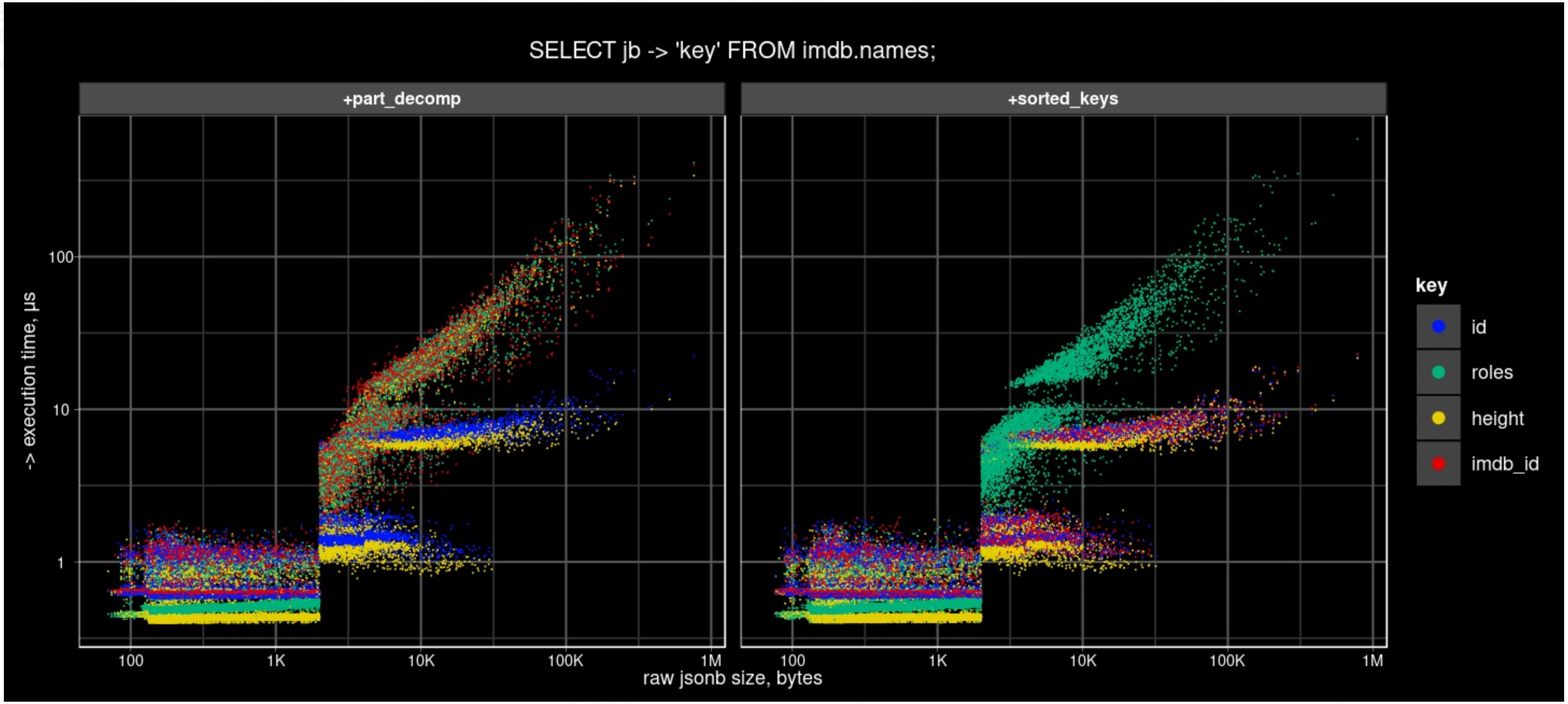
Sorting jsonb keys by length results (IMDB)

- Access to the last short key «imdb_id» now also was speed up.
- There is a big difference in access time (~5x) between inline and TOASTed values.

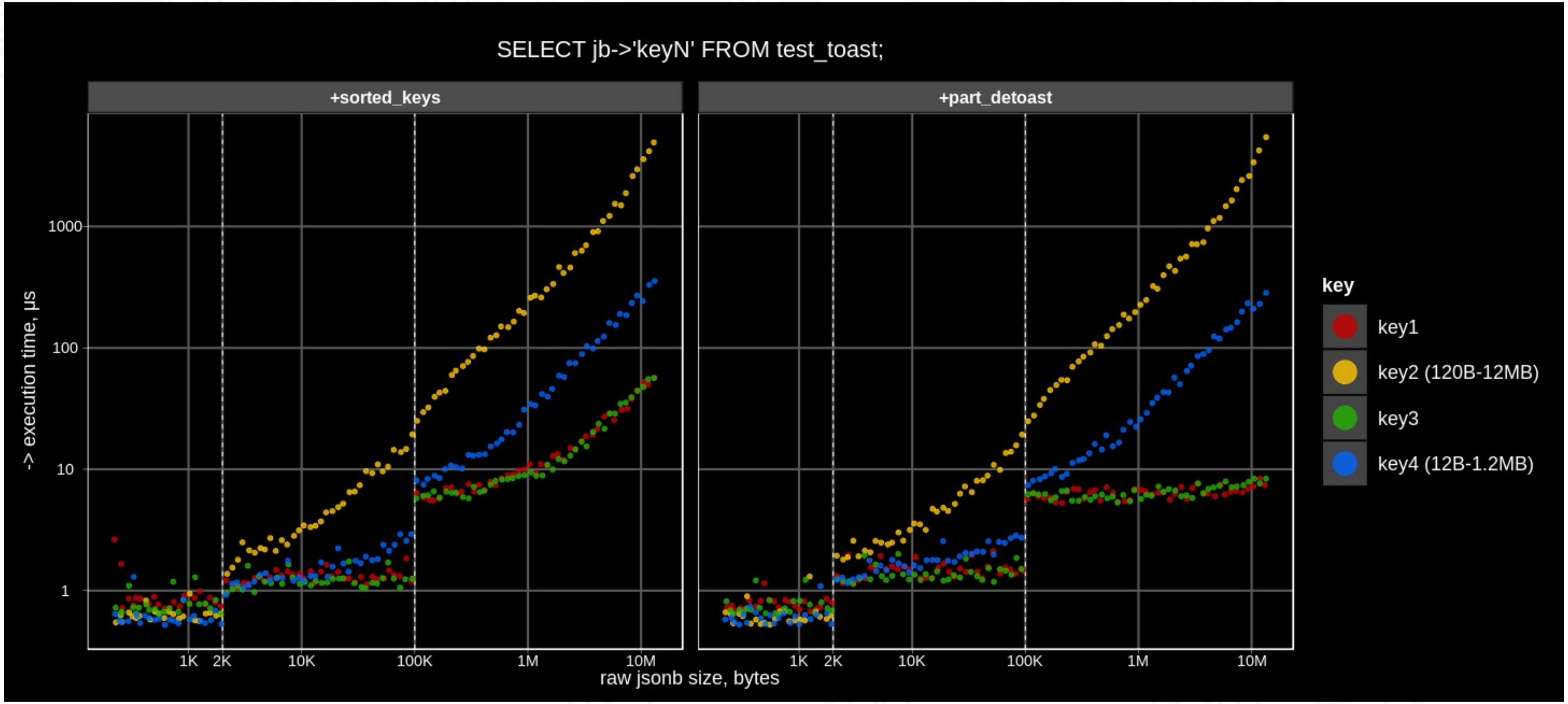


Partial deTOASTing

- We used patch «de-TOAST'ing using a iterator» from the CommitFest. It was originally developed by Binguo Bao at GSOC 2019.
- This patch gives ability to deTOAST and decompress chunk by chunk. So if we need only the jsonb header and first keys from the first chunk, only that first chunk will be read (actually, some index blocks also will be read).
- We modified patch adding ability do decompress only the needed prefix of TOAST chunks.

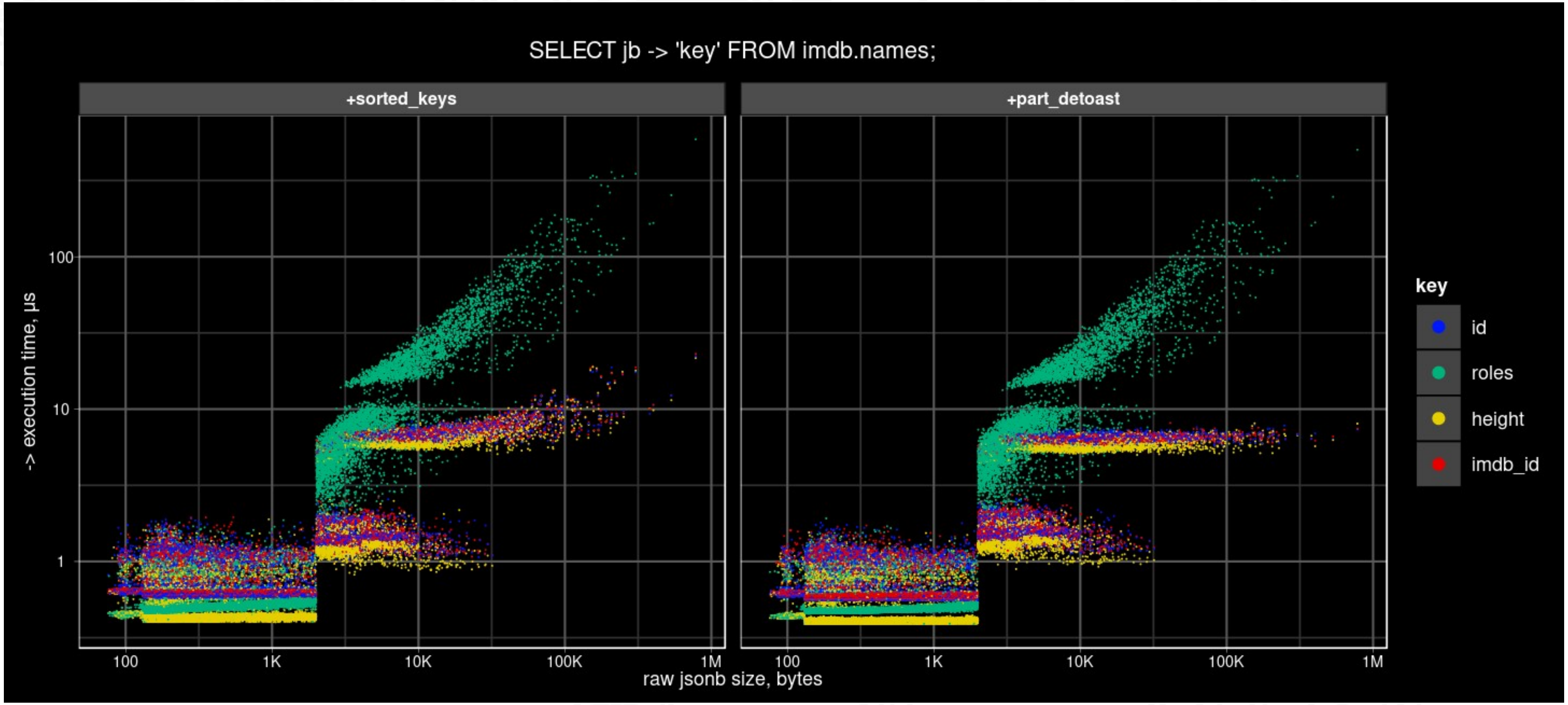
Partial deTOASTing results (synthetic)

Partial deTOASTing speeds up only access to the short keys of long jsonbs, making access time almost independent of jsonb size.



Partial deTOASTing results (IMDB)

- Results are the same, but not so noticeable because the are not many big (> 100KB) jsonbs.
- A big gap in access time (~5x) between inline and TOASTed values is still there.



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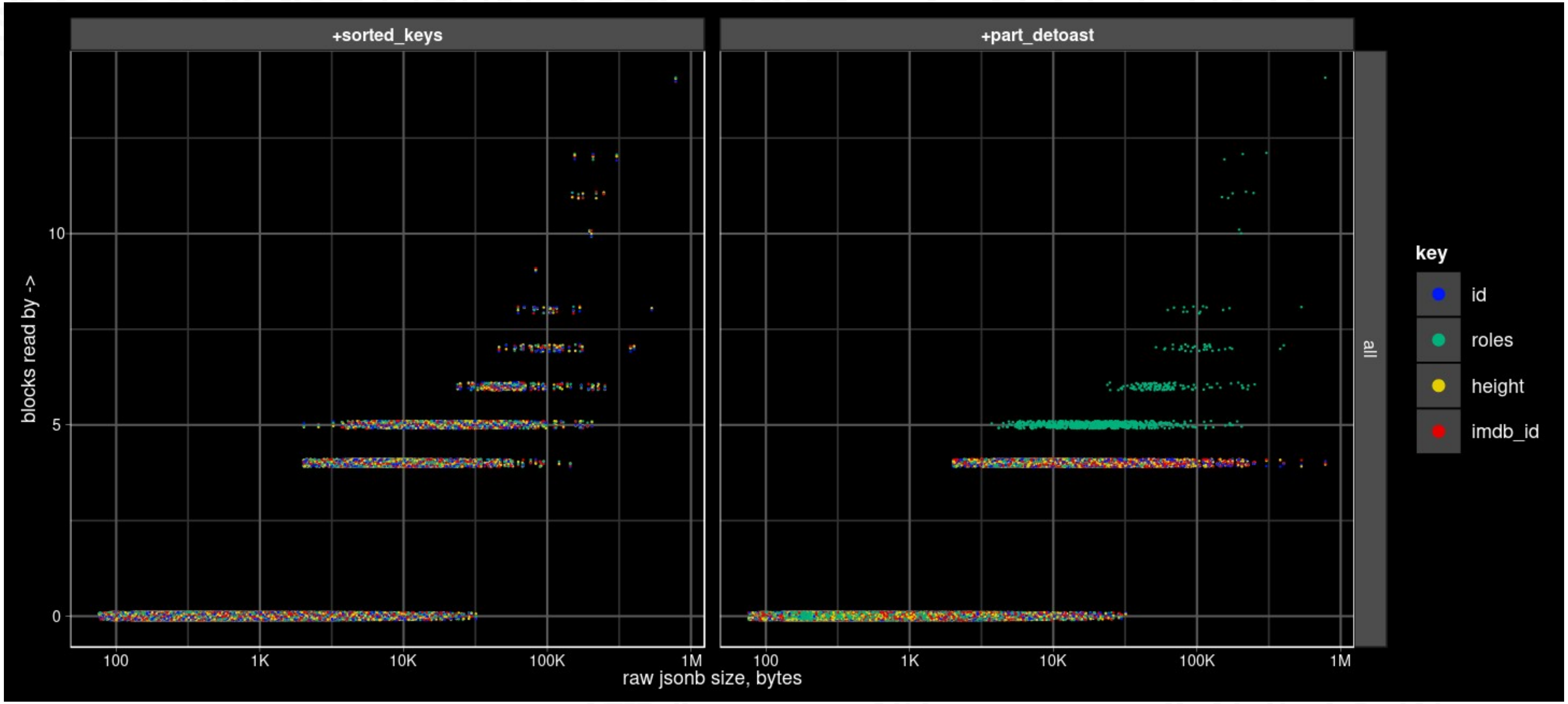
Partial deTOASTing results (IMDB)

- Effect of partial deTOASTing : Arrow operator (→) for short keys always read only 4 blocks (3 index and 1 heap).



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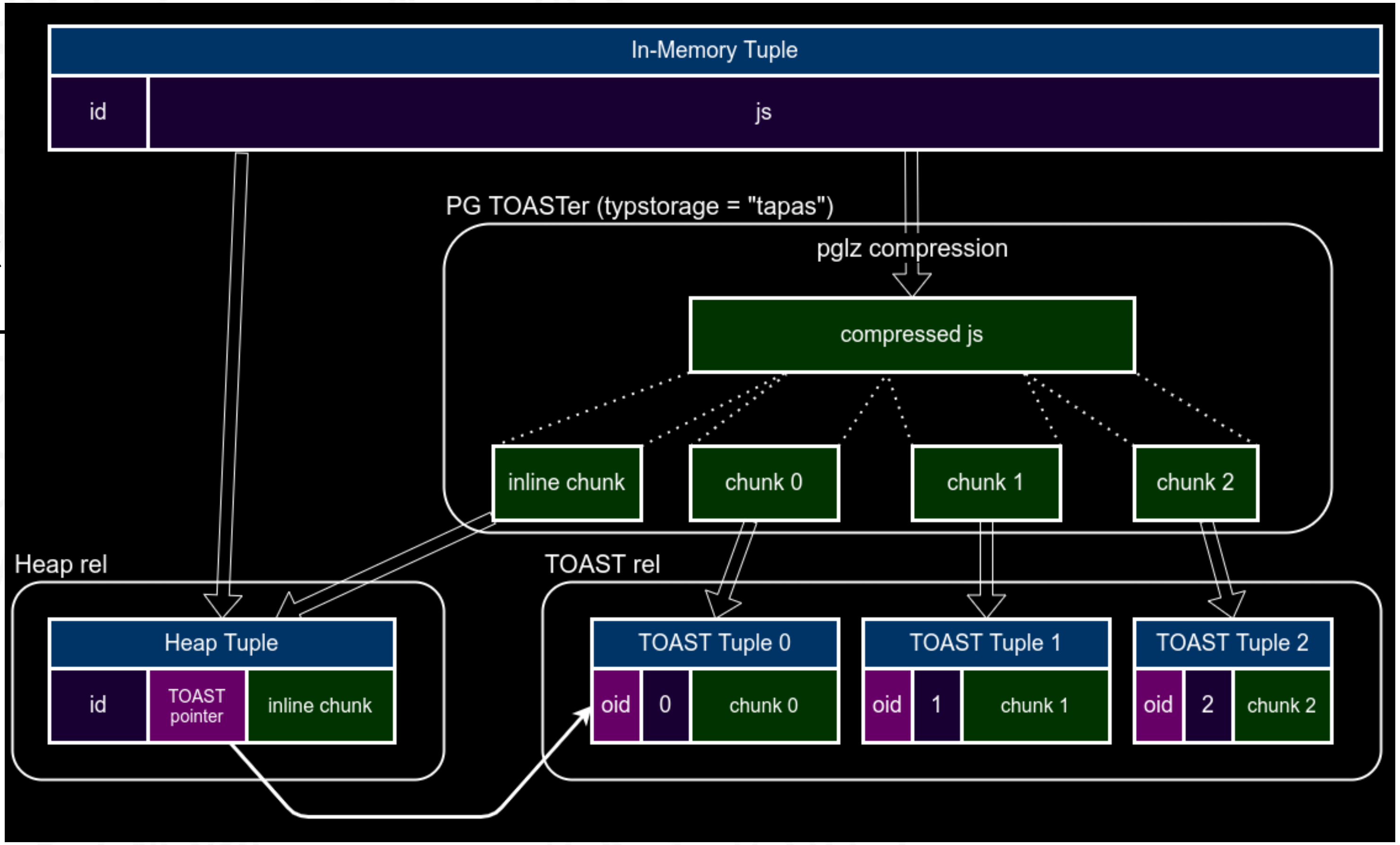
Inline TOAST

- Store first TOAST chunk containing jsonb header and possibly some short keys inline in the heap tuple.
- We added new typstorage «tapas», similar to «extended», it tries to fill the tuple to 2KB (if other attrubutes occupy less than 2KB) with the chunk from the begining of the <u>compressed data</u>.



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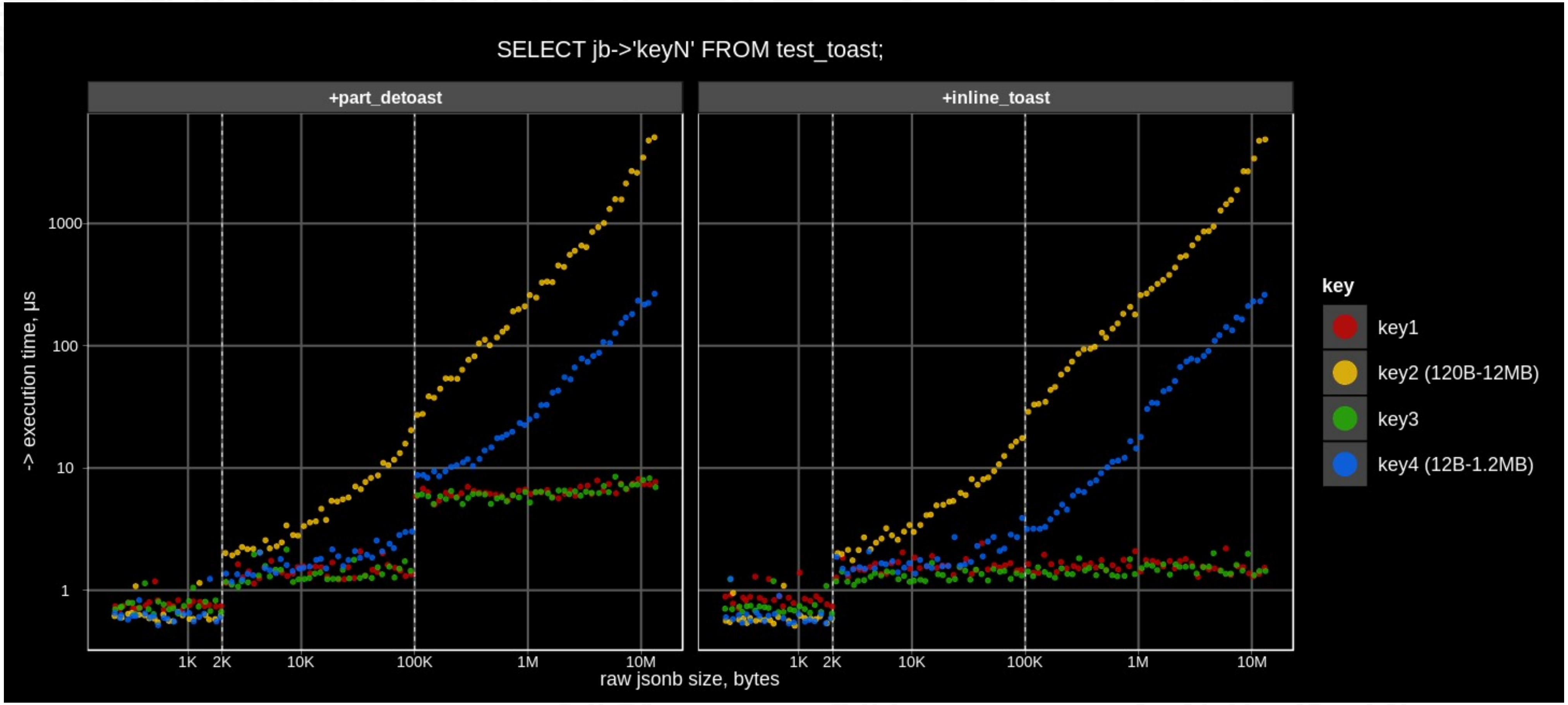
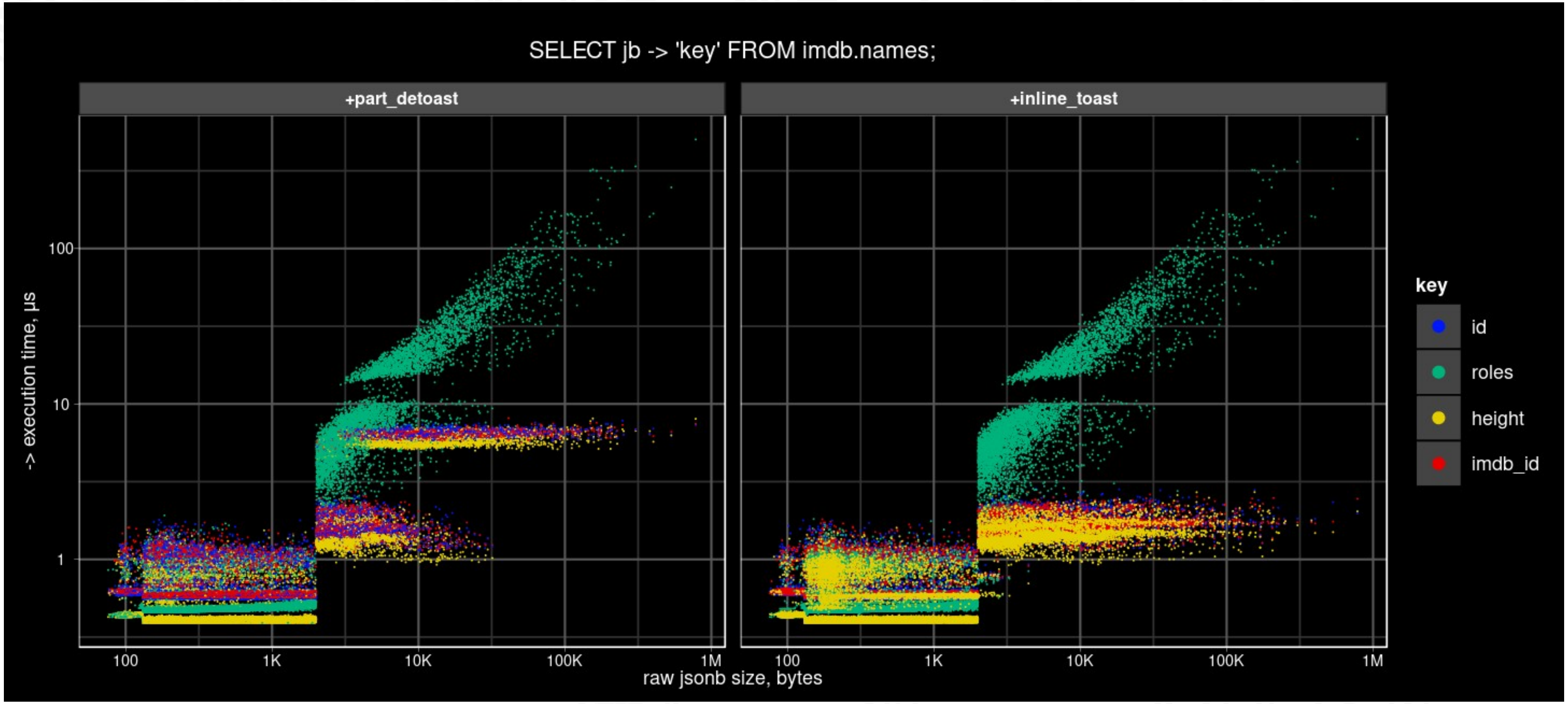
Inline TOAST results (synthetic)

Partial inline TOAST completely removes gap in access time to short keys between long and mid-size jsonbs.



Inline TOAST results (IMDB)

- Results are the same as in synthetic test.
- There is some access time gap between compressed and non-compressed jsonbs.



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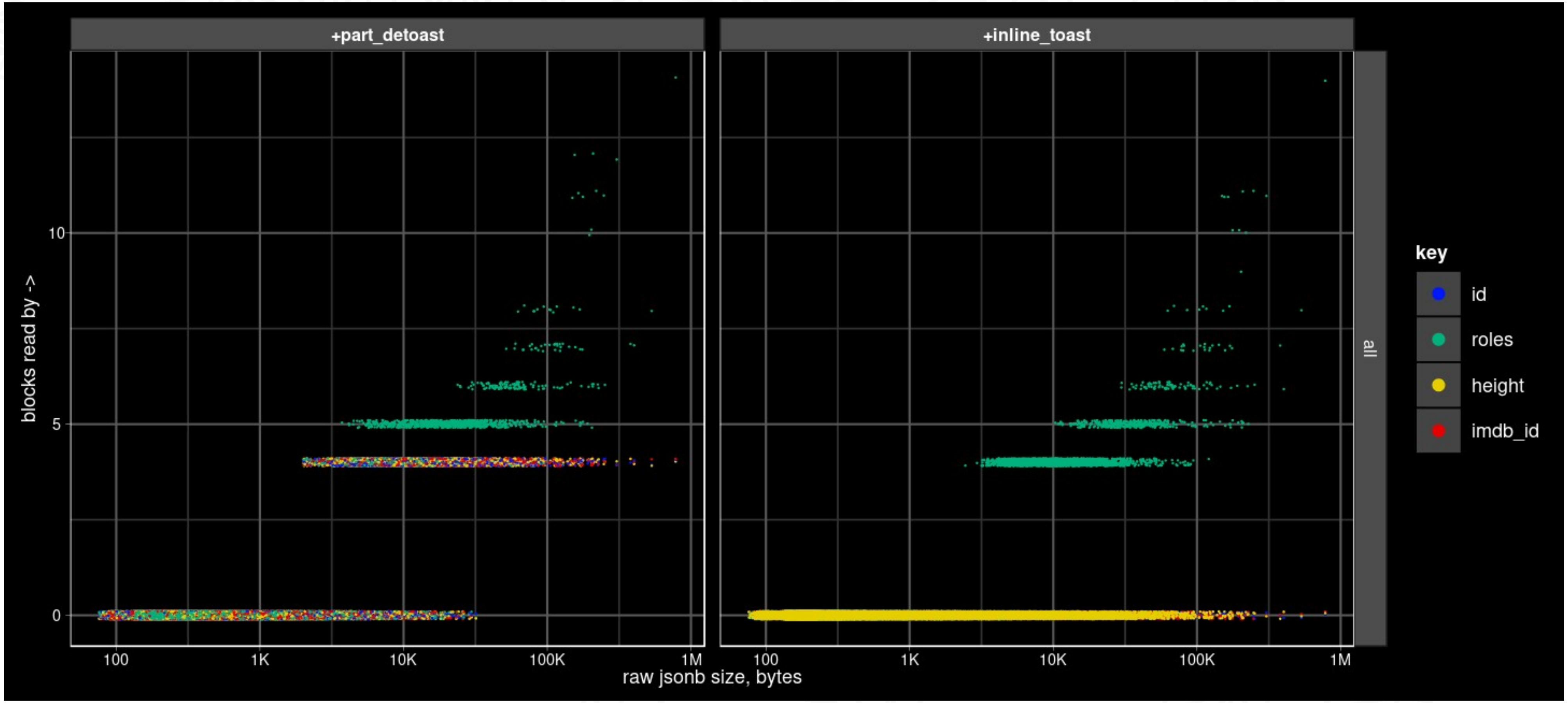
Inline TOAST results (IMDB)

- Effect of inline TOAST : Arrow operator (→) for short keys read no additional blocks.



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JSONB partial update

TOAST was originally designed for atomic data types, it knows nothing about internal structure of composite data types like jsonb, hstore, and even ordinary arrays.

TOAST works only with binary BLOBs, it does not try to find differencies between old and new values of updated attributes. So, when the TOASTed attribute is being updated (does not matter at the beginning or at the end and how much data is changed), its chunks are simply fully copied. The consequences are:

- TOAST storage is duplicated
- WAL traffic is increased in comparison with updates of non-TOASTED attributes, because the whole TOASTed values is logged
- Performance is too low

JSONB partial update: The problem

Example: table with 10K jsonb objects with 1000 keys `{ "1": 1, "2": 2, ... }`.

```
CREATE TABLE t AS
SELECT i AS id, (SELECT jsonb_object_agg(j, j) FROM generate_series(1, 1000) j) js
FROM generate_series(1, 10000) i;

SELECT oid::regclass AS heap_rel,
       pg_size_pretty(pg_relation_size(oid)) AS heap_rel_size,
       reltoastrelid::regclass AS toast_rel,
       pg_size_pretty(pg_relation_size(reltoastrelid)) AS toast_rel_size
FROM pg_class WHERE relname = 't';

 heap_rel | heap_rel_size |        toast_rel        | toast_rel_size
----------+---------------+-------------------------+----------------
 t        | 512 kB        | pg_toast.pg_toast_27227 | 78 MB
```

Each 19 KB jsonb is compressed into 6 KB and stored in 4 TOAST chunks.

```
SELECT pg_column_size(js) compressed_size, pg_column_size(js::text::jsonb) orig_size from t limit 1;
 compressed_size | original_size
-----------------+---------------
            6043 |         18904

SELECT chunk_id, count(chunk_seq) FROM pg_toast.pg_toast_47235 GROUP BY chunk_id LIMIT 1;
 chunk_id | count
----------+-------
    57241 |     4
```

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JSONB partial update: The problem

First, let's try to update of non-TOASTED int column id:

```
SELECT pg_current_wal_lsn(); --> 0/157717F0

UPDATE t SET id = id + 1; -- 42 ms

SELECT pg_current_wal_lsn(); --> 0/158E5B48

SELECT pg_size_pretty(pg_wal_lsn_diff('0/158E5B48','0/157717F0')) AS wal_size;
 wal_size
----------
 1489 kB   (150 bytes per row)

SELECT oid::regclass AS heap_rel,
       pg_size_pretty(pg_relation_size(oid)) AS heap_rel_size,
       reltoastrelid::regclass AS toast_rel,
       pg_size_pretty(pg_relation_size(reltoastrelid)) AS toast_rel_size
FROM pg_class
WHERE relname = 't';
 heap_rel | heap_rel_size |        toast_rel        | toast_rel_size
----------+---------------+-------------------------+----------------
 t        | 1024 kB       | pg_toast.pg_toast_47235 | 78 MB
            (was 512 kB)                              (not changed)
```

JSONB partial update: The problem

Next, let's try to update of TOASTED jsonb column js:

```
SELECT pg_current_wal_lsn(); --> 0/158E5B48

UPDATE t SET js = js – '1'; -- 12316 ms (was 42 ms, ~300x slower)

SELECT pg_current_wal_lsn(); --> 0/1DB10000

SELECT pg_size_pretty(pg_wal_lsn_diff('0/1DB10000','0/158E5B48')) AS wal_size;
 wal_size
----------
 130 MB    (13 KB per row; was 1.5 MB, ~87x more)

SELECT oid::regclass AS heap_rel,
       pg_size_pretty(pg_relation_size(oid)) AS heap_rel_size,
       reltoastrelid::regclass AS toast_rel,
       pg_size_pretty(pg_relation_size(reltoastrelid)) AS toast_rel_size
FROM pg_class
WHERE relname = 't';
 heap_rel | heap_rel_size |        toast_rel        | toast_rel_size
----------+---------------+-------------------------+---------------
 t        | 1528 kB       | pg_toast.pg_toast_47235 | 156 MB
            (was 1024 kB)                             (was 78 MB, 2x more)
```

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Partial update using Shared TOAST

- The previous optimizations are great for SELECT, but don’t help with UPDATE, since TOAST consider jsonb as an atomic binary blob – change part, copy the whole.
- Idea: Keep INLINE short fields (*uncompressed*) and TOAST pointers to long fields to let update short fields without modification of TOAST chunks, which will be shared between versions.
- Currently, this works only for root objects fields, so the longest fields of jsonb object are TOASTed until the whole tuple fits into the page (typically, remaining size of jsonb becomes < ~2000 bytes).
- But this technique can also be applied to array elements or element ranges. We plan to try to implement it later, it needs more invasive jsonb API changes.
- Currently, jsonb hook is hardcoded into TOAST pass #1, but in the future it will become custom datatype TOASTer using `pg_type.typtoast`.

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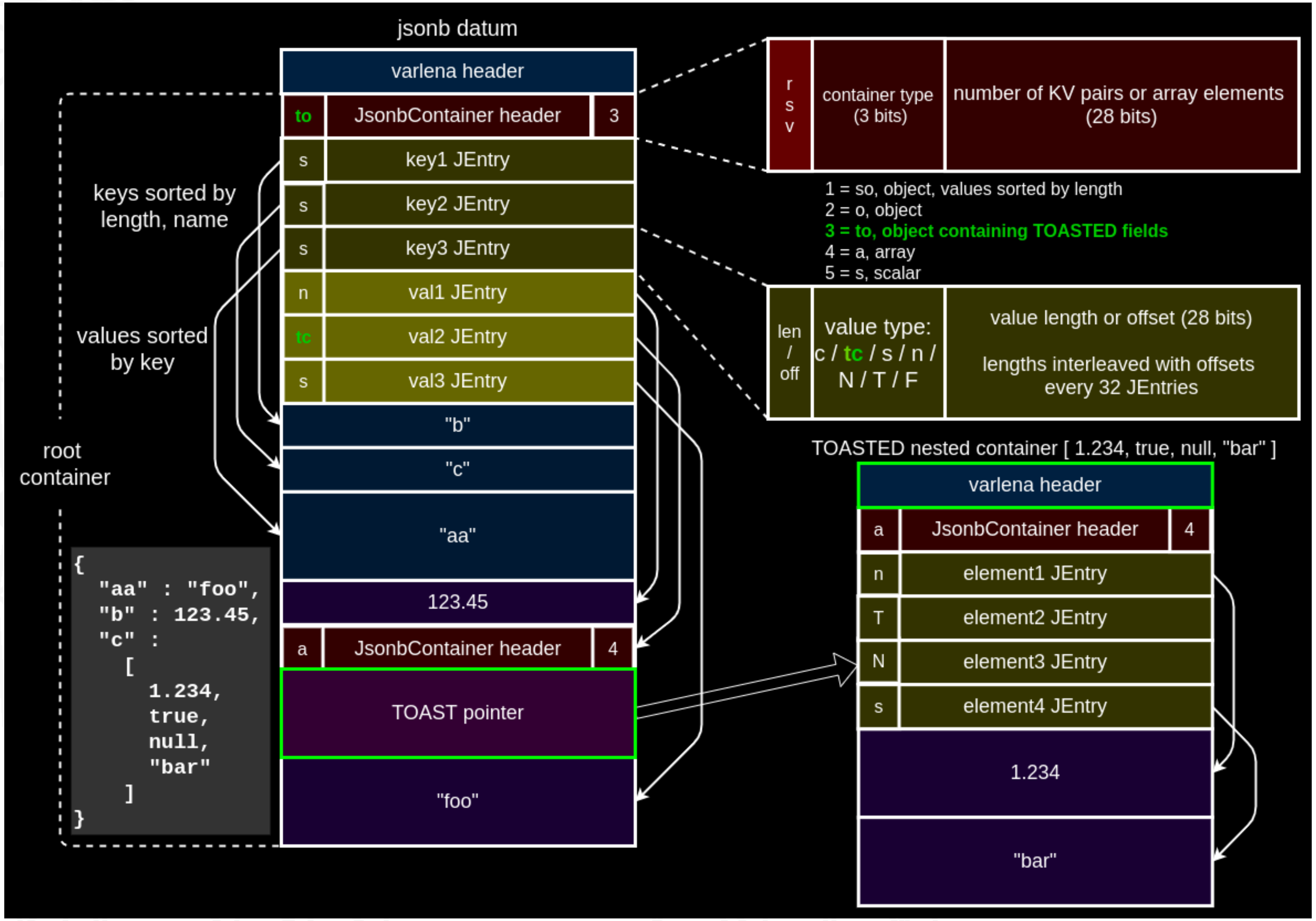
Shared TOAST – jsonb format extensions

- Added special "TOASTed container" `JEntry` type. `JsonbContainer` header is left inline, but the body is replaced with a pointer.
- Added "TOASTed object" `JsonbContainer` type to mark object with TOAST pointers.
- TOASTed subcontainers are stored as plain jsonb datums (`varlena` header added).



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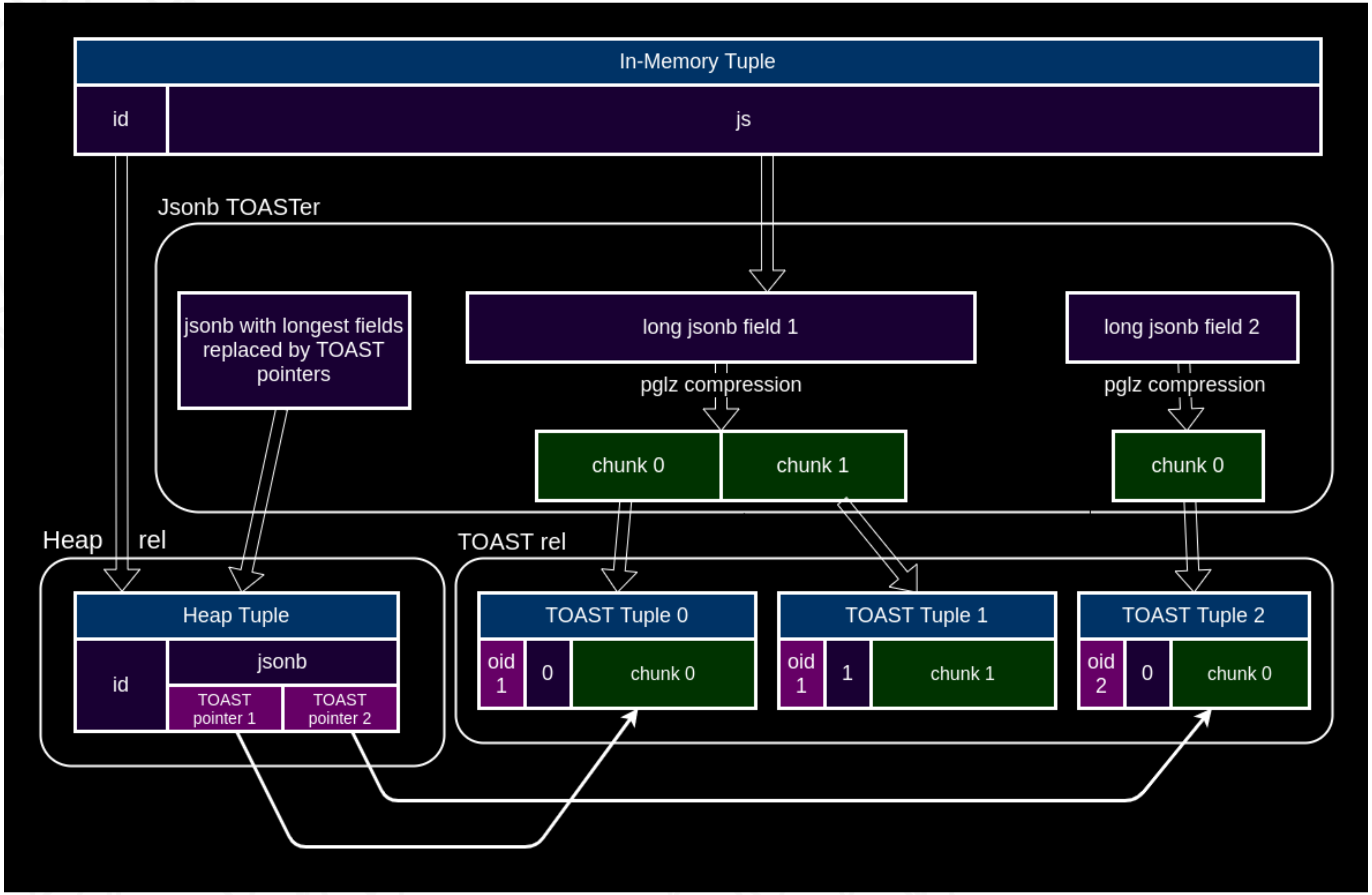
Shared TOAST – tuple structure

- In this example two largest fields of jsonb are TOASTed separately
- TOASTed jsonb contains two TOAST pointers
- Operators like -> can simply return TOAST pointer as external datum, accessing only the inline part of jsonb



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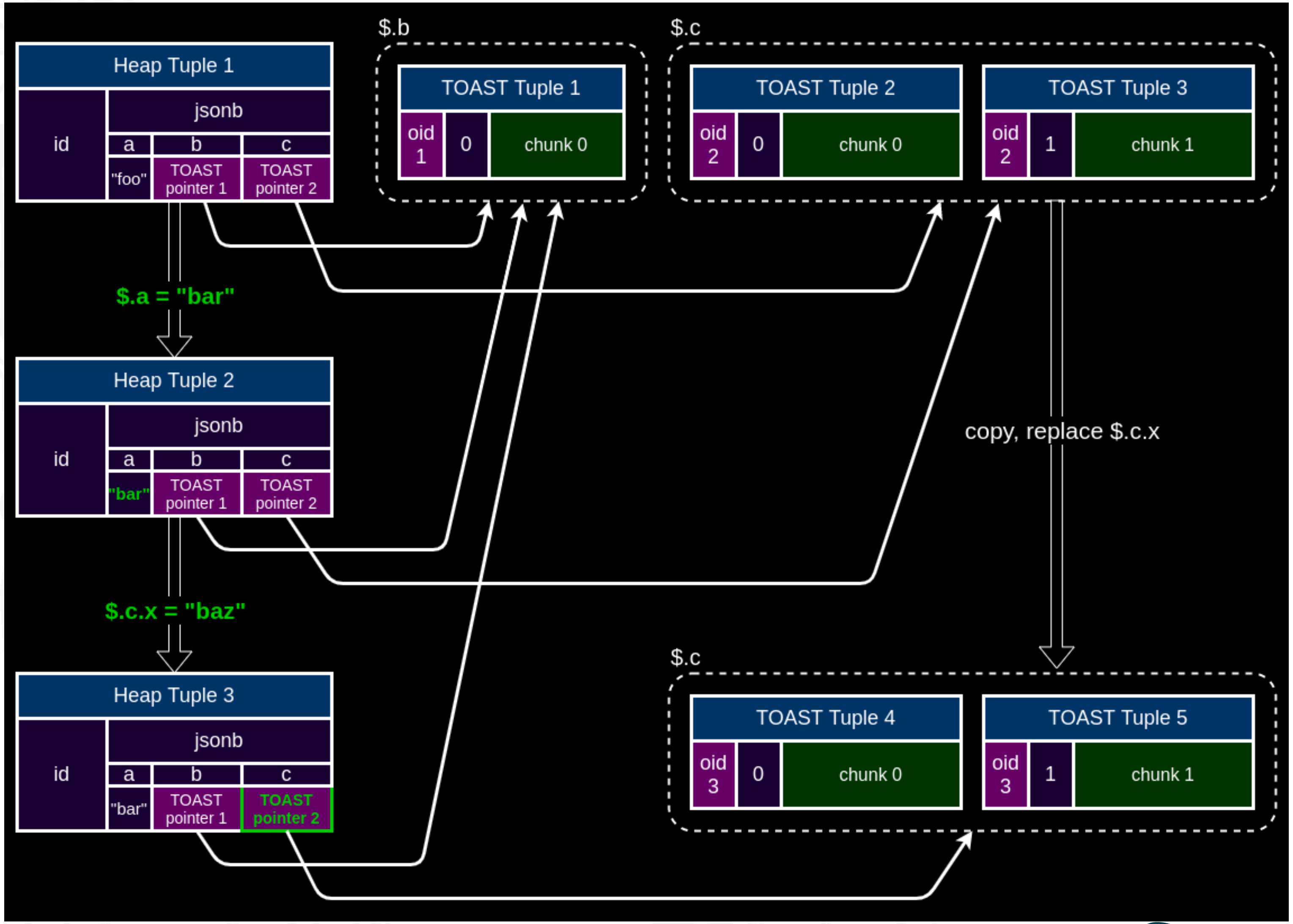
Shared TOAST – update

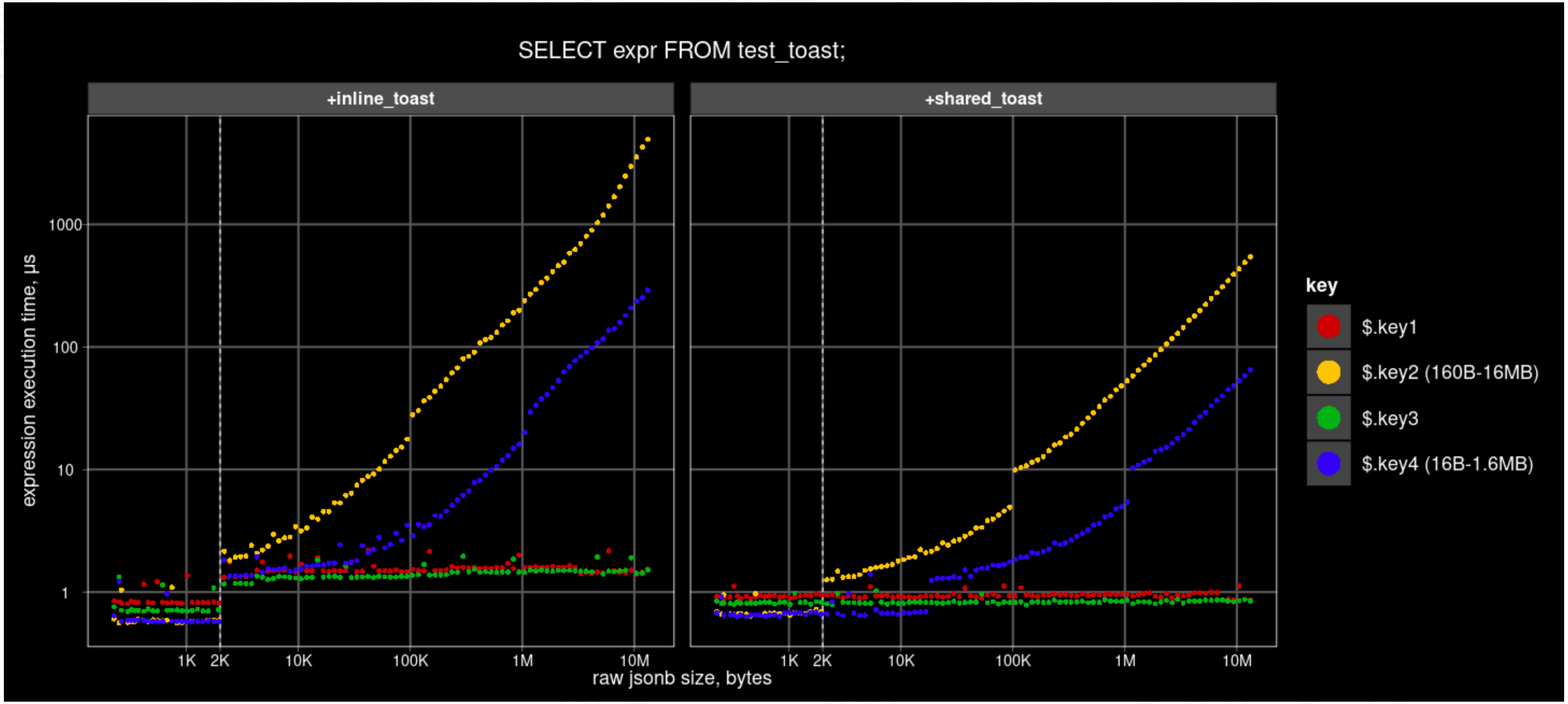
- When the short inline field is updated, only the new version of inline data is created.
- When some part of the long field is updated, the whole container is copied, updated and then TOASTed back with new oid (in the future oids can be shared).
- Unchanged TOASTed fields are always shared.



PostgresPro

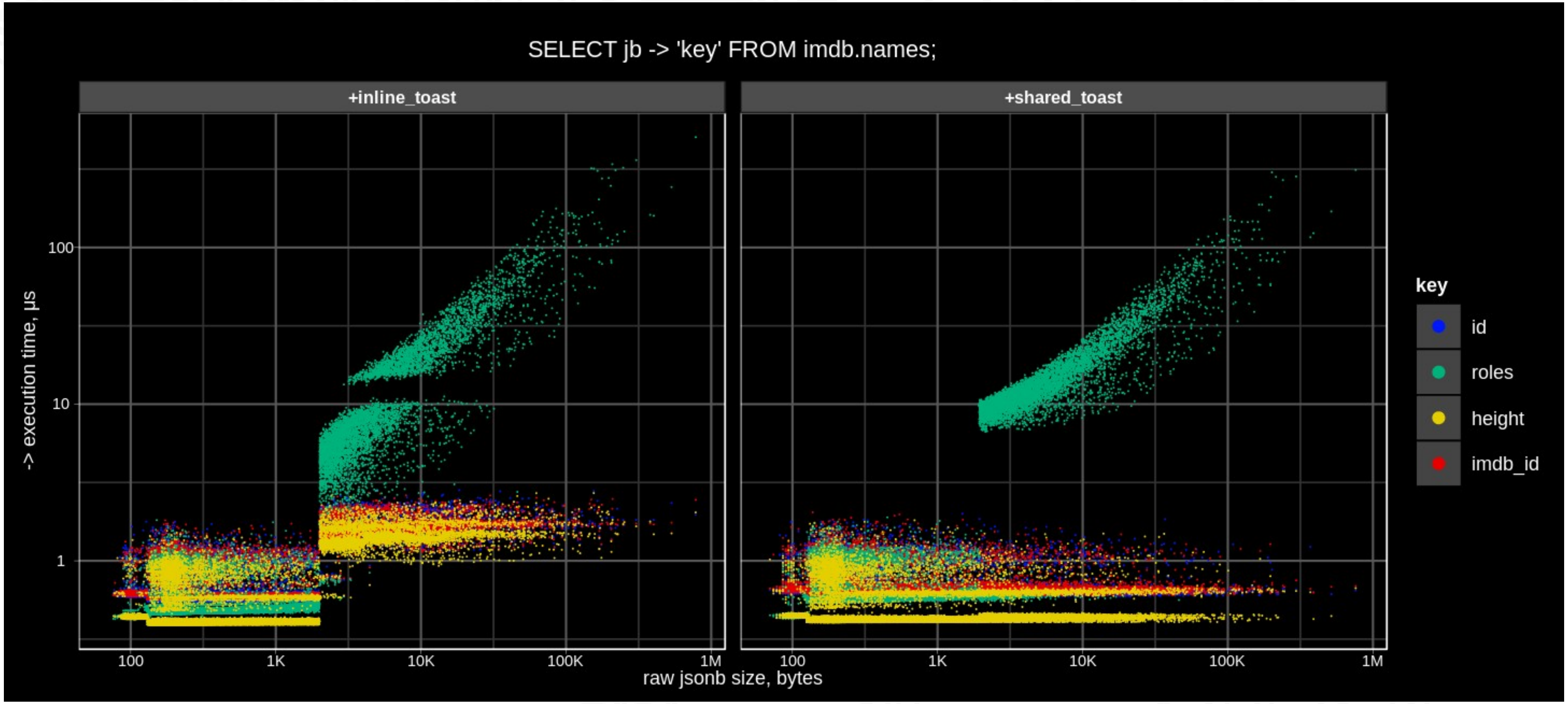
Shared TOAST – access results (synthetic)

Gap in access time to short keys has completely removed. Mid-size fields are stored compressed inline inside the jsonb. Long fields are compressed and TOASTed.



Shared TOAST – access results (IMDB)

- Results are the same as in synthetic test.
- Access to all short keys has improved.



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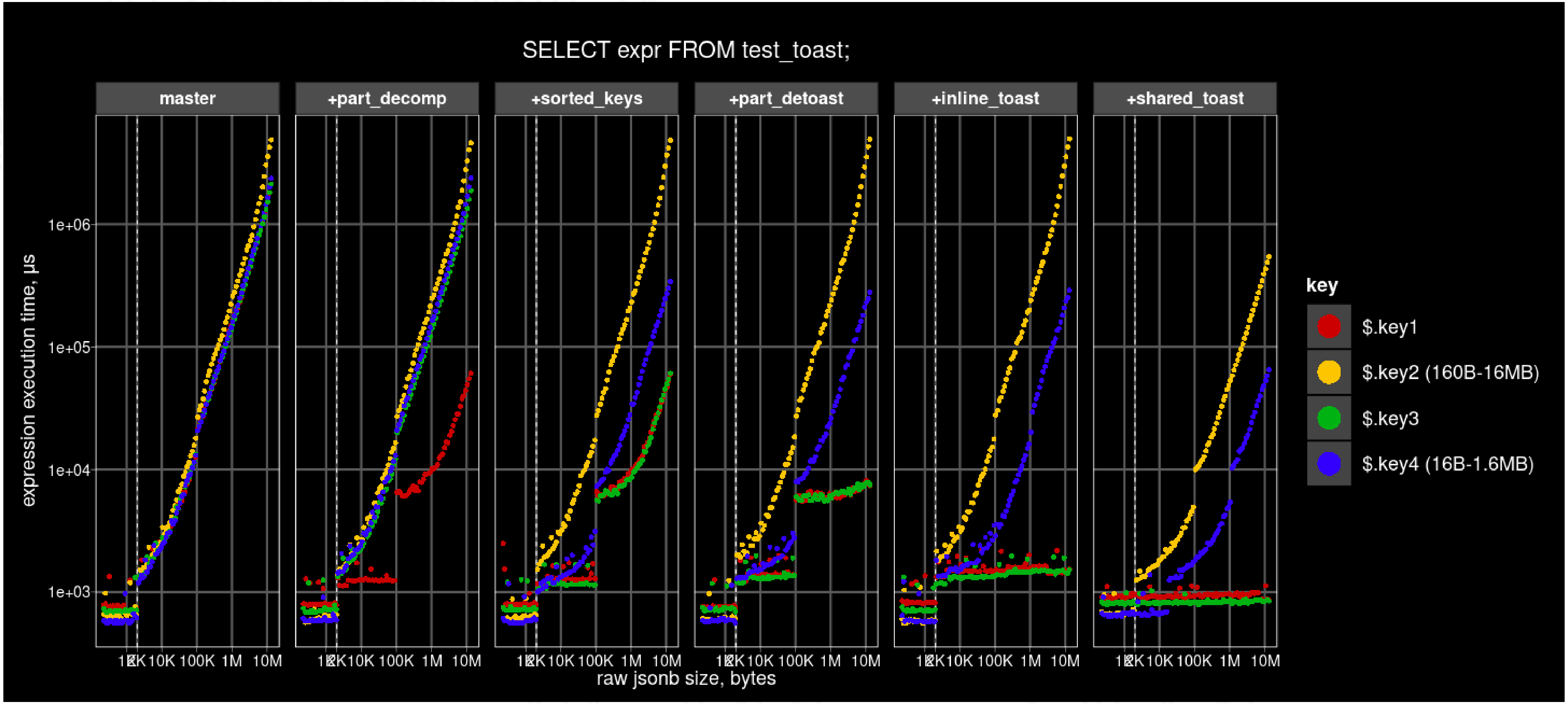
Step-by-step results (access key,synthetic)



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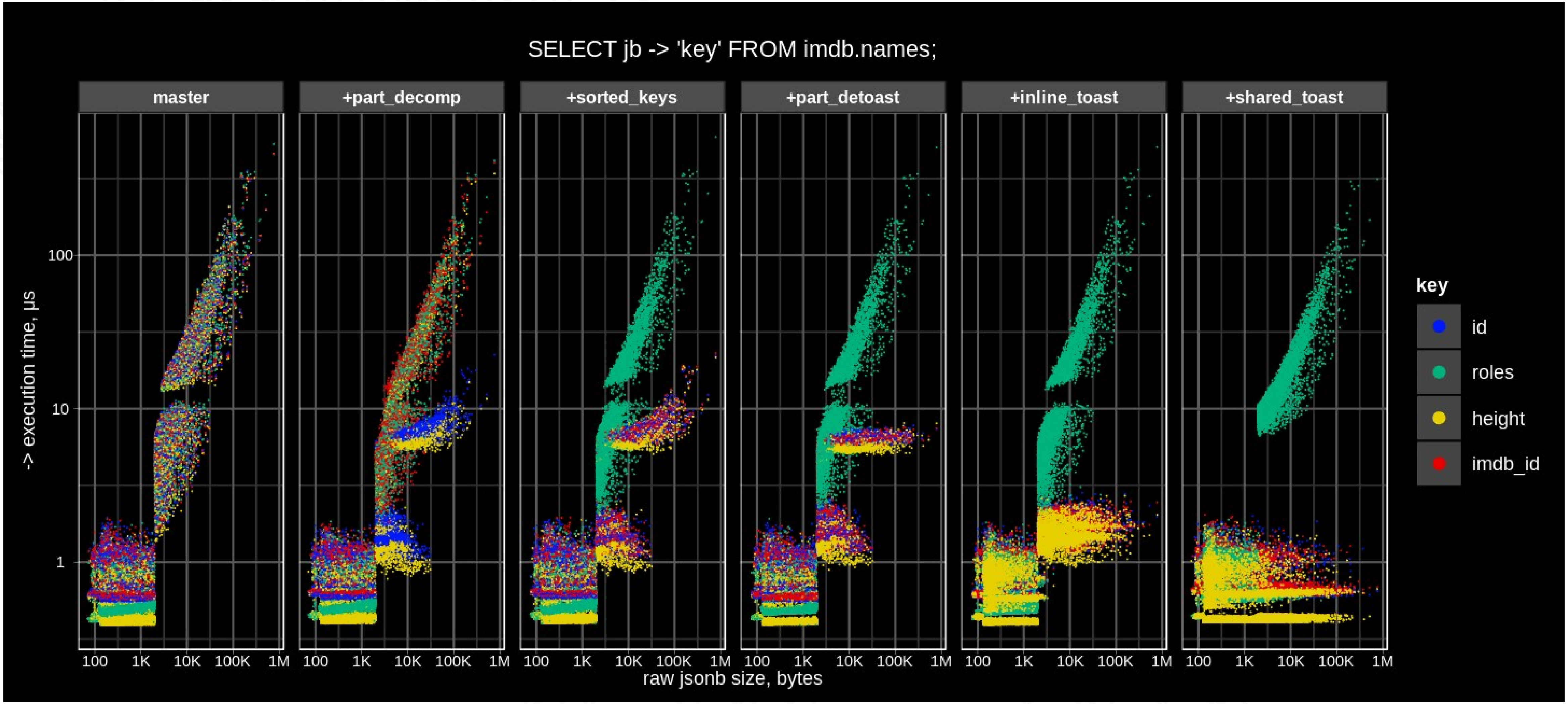
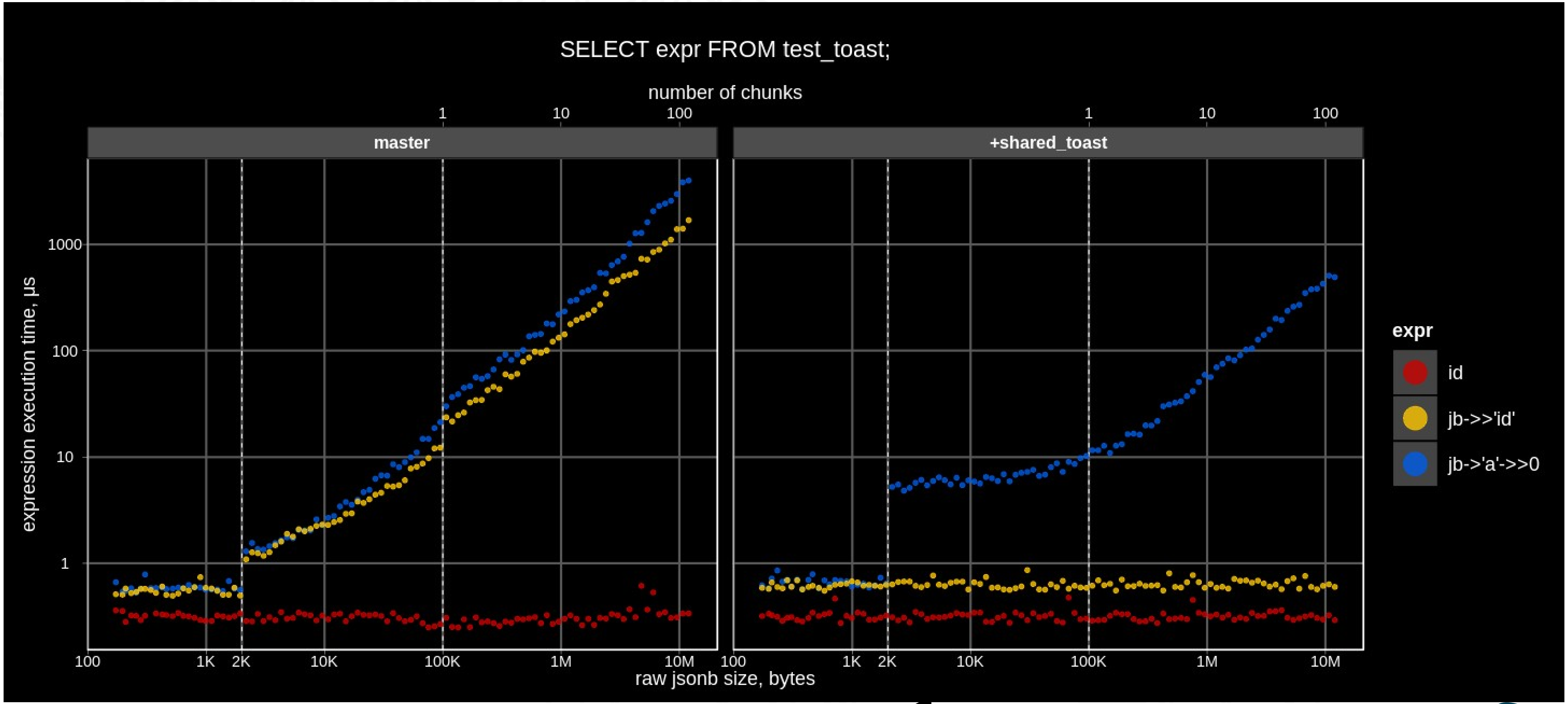
Step-by-step results (access key, IMDB)



PostgresPro

Popular mistake: CREATE TABLE qq (jsonb)

(id, {...}::jsonb) vs ({id,...}::jsonb)

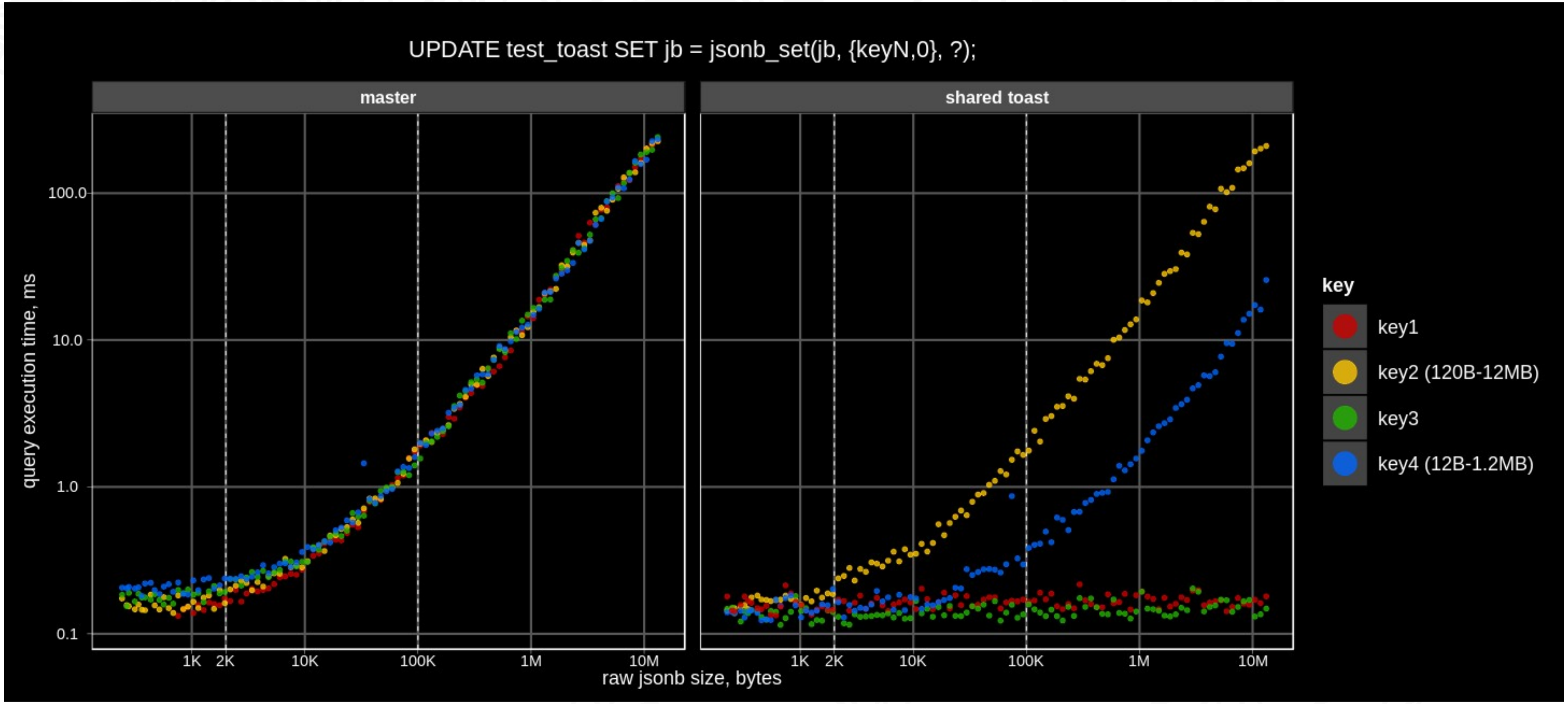


Large jsonb is TOASTed !

PostgresPro

Shared TOAST – update results (synthetic)

- Update time of short keys <u>does not depend</u> on total jsonb size
- Update time of TOASTed fields <u>depends only on their own size</u>



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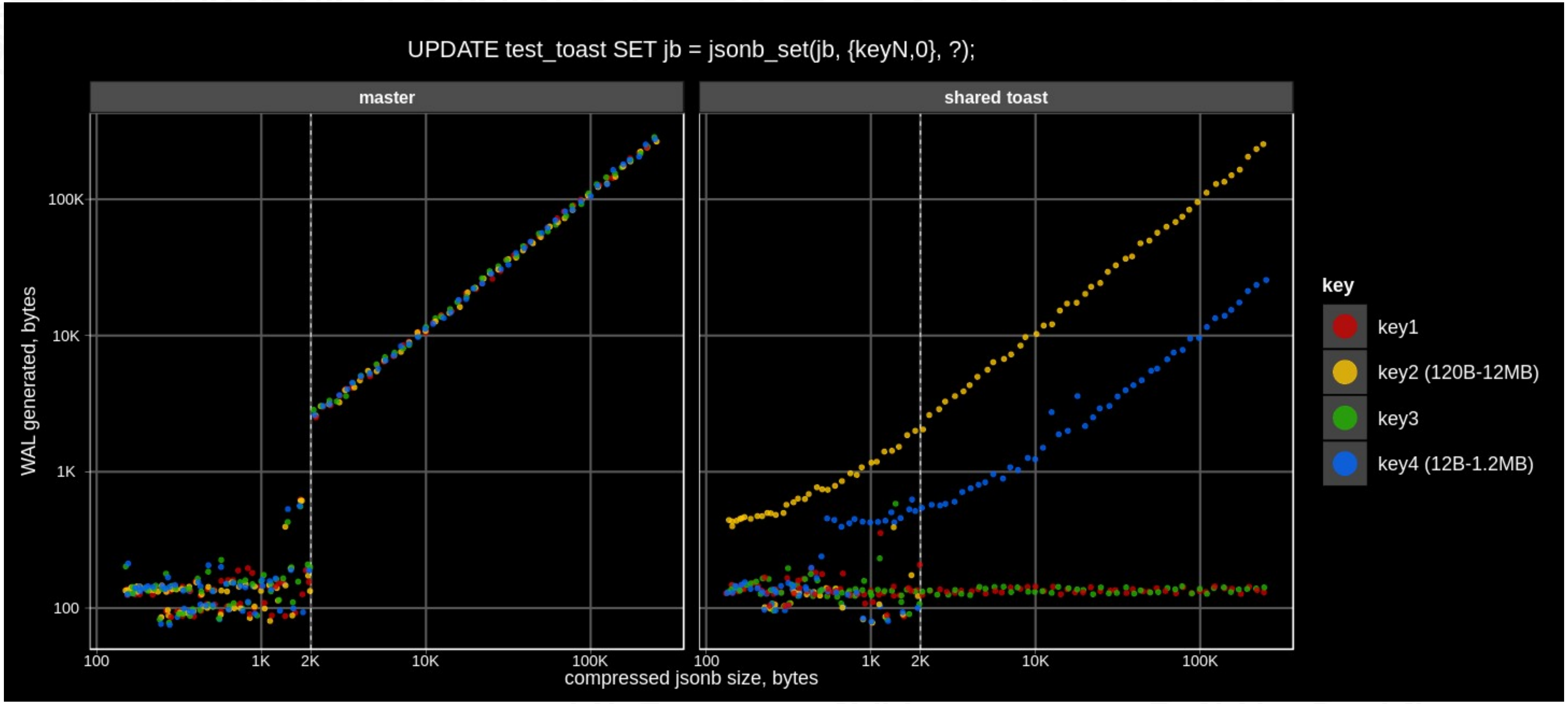
Shared TOAST – update results (synthetic)

- WAL traffic due to update of short and mid-size keys has greatly decreased



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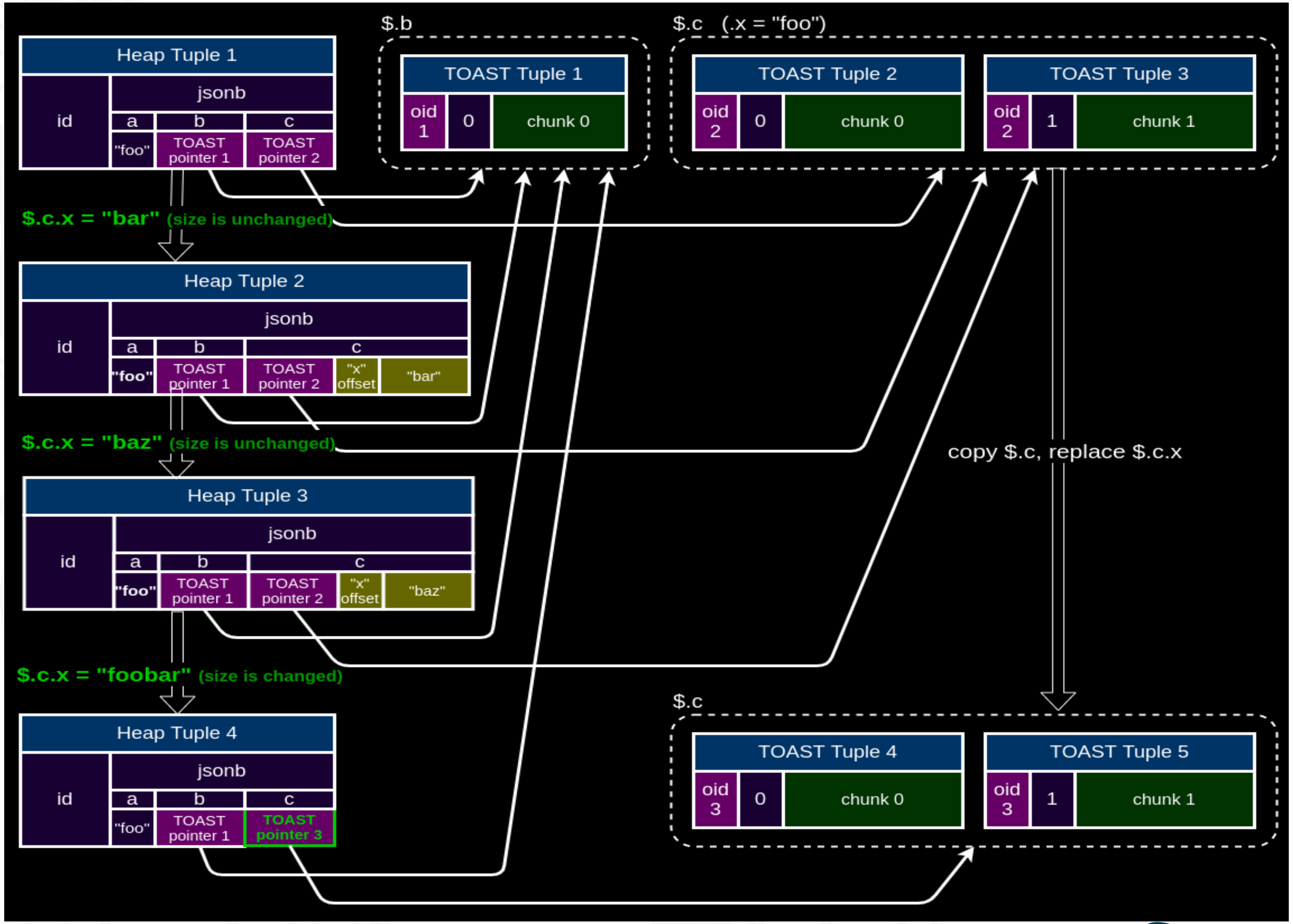
Shared TOAST – in-place updates

- Copying of shared TOASTs can be avoided when the size and type of updated part is not changed – there is no need to rewrite JEntries, only the value needs to be replaced
- jsonb_set() checks this special case accessing only the minimal header part needed for fetching offset, length and type of the old value
- If the length is not changed, created “diff” TOAST pointer with offset and new value



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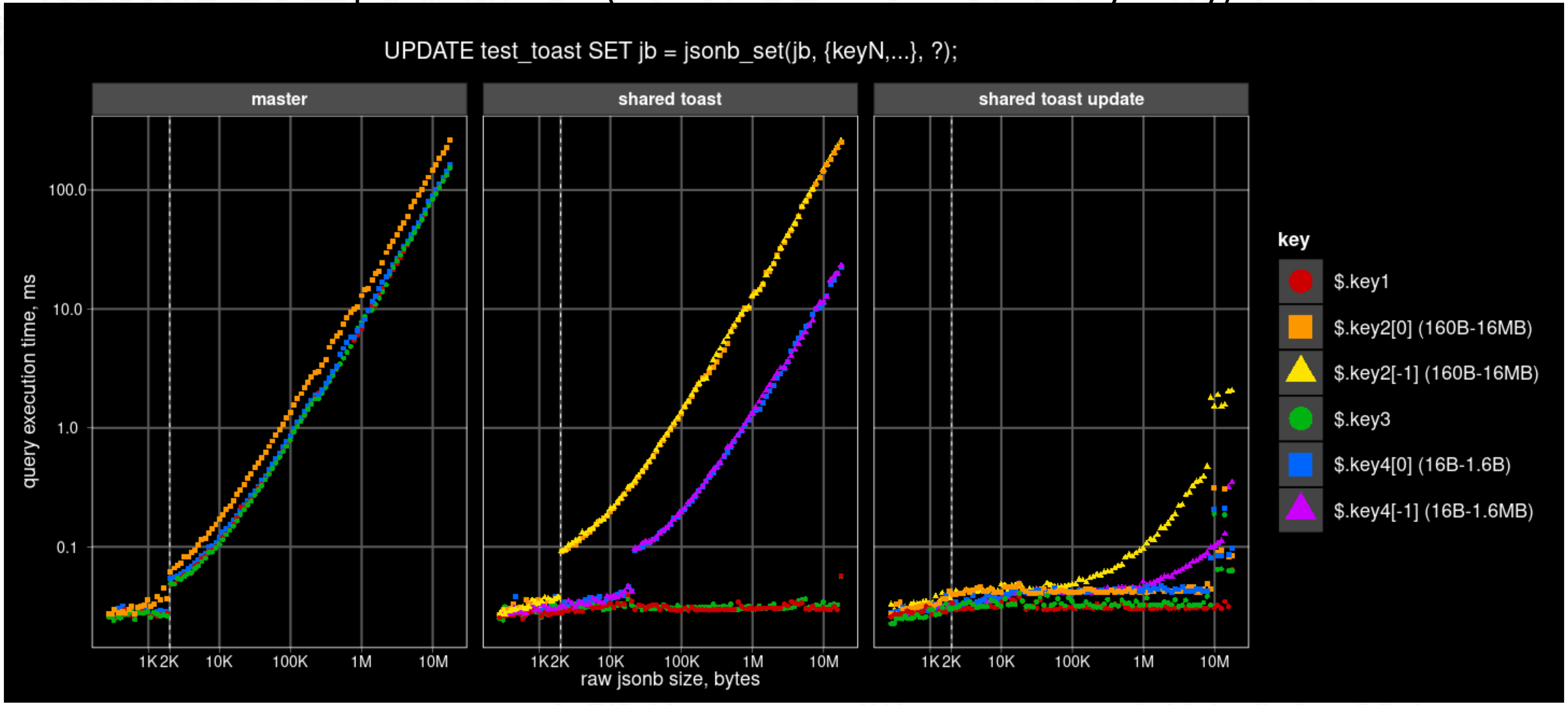
Shared TOAST – in-place update results (synthetic)

Update time of array elements depends on their position:

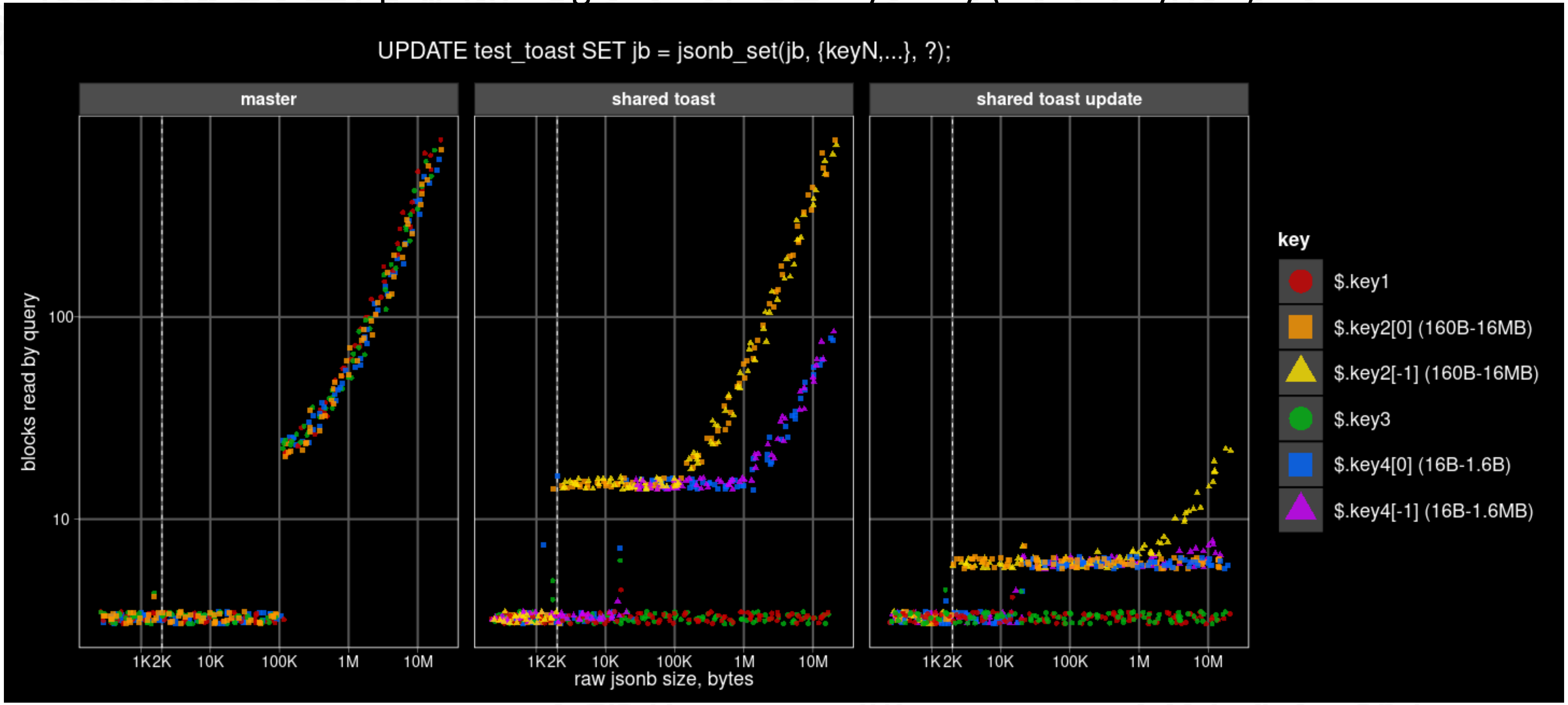
- first elements updated very fast (like inline fields)
- last elements updated slower (need to read the whole JEntry array)



Shared TOAST – in-place update results (synthetic)

Number of blocks read depends on element position:

- first elements do not require reading of additional blocks
- last elements require reading the whole JEntry array (4B * array size)



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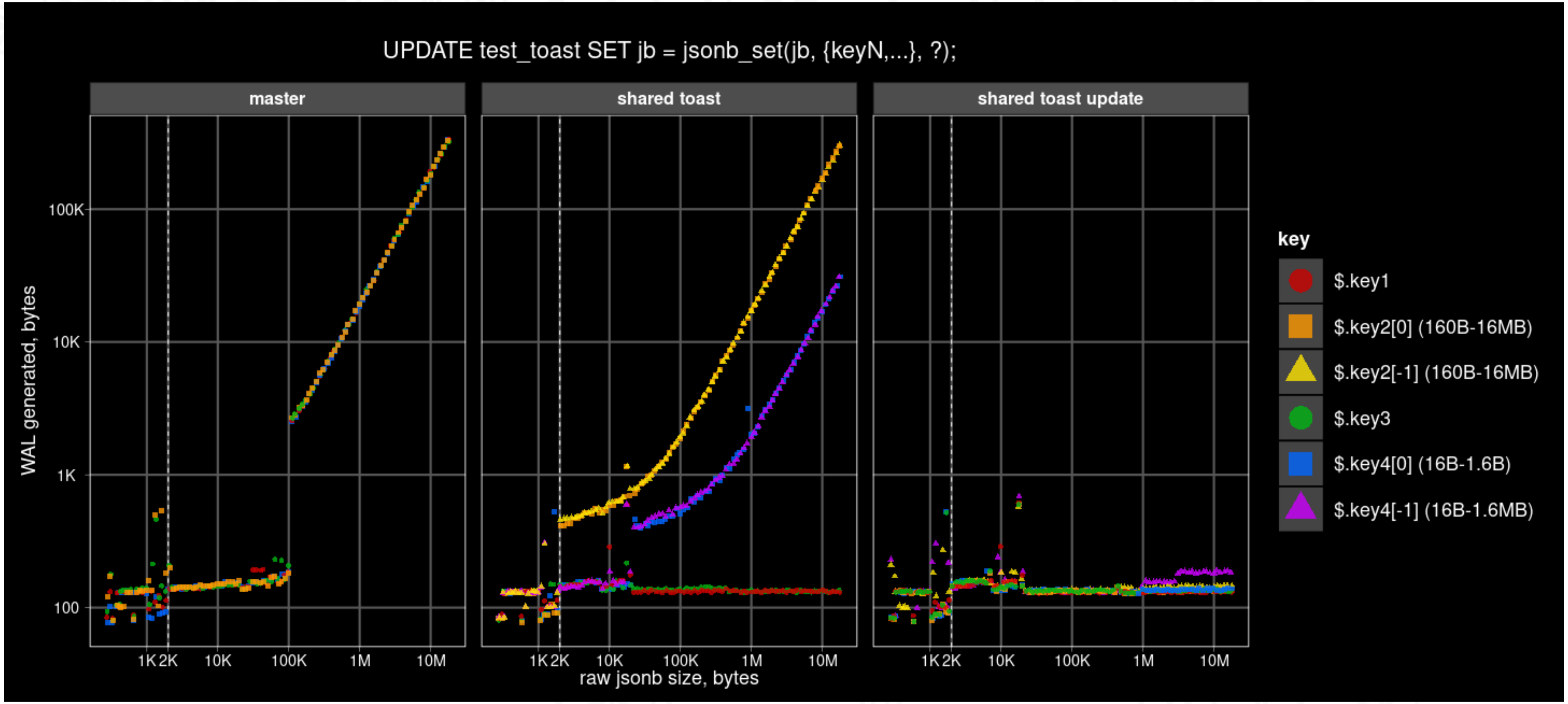
Shared TOAST – in-place update results (synthetic)

- WAL size of in-place updates is <u>almost independent</u> on element position
- Only inline data with TOAST pointer diff are logged



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Conclusions

A sequence of rather simple and straightforward algorithms and storage optimizations based on GSON API, without any major changes to the JSONB API, have lead to significant performance improvements (10X speedup for SELECT and much cheaper UPDATEs):

- Popular jsonb workload (short metadata and large data) has greatly improved.
- Accumulation of diffs for incremental updates and storing them inline looks promising for updates of TOASTed containers.
- Github: https://github.com/postgrespro/postgres/tree/jsonb_shared_toast
- Slides of this talk (PDF)
- The same optimizations can be applied to any data types with random access to parts of data (arrays, hstore, movie, pdf …). See example for appendable bytea in ADDENDUM.

- Jsonb is ubiquitous and is continuously developing
  - JSON[B] Roadmap V2, Postgres Professional Webinar, Sep 17, 2020
  - JSON[B] Roadmap V3, Postgres Build 2020, Dec 8, 2020

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TODO

- We need to support uniform access to nested objects and array elements and their updates, probably, use versioned tree-like structures on TOAST chunks. Currently, with simple linear chain of TOAST chunks:
    - Access time for nested elements depends on their depth in case of nested TOASTing, because one have to read from TOAST the whole chain of container headers
    - In-place updates of elements of long arrays depends on their position, so the update of the last elements is slower than update of the first elements.
    - Think about of versioned tree-like structures on TOAST chunks. Simple linear TOAST chains are not sufficient for this.
- Optimization of incremental updates (x=1, y=2, x=0…)
- Non-in-inplaced updates, as well as insertion and removal of elements/fields without total copying are not yet optimized.
- More benchmarks

Contact obartunov@postgrespro.ru, n.gluhov@postgrespro.ru for collaboration.

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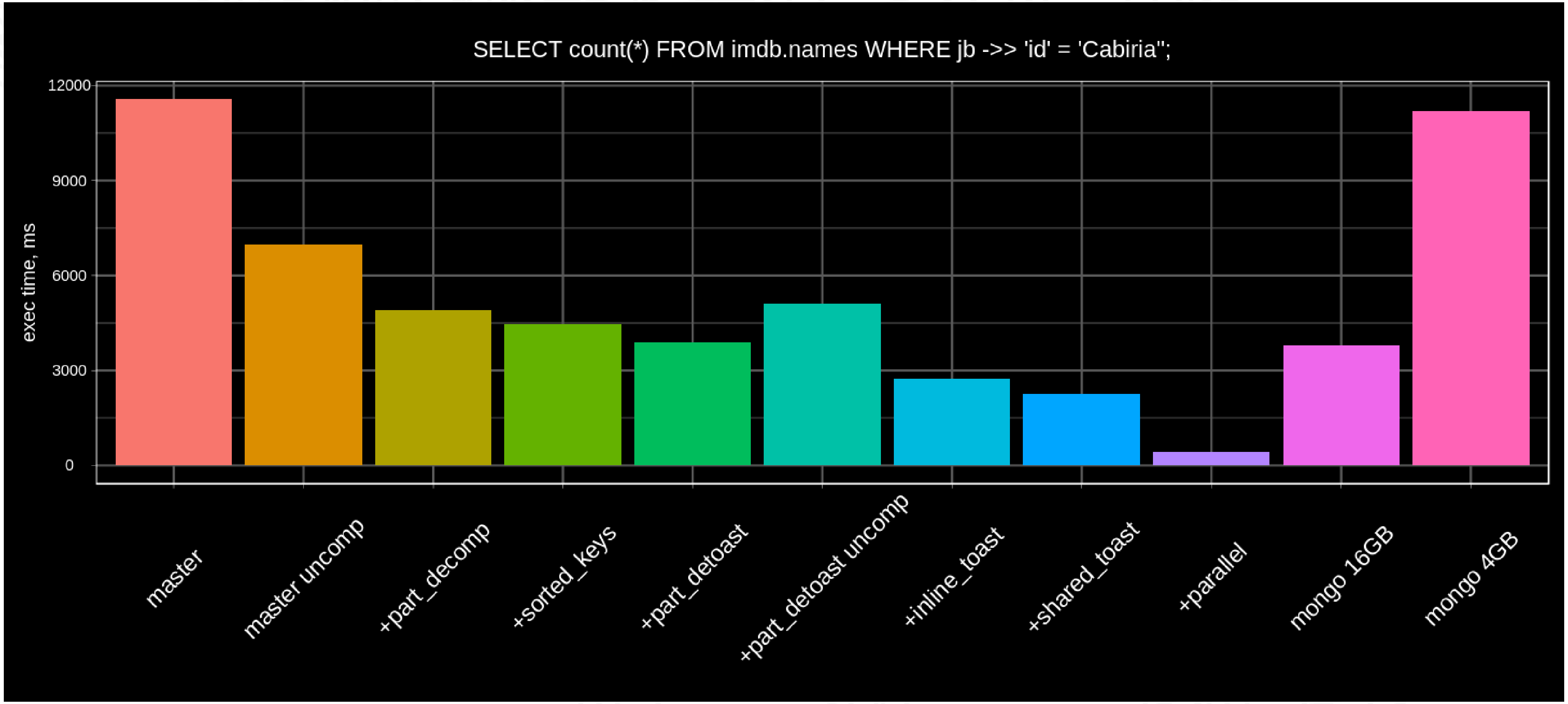
Non-scientific comparison PG vs Mongo

- Seqscan, PG - in-memory, Mongo (4.4.4): 16Gb (in-memory), 4GB (1/2)



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ALL
YOU
NEED
POSTGRES
IS

Unpredictable performance of jsonb

Small update cause 10 times slowdown !

```
CREATE TABLE test (jb jsonb);
ALTER TABLE test ALTER COLUMN jb SET STORAGE EXTERNAL;
INSERT INTO test
SELECT
  jsonb_build_object(
  'id', i,
  'foo', (select jsonb_agg(0) from generate_series(1, 1960/12)) -- [0,0,0, ...]
  ) jb
FROM
  generate_series(1, 10000) i;
```

```
=# EXPLAIN(ANALYZE, BUFFERS) SELECT jb->'id' FROM test;
                                QUERY PLAN
-------------------------------------------------------------------------------------------------------
 Seq Scan on test  (cost=0.00..2625.00 rows=10000 width=32) (actual time=0.014..6.128 rows=10000 loops=1)
   Buffers: shared hit=2500
 Planning:
   Buffers: shared hit=5
 Planning Time: 0.087 ms
 Execution Time: 6.583 ms
(6 rows)

 =# UPDATE test SET jb = jb || '{"bar": "baz"}';
 =# VACUUM FULL test; -- remove old versions

=# EXPLAIN (ANALYZE, BUFFERS) SELECT jb->'id' FROM test;
                                QUERY PLAN
-------------------------------------------------------------------------------------------------------
 Seq Scan on test  (cost=0.00..2675.40 rows=10192 width=32) (actual time=0.067..65.511 rows=10000 loops=1)
   Buffers: shared hit=30064
 Planning Time: 0.044 ms
 Execution Time: 66.889 ms
(4 rows)
```

Row gets TOASTed ! See ADDENDUM for details

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The Curse of TOAST

- Original JSONBs stored inline in heap tuples (2500 pages with 4 tuples per page):

```
CREATE EXTENSION pageinspect;
SELECT lp_len FROM heap_page_items(get_raw_page('test', 0));
 lp_len
--------
   2022
   2022
   2022
   2022
(4 rows)
```

- JSONBs after update became larger than 2K and postgres replaced them by pointer to special TOAST relation (see TOAST explained in ADDENDUM), so the tuple length is greatly decreased (64 pages with 157 tuples per page):

```
SELECT lp_len FROM heap_page_items(get_raw_page('test', 0));
 lp_len
--------
     42
     42
    ...
     42
(156 rows)
```

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The Curse of TOAST

- JSONB data has moved into TOAST relation:

```
SELECT reltoastrelid::regclass toast_rel FROM pg_class
WHERE oid = 'test'::regclass;
        toast_rel
-------------------------
 pg_toast.pg_toast_16460
(1 row)
```

- Each JSONB is splitted into two TOAST chunks, that implicitly joined by index to attribute, when its value is fetched. Chunks belonging to the one attribute has the same `chunk_id`, which stored in TOAST pointer:

```
SELECT chunk_id, chunk_seq, length(chunk_data) FROM pg_toast.pg_toast_16460;
 chunk_id | chunk_seq | length
----------+-----------+--------
    16466 |         0 |   1996
    16466 |         1 |     10
    16467 |         0 |   1996
    16467 |         1 |     10
                  ...
 (20000 rows)
```

The Curse of TOAST

- Access to TOASTed JSONB requires reading at least 3 additional buffers:
  - 2 TOAST index buffers (B-tree height is 2)
  - 1 TOAST heap buffer
    - 2 chunks read from the same page, if JSONB size > Page size (8Kb), then more TOAST heap buffers

```
EXPLAIN (ANALYZE, BUFFERS, COSTS OFF, TIMING OFF)
SELECT jb->'id' FROM test;

                   QUERY PLAN
-----------------------------------------------
 Seq Scan on test (actual rows=100 loops=1)
   Buffers: shared hit=30064
         Buffers: shared hit=301
 Planning Time: 0.186 ms
 Execution Time: 56 ms
(6 rows)
```

Table	TOAST
64 buffers +	3 buffers*10000

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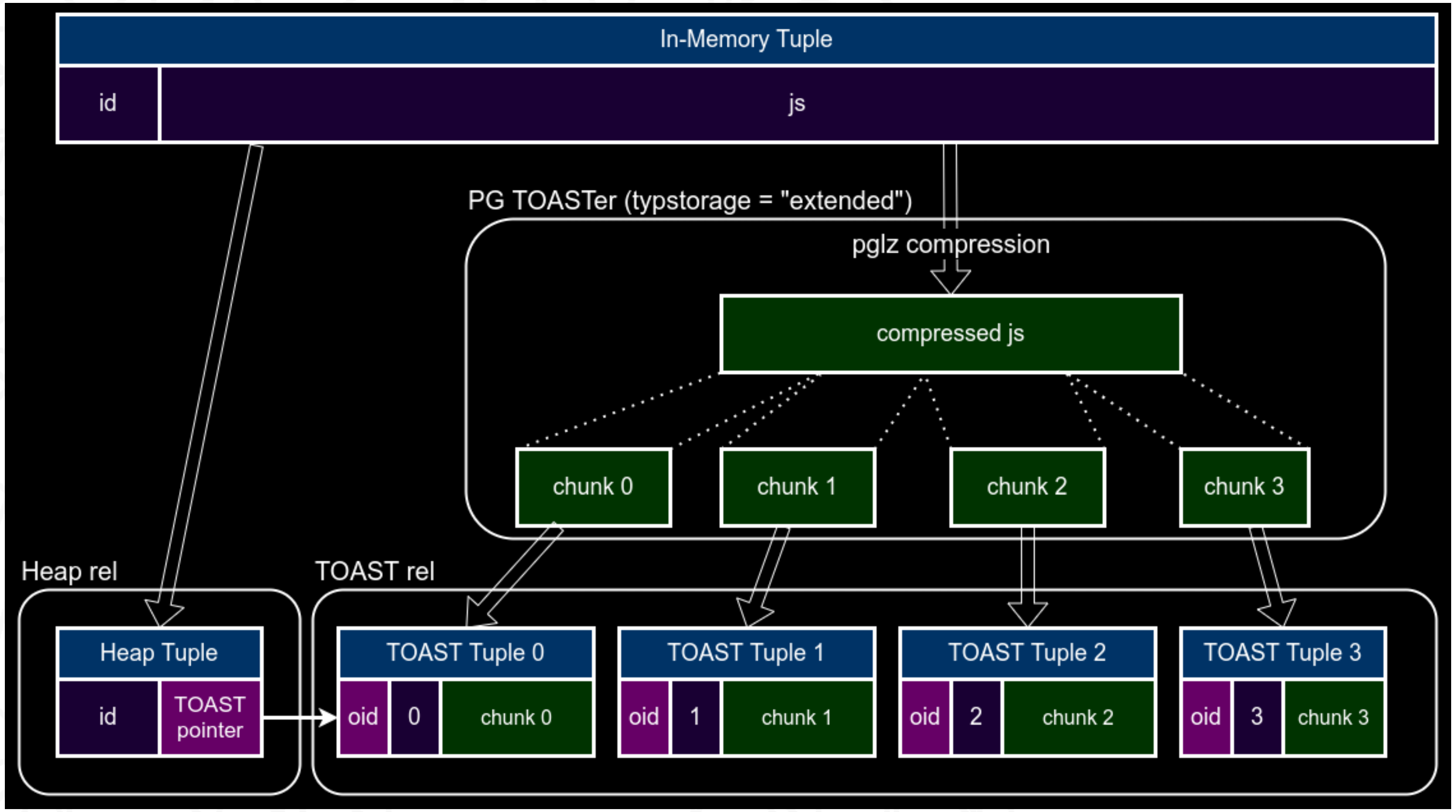
TOAST Explained

The Oversized-Attribute Storage Technique

- TOASTed (large field) values are compressed, then splitted into the fixed-size TOAST chunks (1996B for 8KB page)

- TOAST chunks (along with generated Oid `chunk_id` and sequnce number `chunk_seq`) stored in special TOAST relation `pg_toast.pg_toast_XXX`, created for each table containing TOASTable attributes

- Attribute in the original heap tuple is replaced with TOAST pointer (18 bytes) containing `chunk_id, toast_relid, raw_size, compressed_size`



https://www.postgresql.org/docs/current/storage-toast.html

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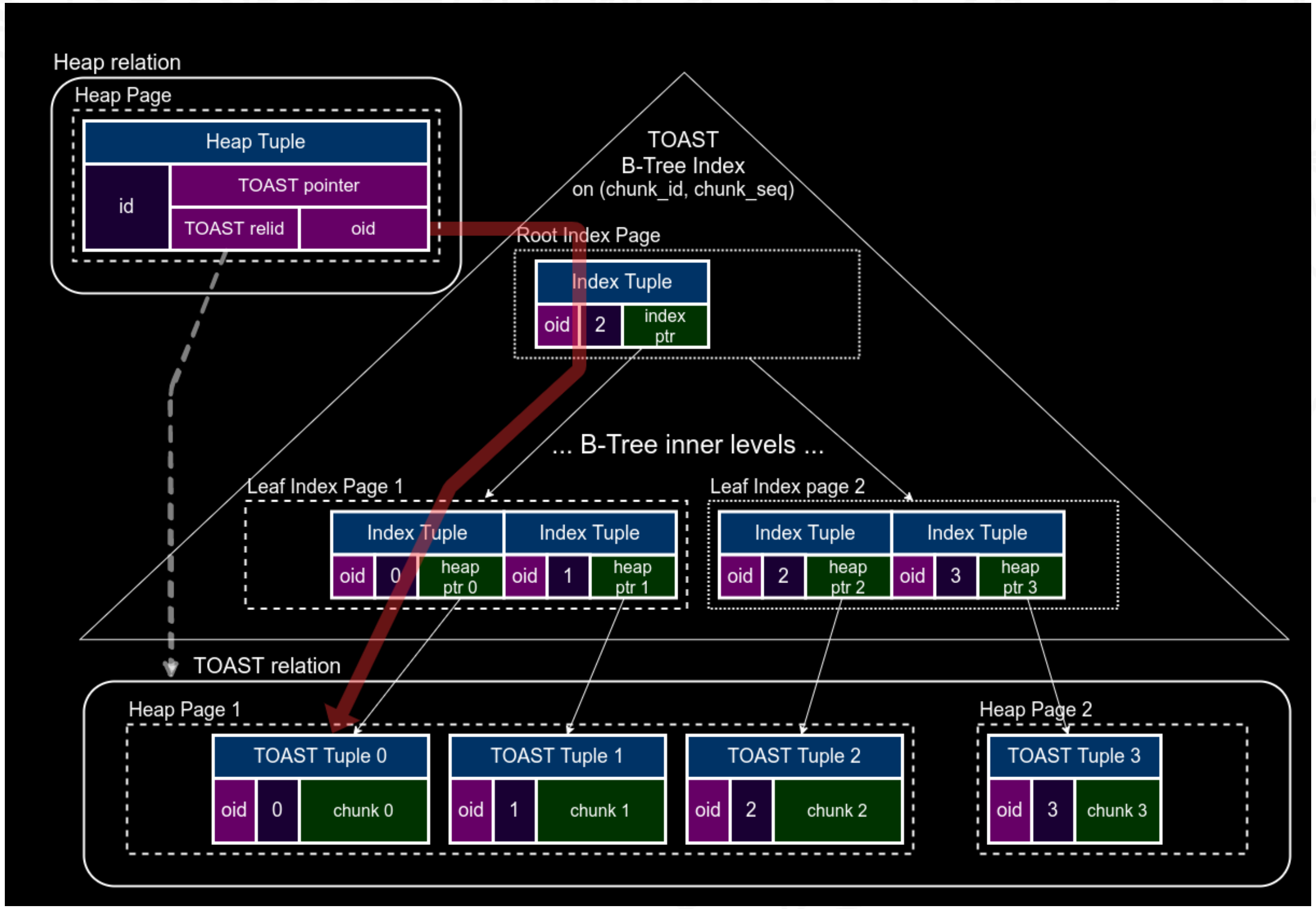
TOAST access

- TOAST pointers does not refer to heap tuples with chunks directly. Instead they contains Oid `chunk_id`, so one need to descent by index (`chunk_id`, `chunk_seq`).



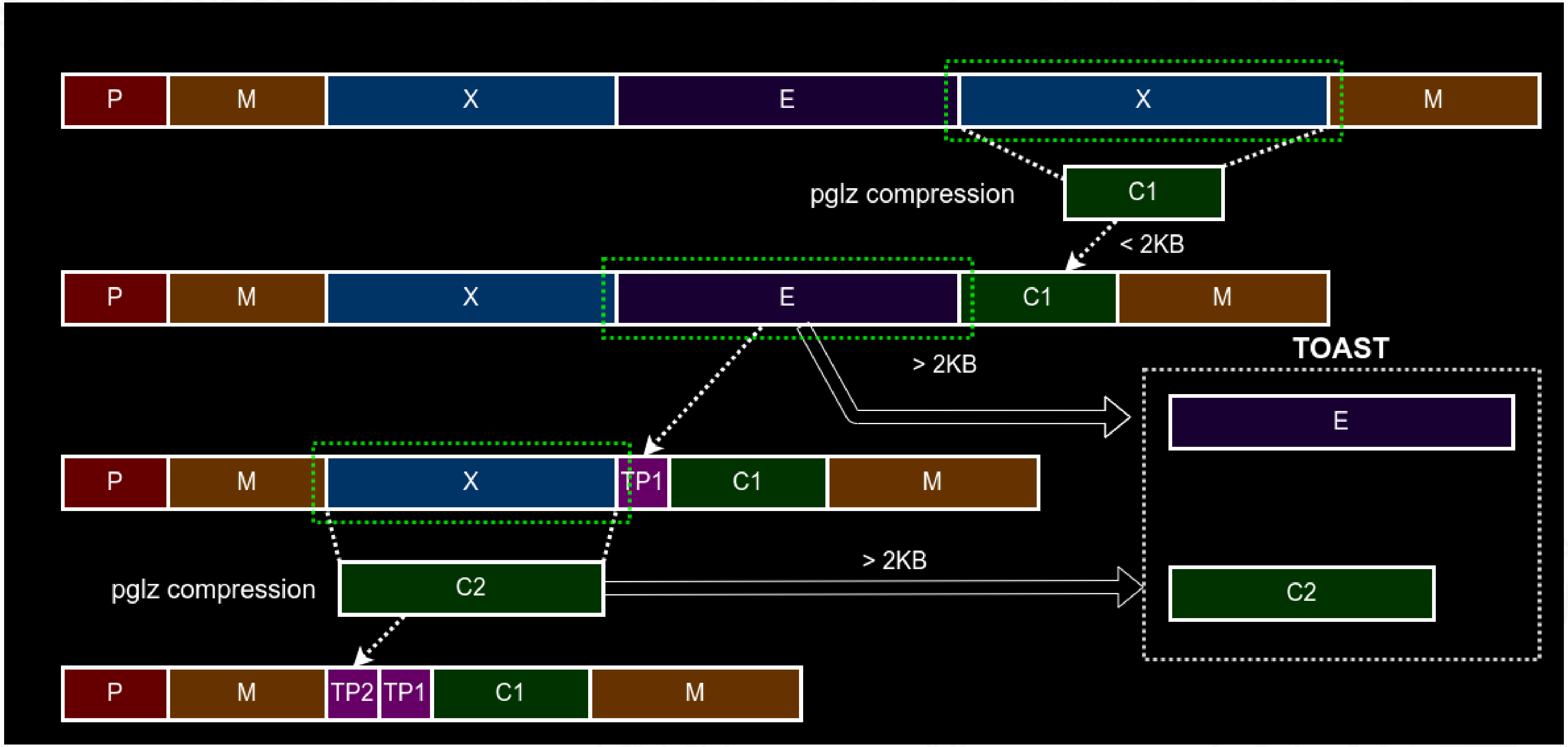
Overhead to read only a few bytes from the first chunk is 3,4 or even 5 additional index blocks.

TOAST passes

- Tuple is TOASTed if its size is more than 2KB (1/4 of page size).
- There are 4 TOAST passes.
- At the each pass considered only attributes of the specific storage type (extended/external or main) starting from the largest one.
- Plain attributes are not TOASTed and not compressed at all.
- The process can stop at every step, if the resulting tuple size becomes less than 2KB.
- If the attributes were copied from the other table, they can already be compressed or TOASTed.
- TOASTed attributes are replaced with TOAST pointers.

TOAST pass #1

- Only "extended" and "external" attributes are considered, "extended" attributes are compressed. If their size is more than 2KB, they are TOASTed.



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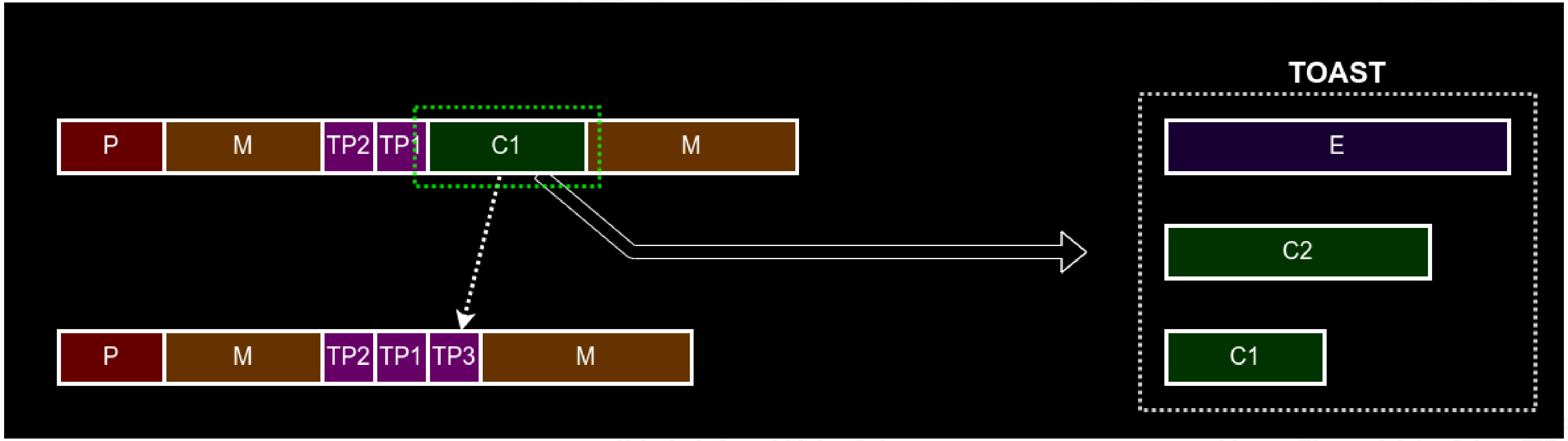
TOAST pass #2

- Only "extended" and "external" attributes (that were not TOASTed in the previous pass) are considered.
- Each attribute is TOASTed, until the resulting tuple size < 2KB.



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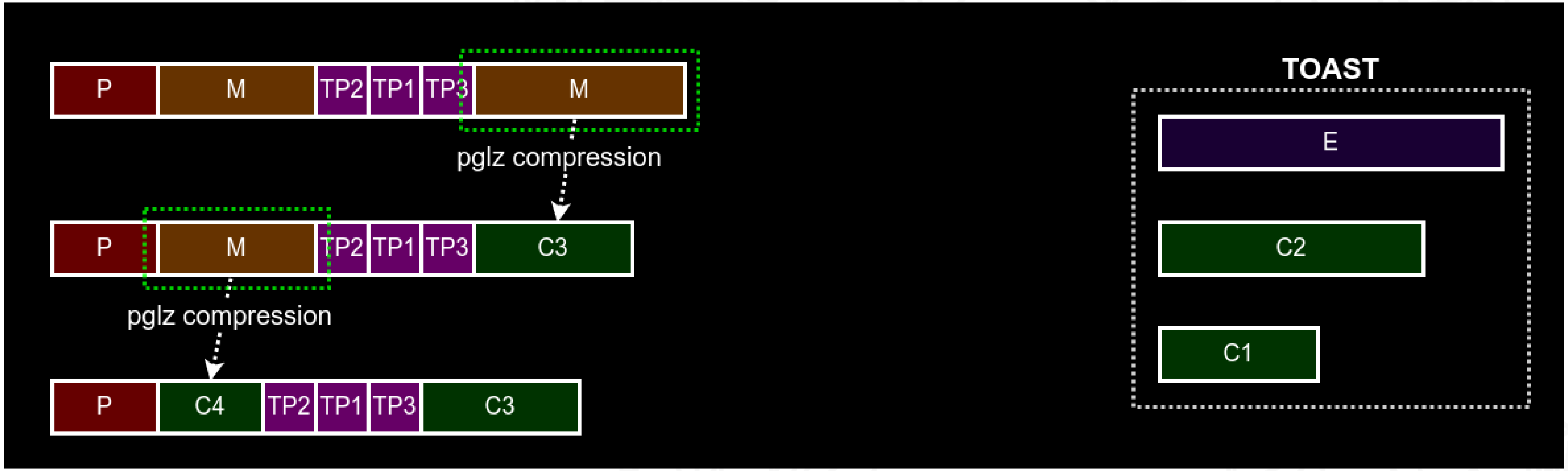
TOAST pass #3

- Only "main" attributes are considered.
- Each attribute is compresed, until the resulting tuple size < 2KB.



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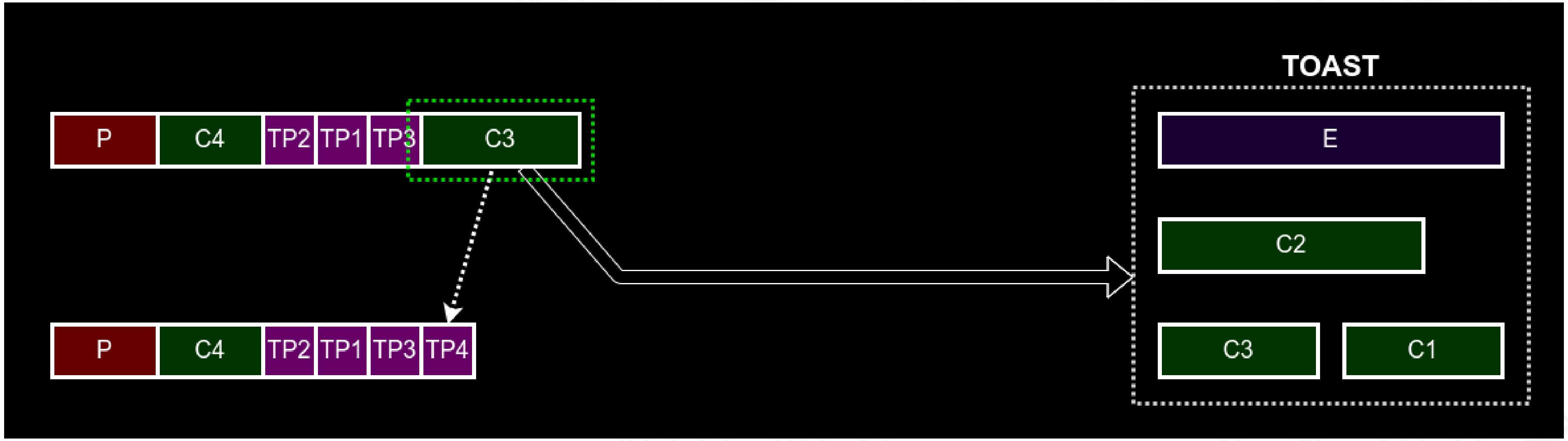
TOAST pass #4

- Only "main" attributes are considered.
- Each attribute is TOASTed, until the resulting tuple size < 2KB.



Appendable bytea: Motivational example

- A table with 100 MB bytea (uncompressed):

```
CREATE TABLE test (data bytea);
ALTER TABLE test ALTER COLUMN data SET STORAGE EXTERNAL;
INSERT INTO test SELECT repeat('a', 100000000)::bytea data;
```

- Append 1 byte to bytea:

```
EXPLAIN (ANALYZE, BUFFERS, COSTS OFF)
UPDATE test SET data = data || 'x'::bytea;

 Update on test (actual time=1359.229..1359.232 rows=0 loops=1)
   Buffers: shared hit=238260 read=12663 dirtied=25189 written=33840
   ->  Seq Scan on test (actual time=155.499..166.509 rows=1 loops=1)
         Buffers: shared hit=12665
 Planning Time: 0.127 ms
 Execution Time: 1382.959 ms
```

>1 second to append 1 byte !!!
Table size doubled to 200 MB, 100 MB of WAL generated.

- Thanks to Alexander ? who raised the problem of (non-effective) streaming into bytea at PGConf.Online !

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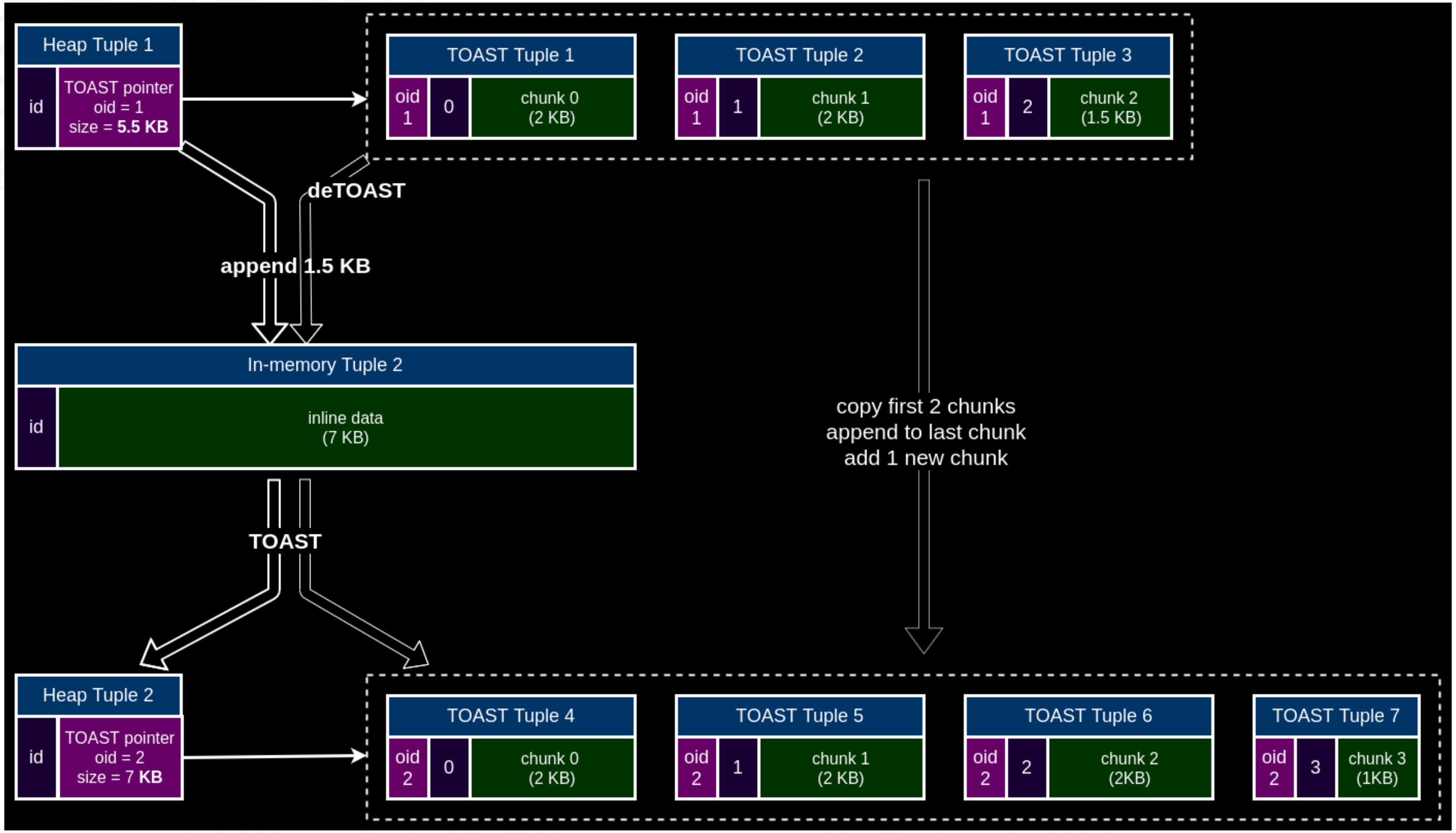
Motivational example (explanation)

- Current TOAST is not sufficient for partial updates
- All data is deTOASTed before in-memory modification
- Updated data is TOASTed back after modification with new TOAST oid



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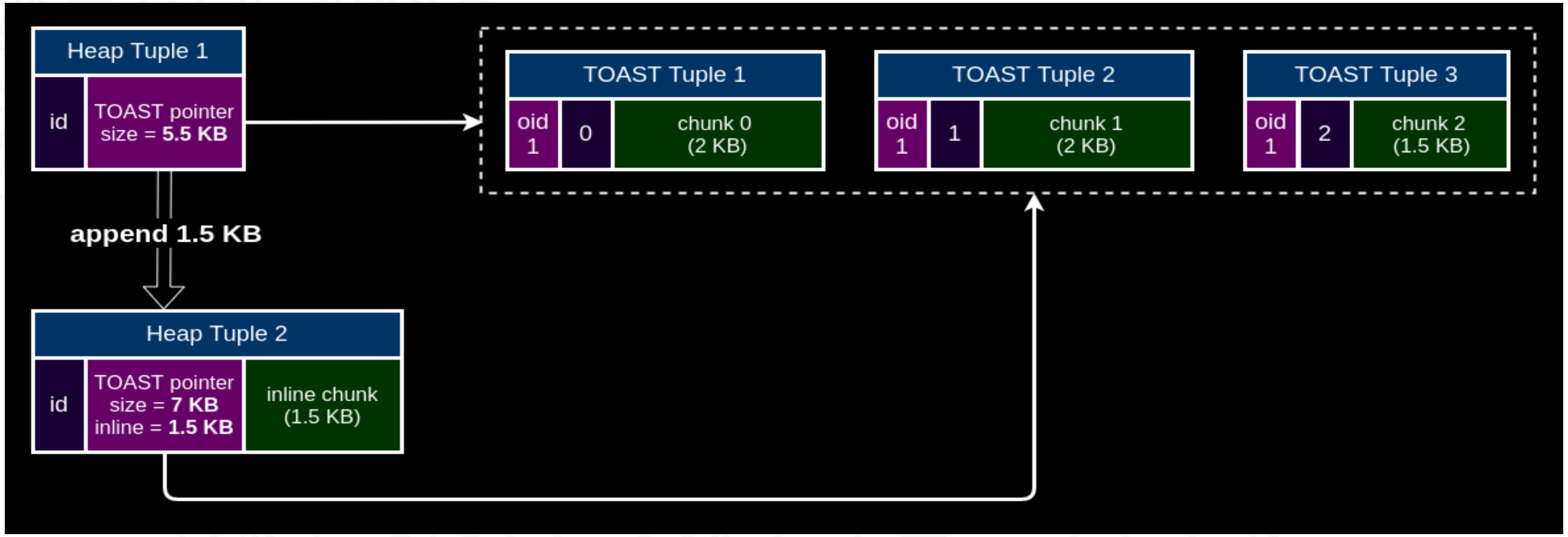
Appendable bytea: Solution

- Special datum format: TOAST pointer + inline data
- Inline data serves as a buffer for TOASTing
- Operator || does not deTOAST data, it appends inline data producing datum in the new format



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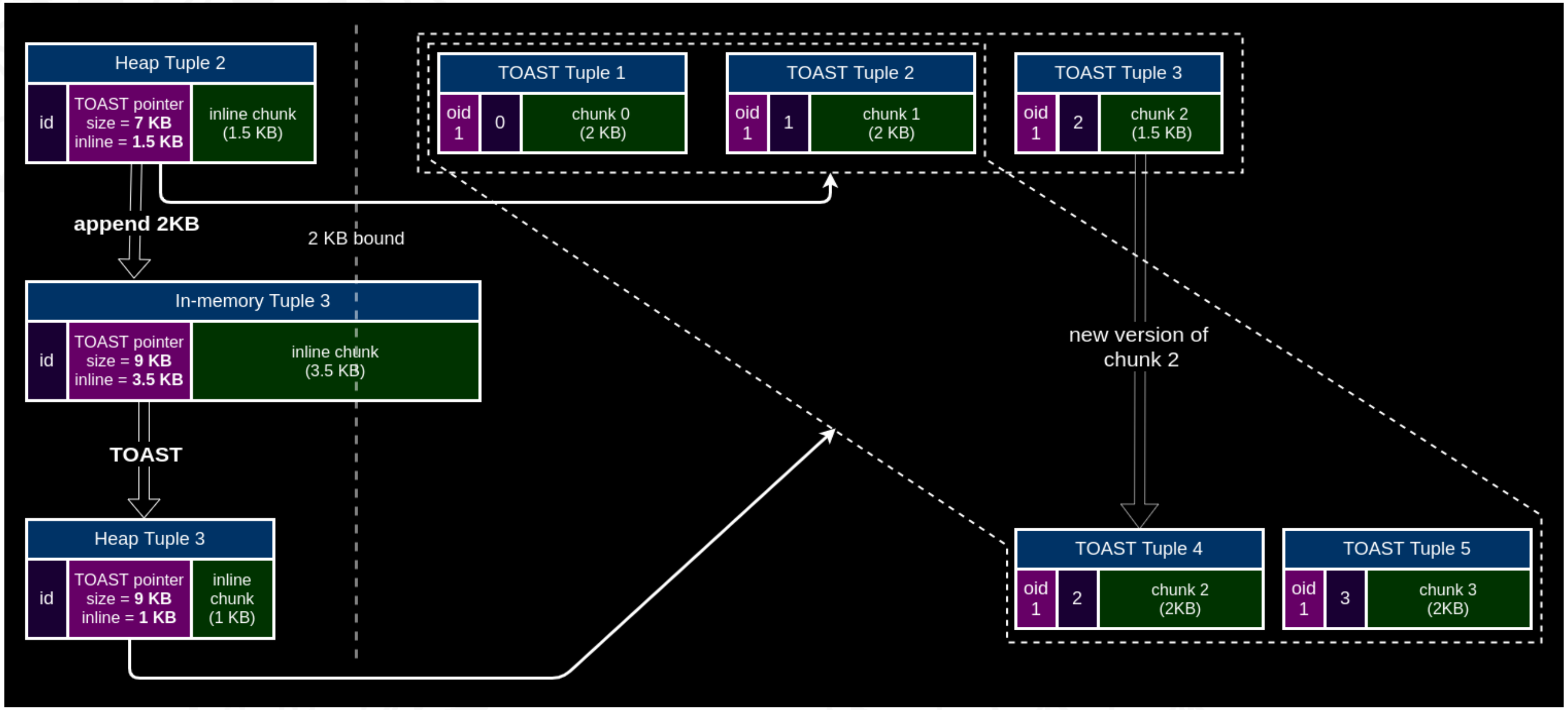
Appendable bytea: Solution

- When size of inline data exceeds 2 KB, TOASTer recognizes changes in old and new datums and TOASTs only the new inline data with the same TOAST oid
- Last not filled chunk can be rewritten with creation of new tuple version
- First unmodified chunks (0,1) are shared.



Benefit: 5 (3+2) chunks vs 12 (master, 3+4+5)

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Results – motivational example

- Append 1 byte to bytea:

```
EXPLAIN (ANALYZE, BUFFERS, COSTS OFF)
UPDATE test SET data = data || 'x'::bytea;
```

- ```
  Update on test (actual time=0.060..0.061 rows=0 loops=1)
    Buffers: shared hit=2  (was 12665)
    ->  Seq Scan on test (actual time=0.017..0.020 rows=1 loops=1)
          Buffers: shared hit=1
  Planning Time: 0.727 ms
  Execution Time: 0.496 ms (was 1382 ms)
  ```

2750x speed up!

- Table size remains 100 MB
- Only 143 bytes of WAL generated (was 100 MB)
- No unnecessary buffer reads and writes

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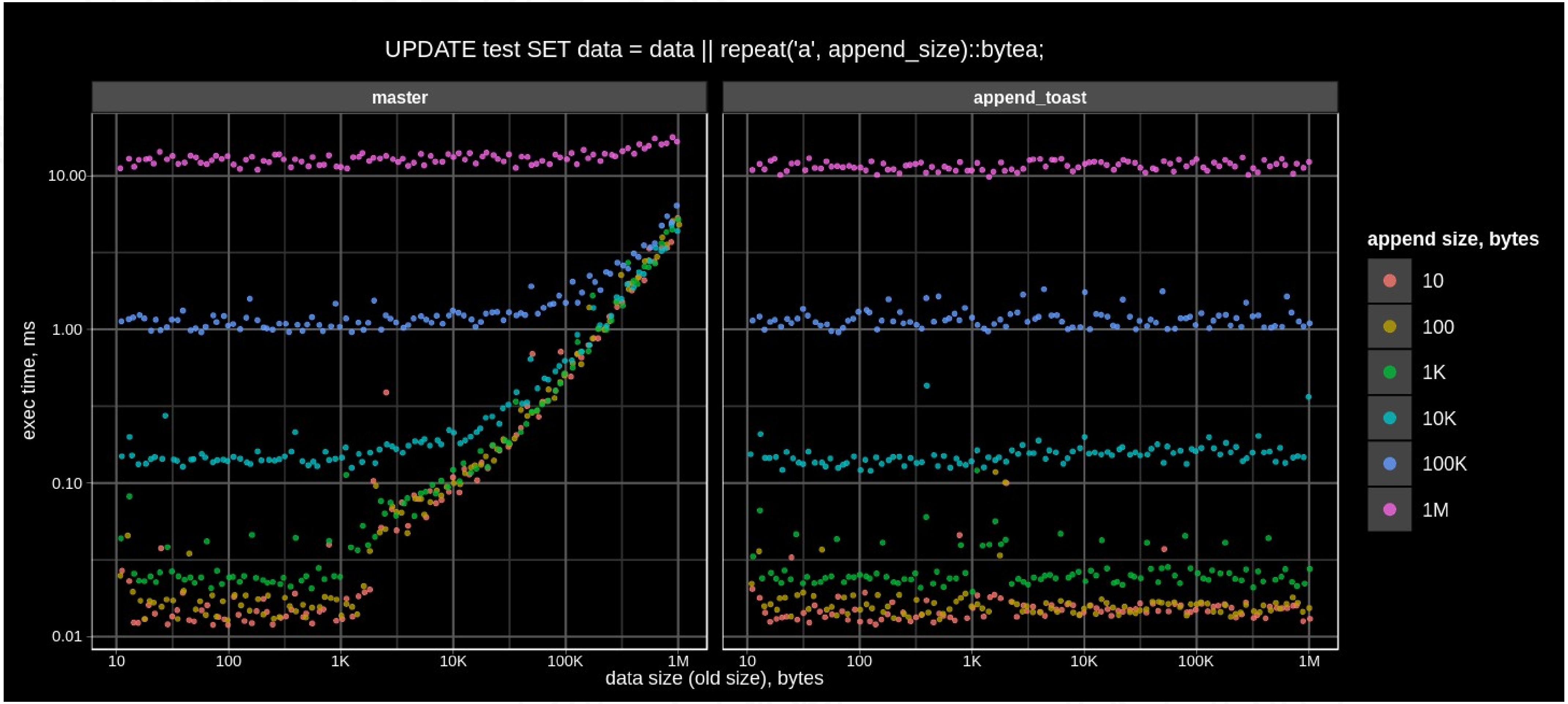
  ```

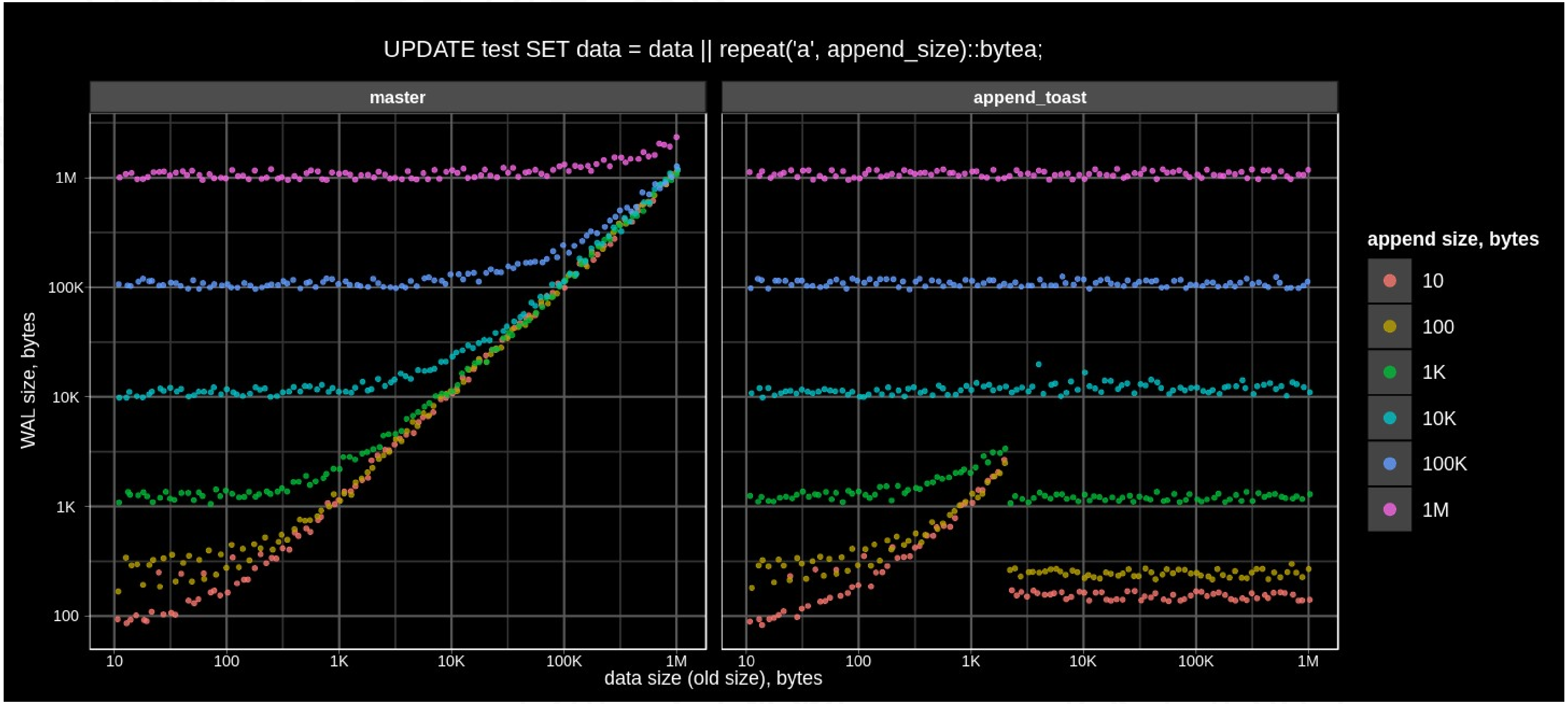
Appendable bytea: append to bytea (time)



O(OLD + NEW)

O(APPEND SIZE)

Appendable bytea: append to bytea (WAL)



OLD + NEW

INLINED ~~OLD~~ + NEW

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Appendable bytea: stream

Stream organized as follows:

- 1 row (id, bytea) grows from 0 up to 1Mb

```
UPDATE test SET data = data || repeat('a', append_size)::bytea WHERE id = 0; COMMIT;
```

- append_size = 10b, 100b,…,100Kb
- pg_stat_statements: time, blocks r/rw, wal

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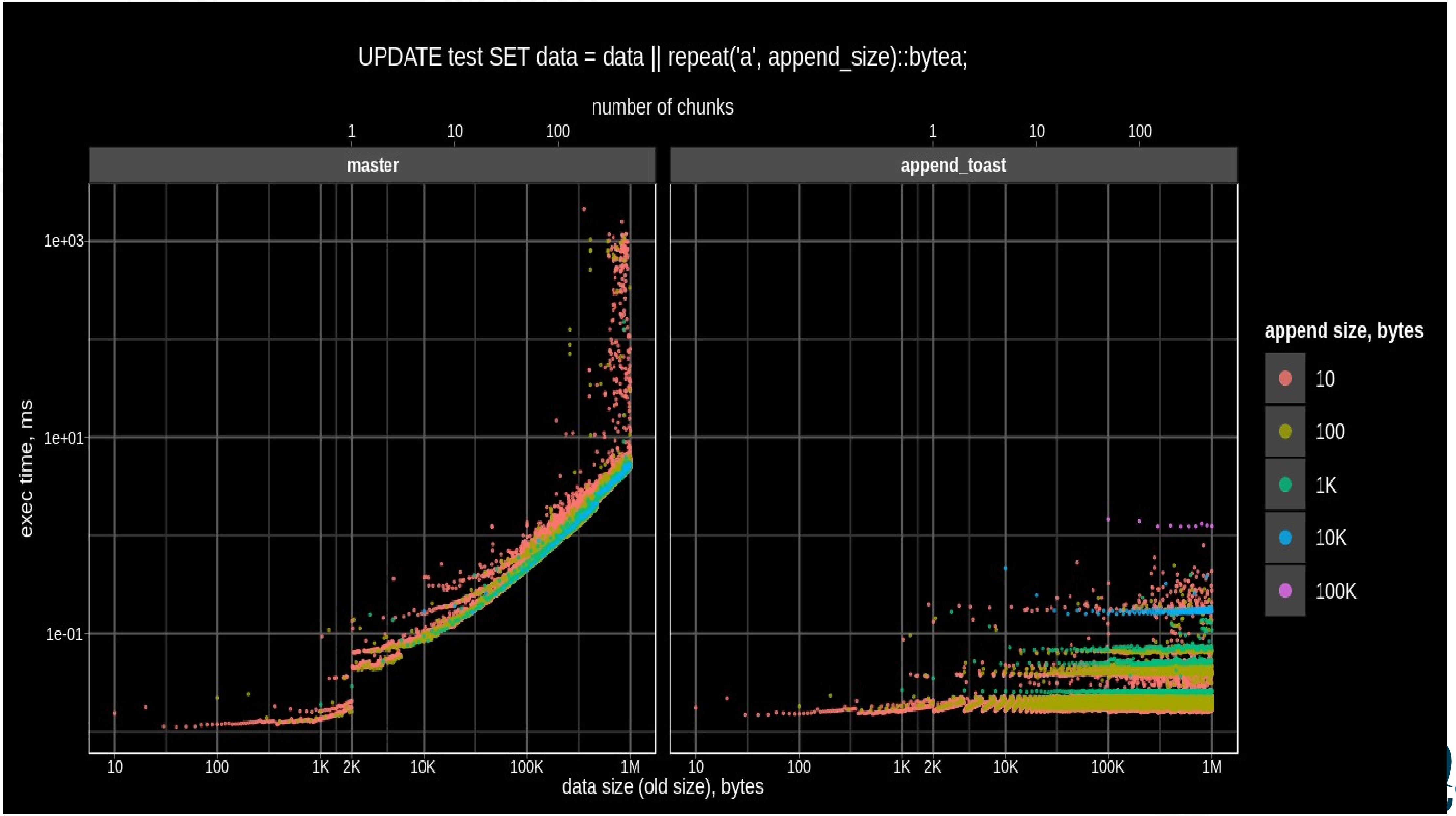
Appendable bytea: stream (time)



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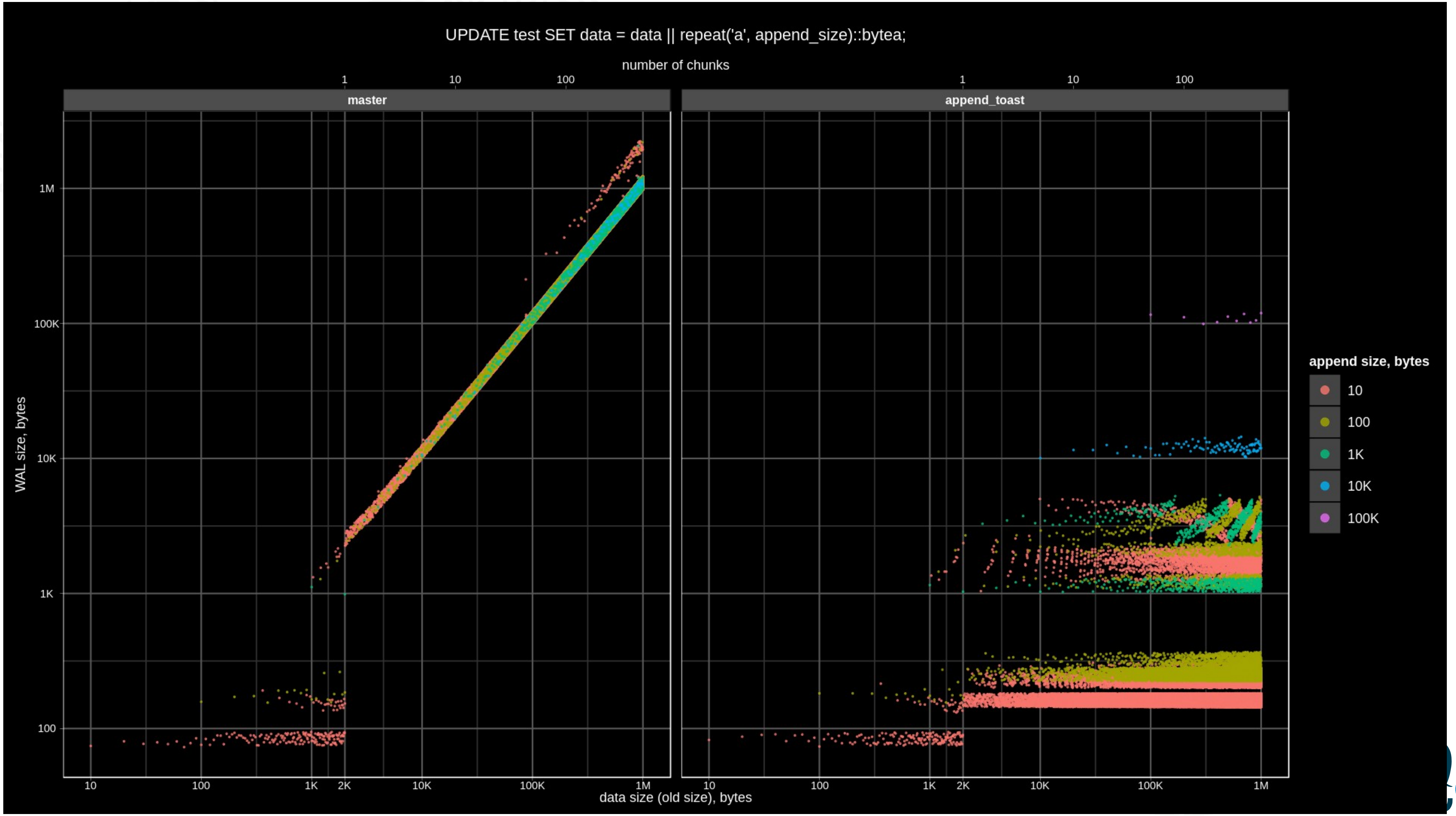
Appendable bytea: stream (WAL)



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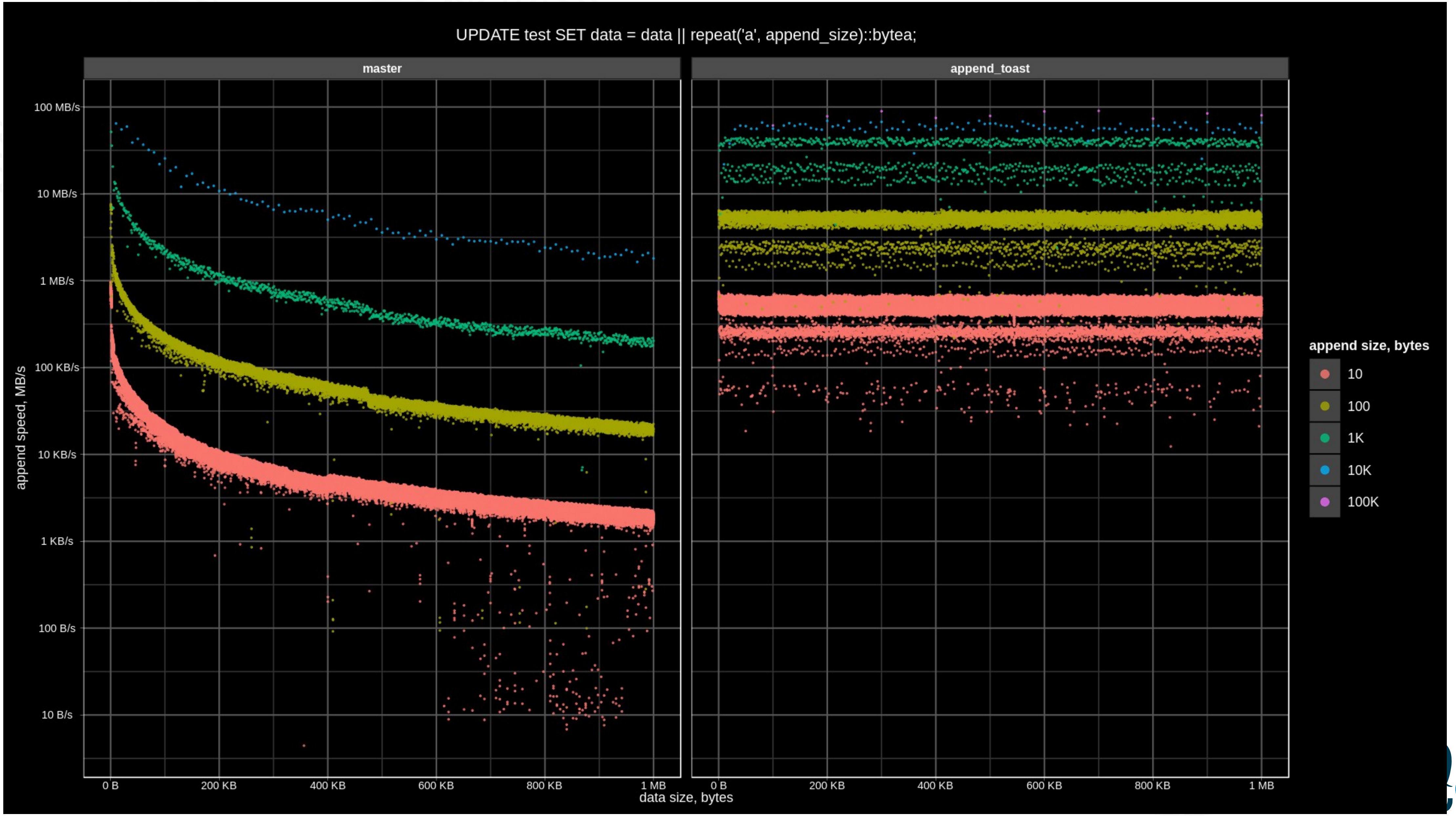
Appendable bytea: stream (througput MB/s)



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