Øredev 2023-11-09

DuckDB

Harnessing in-process analytics for data science and beyond

Gábor Szárnyas
Developer Relations Advocate

DuckDB Labs

About me

Gábor Szárnyas

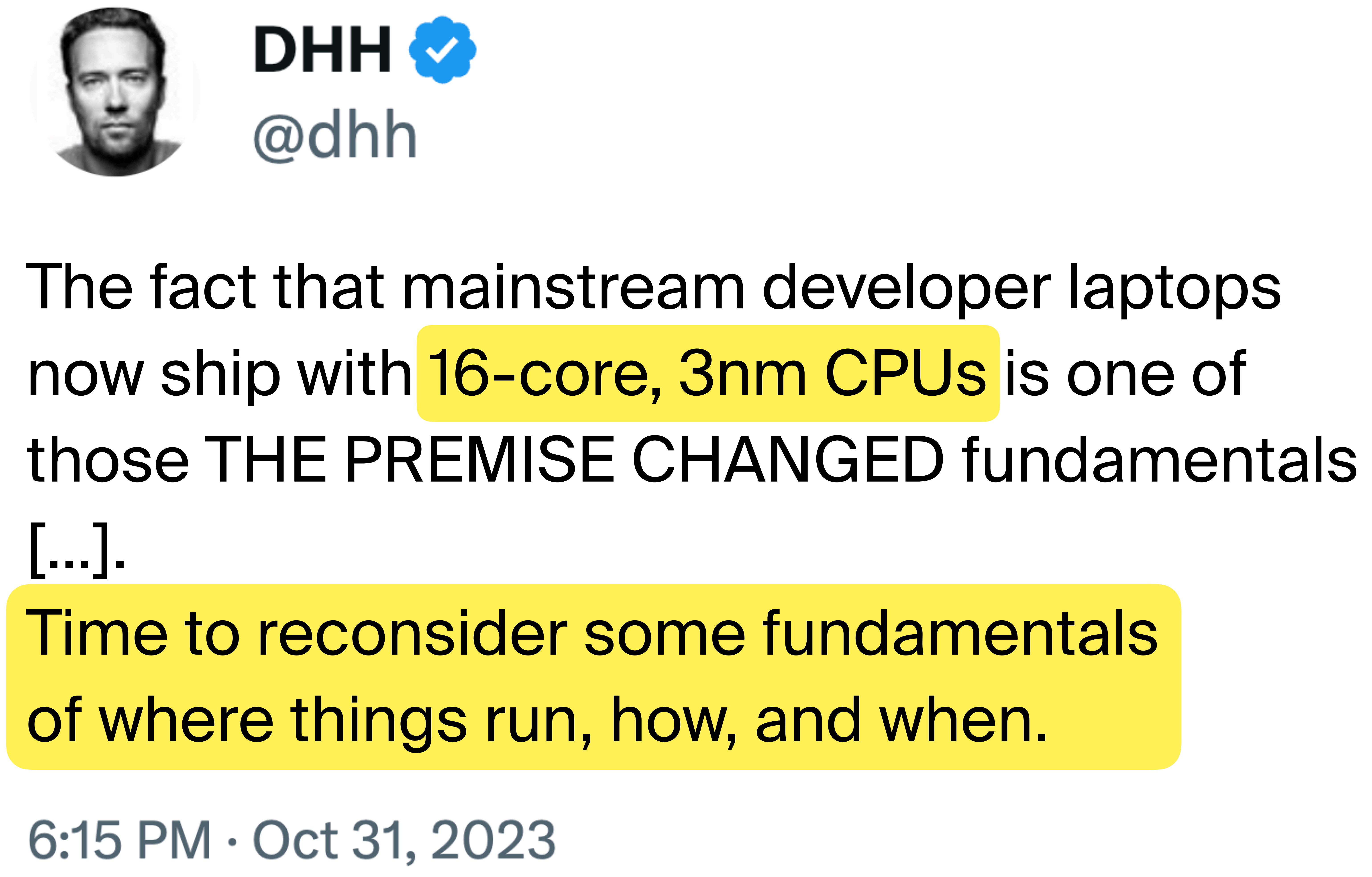
- 2014–2023: PhD + postdoc
- Research: benchmarks, graph processing

DuckDB Labs

- Startup with ≈18 people
- Based in Amsterdam

DuckDB Labs

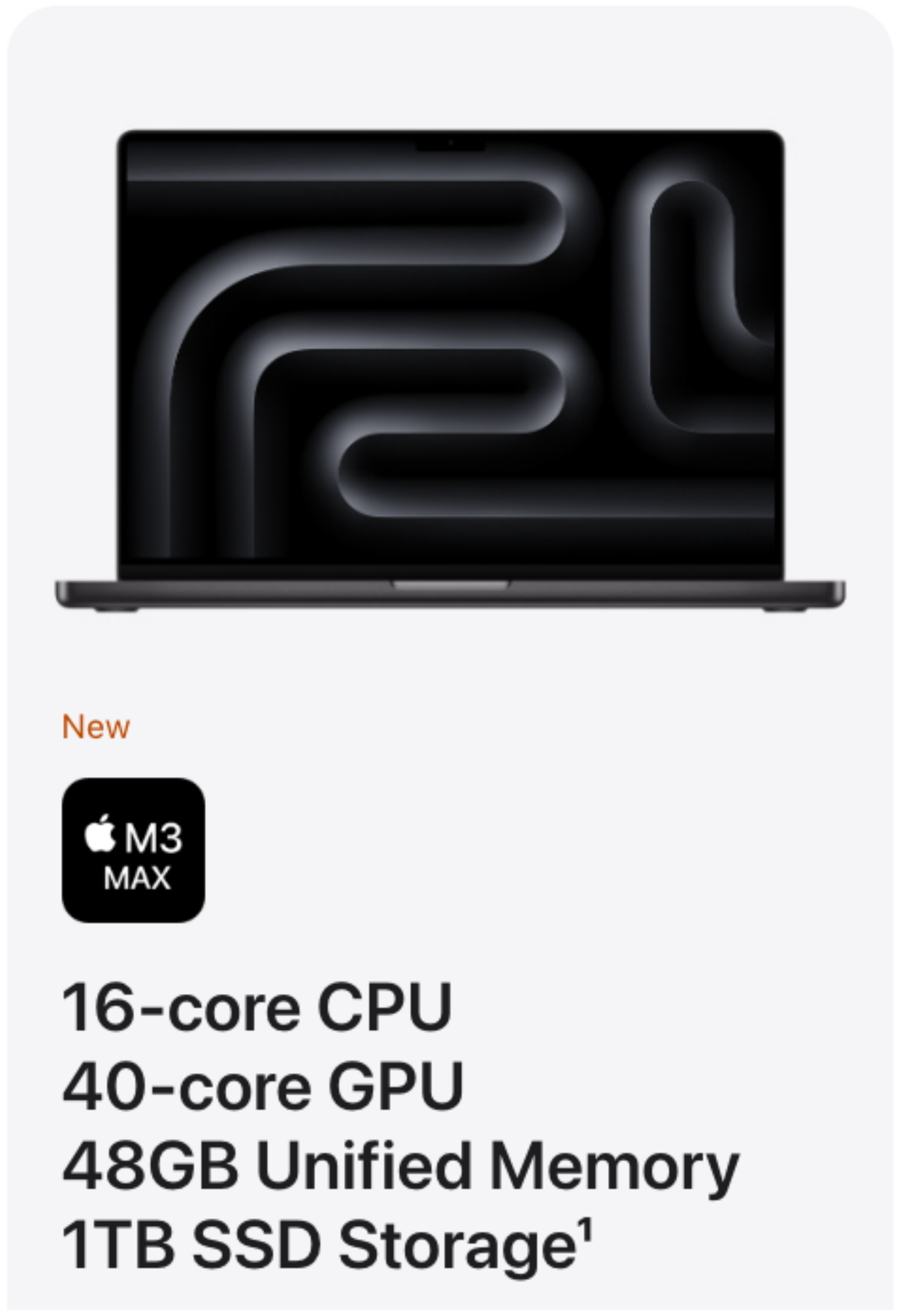
Context



DHH
@dhh

The fact that mainstream developer laptops now ship with 16-core, 3nm CPUs is one of those THE PREMISE CHANGED fundamentals [...].
Time to reconsider some fundamentals of where things run, how, and when.

6:15 PM · Oct 31, 2023

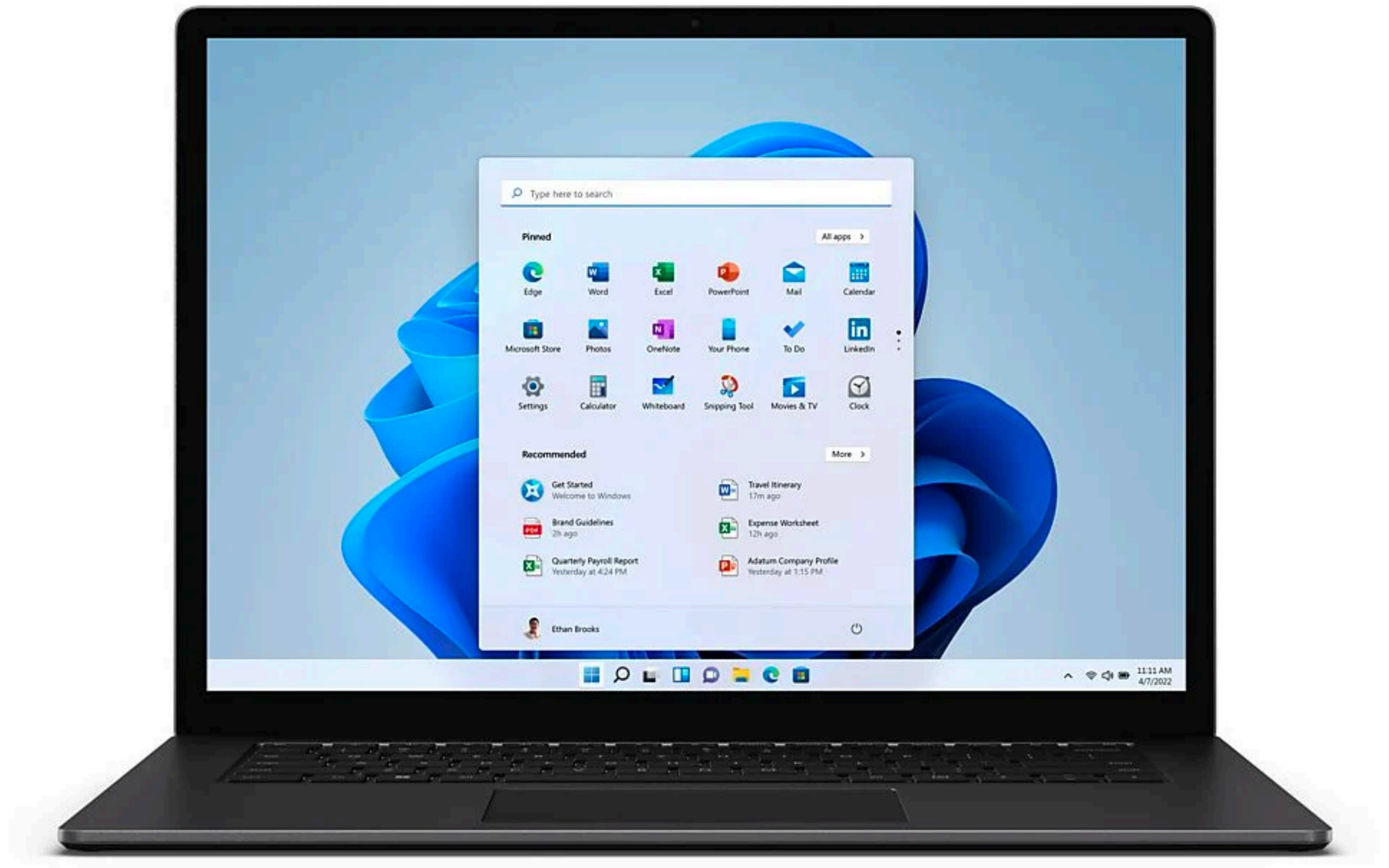


New

M3 MAX

16-core CPU
40-core GPU
48GB Unified Memory
1TB SSD Storage[1]

DuckDB is an analytical database system built for powerful end-user devices



DuckDB's key properties

An analytical SQL database

Built to be portable and fast

Developed since 2018

Written in C++11

Open-source under the MIT license

In-process

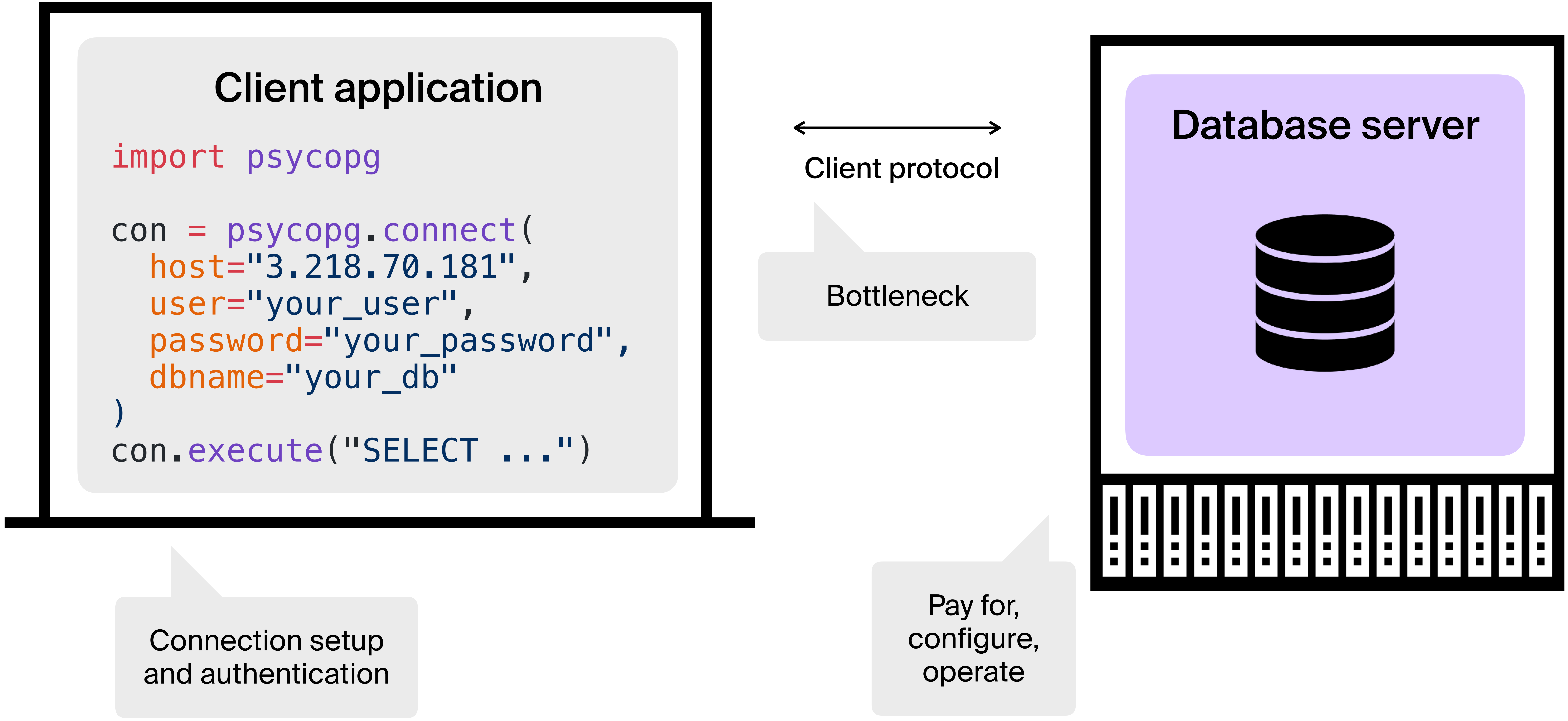
Portable

Fast

Open-source

Deployment model

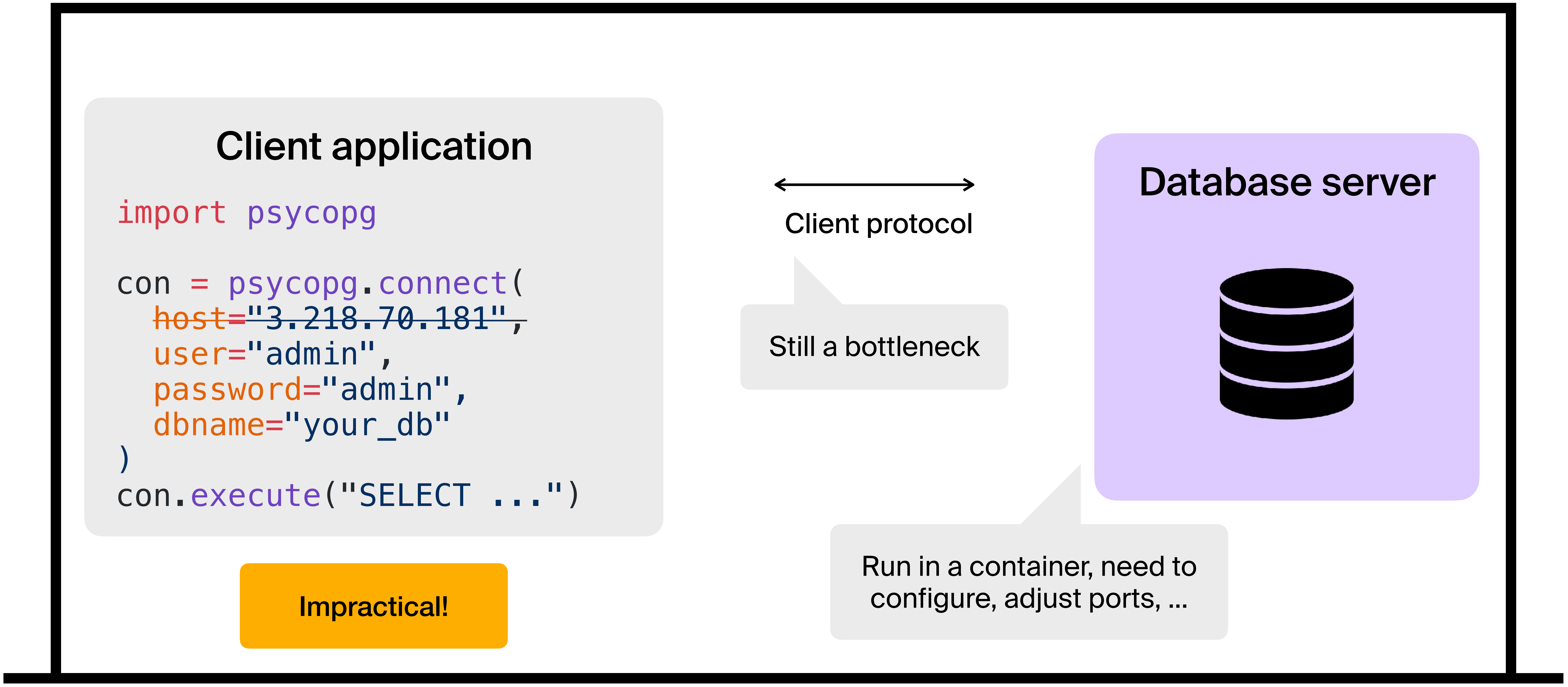
Client–server setup



Client application
Client protocol
Bottleneck
Database server
Connection setup and authentication
Pay for, configure, operate

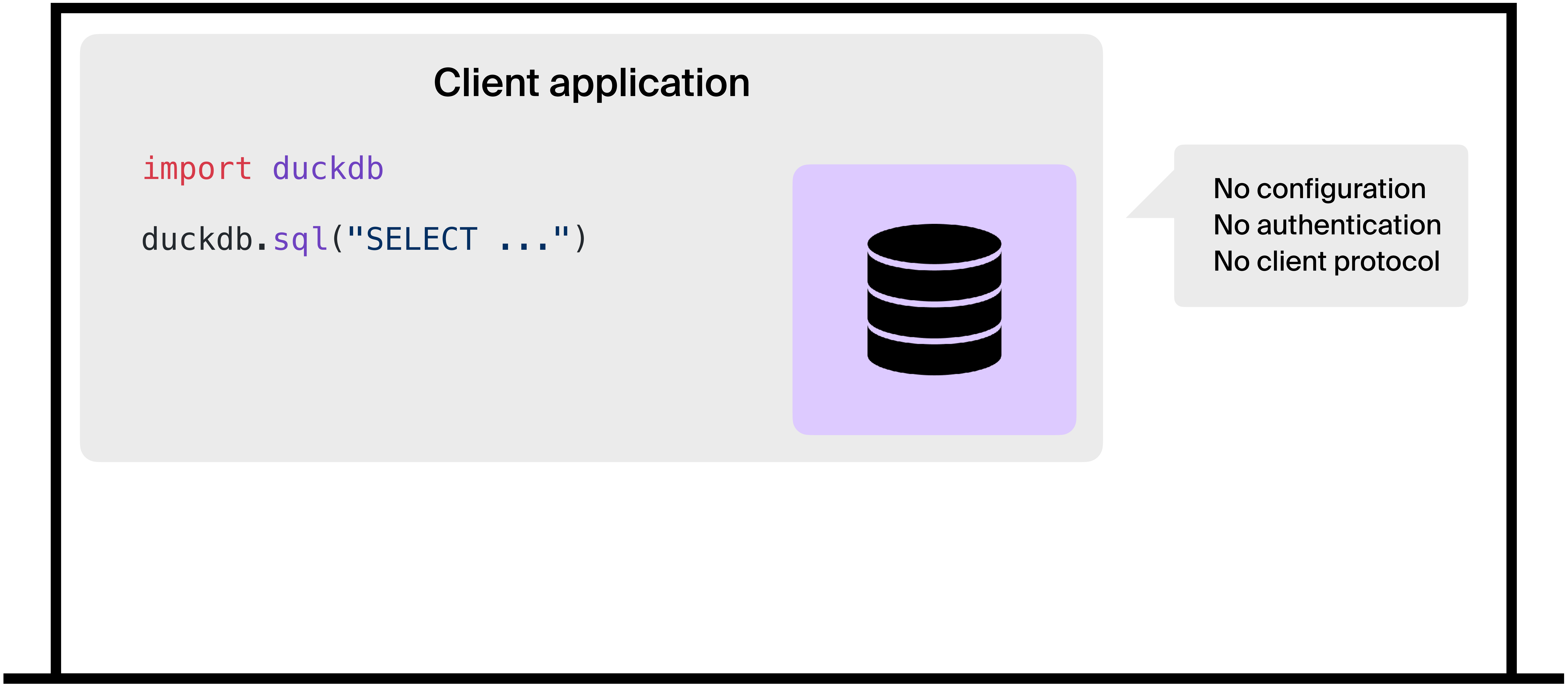
```
import psycopg

con = psycopg.connect(
  host="3.218.70.181",
  user="your_user",
  password="your_password",
  dbname="your_db"
)
con.execute("SELECT ...")
```

Client–server setup



```python
import psycopg

con = psycopg.connect(
  ~~host="3.218.70.181",~~
  user="admin",
  password="admin",
  dbname="your_db"
)
con.execute("SELECT ...")
```

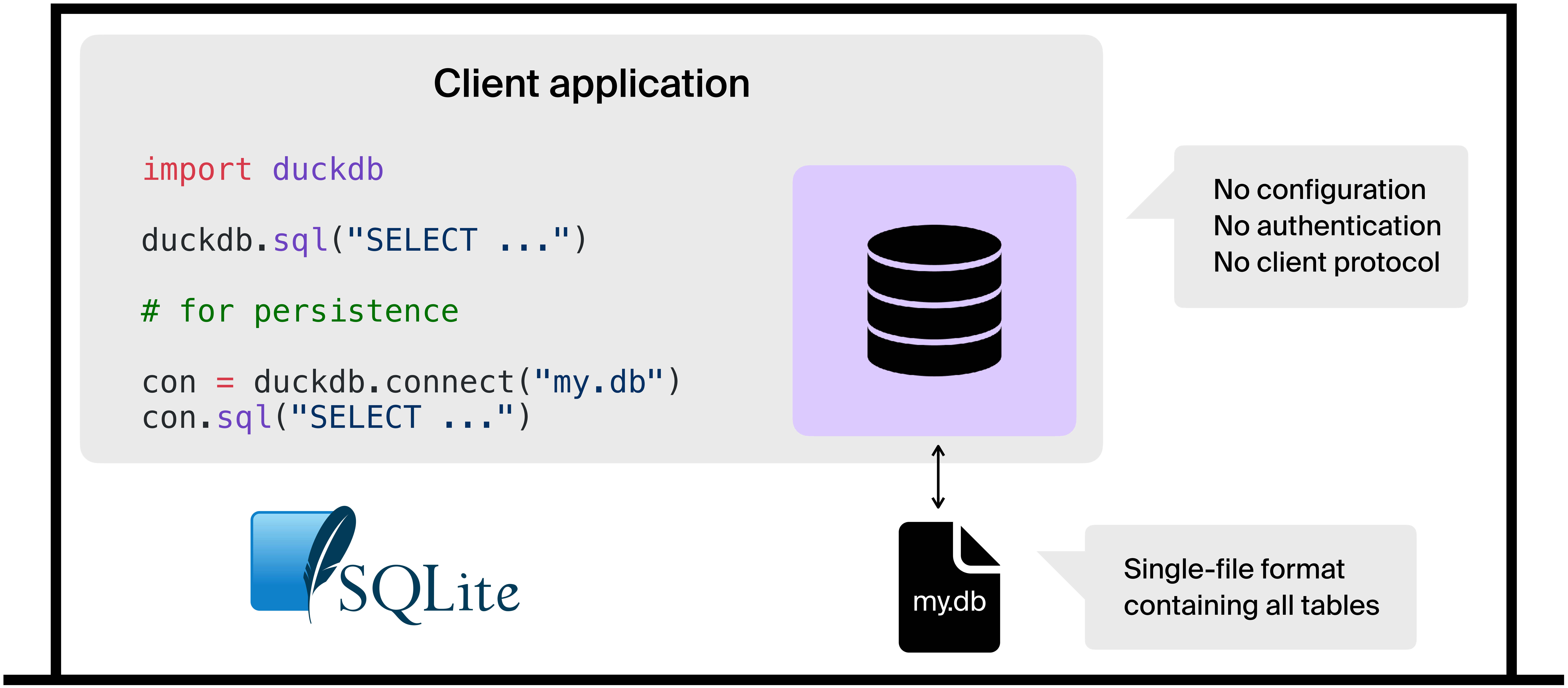
In-process setup



```python
import duckdb

duckdb.sql("SELECT ...")
```

No configuration
No authentication
No client protocol

In-process setup



Client application

```python
import duckdb

duckdb.sql("SELECT ...")

# for persistence

con = duckdb.connect("my.db")
con.sql("SELECT ...")
```

No configuration
No authentication
No client protocol

Single-file format
containing all tables

Database systems

	Transactional	Analytical
In-process	SQLite	DuckDB
Client–server	MySQL™ PostgreSQL	snowflake VERTICA

Portable

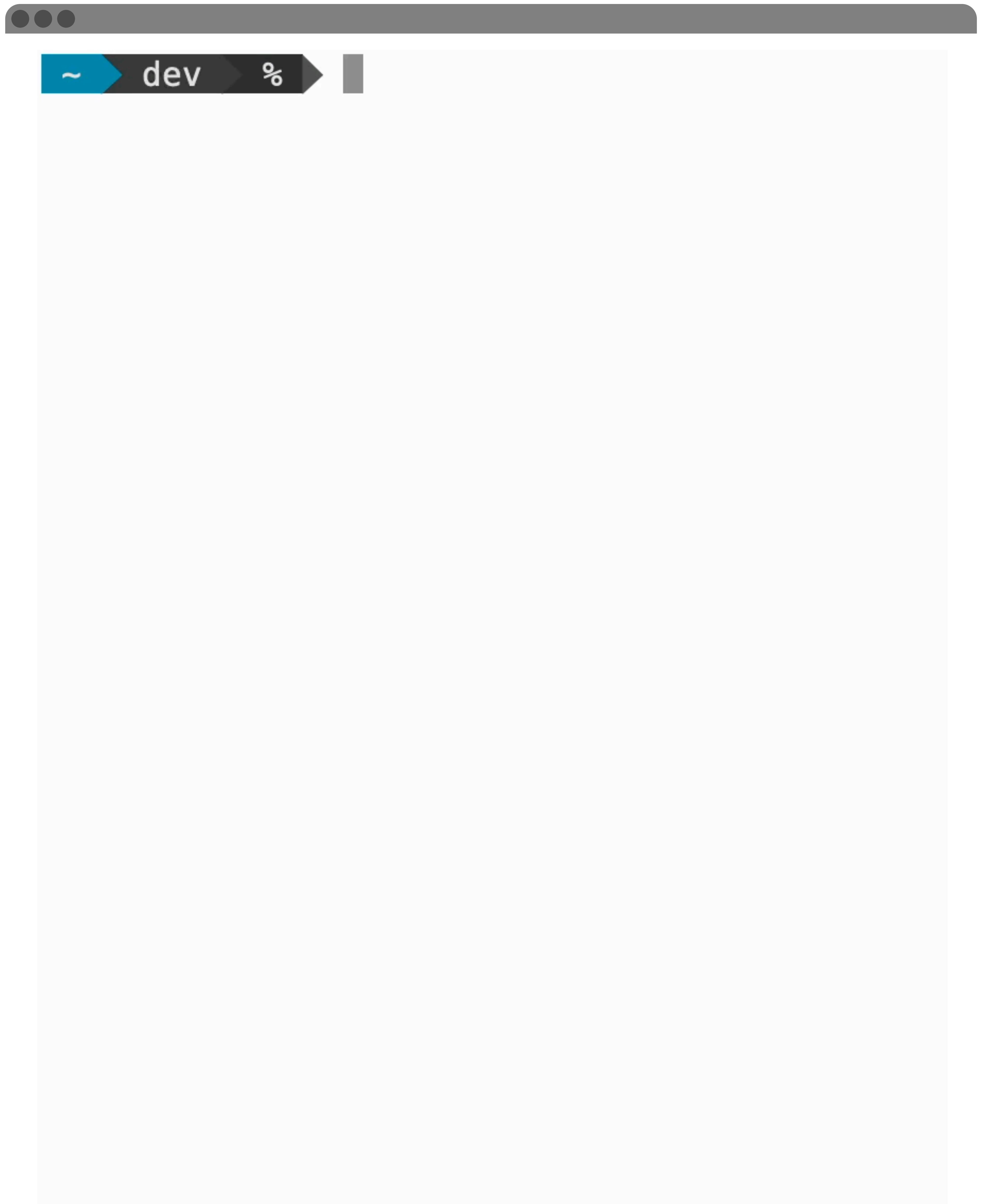
Installing DuckDB

You can get started with DuckDB in **<15 seconds** on most popular platforms

This includes:

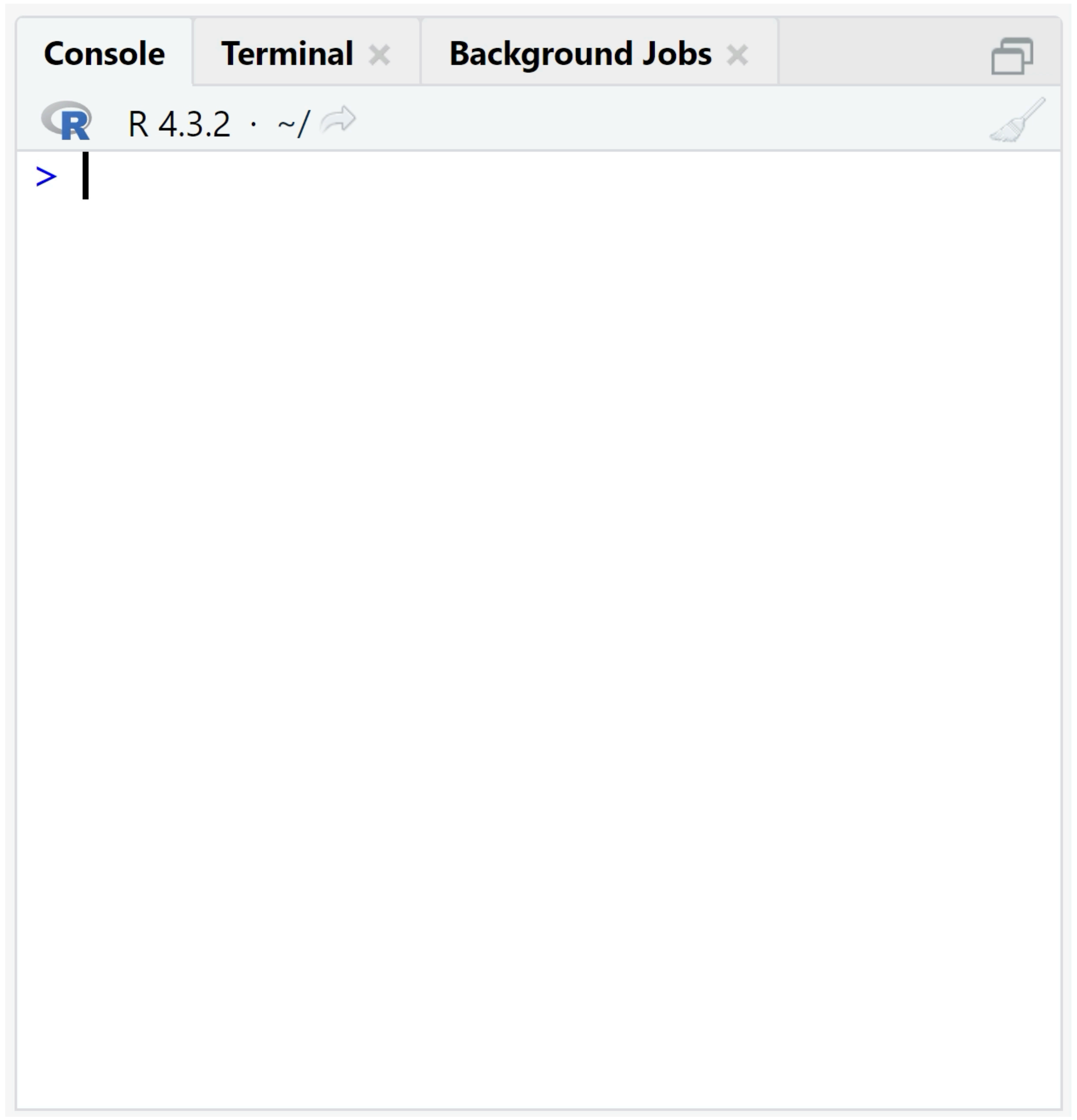
- Typing the commands
- Downloading the packages from the internet
- Launching DuckDB

macOS: Python package



```
~ dev %
```

Windows: R package



```
R 4.3.2 · ~/
>
```

...and more

```
pip install duckdb
```

```
npm install duckdb
```

```
install.packages("duckdb")
```

```
org.duckdb:duckdb_jdbc
```

```
Pkg.add("DuckDB")
```

```
cargo add duckdb
```

Why is installation so fast?

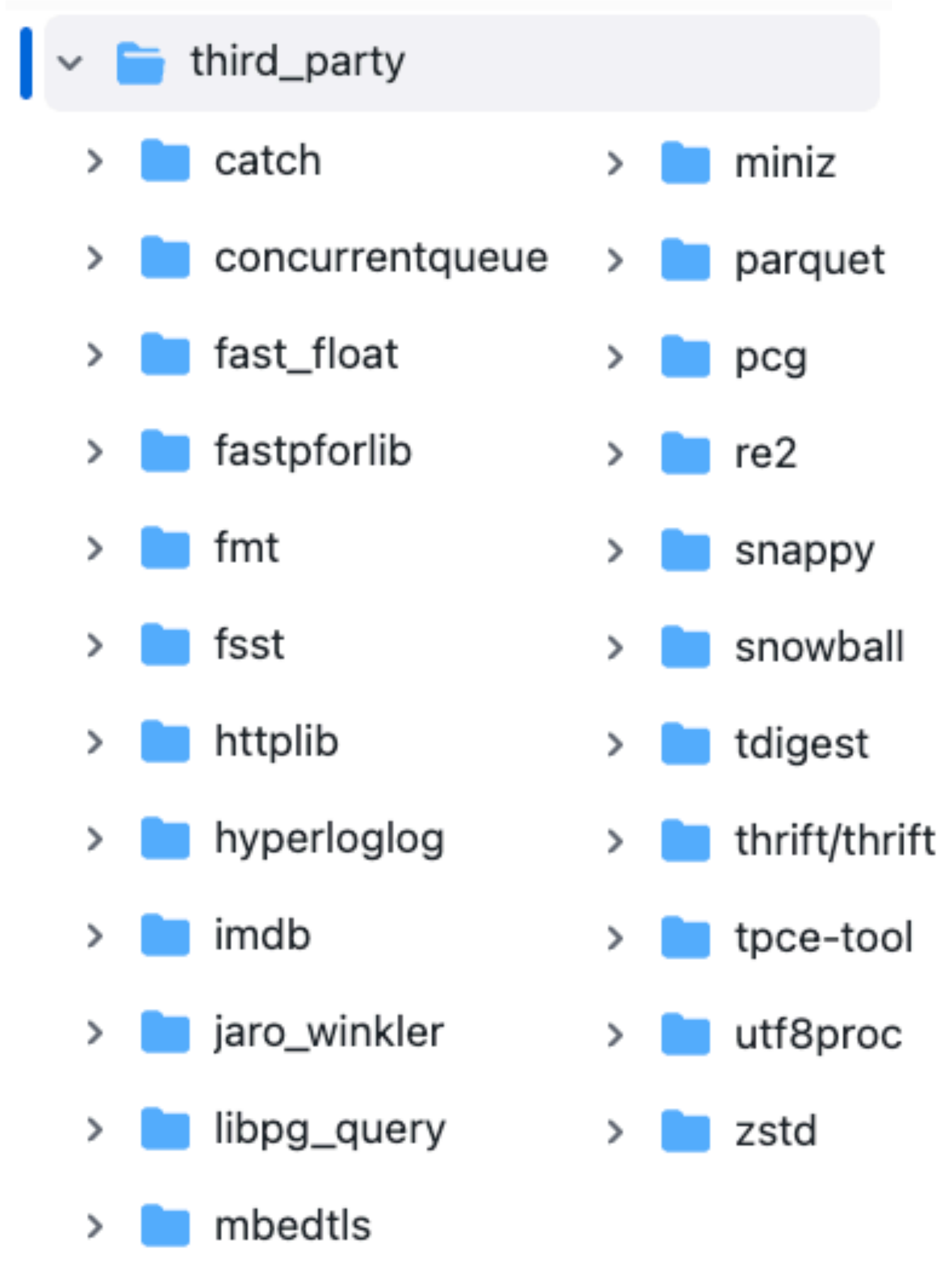
DuckDB has zero external dependencies

Dependencies are vendored in the codebase

Pure C/C++ codebase

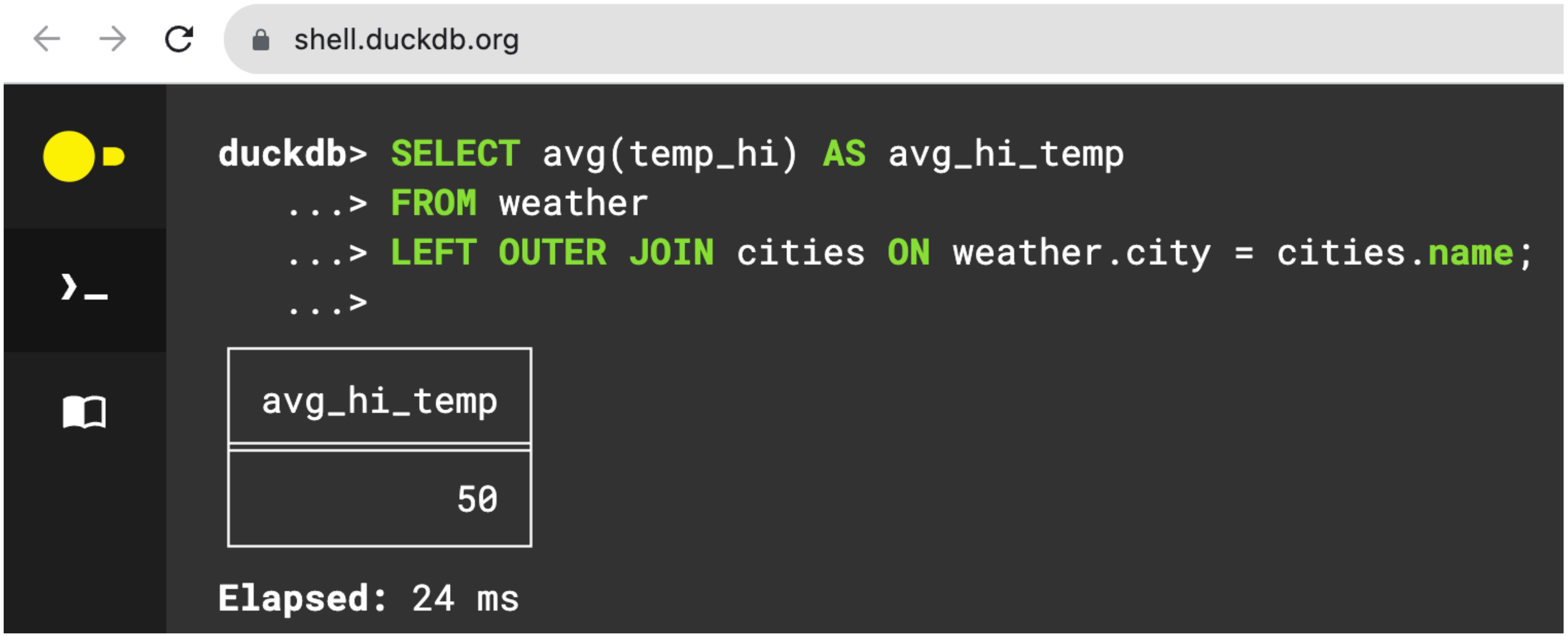
Portable anywhere with a C++11 compiler

Small binary packages



```
third_party
  catch             miniz
  concurrentqueue   parquet
  fast_float        pcg
  fastpforlib       re2
  fmt               snappy
  fsst              snowball
  httplib           tdigest
  hyperloglog       thrift/thrift
  imdb              tpce-tool
  jaro_winkler      utf8proc
  libpg_query       zstd
  mbedtls
```

WebAssembly (Wasm)



```
duckdb> SELECT avg(temp_hi) AS avg_hi_temp
   ...> FROM weather
   ...> LEFT OUTER JOIN cities ON weather.city = cities.name;
   ...>
┌─────────────┐
│ avg_hi_temp │
╞═════════════╡
│          50 │
└─────────────┘
Elapsed: 24 ms
```

Fast

CSV reader performance

Test data: LDBC social network data set

Setup: M2Pro CPU, 32GB RAM, DuckDB v0.9.1

CSV size	Load time	Database size
3.4 GB	3.2 s	1 GB
35 GB	27 s	10 GB
360 GB	4 min 54 s	104 GB

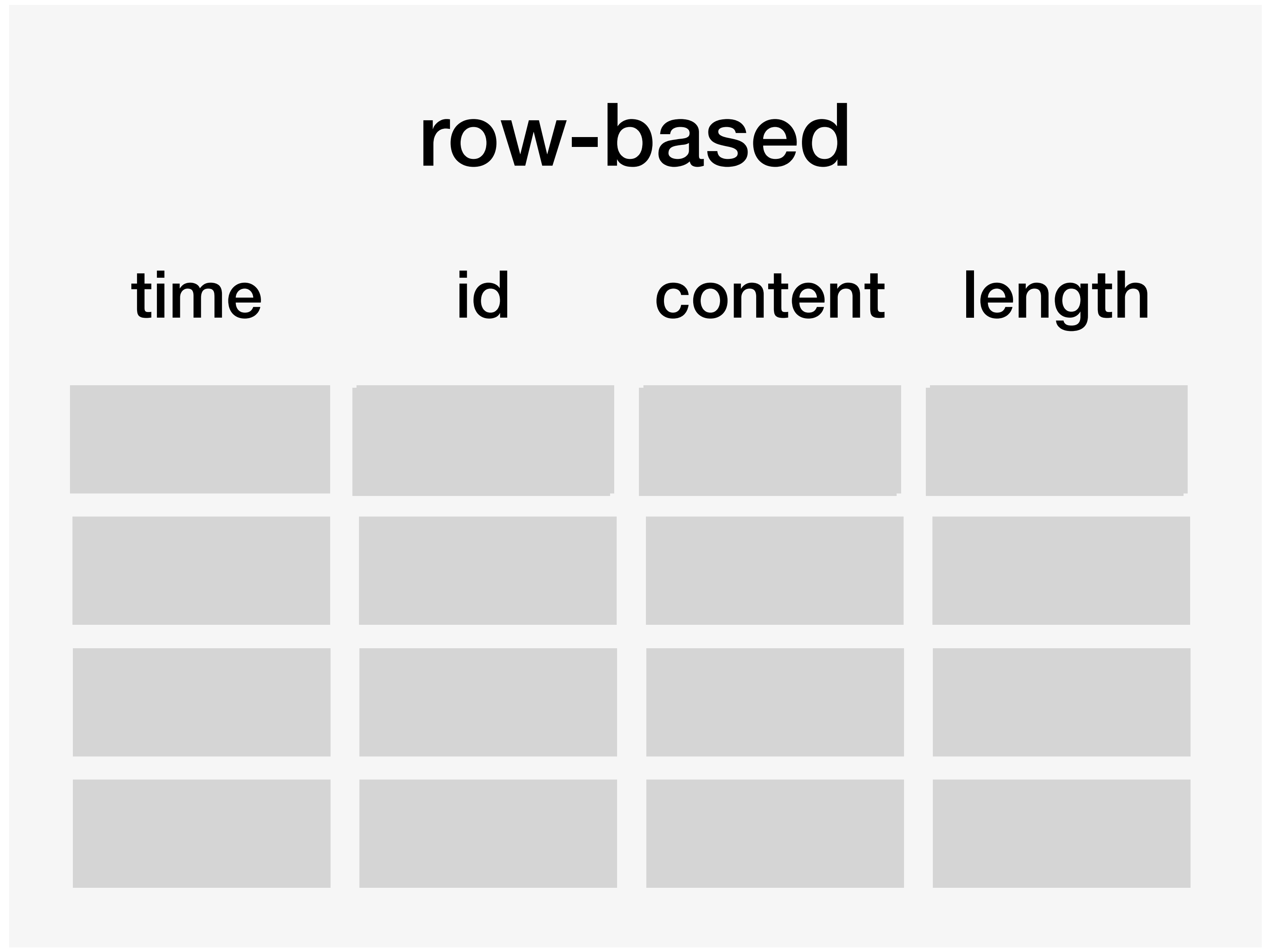
≈3.5x compression

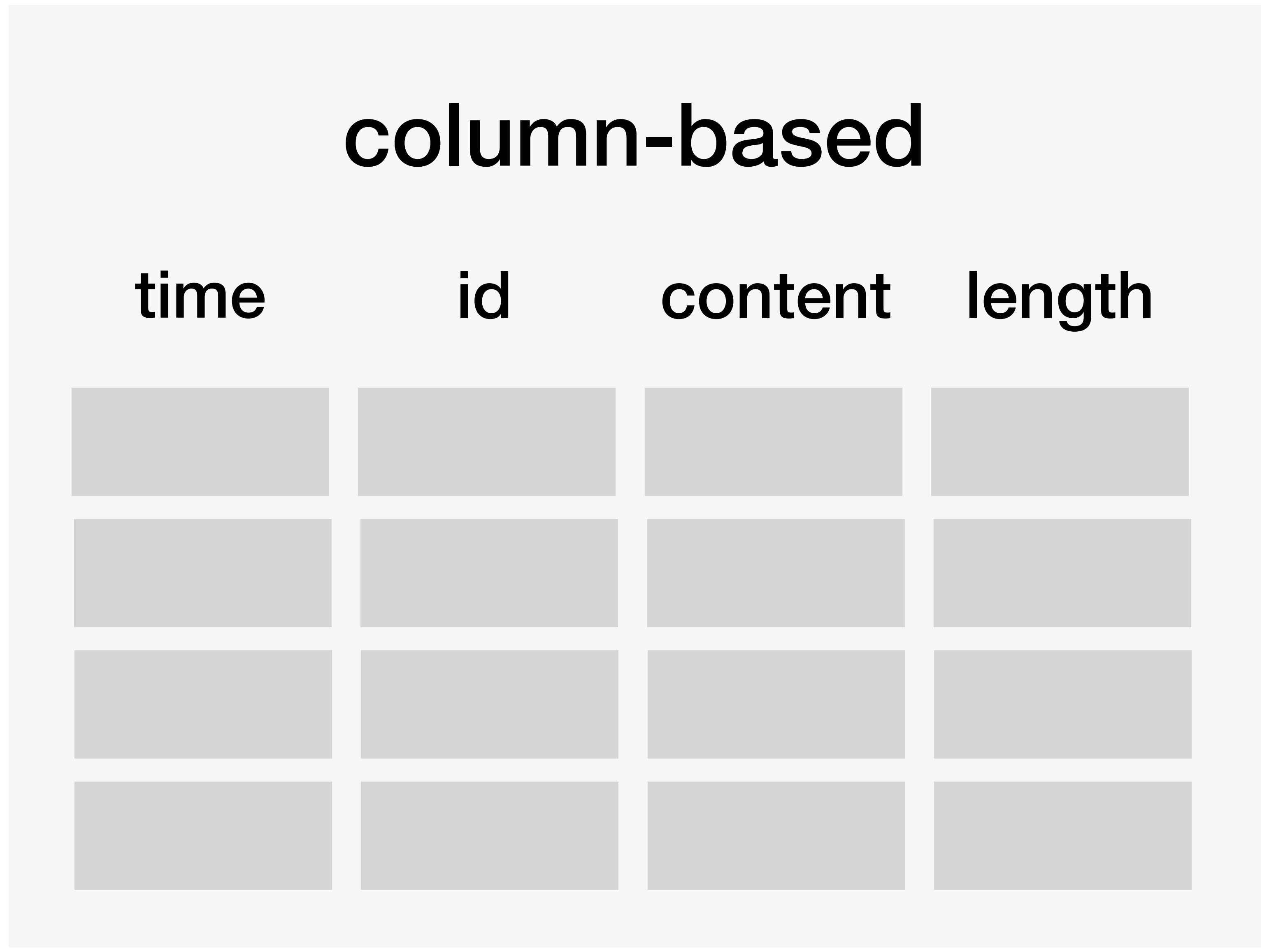
>1.2 GB/s for reading CSV, parsing, and writing to DuckDB

Demo

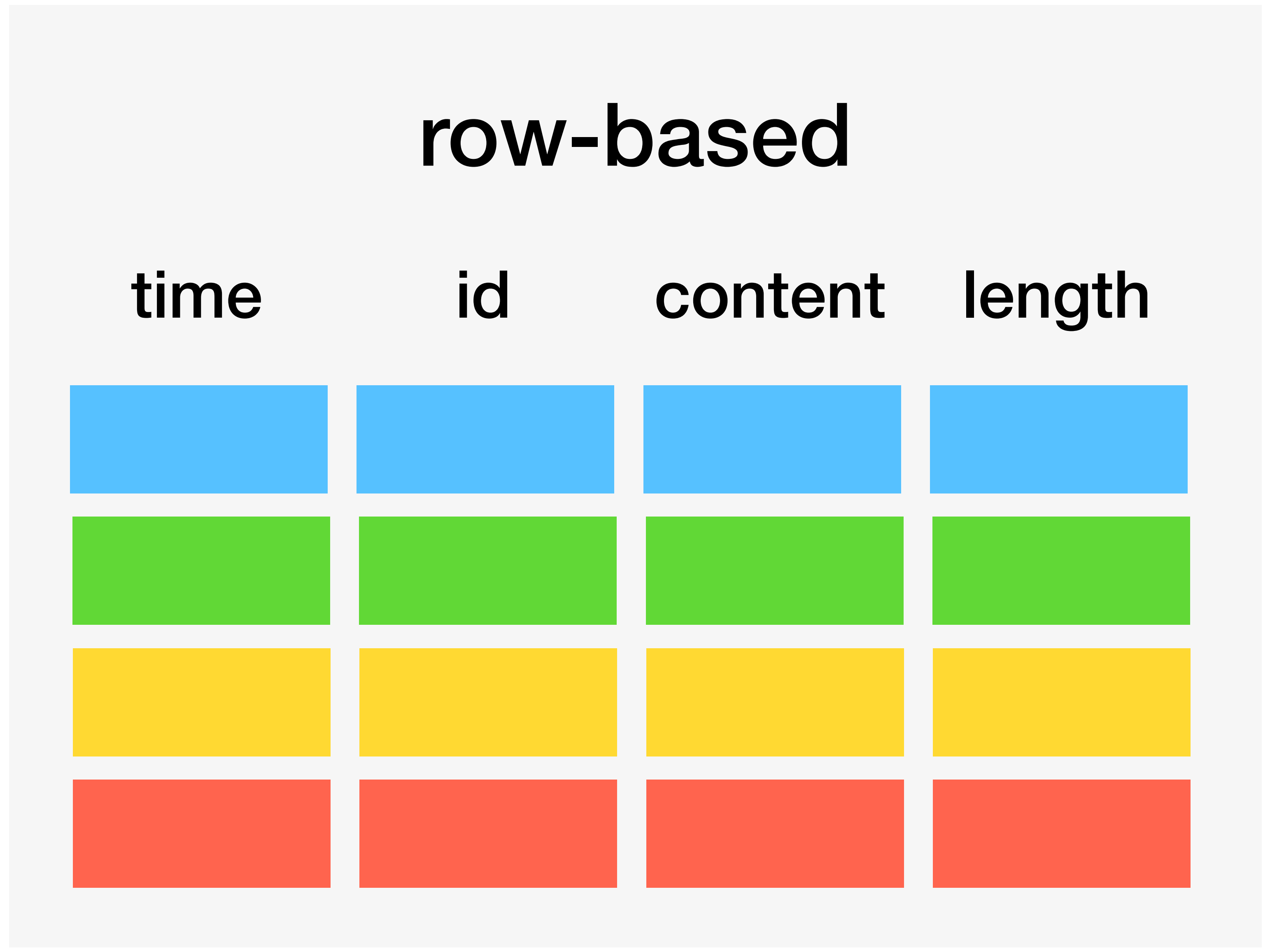
Internals

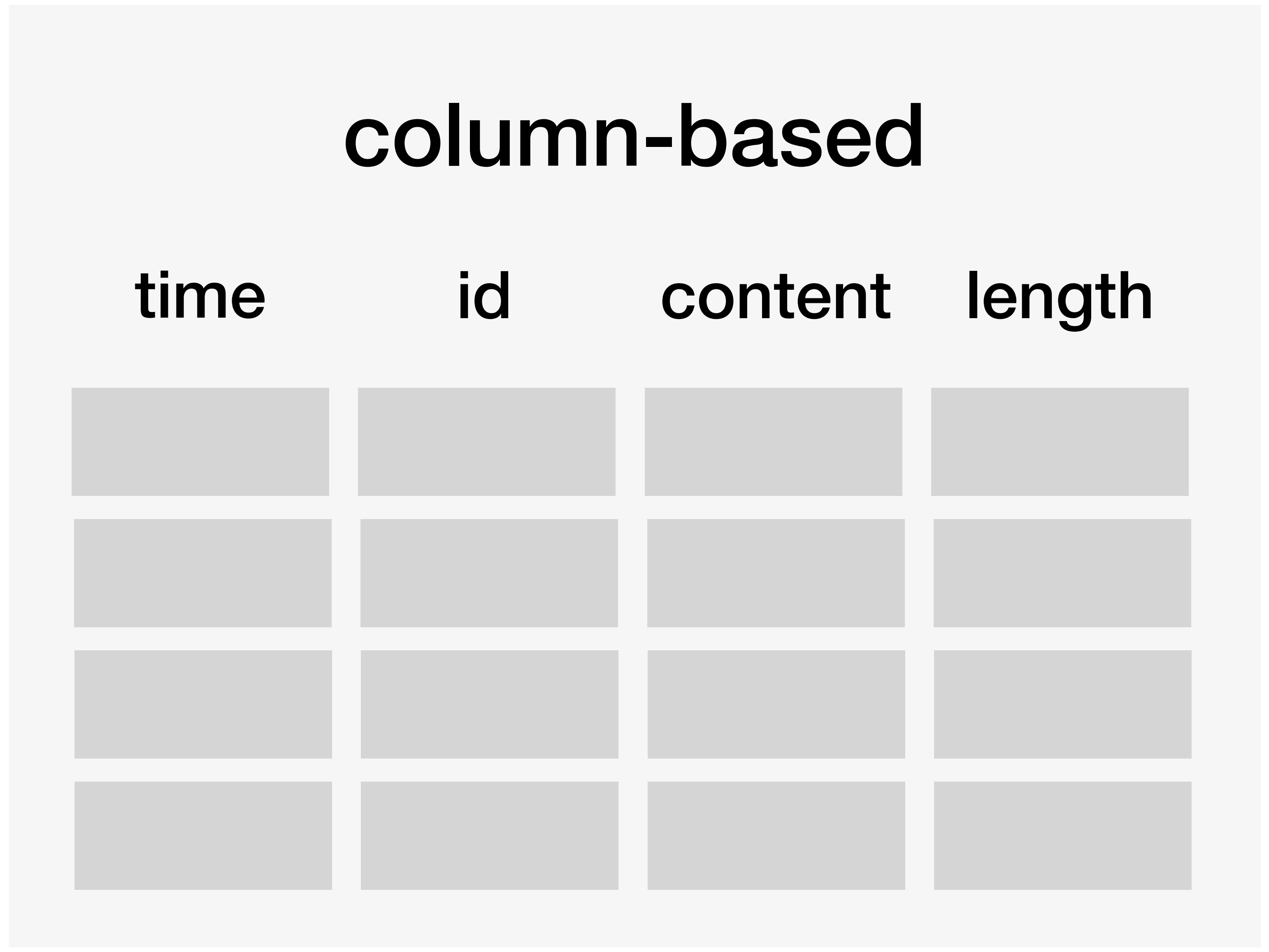
Storage


row-based
time
id
content
length

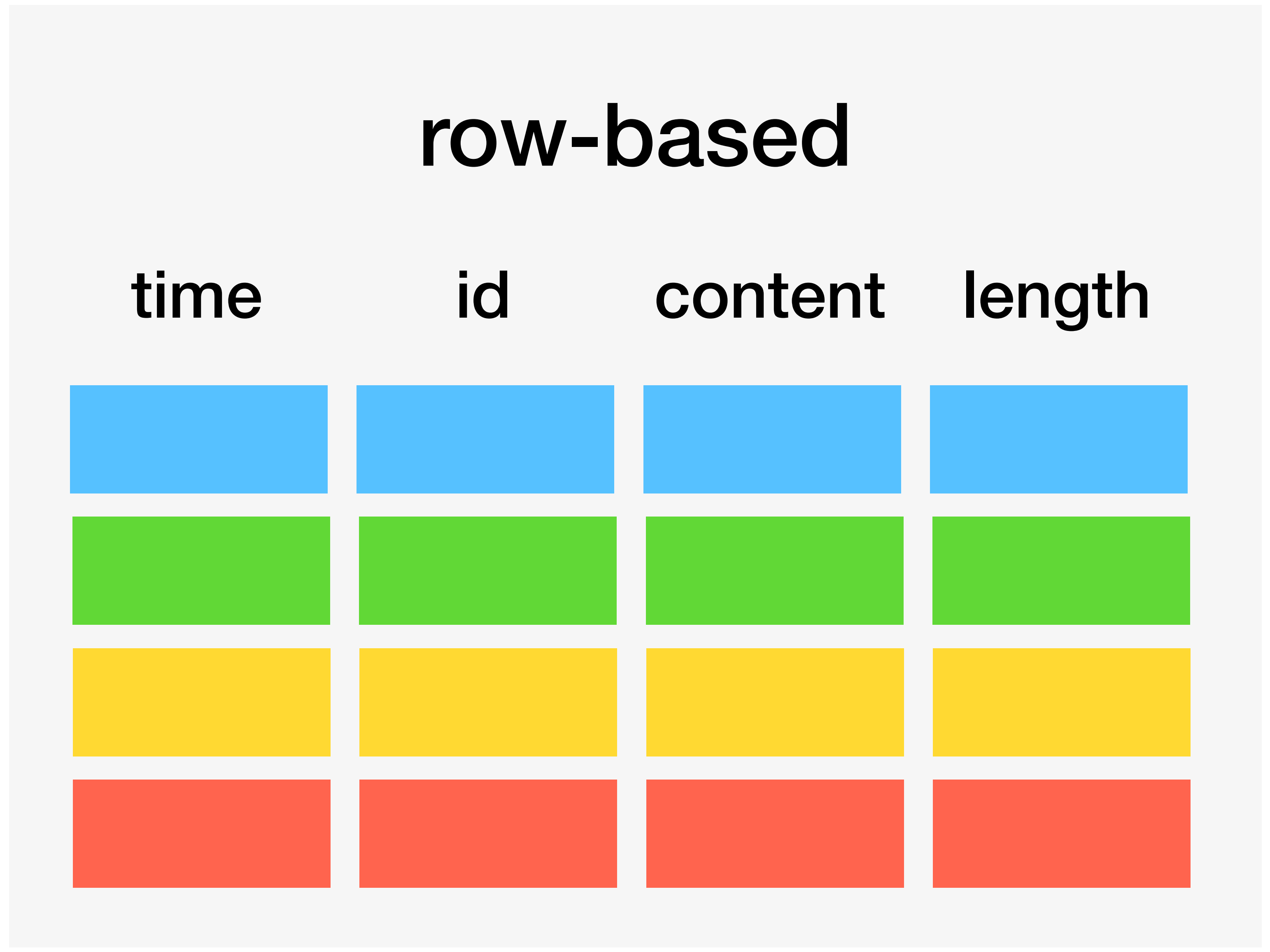

column-based
time
id
content
length

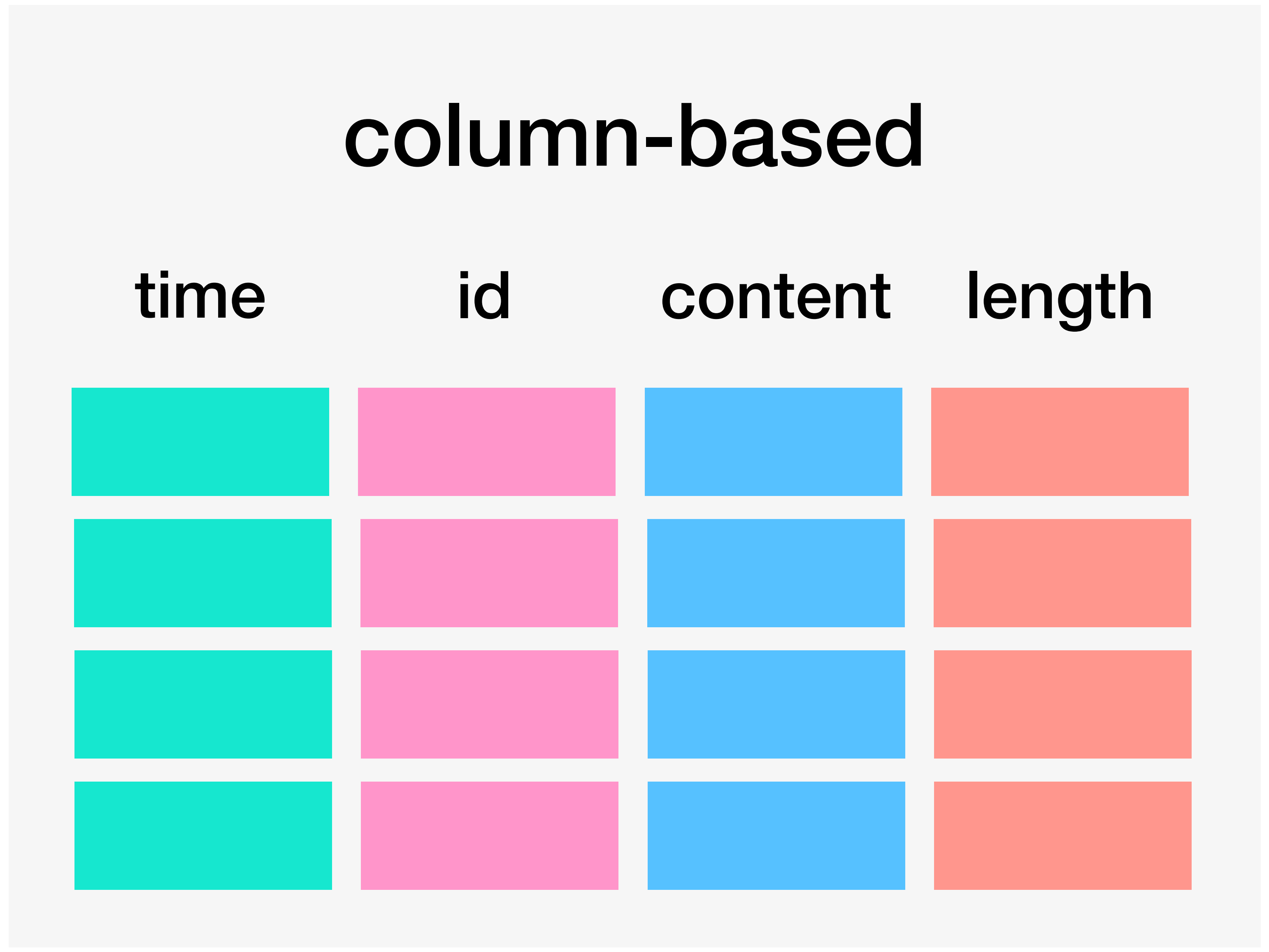
Storage


row-based
time
id
content
length

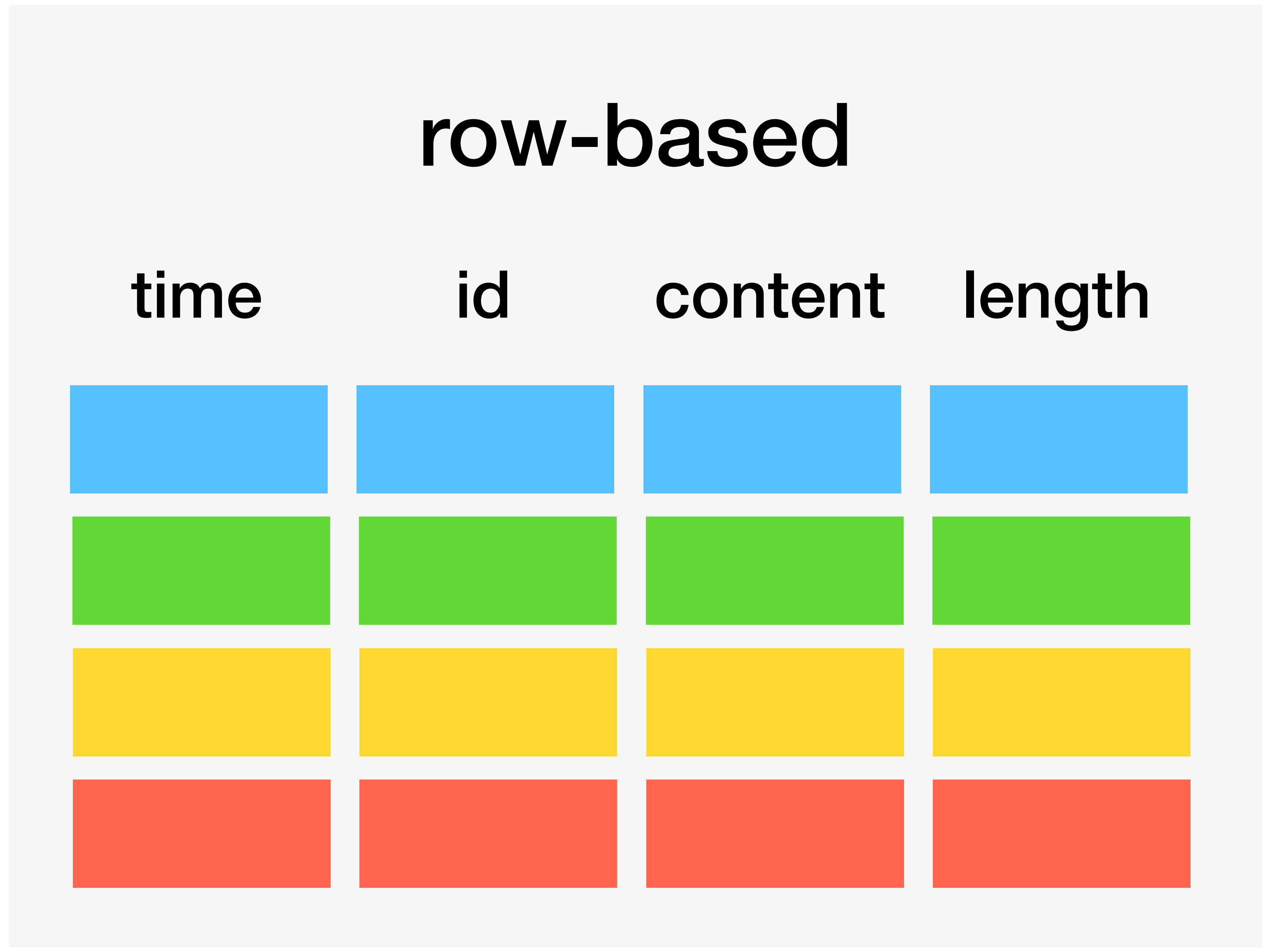

column-based
time
id
content
length

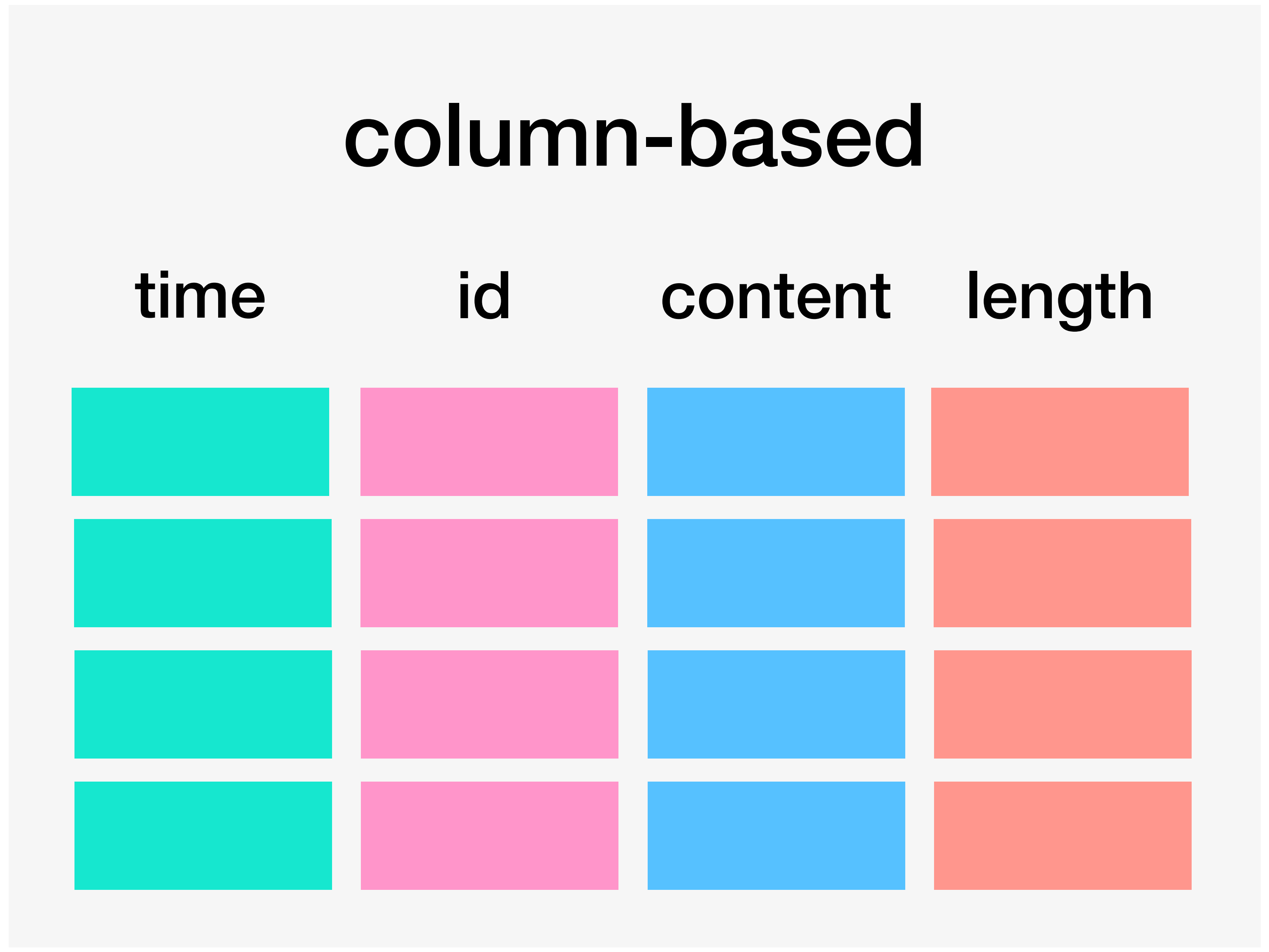
Storage

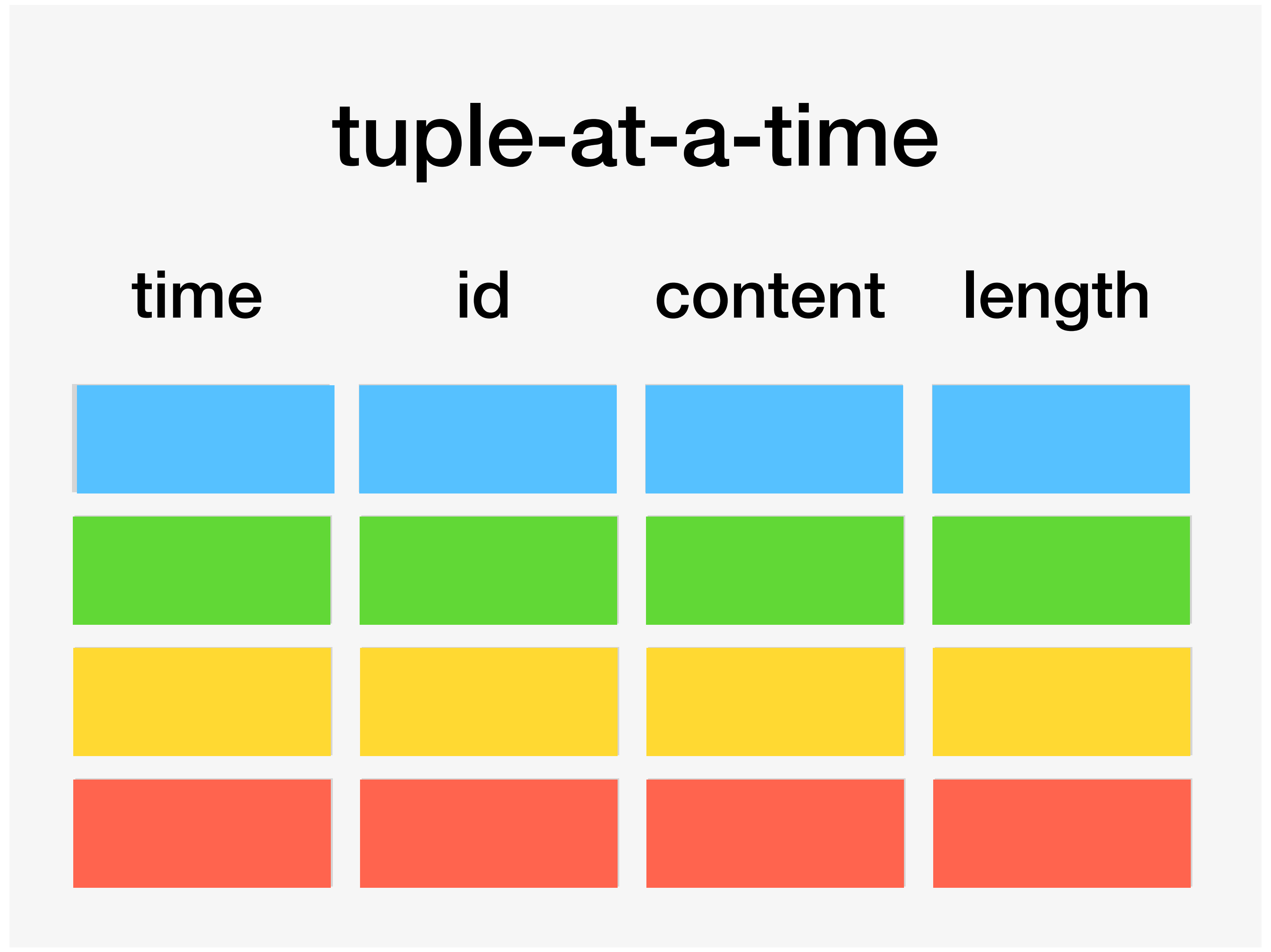

row-based
time
id
content
length

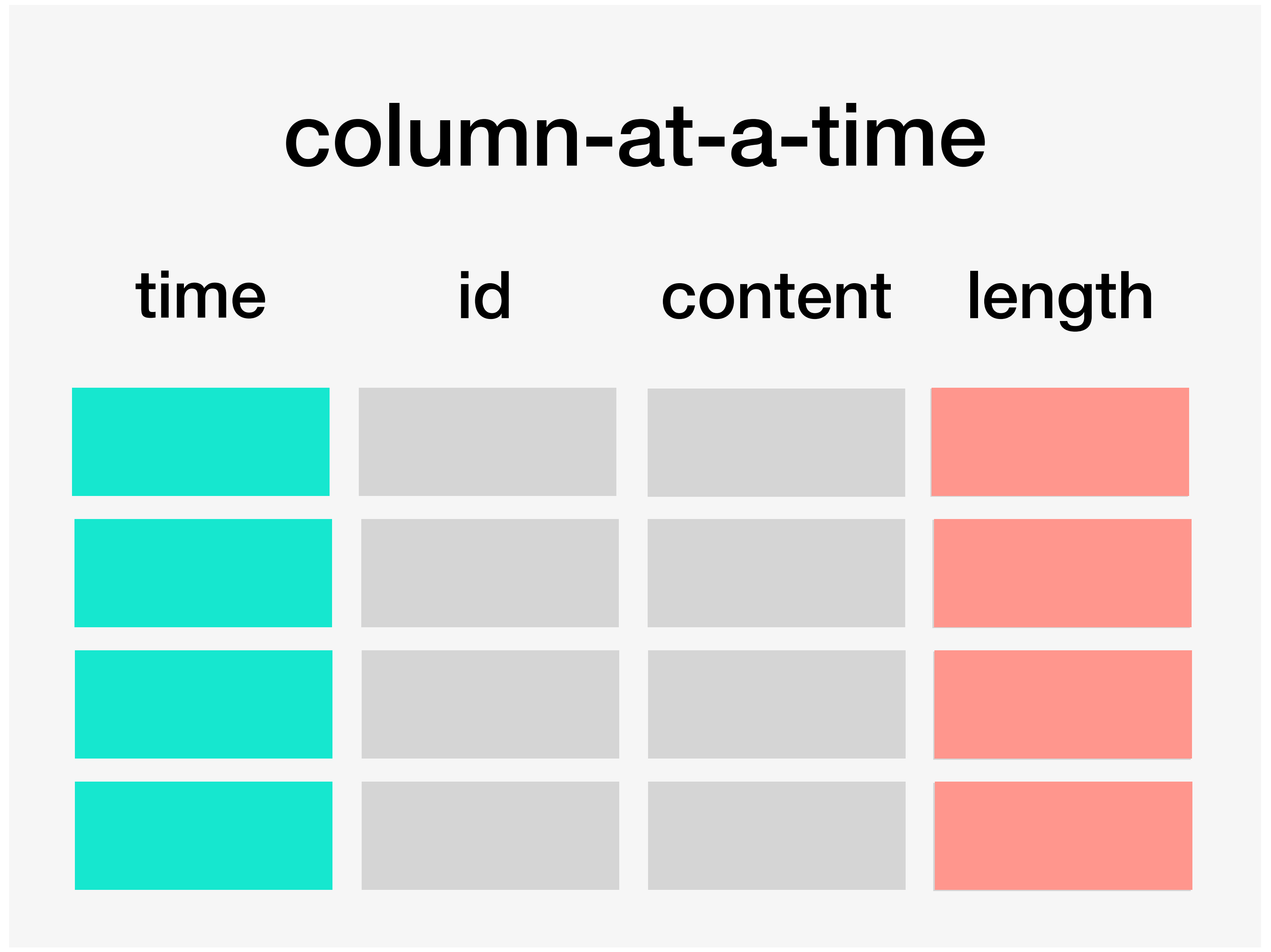

column-based
time
id
content
length

Execution

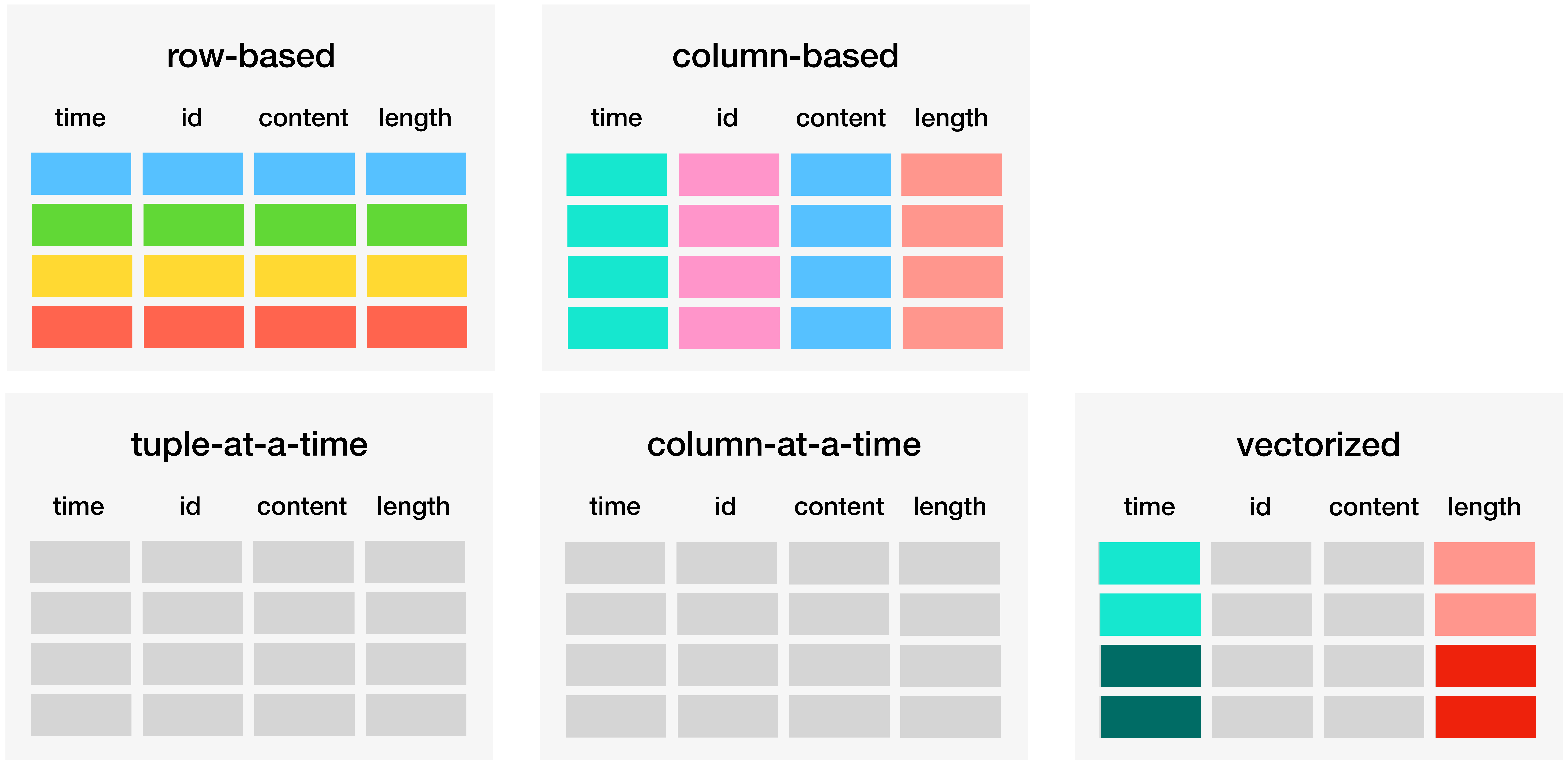

row-based
time
id
content
length


column-based
time
id
content
length

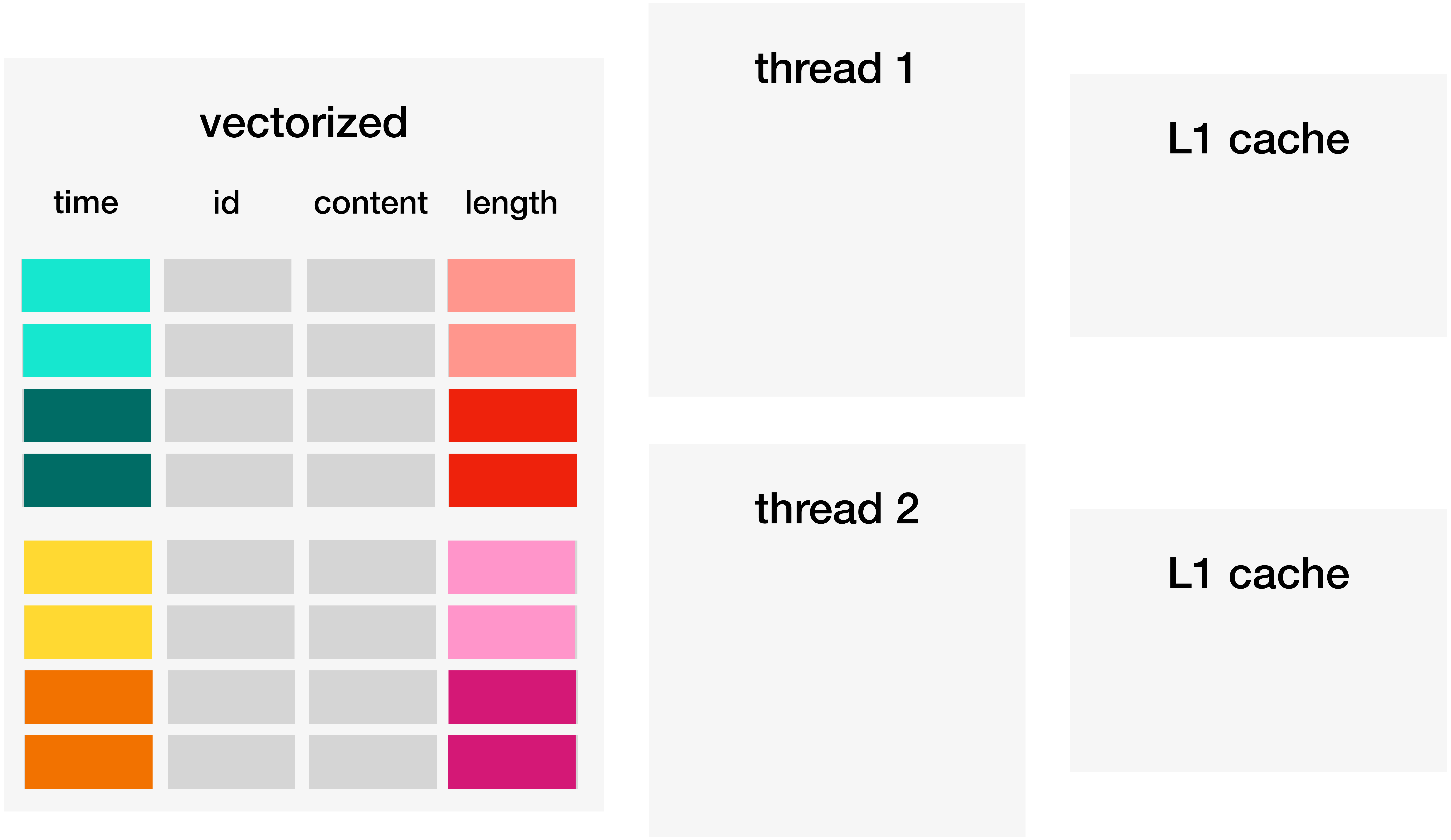

tuple-at-a-time
time
id
content
length


column-at-a-time
time
id
content
length

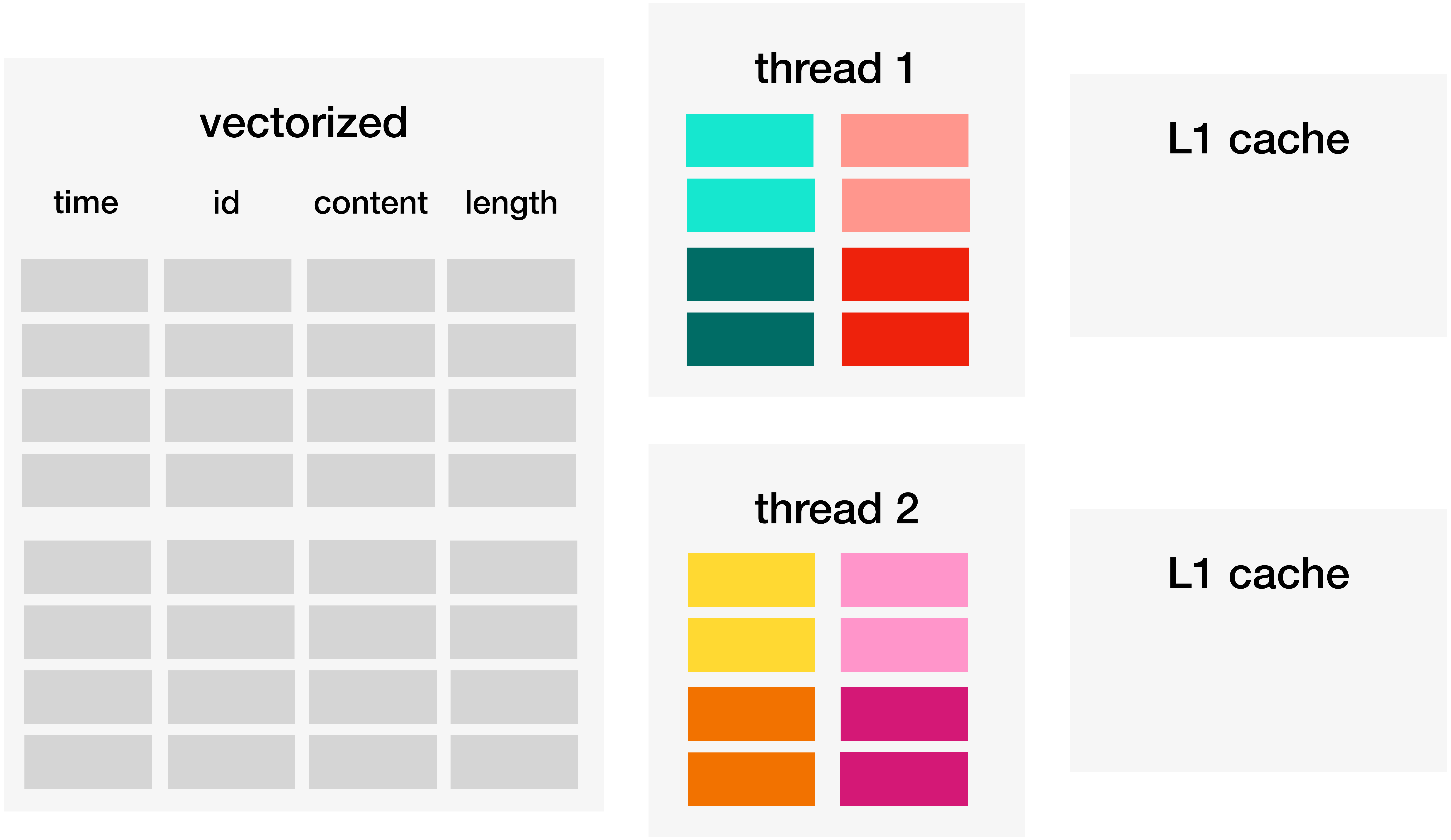
Execution


row-based
time
id
content
length
column-based
time
id
content
length
tuple-at-a-time
time
id
content
length
column-at-a-time
time
id
content
length
vectorized
time
id
content
length

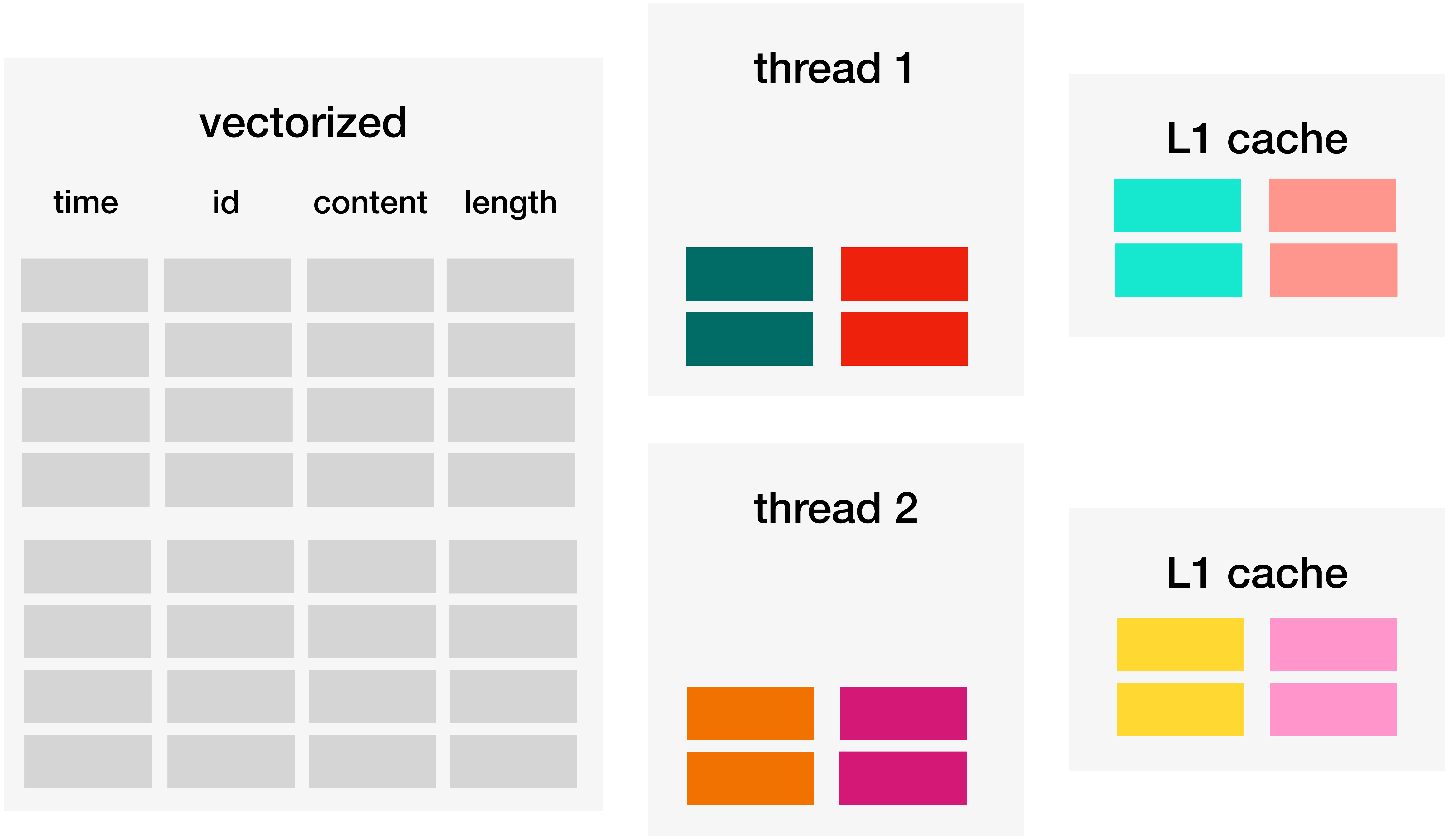
Vectorized execution



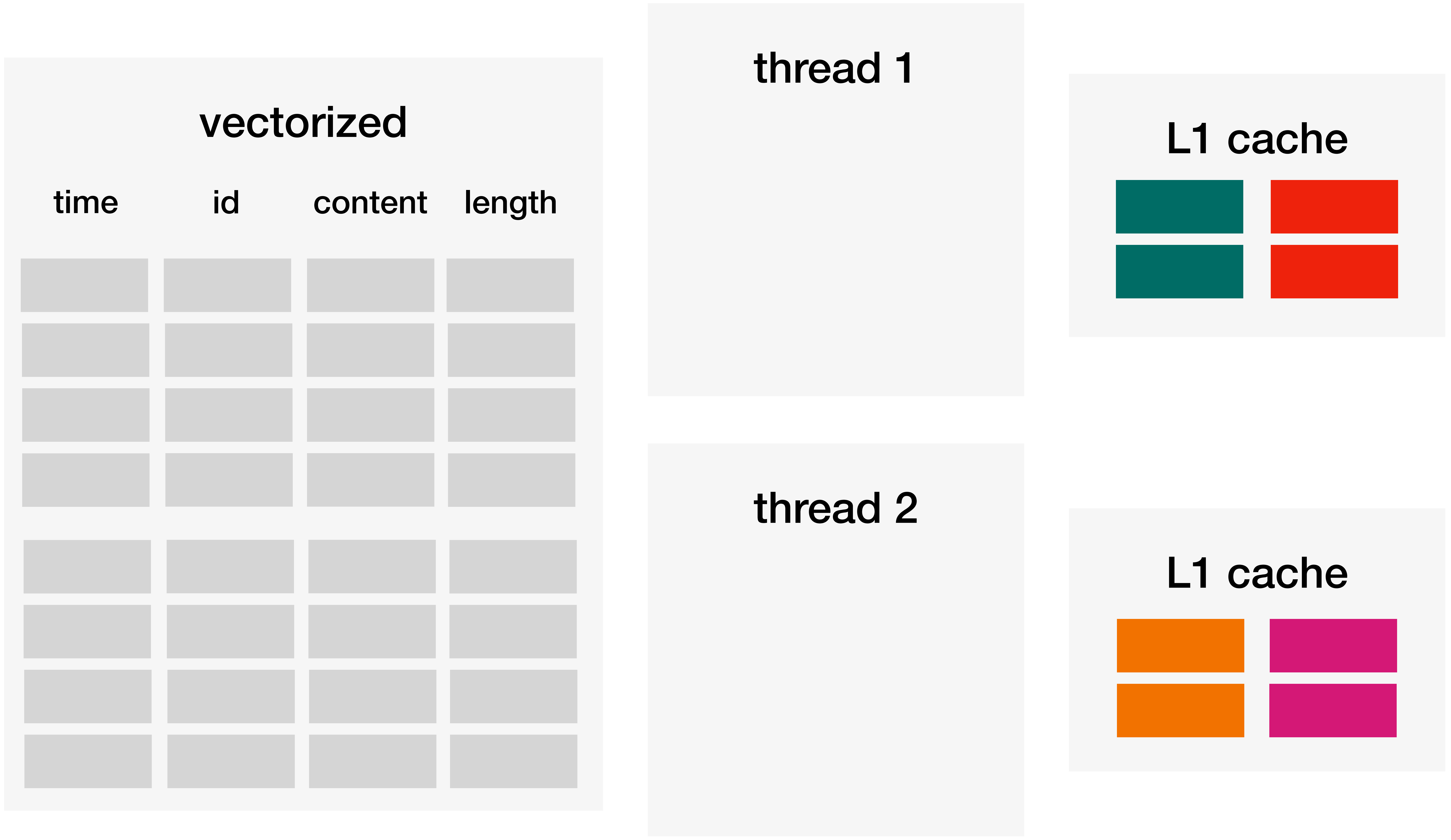
Vectorized execution



Vectorized execution



Vectorized execution



Vectors fit into
L1 cache (32–128kB)

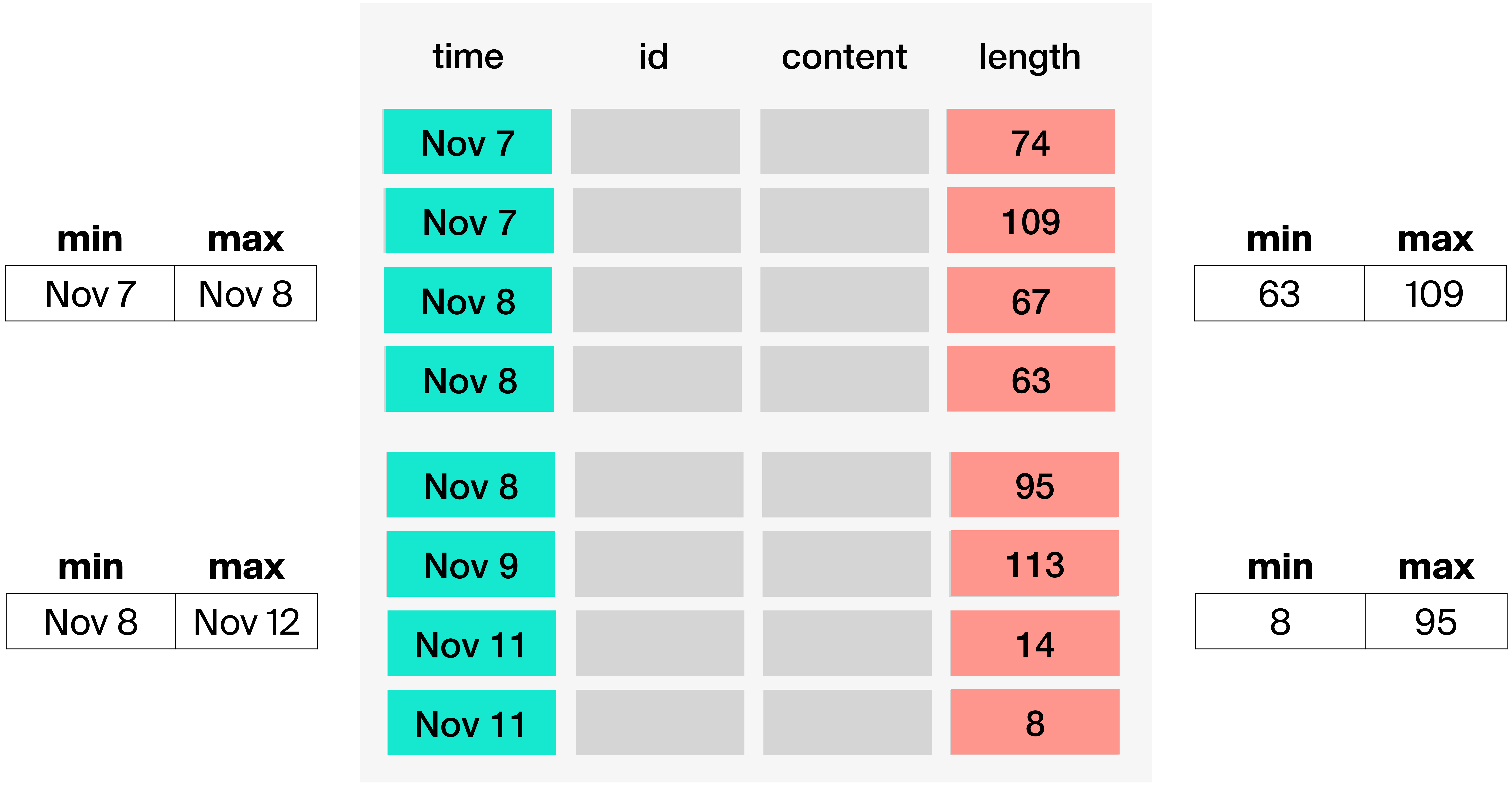
SIMD vectorization
(AVX-512: 8×64-bit ints)

Modern compilers
auto-vectorize code

Parallelization along
row groups

Indexing: Zone maps

For each column, DuckDB creates zone maps (a.k.a. min-max indexes)



min	max
Nov 7	Nov 8

time	id	content	length
Nov 7			74
Nov 7			109
Nov 8			67
Nov 8			63
Nov 8			95
Nov 9			113
Nov 11			14
Nov 11			8

min	max
63	109

min	max
Nov 8	Nov 12

min	max
8	95

Indexing with the Adaptive Radix Tree (ART)

DuckDB supports secondary indexes:

- implicit indexes – primary key, foreign key, unique
- explicit indexes – `CREATE [UNIQUE] INDEX`

Tradeoffs:

- speed-up for high selectivity lookups
- negative performance impact for updates

Rule of thumb:

Most of the time indexes are not needed

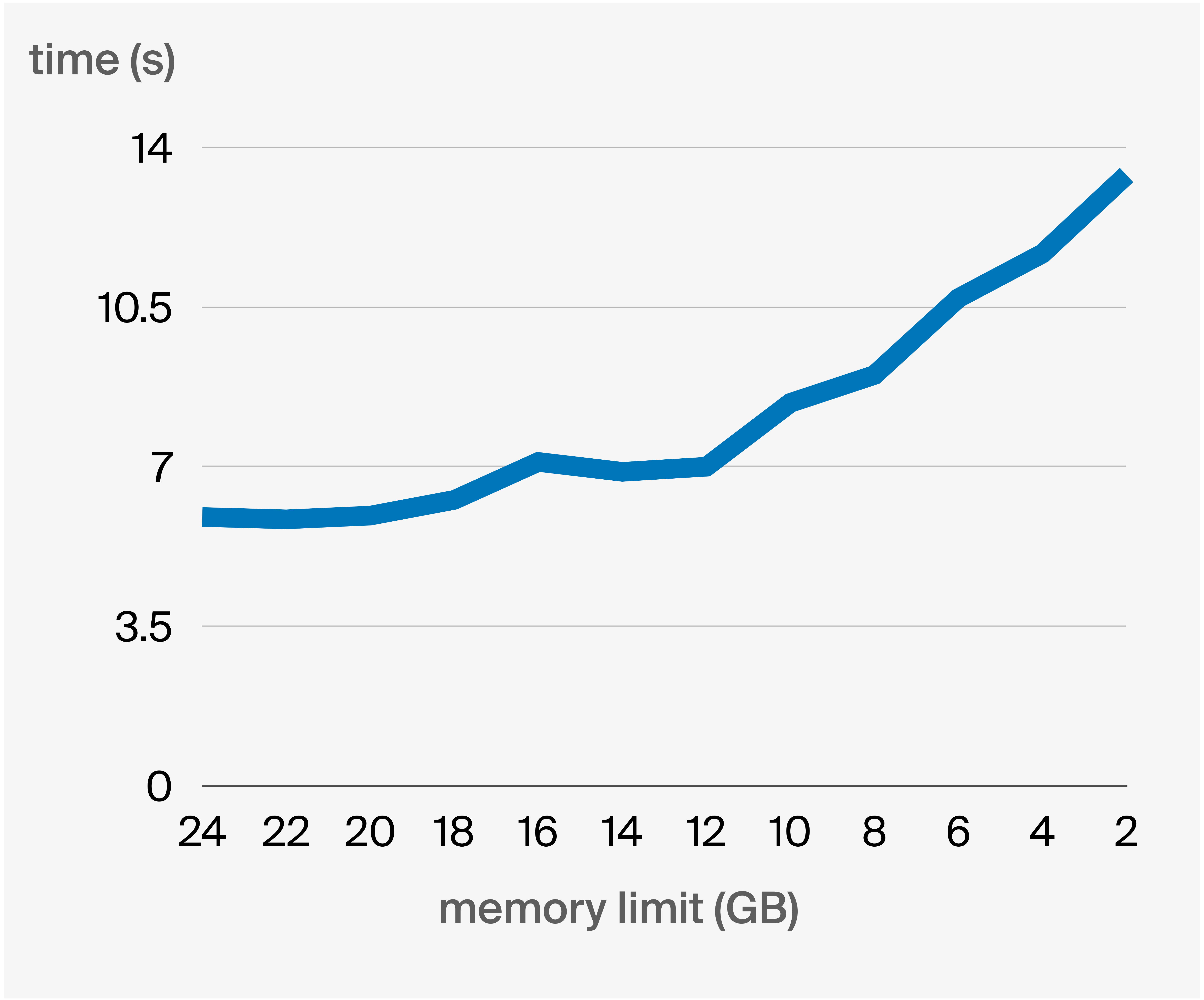
Larger-than-memory execution: Joins and aggregations

Larger-than-memory execution

- Graceful degradation
- Always try to finish

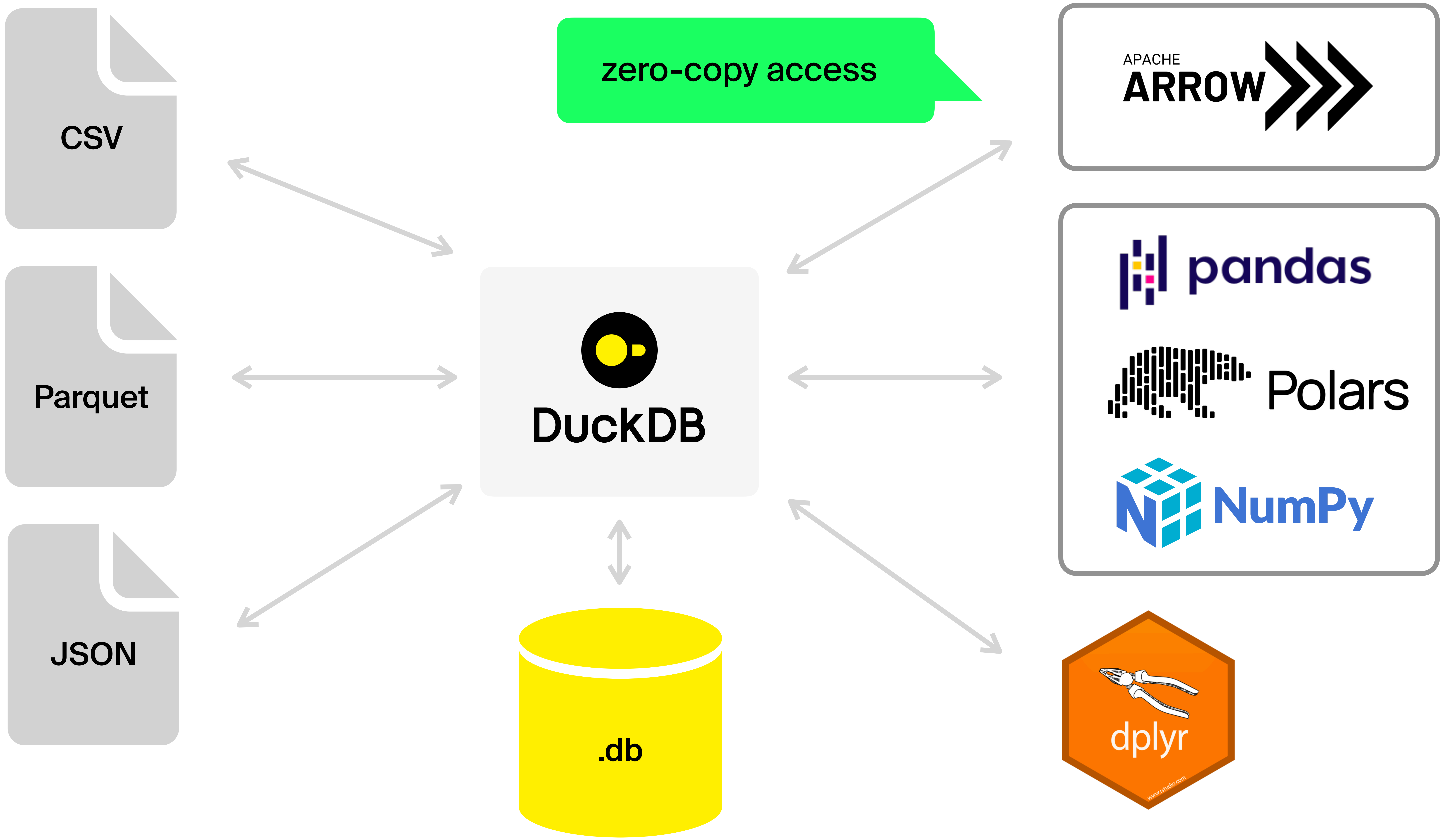
Example:

- TPC-H SF100
- Query 7



Feature-rich

Input and output formats

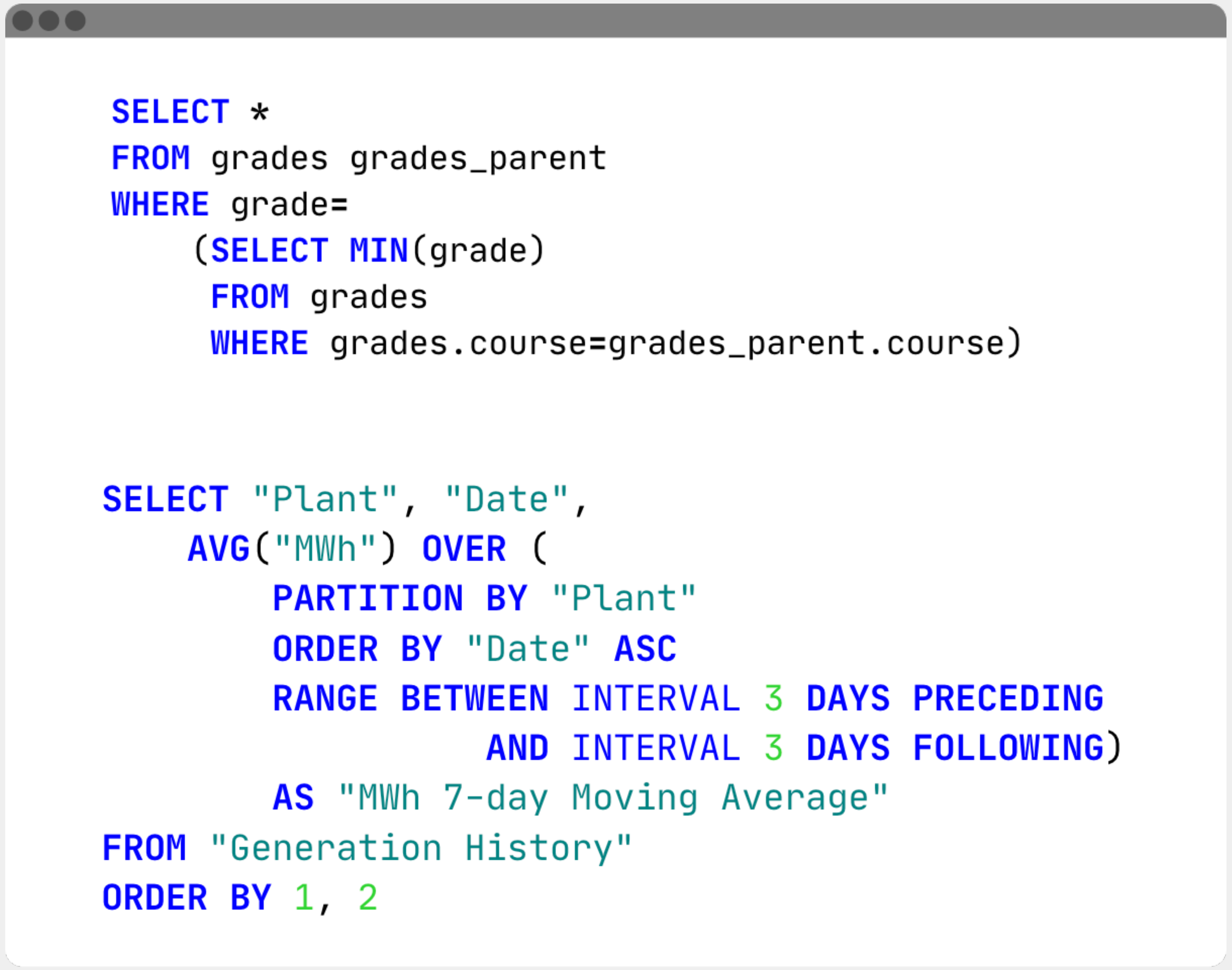


Query language

PostgreSQL dialect:

- Subqueries
- Window functions
- Common table extensions
- Lateral joins
- Range joins
- AsOf joins
- Pivoting and unpivoting tables

"Friendly SQL" extensions



```
SELECT *
FROM grades grades_parent
WHERE grade=
    (SELECT MIN(grade)
     FROM grades
     WHERE grades.course=grades_parent.course)


SELECT "Plant", "Date",
    AVG("MWh") OVER (
        PARTITION BY "Plant"
        ORDER BY "Date" ASC
        RANGE BETWEEN INTERVAL 3 DAYS PRECEDING
                  AND INTERVAL 3 DAYS FOLLOWING)
        AS "MWh 7-day Moving Average"
FROM "Generation History"
ORDER BY 1, 2
```

DuckDB SQL: FROM-first syntax

Common pattern:

```sql
SELECT *
FROM Comment;
```

Friendly variant:

```sql
FROM Comment;
```

DuckDB SQL: EXCLUDE columns

Common pattern:

```
SELECT
  creationDate, id, locationIP, browserUsed, content,
  length, CreatorPersonId, LocationCountryId
FROM Comment;
```

Friendly variant:

```
SELECT * EXCLUDE (ParentCommentId, ParentPostId)
FROM Comment;
```

DuckDB SQL: GROUP BY ALL

Common pattern:

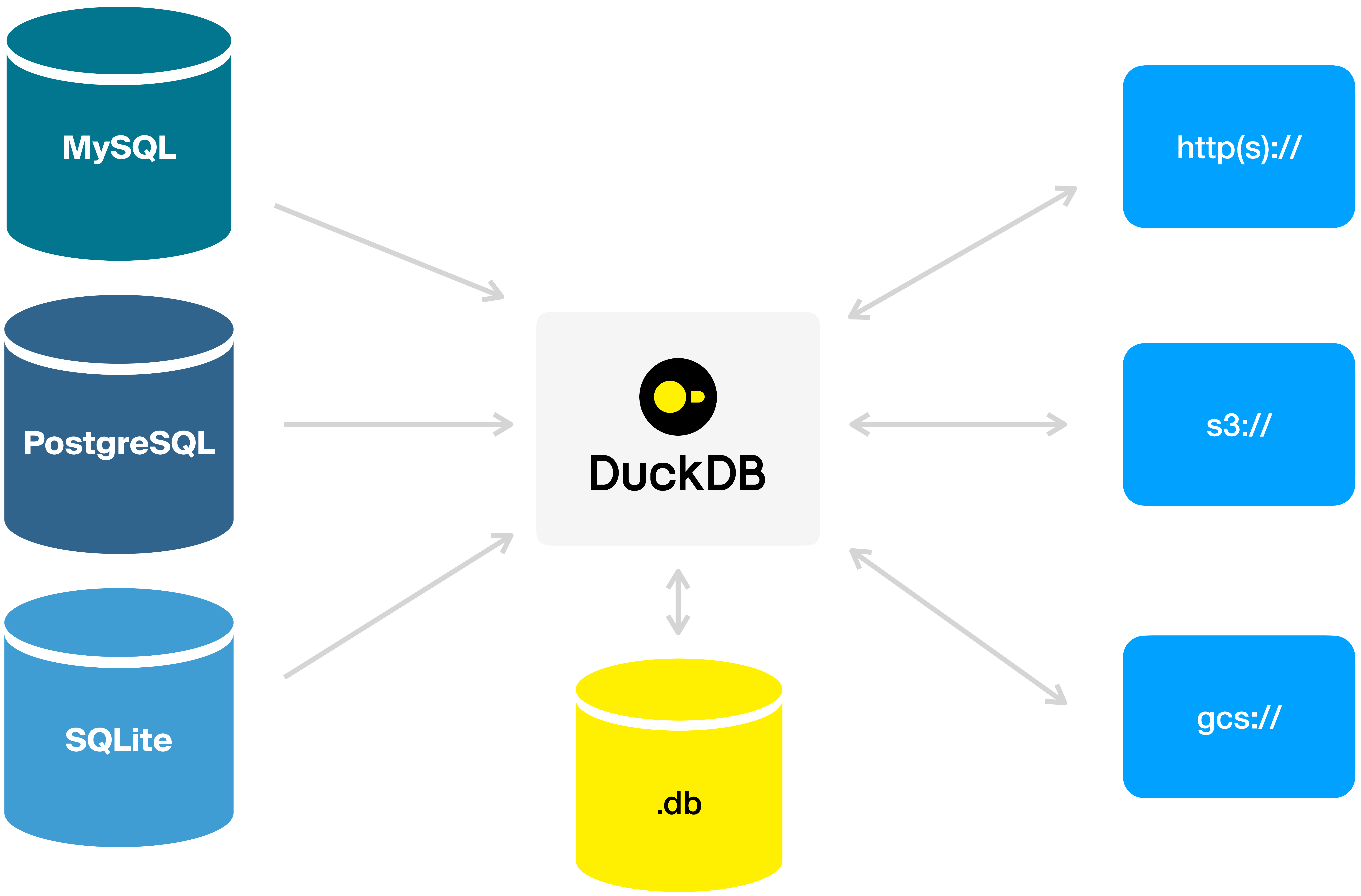
```
SELECT month(creationDay), count(*) AS numComments
FROM Comment;

--> syntax error
```

Friendly variant:

```
SELECT month(creationDay), count(*) AS numComments
FROM Comment
GROUP BY ALL;
```

Extensions

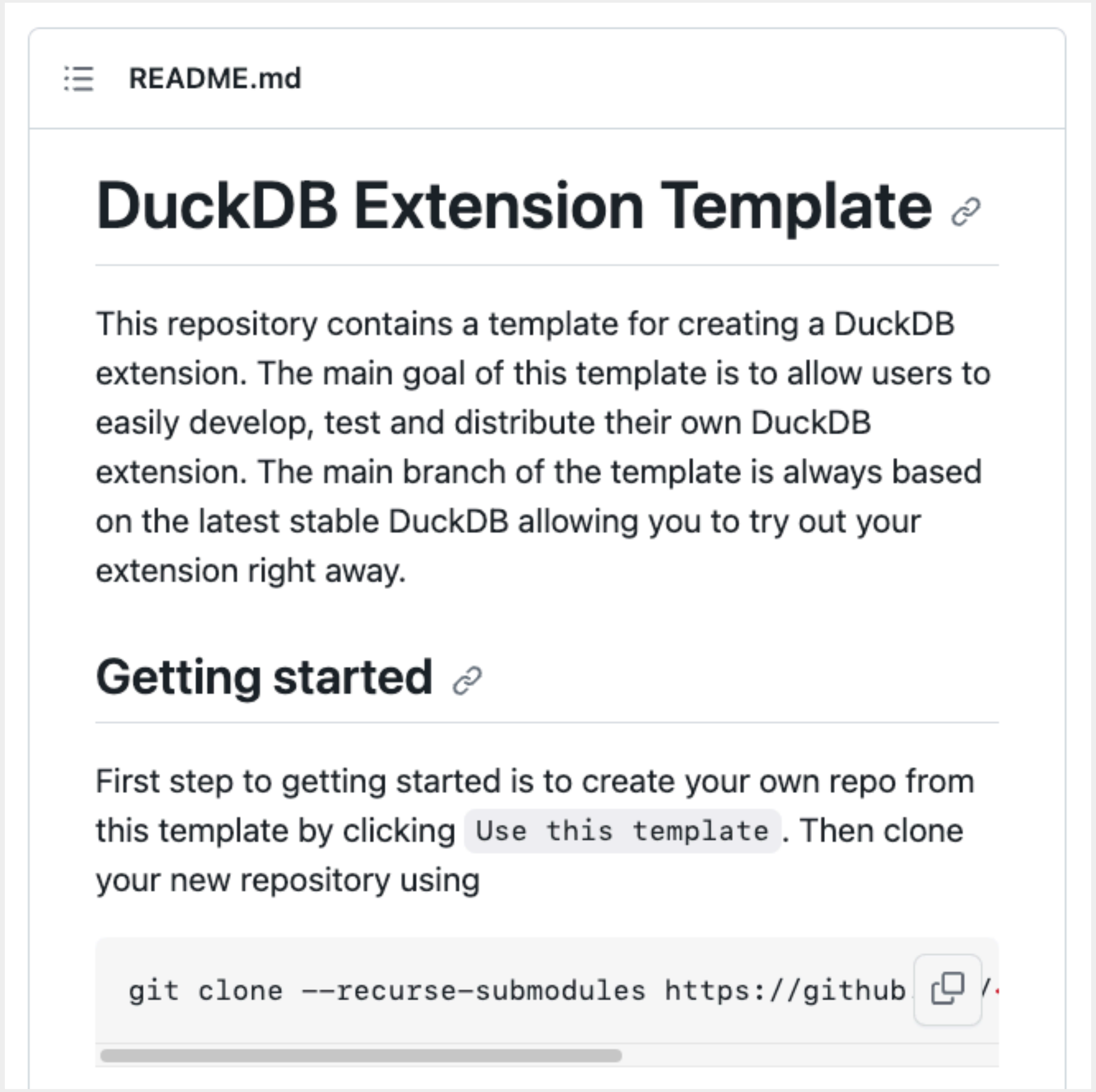
Data sources and destinations



Extensions

- Powerful extension mechanism:
  - new types and functions
  - data formats
  - operators
  - SQL syntax
  - memory allocator

- Many DuckDB features are implemented as extensions
  - httpfs
  - JSON
  - Parquet



README.md

DuckDB Extension Template

This repository contains a template for creating a DuckDB extension. The main goal of this template is to allow users to easily develop, test and distribute their own DuckDB extension. The main branch of the template is always based on the latest stable DuckDB allowing you to try out your extension right away.

Getting started

First step to getting started is to create your own repo from this template by clicking `Use this template`. Then clone your new repository using

```
git clone --recurse-submodules https://github
```

Parquet + httpfs extensions to query stock data

```sql
SELECT avg(price)
FROM 'https://duckdb.org/data/prices.parquet'
WHERE ticker = 'MSFT';
```

```
┌────────────┐
│ avg(price) │
│   double   │
├────────────┤
│        2.0 │
└────────────┘
```

It's not a full download:

- HTTP range requests so seek to the required data
- Only touch the ticker and price columns

Spatial extension

- Adds PostGIS-like functionality: geospatial types for points, polygons, etc.
- Adds functions for calculating distances

Example: aerial distance on the New York taxi data set

```sql
SELECT
  st_point(pickup_latitude, pickup_longitude) as pickup_point,
  st_point(dropoff_latitude, dropoff_longitude) as dropoff_point,
  dropoff_datetime::TIMESTAMP - pickup_datetime::TIMESTAMP AS time,
  trip_distance,
  st_distance(
    st_transform(pickup_point,  'EPSG:4326', 'ESRI:102718'),
    st_transform(dropoff_point, 'EPSG:4326', 'ESRI:102718')) / 5280 AS aerial_distance,
  trip_distance - aerial_distance AS diff
FROM rides
WHERE diff > 0
ORDER BY diff DESC;
```

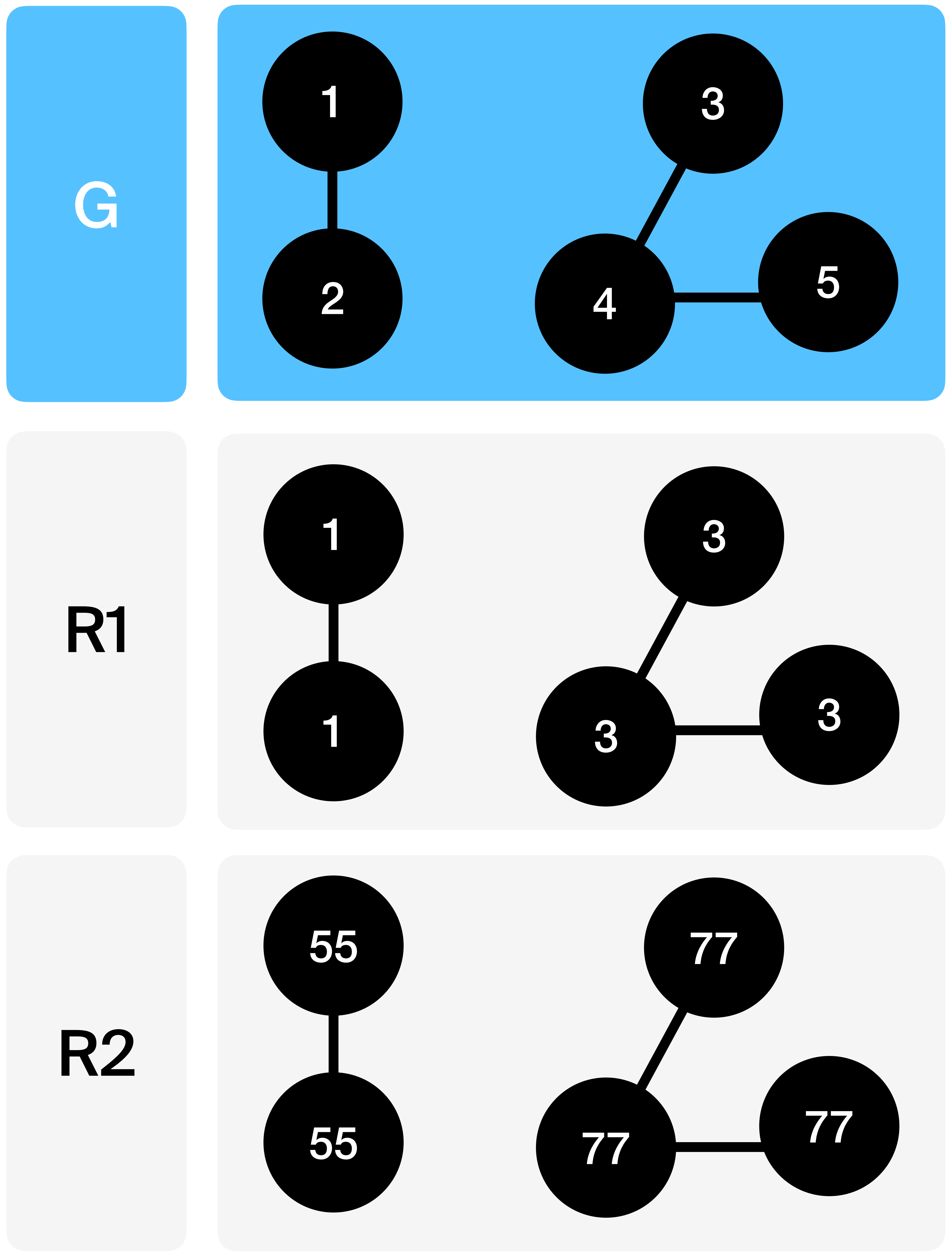
DuckDB

Harnessing in-process analytics for data science <u>and beyond</u>

Gábor Szárnyas
Developer Relations Advocate

DuckDB Labs

Modernizing a graph algorithm benchmark



Context:

Graph benchmark from 2015 (legacy code!)

Goal: find connected components quickly

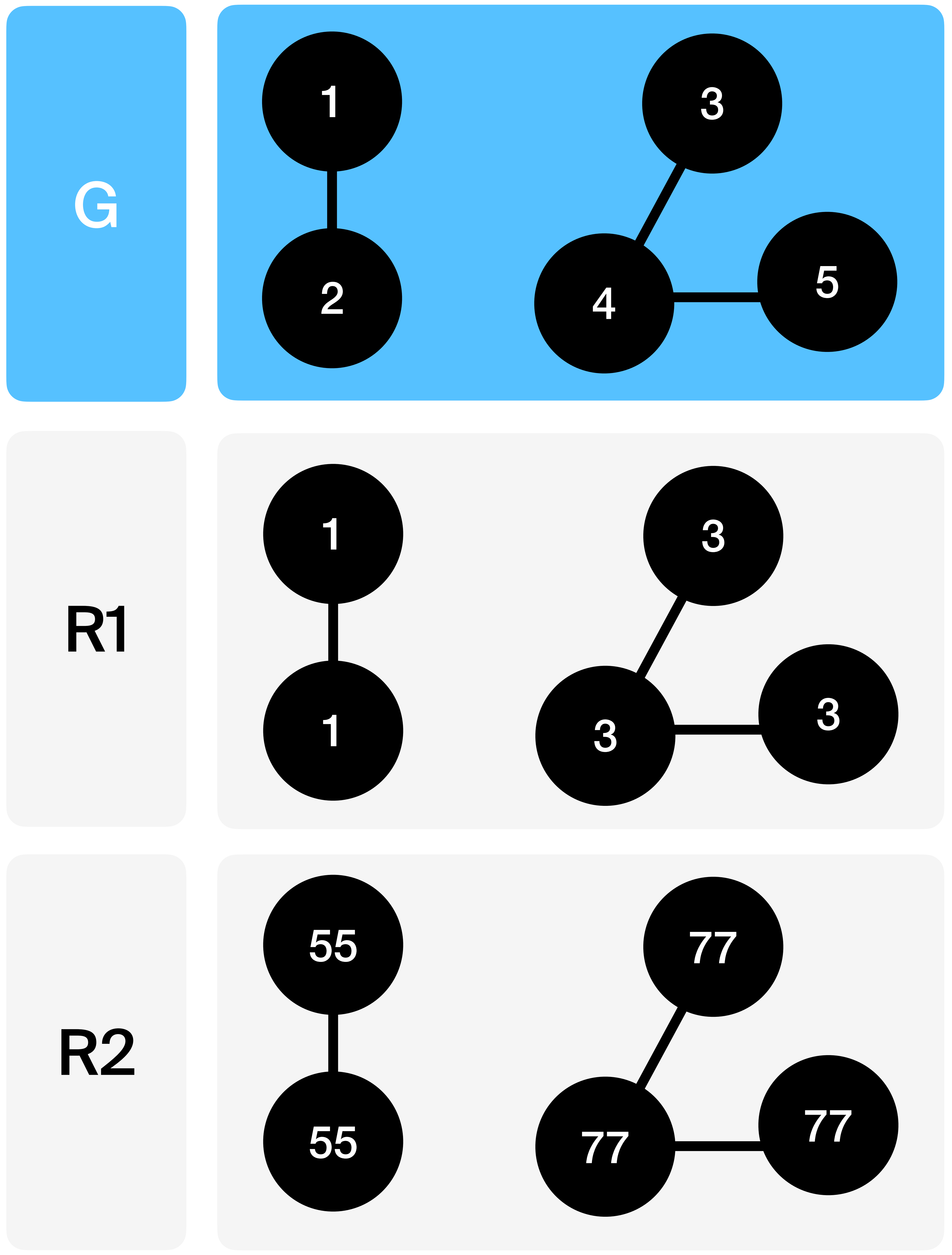
Validation rule:

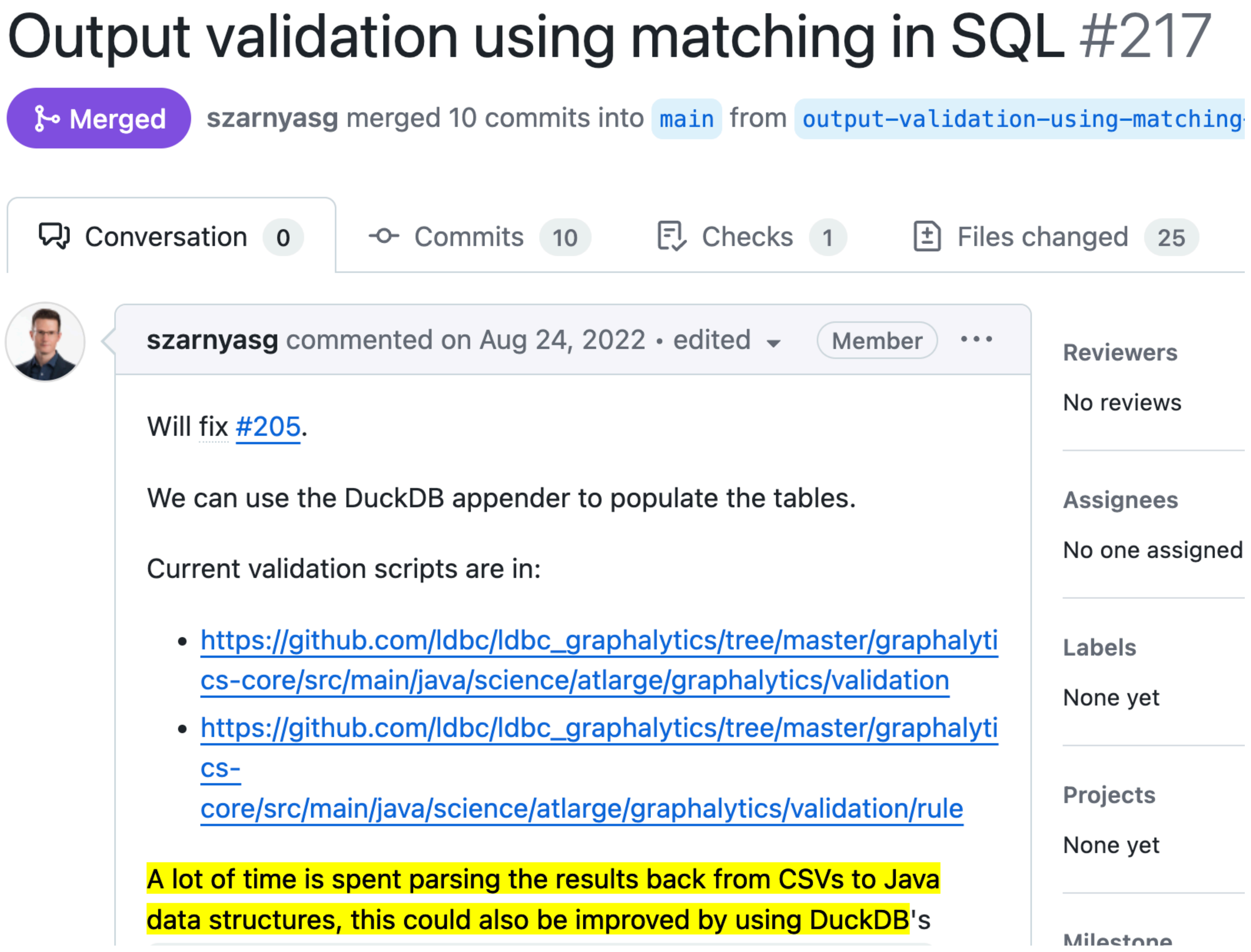
The result encode equivalence classes (R1=R2)

Problem:

The validation became very slow for large graphs (single-threaded Java code building hashmaps)

Modernizing a graph algorithm benchmark





Output validation using matching in SQL #217

szarnyasg merged 10 commits into `main` from `output-validation-using-matching`

szarnyasg commented on Aug 24, 2022 • edited

Will fix #205.

We can use the DuckDB appender to populate the tables.

Current validation scripts are in:

- https://github.com/ldbc/ldbc_graphalytics/tree/master/graphalytics-core/src/main/java/science/atlarge/graphalytics/validation
- https://github.com/ldbc/ldbc_graphalytics/tree/master/graphalytics-core/src/main/java/science/atlarge/graphalytics/validation/rule

A lot of time is spent parsing the results back from CSVs to Java data structures, this could also be improved by using DuckDB's

Reviewers
No reviews

Assignees
No one assigned

Labels
None yet

Projects
None yet

Milestone

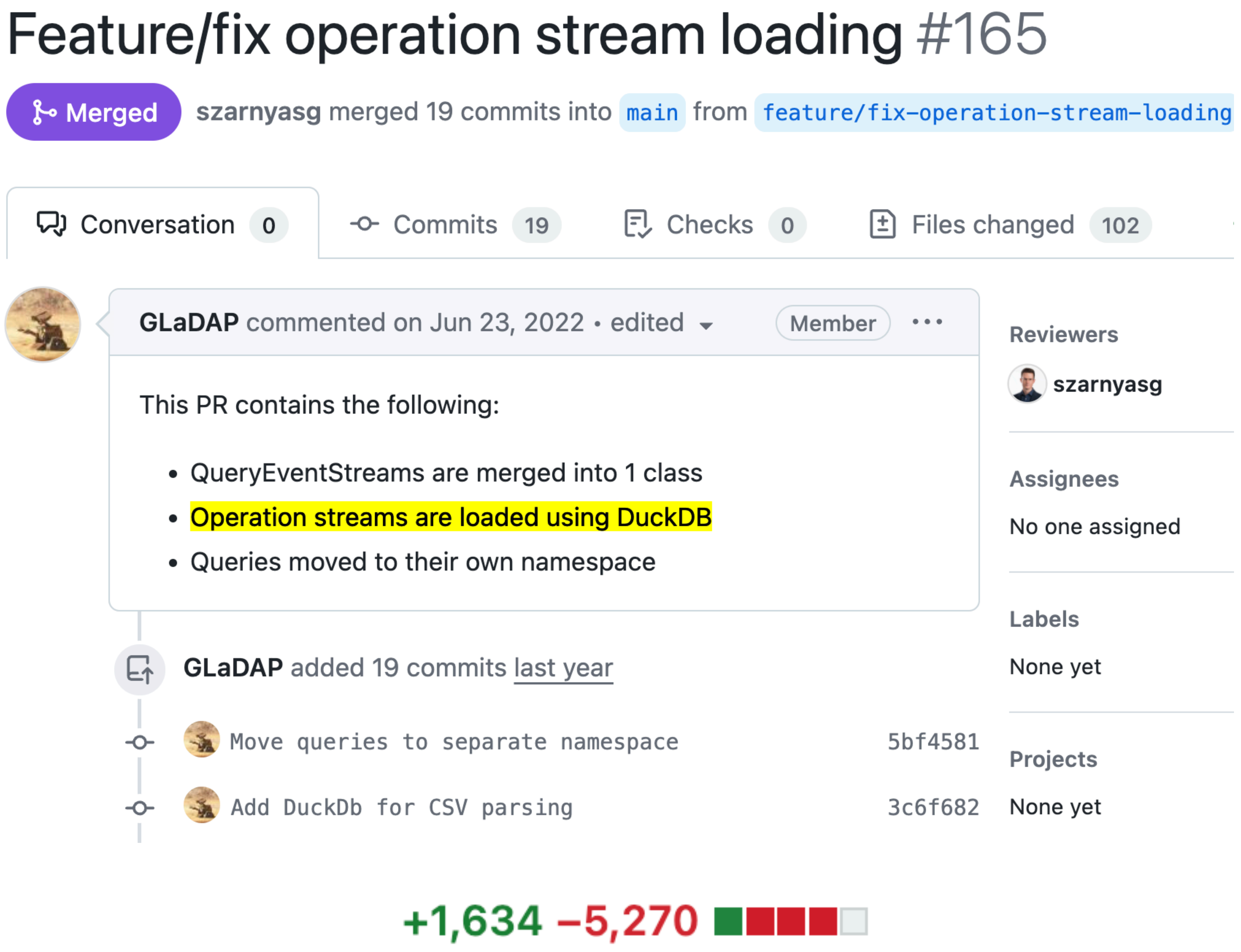
+338 −457 🟩🟩🟥🟥⬜

More benchmark framework use cases

- Output validation
- Loading operation streams
- Query parameter generation
- Reading input parameters
- Preprocessing raw data
- Partitioning update streams
- Analyzing results

None of this is a DB problem...

But they are bulky operations on heavily structured data.



Feature/fix operation stream loading #165

Merged szarnyasg merged 19 commits into `main` from `feature/fix-operation-stream-loading`

GLaDAP commented on Jun 23, 2022 • edited · Member

This PR contains the following:

- QueryEventStreams are merged into 1 class
- Operation streams are loaded using DuckDB
- Queries moved to their own namespace

GLaDAP added 19 commits last year

```
Move queries to separate namespace    5bf4581
Add DuckDb for CSV parsing            3c6f682
```

Reviewers: szarnyasg

Assignees: No one assigned

Labels: None yet

Projects: None yet

+1,634 −5,270 🟩🟥🟥🟥⬜

Use cases

Saving costs:

- Replacing (parts of) data warehouse jobs
- Running computation locally

Building block in applications:

- Just to perform a simple step
- E.g., converting from Parquet to CSV

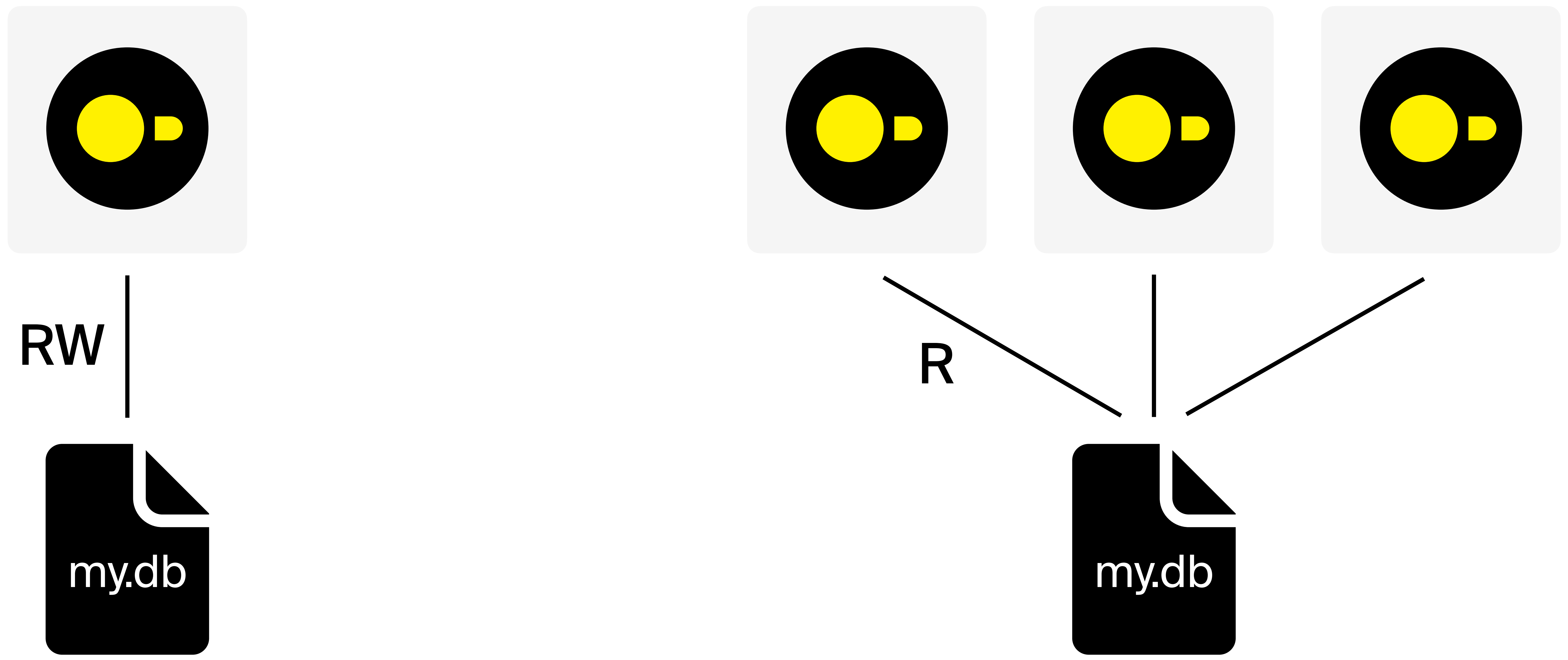
Education:

- Easy-to-install, open, standards-compliant system
- No configuration, no DBA

Limitations

Concurrency control

- ACID compliance via multi-version concurrency control (MVCC)
- WAL (write-ahead log) for recovery
- Not a good fit for write-heavy transactional workloads



Distributed execution

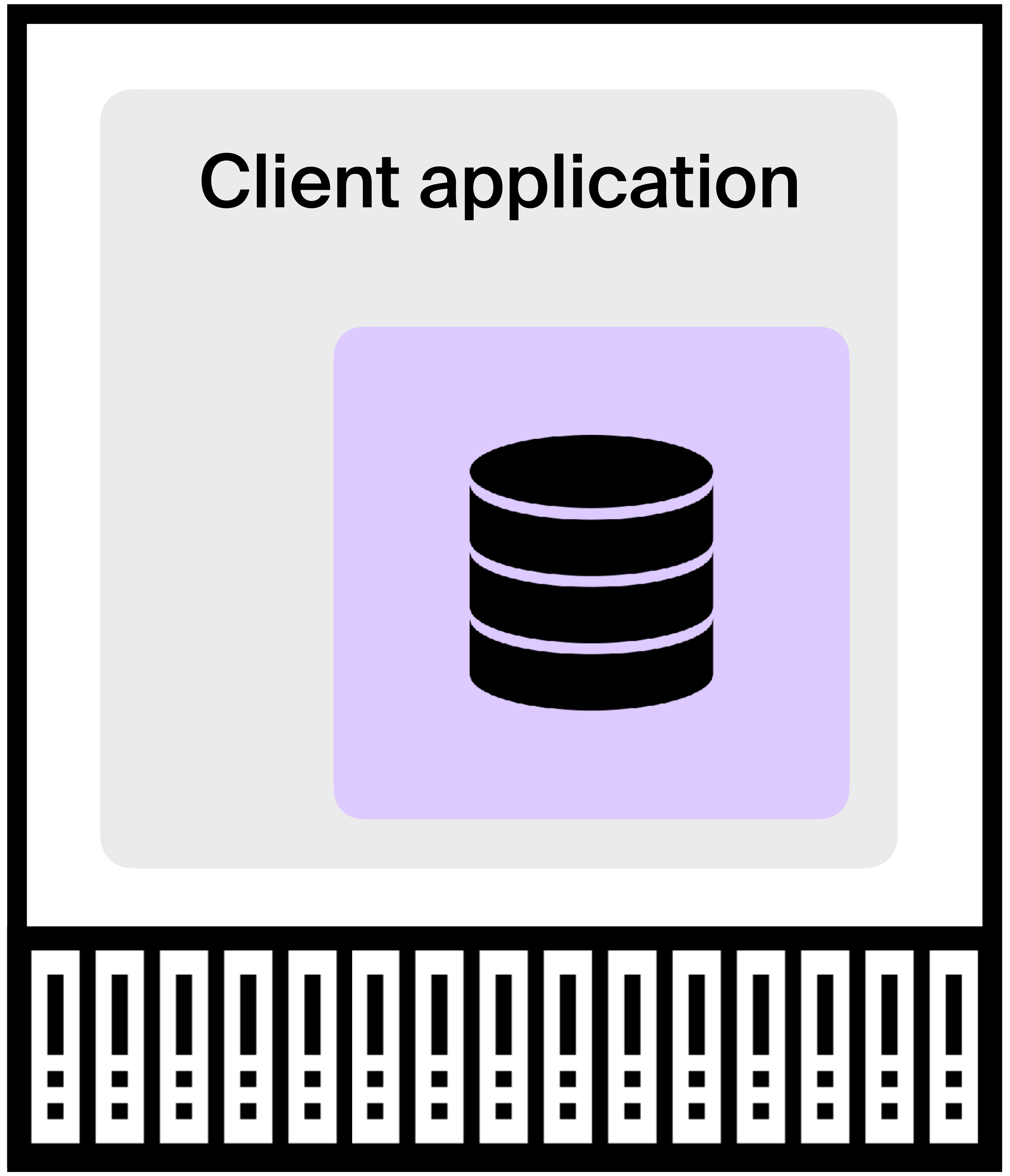
DuckDB only supports **single-node** execution

DuckDB can **scale up:**
- r6id.32xlarge instances have 1TB RAM for <$10/h
- x1e.32xlarge instances have 4TB RAM for ≈$28/h

Store the data in S3, run short bursts of workloads

Larger than memory execution allows scaling for TBs

For tens of TBs, a distributed setup is beneficial



The DuckDB landscape

DuckDB versions

v0.9	Current version
v0.10	Early next year
v1.0	Later next year

v1.0

- Stable file format
- Stability and maturity improvements
- Performance optimizations

Organizations around DuckDB

DuckDB

DuckDB Labs

MotherDuck

Wrapping up...

DuckDB is old-school with state of the art internals

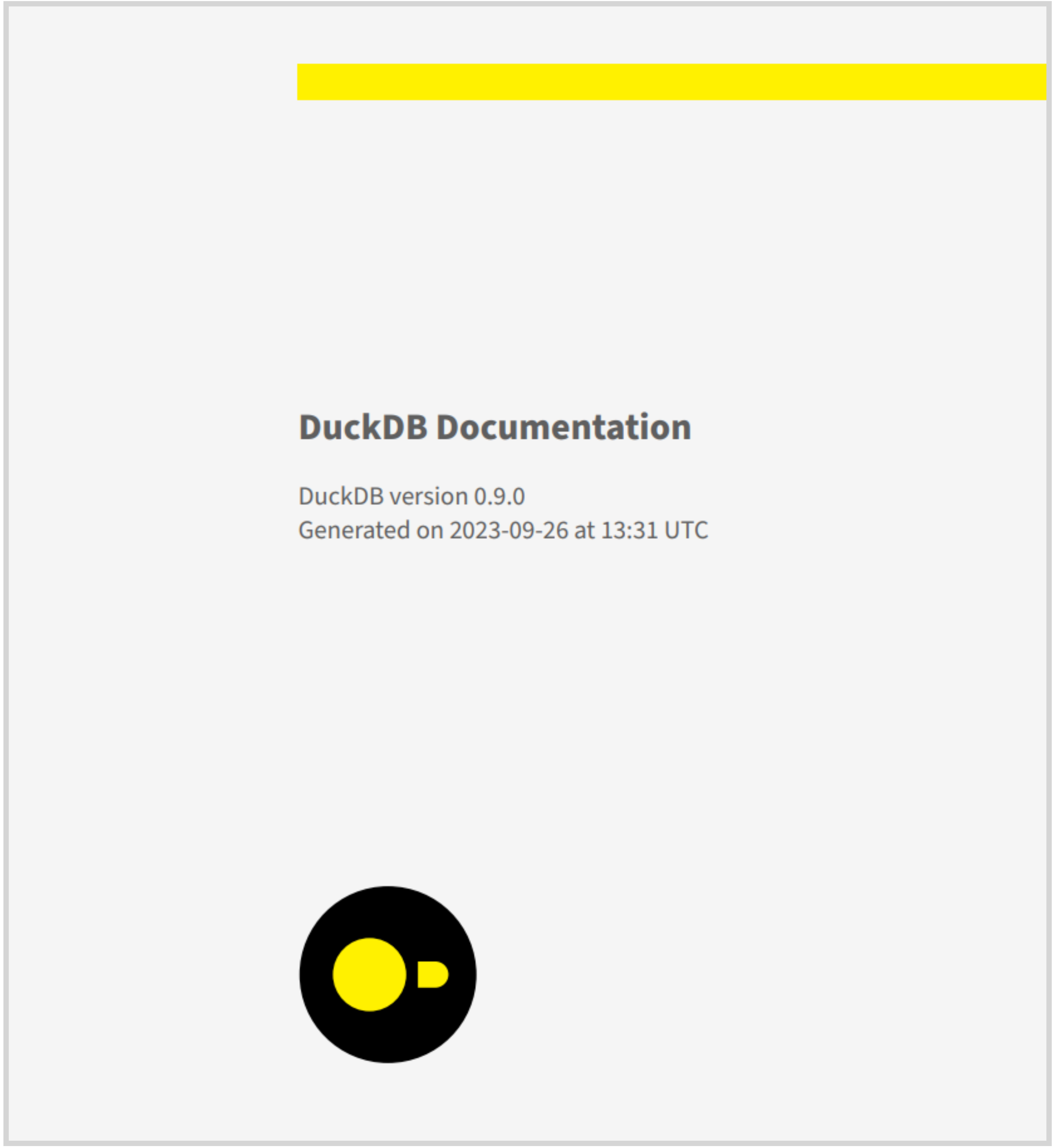
Classic open-source project

Full-fledged CLI client

Works when you're offline

No vendor lock-in

```
EXPORT DATABASE 'my_db' (FORMAT CSV);
EXPORT DATABASE 'my_db' (FORMAT PARQUET);
```

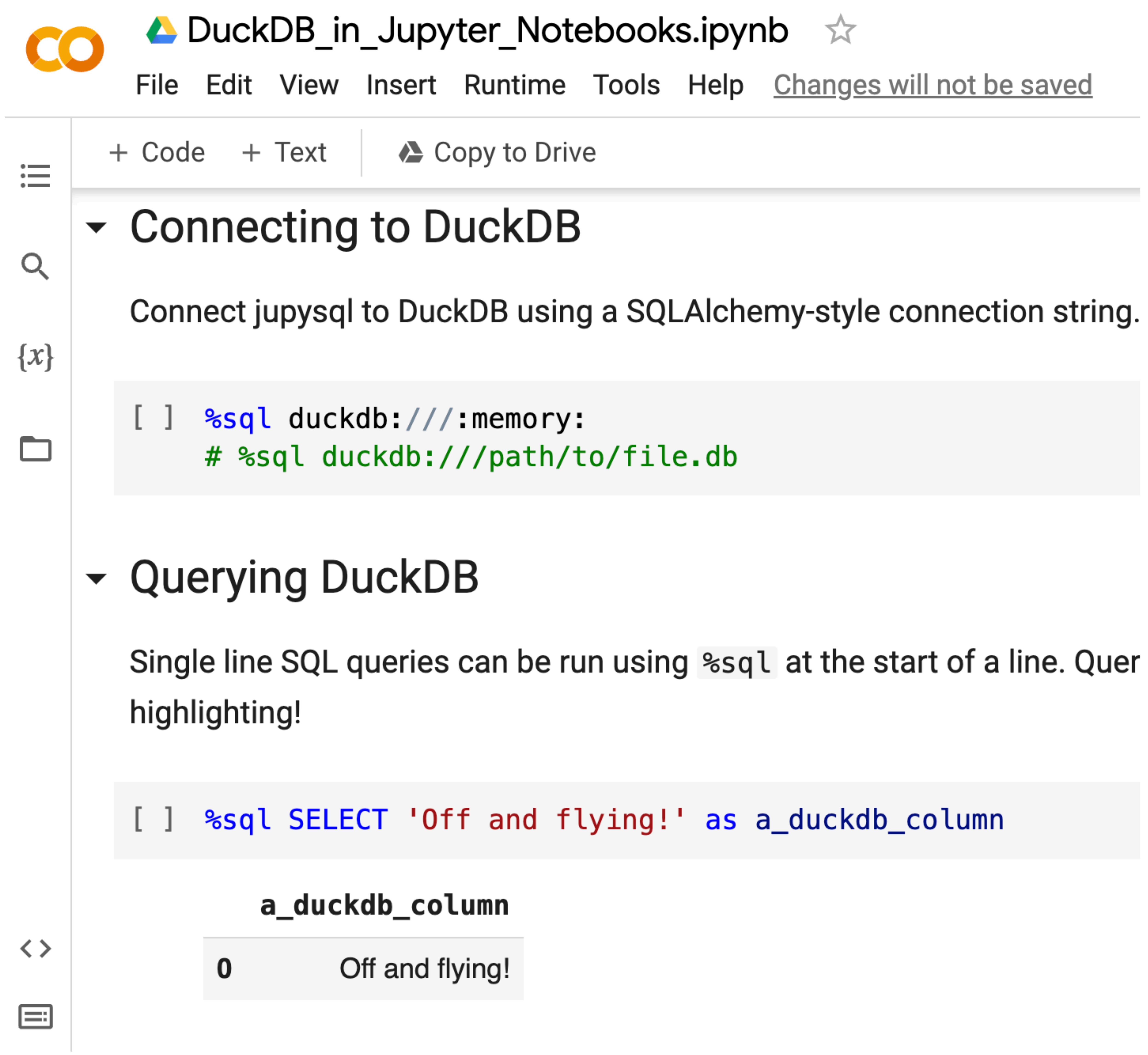


DuckDB Documentation

DuckDB version 0.9.0
Generated on 2023-09-26 at 13:31 UTC

Give DuckDB a spin!

Google Colab, shell.duckdb.org


DuckDB_in_Jupyter_Notebooks.ipynb
File Edit View Insert Runtime Tools Help Changes will not be saved
+ Code + Text Copy to Drive

Connecting to DuckDB

Connect jupysql to DuckDB using a SQLAlchemy-style connection string.

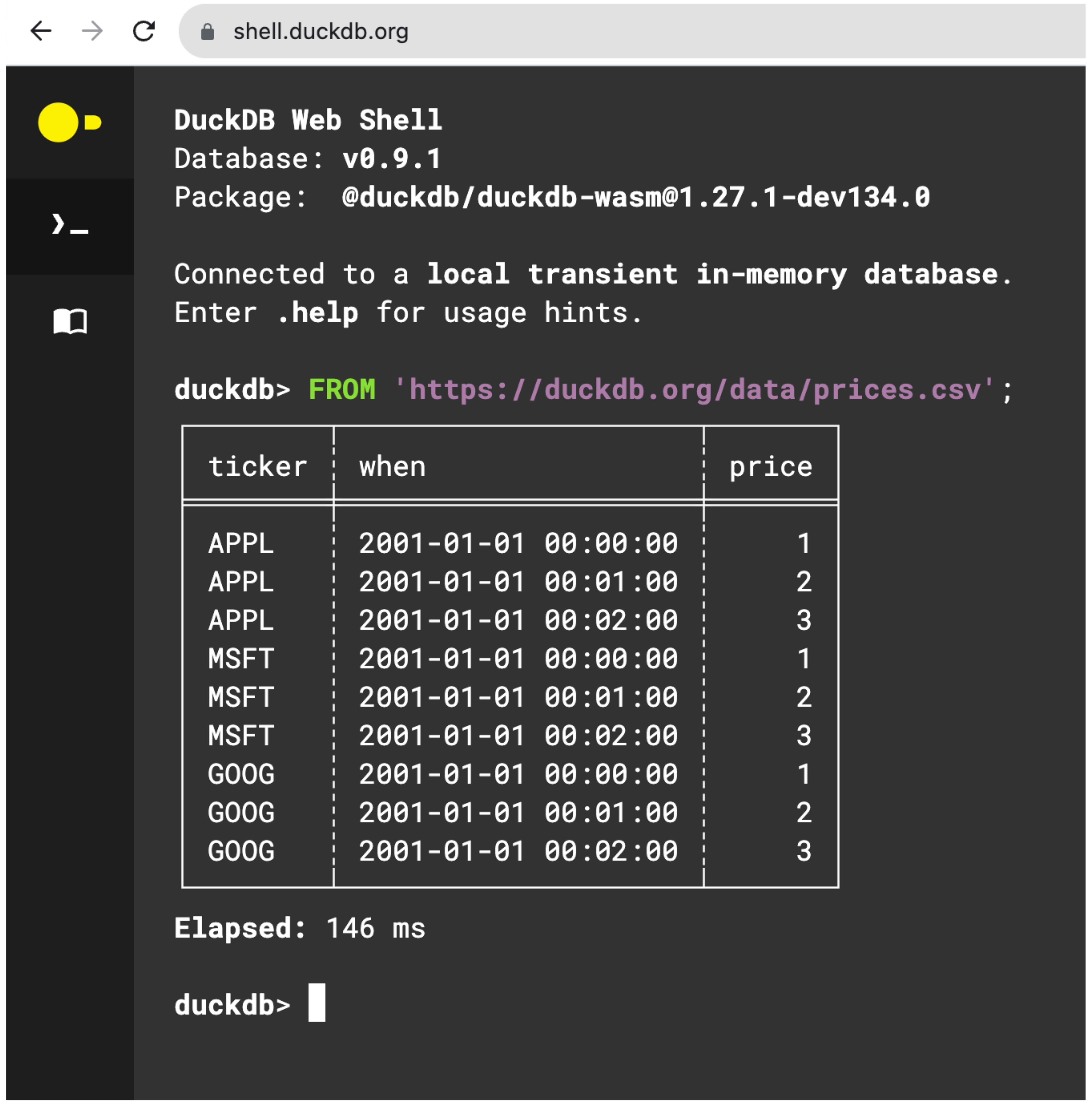
```
[ ] %sql duckdb:///:memory:
    # %sql duckdb:///path/to/file.db
```

Querying DuckDB

Single line SQL queries can be run using `%sql` at the start of a line. Quer highlighting!

```
[ ] %sql SELECT 'Off and flying!' as a_duckdb_column
```

	a_duckdb_column
0	Off and flying!



```
DuckDB Web Shell
Database: v0.9.1
Package:  @duckdb/duckdb-wasm@1.27.1-dev134.0

Connected to a local transient in-memory database.
Enter .help for usage hints.

duckdb> FROM 'https://duckdb.org/data/prices.csv';
┌────────┬─────────────────────┬───────┐
│ ticker │ when                │ price │
╞════════╪═════════════════════╪═══════╡
│ APPL   │ 2001-01-01 00:00:00 │     1 │
│ APPL   │ 2001-01-01 00:01:00 │     2 │
│ APPL   │ 2001-01-01 00:02:00 │     3 │
│ MSFT   │ 2001-01-01 00:00:00 │     1 │
│ MSFT   │ 2001-01-01 00:01:00 │     2 │
│ MSFT   │ 2001-01-01 00:02:00 │     3 │
│ GOOG   │ 2001-01-01 00:00:00 │     1 │
│ GOOG   │ 2001-01-01 00:01:00 │     2 │
│ GOOG   │ 2001-01-01 00:02:00 │     3 │
└────────┴─────────────────────┴───────┘
Elapsed: 146 ms

duckdb>
```

Stay in touch

discord.duckdb.org

@duckdb

duckdb.org