Accelerating QuestDB: Lessons from A 6x Query Performance Boost

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QuestDB

The database is the bottleneck

- Every developer in the 90s

Common use case for a time-series database

Real-time dashboards on recent data.

Real-time decision making (i.e. payment fraud).

Historical queries aggregated by time chunks.

Meet QuestDB: OSS time-series database

- https://github.com/questdb/questdb (Apache License 2.0)
- High-speed ingestion: InfluxDB line protocol over TCP or HTTP
- Columnar storage format (native or Parquet), partitioned and ordered by time
- Written in Java (90%) and C++/Rust (10%)
- Uses in-house replacement of Java's standard library
- Zero GC, SIMD, parallel SQL execution, SQL JIT compiler
- SQL with time-series extensions: PGWire, HTTP API

Time-series databases high level overview

- Time Series Databases specialise in very fast ingestion, very fast queries over nascent data, and powerful time-based analytical queries.
- They focus on nascent data, deleting, downsampling, or slowing-down older data.

Time-series SQL extensions

```sql
SELECT pickup_datetime, count() FROM trips
WHERE pickup_datetime in '2016-06-13;1M;1y;3'
SAMPLE BY 1w;

select timestamp, avg(price) from
(read_parquet('trades.parquet')
timestamp(timestamp)) sample by 15m;

SELECT * FROM trades
WHERE symbol in ('BTC-USDT', 'ETH-USDT')
LATEST ON timestamp PARTITION BY symbol;
```

```sql
SELECT
  timestamp, symbol, side, sum(amount) as volume
FROM trades
WHERE side = 'sell' AND timestamp IN today()
SAMPLE BY 1m FILL(NULL);

SELECT pickup_datetime, fare_amount, timestamp, tempF,
windDir FROM trips ASOF JOIN weather WHERE
pickup_datetime in '2018-06-01';
```

QuestDB in action: quick showcase

https://dashboard.demo.questdb.io/d/fb13b4ab-b1c9-4a54-a920-b60c5fb0363f/public-dashboard-questdb-io-use-cases-crypto?orgId=1&refresh=750ms

https://demo.questdb.io

https://github.com/questdb/time-series-streaming-analytics-template


YES,
BUT
Ratings & Reviews
5.0
out of 5
(1)
based on 1 review
_yes_but
Gudim.

What makes a decent analytical database?

- SQL
- Columnar storage format
- All HW resources (CPU & RAM) are available for faster query execution
- Complex queries with GROUP BY / JOIN / filter over large volumes of data, not necessarily accessed over time

How do you improve analytical DB capabilities?

- ClickBench - https://github.com/ClickHouse/ClickBench
  - Results accepted by ClickHouse: https://benchmark.clickhouse.com
- db-benchmark - https://github.com/duckdblabs/db-benchmark
  - Results accepted by DuckDB: https://duckdblabs.github.io/db-benchmark
- TPC benchmarks - https://www.tpc.org
- TSBS - https://github.com/timescale/tsbs
  - Time-series specific, not maintained

ClickBench

- Created by ClickHouse team in 2022
- Single table with 105 columns and 99M rows (Yandex search events)
- Includes data import, e.g. in CSV, but the main focus is on queries
- 43 queries with complex GROUP BY, WHERE, and ORDER BY clauses
- Only a few of the queries make use of time (QuestDB was already fast there)
- Run on different machines, but most popular are AWS EC2 instances with EBS volumes

https://github.com/ClickHouse/ClickBench/tree/main

Some sample queries

```
SELECT COUNT(*) FROM hits;
SELECT COUNT(*) FROM hits WHERE AdvEngineID <> 0;
SELECT count_distinct(UserID) FROM hits;
SELECT count_distinct(SearchPhrase) FROM hits;
SELECT UserID FROM hits WHERE UserID = 435090932899640449;

SELECT ClientIP, ClientIP - 1, ClientIP - 2, ClientIP - 3, COUNT(*) AS c FROM hits GROUP
BY ClientIP, ClientIP - 1, ClientIP - 2, ClientIP - 3 ORDER BY c DESC LIMIT 10;

SELECT TraficSourceID, SearchEngineID, AdvEngineID, CASE WHEN (SearchEngineID = 0 AND
AdvEngineID = 0) THEN Referer ELSE '' END AS Src, URL AS Dst, COUNT(*) AS PageViews FROM
hits WHERE CounterID = 62 AND EventTime >= '2013-07-01T00:00:00Z' AND EventTime <=
'2013-07-31T23:59:59Z' AND IsRefresh = 0 GROUP BY TraficSourceID, SearchEngineID,
AdvEngineID, Src, Dst ORDER BY PageViews DESC LIMIT 1000, 1010;

SELECT TraficSourceID, SearchEngineID, AdvEngineID, CASE WHEN (SearchEngineID = 0 AND
AdvEngineID = 0) THEN Referer ELSE '' END AS Src, URL AS Dst, COUNT(*) AS PageViews FROM
hits WHERE CounterID = 62 AND EventTime >= '2013-07-01T00:00:00Z' AND EventTime <=
'2013-07-31T23:59:59Z' AND IsRefresh = 0 GROUP BY TraficSourceID, SearchEngineID,
AdvEngineID, Src, Dst ORDER BY PageViews DESC LIMIT 1000, 1010;
```

Some sample queries

```
SELECT SUM(ResolutionWidth), SUM(ResolutionWidth + 1), SUM(ResolutionWidth + 2), SUM(ResolutionWidth + 3),
SUM(ResolutionWidth + 4), SUM(ResolutionWidth + 5), SUM(ResolutionWidth + 6), SUM(ResolutionWidth + 7),
SUM(ResolutionWidth + 8), SUM(ResolutionWidth + 9), SUM(ResolutionWidth + 10), SUM(ResolutionWidth + 11),
SUM(ResolutionWidth + 12), SUM(ResolutionWidth + 13), SUM(ResolutionWidth + 14), SUM(ResolutionWidth + 15),
SUM(ResolutionWidth + 16), SUM(ResolutionWidth + 17), SUM(ResolutionWidth + 18), SUM(ResolutionWidth + 19),
SUM(ResolutionWidth + 20), SUM(ResolutionWidth + 21), SUM(ResolutionWidth + 22), SUM(ResolutionWidth + 23),
SUM(ResolutionWidth + 24), SUM(ResolutionWidth + 25), SUM(ResolutionWidth + 26), SUM(ResolutionWidth + 27),
SUM(ResolutionWidth + 28), SUM(ResolutionWidth + 29), SUM(ResolutionWidth + 30), SUM(ResolutionWidth + 31),
SUM(ResolutionWidth + 32), SUM(ResolutionWidth + 33), SUM(ResolutionWidth + 34), SUM(ResolutionWidth + 35),
SUM(ResolutionWidth + 36), SUM(ResolutionWidth + 37), SUM(ResolutionWidth + 38), SUM(ResolutionWidth + 39),
SUM(ResolutionWidth + 40), SUM(ResolutionWidth + 41), SUM(ResolutionWidth + 42), SUM(ResolutionWidth + 43),
SUM(ResolutionWidth + 44), SUM(ResolutionWidth + 45), SUM(ResolutionWidth + 46), SUM(ResolutionWidth + 47),
SUM(ResolutionWidth + 48), SUM(ResolutionWidth + 49), SUM(ResolutionWidth + 50), SUM(ResolutionWidth + 51),
SUM(ResolutionWidth + 52), SUM(ResolutionWidth + 53), SUM(ResolutionWidth + 54), SUM(ResolutionWidth + 55),
SUM(ResolutionWidth + 56), SUM(ResolutionWidth + 57), SUM(ResolutionWidth + 58), SUM(ResolutionWidth + 59),
SUM(ResolutionWidth + 60), SUM(ResolutionWidth + 61), SUM(ResolutionWidth + 62), SUM(ResolutionWidth + 63),
SUM(ResolutionWidth + 64), SUM(ResolutionWidth + 65), SUM(ResolutionWidth + 66), SUM(ResolutionWidth + 67),
SUM(ResolutionWidth + 68), SUM(ResolutionWidth + 69), SUM(ResolutionWidth + 70), SUM(ResolutionWidth + 71),
SUM(ResolutionWidth + 72), SUM(ResolutionWidth + 73), SUM(ResolutionWidth + 74), SUM(ResolutionWidth + 75),
SUM(ResolutionWidth + 76), SUM(ResolutionWidth + 77), SUM(ResolutionWidth + 78), SUM(ResolutionWidth + 79),
SUM(ResolutionWidth + 80), SUM(ResolutionWidth + 81), SUM(ResolutionWidth + 82), SUM(ResolutionWidth + 83),
SUM(ResolutionWidth + 84), SUM(ResolutionWidth + 85), SUM(ResolutionWidth + 86), SUM(ResolutionWidth + 87),
SUM(ResolutionWidth + 88), SUM(ResolutionWidth + 89) FROM hits;
```

https://tinyurl.com/clickbench-2022-10

ClickBench — a Benchmark For Analytical DBMS

Methodology | Reproduce and Validate the Results | Add a System | Report Mistake | Hardware Benchmark

System: All | Athena (partitioned) | Athena (single) | Aurora for MySQL | Aurora for PostgreSQL | ByteHouse | Citus | clickhouse-local (partitioned) | clickhouse-local (single) | ClickHouse | ClickHouse (zstd) | CrateDB | Databend | datafusion | Druid | DuckDB | Elasticsearch | Elasticsearch (tuned) | Greenplum | HeavyAI | Infobright | MariaDB ColumnStore | MariaDB | MonetDB | MongoDB | MySQL (MyISAM) | MySQL | Pinot | PostgreSQL | QuestDB (partitioned) | QuestDB | Redshift | SingleStore | Snowflake | SQLite | StarRocks (tuned) | StarRocks | TimescaleDB (compression) | TimescaleDB

Type: All | stateless | managed | Java | column-oriented | C++ | MySQL compatible | row-oriented | C | PostgreSQL compatible | ClickHouse derivative | embedded | Rust | search | document | time-series

Machine: All | serverless | 16acu | L | M | S | XS | c6a.4xlarge, 500gb gp2 | c6a.metal, 500gb gp2 | f16s v2 | c6a.4xlarge, 1500gb gp2 | ra3.16xlarge | ra3.4xlarge | ra3.xlplus | S24 | S2 | 2XL | 3XL | 4XL | XL

Cluster size: All | 1 | 2 | 4 | 8 | 12 | 16 | 32 | 64 | 128 | serverless | undefined

Metric: Cold Run | Hot Run | Load Time | Storage Size

System & Machine	Relative time (lower is better)
ClickHouse (c6a.metal, 500gb gp2):	×1.30
StarRocks (c6a.metal, 500gb gp2):	×1.69
StarRocks (c6a.4xlarge, 500gb gp2):	×3.34
ClickHouse (c6a.4xlarge, 500gb gp2):	×3.54
ByteHouse (L):	×3.77
Redshift (4×ra3.4xlarge):	×3.86
Snowflake (8×L):	×4.50
SingleStore (2×S2)†:	×5.30
ByteHouse (M):	×5.88
Snowflake (4×M):	×6.16
Redshift (4×ra3.xlplus):	×6.92
ByteHouse (S):	×7.53
Snowflake (2×S):	×8.62
MonetDB (c6a.4xlarge, 500gb gp2):	×8.81
SingleStore (c6a.4xlarge, 500gb gp2)†:	×9.40
ByteHouse (XS):	×12.55
Snowflake (XS):	×12.55
DuckDB (c6a.4xlarge, 500gb gp2)†:	×22.44
Pinot (c6a.4xlarge, 500gb gp2)†:	×22.54
Greenplum (c6a.4xlarge, 500gb gp2):	×26.33
datafusion (f16s v2):	×31.84
QuestDB (c6a.4xlarge, 500gb gp2):	×33.89
Databend (c6a.4xlarge, 500gb gp2):	×33.93
MariaDB ColumnStore (c6a.4xlarge, 500gb gp2)†:	×46.38
CrateDB (c6a.4xlarge, 500gb gp2)†:	×47.81
Elasticsearch (c6a.4xlarge, 1500gb gp2):	×57.81
TimescaleDB (compression) (c6a.4xlarge, 500gb gp2):	×68.01
Druid (c6a.4xlarge, 500gb gp2)†:	×117.77
HeavyAI (c6a.4xlarge, 500gb gp2)†:	×127.44
Citus (c6a.4xlarge, 500gb gp2):	×173.17

https://tinyurl.com/clickbench-2023-08-18

System: All | Athena (partitioned) | Athena (single) | Aurora for MySQL | Aurora for PostgreSQL | ByConity | ByteHouse | chDB | Citus | ClickHouse (data lake, partitioned) | ClickHouse (Parquet, partitioned) | ClickHouse (Parquet, single) | ClickHouse (web) | ClickHouse | ClickHouse (tuned) | ClickHouse (zstd) | ClickHouse Cloud (AWS) | ClickHouse Cloud (GCP) | CrateDB | Databend | DataFusion (Parquet, single) | Apache Doris | Druid | DuckDB (Parquet, partitioned) | DuckDB | Elasticsearch | Elasticsearch (tuned) | Greenplum | HeavyAI | Hydra | Infobright | Kinetica | MariaDB ColumnStore | MariaDB | MonetDB | MongoDB | MySQL (MyISAM) | MySQL | Pinot | PostgreSQL (tuned) | PostgreSQL | QuestDB (partitioned) | QuestDB | Redshift | SelectDB | SingleStore | Snowflake | SQLite | StarRocks | TimescaleDB (compression) | TimescaleDB

Type: All | stateless | managed | Java | column-oriented | C++ | MySQL compatible | row-oriented | C | PostgreSQL compatible | ClickHouse derivative | embedded | serverless | aws | gcp | Rust | search | document | time-series

Machine: All | serverless | 16acu | c6a.4xlarge, 500gb gp2 | L | M | S | XS | c6a.metal, 500gb gp2 | c5n.4xlarge, 500gb gp2 | c5.4xlarge, 500gb gp2 | 192GB | 24GB | 360GB | 48GB | 720GB | 96GB | 708GB | m5d.24xlarge | m6i.32xlarge | c6a.4xlarge, 1500gb gp2 | dc2.8xlarge | ra3.16xlarge | ra3.4xlarge | ra3.xlplus | S2 | S24 | 2XL | 3XL | 4XL | XL

Cluster size: All | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 | serverless | undefined

Metric: Cold Run | Hot Run | Load Time | Storage Size

System & Machine	Relative time (lower is better)
StarRocks (c6a.metal, 500gb gp2):	×1.77
ClickHouse (c6a.metal, 500gb gp2):	×1.77
Databend (c6a.metal, 500gb gp2):	×1.83
SelectDB (c6a.metal, 500gb gp2):	×2.28
DuckDB (c6a.metal, 500gb gp2):	×3.32
Databend (c6a.4xlarge, 500gb gp2):	×3.39
SelectDB (c6a.4xlarge, 500gb gp2):	×3.43
ClickHouse (c6a.4xlarge, 500gb gp2):	×3.86
Apache Doris (c6a.4xlarge, 500gb gp2):	×4.27
StarRocks (c6a.4xlarge, 500gb gp2):	×4.30
DuckDB (c6a.4xlarge, 500gb gp2):	×4.64
Snowflake (16×XL):	×5.29
ByConity (c6a.4xlarge, 500gb gp2):	×5.77
ByteHouse (L):	×5.83
chDB (c6a.metal, 500gb gp2):	×6.18
Snowflake (8×L):	×6.97
SingleStore (S2)†:	×8.20
ByteHouse (M):	×9.09
Snowflake (4×M):	×9.53
Redshift (4×ra3.xlplus):	×10.71
chDB (c6a.4xlarge, 500gb gp2):	×11.56
ByteHouse (S):	×11.64
DataFusion (Parquet, single) (c6a.4xlarge, 500gb gp2)†:	×11.96
Snowflake (2×S):	×13.34
MonetDB (c6a.4xlarge, 500gb gp2):	×13.63
SingleStore (c6a.4xlarge, 500gb gp2)†:	×14.55
QuestDB (partitioned) (c6a.metal, 500gb gp2)†:	**×15.85**
ByteHouse (XS):	×19.42
Snowflake (XS):	×19.42
QuestDB (c6a.4xlarge, 500gb gp2):	×20.33
Greenplum (c6a.4xlarge, 500gb gp2):	×32.41
Pinot (c6a.4xlarge, 500gb gp2)†:	×34.88
Hydra (c6a.4xlarge, 500gb gp2):	×45.98

https://github.com/ClickHouse/ClickBench/blob/main/questdb-partitioned/results/c6a.metal.json https://tinyurl.com/clickbench-2024-09

System: All | AlloyDB | AlloyDB (tuned) | Athena (partitioned) | Athena (single) | Aurora for MySQL | Aurora for PostgreSQL | ByConity | ByteHouse | chDB (DataFrame) | chDB (Parquet, partitioned) | chDB | Citus | ClickHouse Cloud (aws) | ClickHouse Cloud (aws) Parallel Replicas ON | ClickHouse Cloud (Azure) | ClickHouse Cloud (Azure) Parallel Replica ON | ClickHouse Cloud (Azure) Parallel Replicas ON | ClickHouse Cloud (gcp) | ClickHouse Cloud (gcp) Parallel Replicas ON | ClickHouse (data lake, partitioned) | ClickHouse (data lake, single) | ClickHouse (Parquet, partitioned) | ClickHouse (Parquet, single) | ClickHouse (web) | ClickHouse | ClickHouse (tuned) | ClickHouse (tuned, memory) | Cloudberry | CrateDB | Crunchy Bridge for Analytics (Parquet) | Databend | DataFusion (Parquet, partitioned) | DataFusion (Parquet, single) | Apache Doris | Druid | DuckDB (DataFrame) | DuckDB (Parquet, partitioned) | DuckDB | Elasticsearch | Elasticsearch (tuned) | GlareDB | Greenplum | HeavyAI | Hydra | Infobright | Kinetica | MariaDB ColumnStore | MariaDB | MonetDB | MongoDB | Motherduck | MySQL (MyISAM) | MySQL | Oxla | Pandas (DataFrame) | ParadeDB (Parquet, partitioned) | ParadeDB (Parquet, single) | Pinot | Polars (DataFrame) | PostgreSQL (tuned) | PostgreSQL | QuestDB (partitioned) | QuestDB | Redshift | SingleStore | Snowflake | SQLite | StarRocks | Tablespace | Tembo OLAP (columnar) | TimescaleDB (compression) | TimescaleDB | Umbra

Type: All | C | column-oriented | PostgreSQL compatible | managed | gcp | stateless | Java | C++ | MySQL compatible | row-oriented | ClickHouse derivative | embedded | serverless | dataframe | aws | parallel replicas | Azure | analytical | Rust | search | document | somewhat PostgreSQL compatible | time-series

Machine: All | 16 vCPU 128GB | 8 vCPU 64GB | serverless | 16acu | c6a.4xlarge, 500gb gp2 | L | M | S | XS | c6a.metal, 500gb gp2 | 192GB | 24GB | 360GB | 48GB | 720GB | 96GB | 1430GB | dev | 708GB | c5n.4xlarge, 500gb gp2 | Analytics-256GB (64 vCores, 256 GB) | c5.4xlarge, 500gb gp2 | c6a.4xlarge, 1500gb gp2 | cloud | dc2.8xlarge | ra3.16xlarge | ra3.4xlarge | ra3.xlplus | S2 | S24 | 2XL | 3XL | 4XL | XL | L1 - 16CPU 32GB | c6a.4xlarge, 500gb gp3

Cluster size: All | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 | serverless | dedicated

Metric: Cold Run | Hot Run | Load Time | Storage Size

System & Machine	Relative time (lower is better)
Umbra (c6a.metal, 500gb gp2):	×1.57
Apache Doris (c6a.metal, 500gb gp2):	×2.10
ClickHouse (c6a.metal, 500gb gp2):	×2.15
StarRocks (c6a.metal, 500gb gp2):	×2.32
Umbra (c6a.4xlarge, 500gb gp2):	×2.34
Databend (c6a.metal, 500gb gp2):	×2.40
DuckDB (c6a.metal, 500gb gp2):	×2.60
QuestDB (partitioned) (c6a.metal, 500gb gp2)†:	×3.18
SingleStore (S24)†:	×3.90
DuckDB (c6a.4xlarge, 500gb gp2):	×4.29
ClickHouse (c6a.4xlarge, 500gb gp2):	×4.34
Databend (c6a.4xlarge, 500gb gp2):	×4.45
chDB (DataFrame) (c6a.metal, 500gb gp2):	×4.81
Databend (c5.4xlarge, 500gb gp2):	×4.82
DuckDB (c5.4xlarge, 500gb gp2):	×5.07
Apache Doris (c6a.4xlarge, 500gb gp2):	×5.59
StarRocks (c6a.4xlarge, 500gb gp2):	×5.63
Snowflake (32×2XL):	×5.91
chDB (c6a.metal, 500gb gp2):	×6.09
Tablespace (L1 - 16CPU 32GB):	×6.75
QuestDB (c6a.4xlarge, 500gb gp2):	×7.15
ByConity (c6a.4xlarge, 500gb gp2):	×7.56
ByteHouse (8×L):	×7.64

https://tinyurl.com/clickbench-2025-01-29

System: All | AlloyDB | AlloyDB (tuned) | Athena (partitioned) | Athena (single) | Aurora for MySQL | Aurora for PostgreSQL | ByConity | ByteHouse | chDB (DataFrame) | chDB (Parquet, partitioned) | chDB | Citus | ClickHouse Cloud (aws) | ClickHouse Cloud (azure) | ClickHouse Cloud (gcp) | ClickHouse (data lake, partitioned) | ClickHouse (data lake, single) | ClickHouse (Parquet, partitioned) | ClickHouse (Parquet, single) | ClickHouse (web) | ClickHouse | ClickHouse (tuned) | ClickHouse (tuned, memory) | Cloudberry | CrateDB | Crunchy Bridge for Analytics (Parquet) | Databend | DataFusion (Parquet, partitioned) | DataFusion (Parquet, single) | Apache Doris | Drill | Druid | DuckDB (DataFrame) | DuckDB (memory) | DuckDB (Parquet, partitioned) | DuckDB | Elasticsearch | Elasticsearch (tuned) | GlareDB | Greenplum | HeavyAI | Hydra | Salesforce Hyper (Parquet) | Salesforce Hyper | Infobright | Kinetica | MariaDB ColumnStore | MariaDB | MonetDB | MongoDB | MotherDuck | MySQL (MyISAM) | MySQL | OctoSQL | Opteryx | Oxla | Pandas (DataFrame) | ParadeDB (Parquet, partitioned) | ParadeDB (Parquet, single) | pg_duckdb (MotherDuck enabled) | pg_duckdb | PostgreSQL with pg_mooncake | Pinot | Polars (DataFrame) | Polars (Parquet) | PostgreSQL (tuned) | PostgreSQL | QuestDB | Redshift | SelectDB | SingleStore | Snowflake | Spark | SQLite | StarRocks | Tablespace | Tembo OLAP (columnar) | Timescale Cloud | TimescaleDB (no columnstore) | TimescaleDB | Tinybird (Free Trial) | Umbra | VictoriaLogs

Type: All | C | column-oriented | PostgreSQL compatible | managed | gcp | stateless | Java | C++ | MySQL compatible | row-oriented | ClickHouse derivative | embedded | serverless | dataframe | aws | azure | analytical | Rust | search | document | Go | somewhat PostgreSQL compatible | DataFrame | parquet | time-series

Machine: All | 16 vCPU 128GB | 8 vCPU 64GB | serverless | 16acu | c6a.4xlarge, 500gb gp2 | L | M | S | XS | c6a.metal, 500gb gp2 | 12GiB | 8GiB | 120GiB | 16GiB | 236GiB | 32GiB | 64GiB | c5n.4xlarge, 500gb gp2 | Analytics-256GB (64 vCores, 256 GB) | c5.4xlarge, 500gb gp2 | c6a.4xlarge, 1500gb gp2 | cloud | dc2.8xlarge | ra3.16xlarge | ra3.4xlarge | ra3.xlplus | S2 | S24 | 2XL | 3XL | 4XL | XL | L1 - 16CPU 32GB | c6a.4xlarge, 500gb gp3 | 16 vCPU 64GB | 4 vCPU 16GB | 8 vCPU 32GB

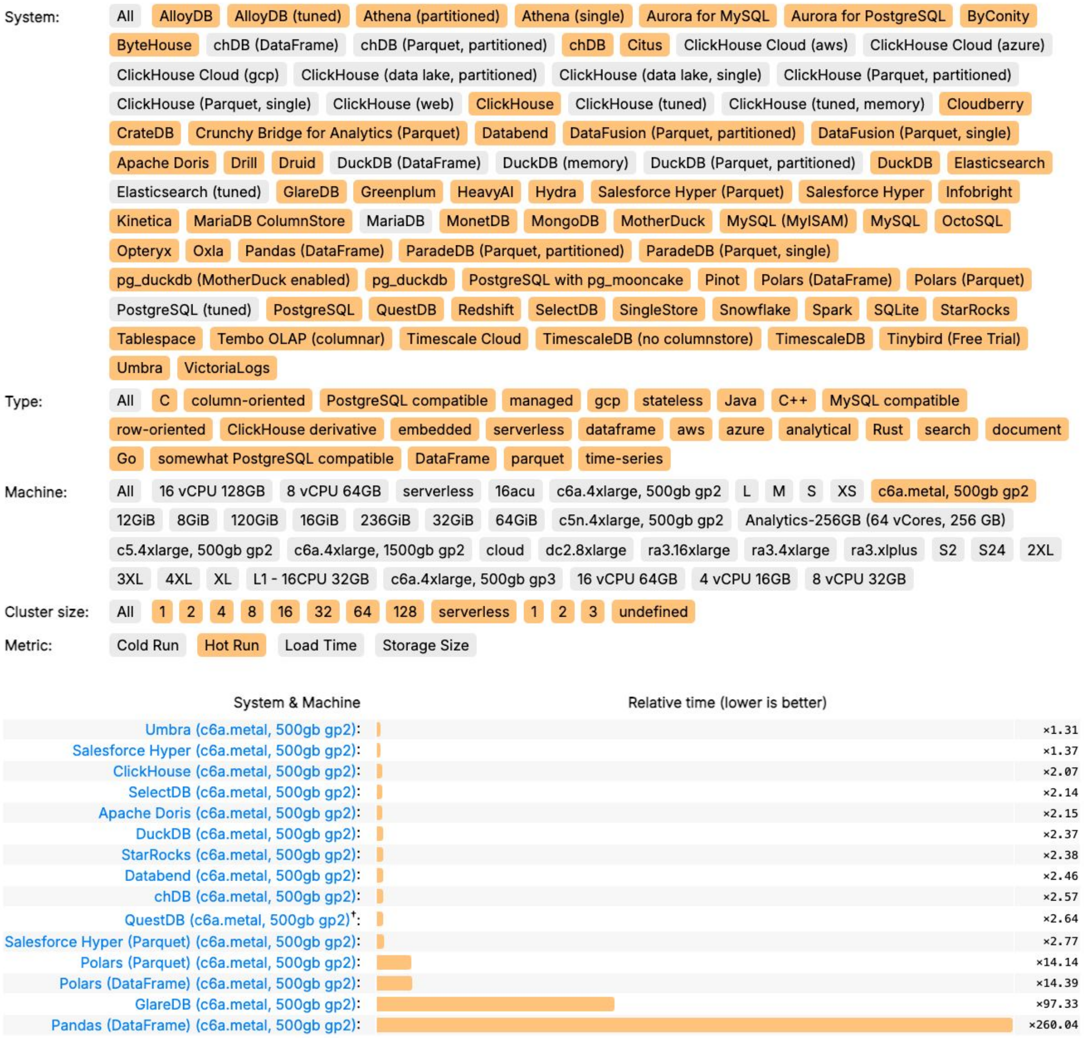
Cluster size: All | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 | serverless | 1 | 2 | 3 | undefined

Metric: Cold Run | Hot Run | Load Time | Storage Size

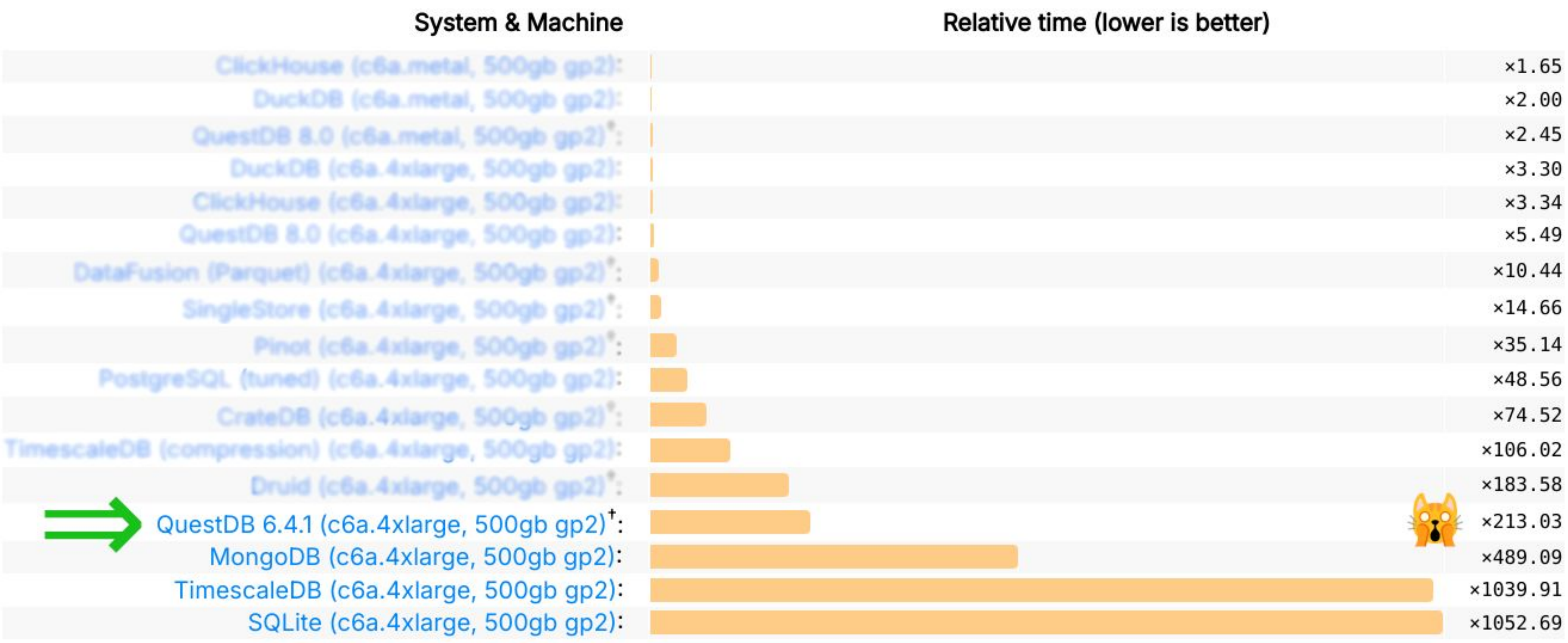
System & Machine	Relative time (lower is better)
Umbra (c6a.metal, 500gb gp2):	×1.51
Salesforce Hyper (c6a.metal, 500gb gp2):	×1.58
ClickHouse (c6a.metal, 500gb gp2):	×2.39
Umbra (c6a.4xlarge, 500gb gp2):	×2.43
SelectDB (c6a.metal, 500gb gp2):	×2.46
Apache Doris (c6a.metal, 500gb gp2):	×2.49
DuckDB (c6a.metal, 500gb gp2):	×2.73
StarRocks (c6a.metal, 500gb gp2):	×2.74
Databend (c6a.metal, 500gb gp2):	×2.84
chDB (c6a.metal, 500gb gp2):	×2.97
QuestDB (c6a.metal, 500gb gp2)†:	**×3.04**
Salesforce Hyper (Parquet) (c6a.metal, 500gb gp2):	×3.19
Salesforce Hyper (c6a.4xlarge, 500gb gp2):	×3.65
SingleStore (S24)†:	×4.62
DuckDB (c6a.4xlarge, 500gb gp2):	×4.89
Databend (c6a.4xlarge, 500gb gp2):	×5.26
ClickHouse (c6a.4xlarge, 500gb gp2):	×5.32
chDB (c6a.4xlarge, 500gb gp2):	×5.53
Databend (c5.4xlarge, 500gb gp2):	×5.71
QuestDB (c6a.4xlarge, 500gb gp2):	×6.35
Apache Doris (c6a.4xlarge, 500gb gp2):	×6.62

https://tinyurl.com/clickbench-2025-01-29

Same hardware (c6a.metal 500gb gp2)



QuestDB in ClickBench: how it started



The Journey, or There and Back Again

- ~2 years of calendar time
- Done along with major features: Write-Ahead-Log (WAL), replication, window functions, Parquet and JSON support, etc.
- ~80 patches, including community contributions
- A number of failed optimization attempts
- Even more plans for further steps

Trivial steps

- Added missing SQL functions, e.g. count_distinct() for integer column types or max()/min() on strings
- Reduced memory footprint of some SQL functions to avoid OOM crashes

```sql
SELECT RegionID, count_distinct(UserID) AS u
FROM hits
GROUP BY RegionID
ORDER BY u DESC
LIMIT 10;
```

QuestDB's JIT compiler

- SQL JIT compiler for filters (WHERE clauses)
- Backend is written in C++ with asmjit library, frontend is in Java
- Emits SIMD (AVX-2) instructions for a subset of filters
- JIT compiled (and Java) filter execution is multi-threaded

```
SELECT count(*)
FROM hits
WHERE AdvEngineID <> 0;
```

Predicate Compile Time:

SQL (Java) -> AST (Java) -> IR (Java) -> machine code (C++)

Predicate Execution Time:

```java
public static native long callFunction(
        long fnAddress,
        long colsAddress,
        long colsSize,
        long varSizeIndexesAddress,
        long varsAddress,
        long varsSize,
        long rowsAddress,
        long rowsSize,
        long rowsStartOffset
);
```

```cpp
inline Ymm cmp_eq_double(Compiler &c, data_type_t type, const Ymm &lhs, const Ymm &rhs) {
    Ymm lhs_copy = c.newYmm();
    Ymm rhs_copy = c.newYmm();
    c.vmovapd(lhs_copy, lhs);
    c.vmovapd(rhs_copy, rhs);
    Ymm dst = c.newYmm();
    Ymm nans = mask_and(c, is_nan(c, type, lhs_copy), is_nan(c, type, rhs_copy));
    Mem sign_mask = vec_sign_mask(c, type);
    c.vsubpd(lhs_copy, lhs_copy, rhs_copy); //(lhs - rhs)
    c.vpand(lhs_copy, lhs_copy, sign_mask); // abs(lhs - rhs)
    double eps[4] = {DOUBLE_EPSILON, DOUBLE_EPSILON, DOUBLE_EPSILON, DOUBLE_EPSILON};
    Mem epsilon = c.newConst(ConstPool::kScopeLocal, &eps, 32);
    c.vcmppd(dst, lhs_copy, epsilon, Predicate::kCmpLT);
    c.vpor(dst, dst, nans);
    return dst;
}
```

JIT compiler improvements

- Expanded supported operators and types

```
SELECT URL, count(*) AS PageViews
FROM hits
WHERE CounterID = 62
  AND EventTime >= '2013-07-01T00:00:00Z'
  AND EventTime <= '2013-07-31T23:59:59Z'
  AND DontCountHits = 0
  AND IsRefresh = 0
  AND URL IS NOT NULL
GROUP BY URL
ORDER BY PageViews DESC
LIMIT 10;
```

SQL rewrites

```sql
SELECT count_distinct(SearchPhrase)
FROM hits;

-- gets rewritten into:
SELECT count(*)
FROM (
  SELECT SearchPhrase
  FROM hits
  WHERE SearchPhrase IS NOT NULL
  GROUP BY SearchPhrase
);
```

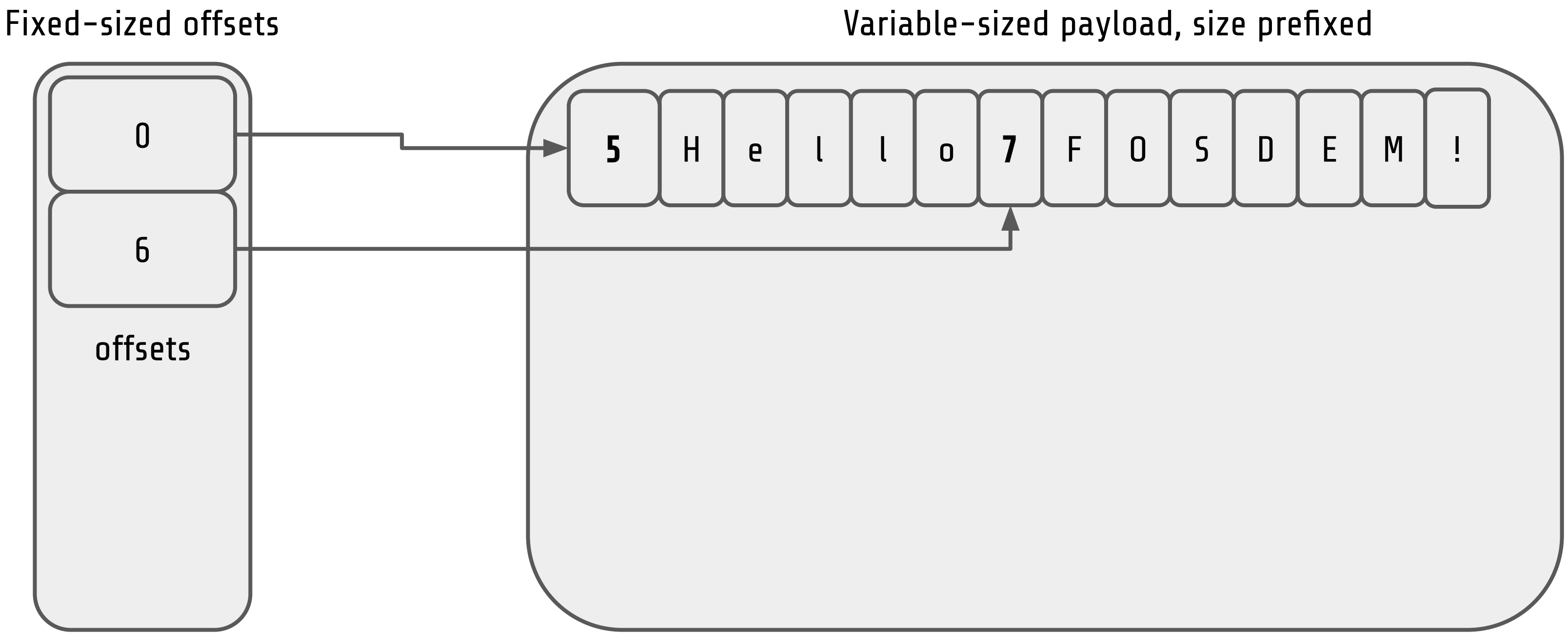
SQL function optimizations #1

```sql
-- uses SWAR-based LIKE operator implementation
SELECT count(*)
FROM hits
WHERE URL LIKE '%google%';
```

SQL function optimizations #2

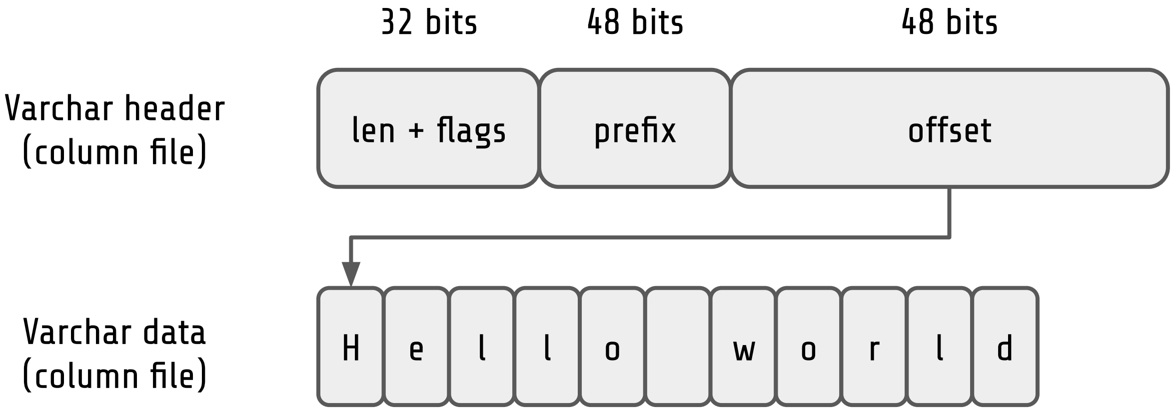
```
-- regexp_replace() uses Java regular expressions, but with a few fast paths
SELECT *
FROM (
  SELECT
    regexp_replace(Referer, '^https?://(?:www\.)?([^/]+)/.*$', '$1') AS k,
    avg(length(Referer)) AS l,
    count(*) AS c,
    min(Referer)
  FROM hits
  WHERE Referer IS NOT NULL
  GROUP BY k
)
WHERE c > 100000
ORDER BY l DESC
LIMIT 25;
```

Old STRING column type - UTF-16 encoded



New VARCHAR column type

- Introduced VARCHAR type (UTF-8) instead of old STRING type (UTF-16)
- Layout is similar to what Andy Pavlo calls "German Strings", but with some differences, including an ASCII bit flag



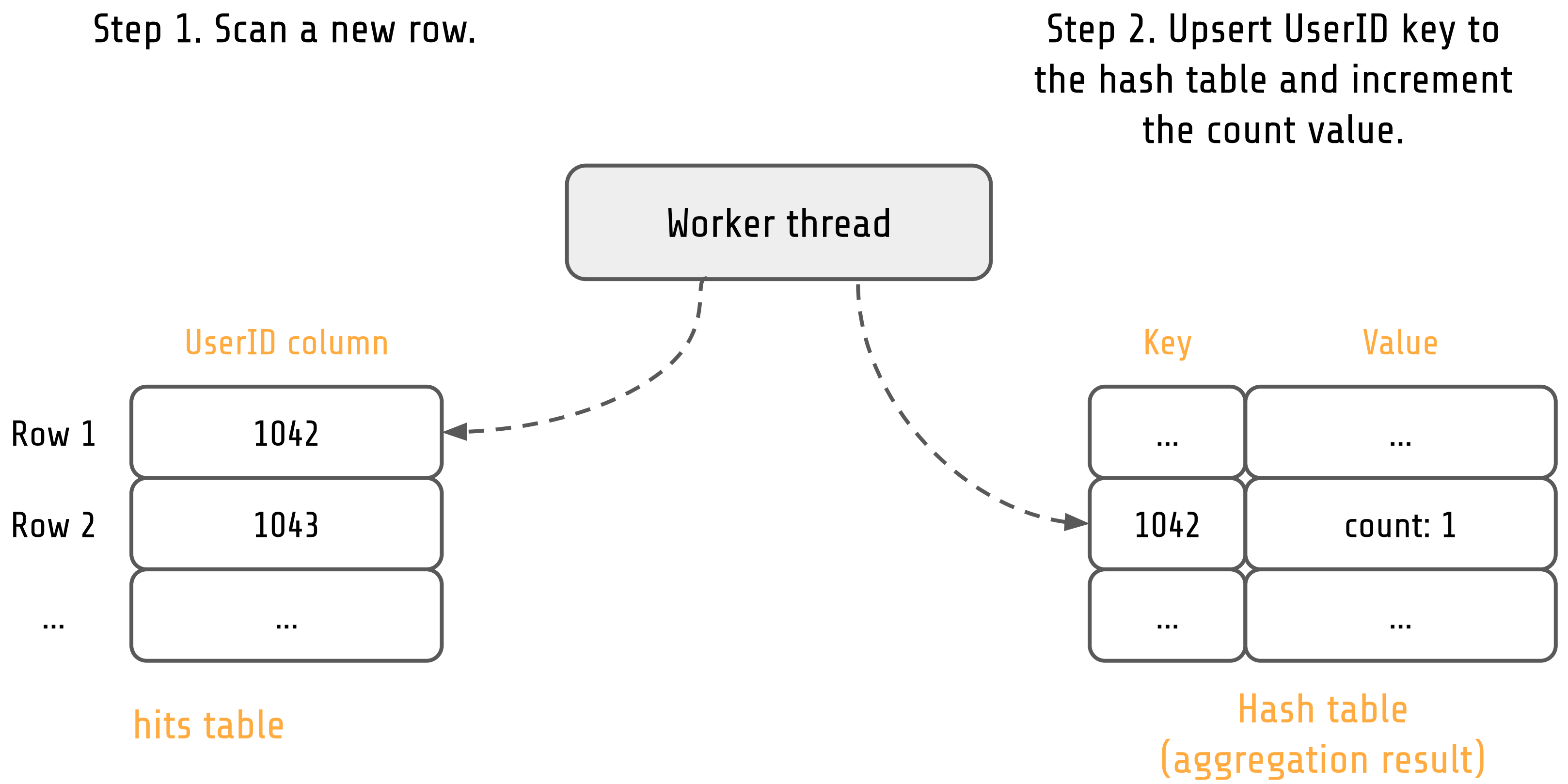
The elephant in the room

- Only a few GROUP BY queries ran parallel (and used SIMD)

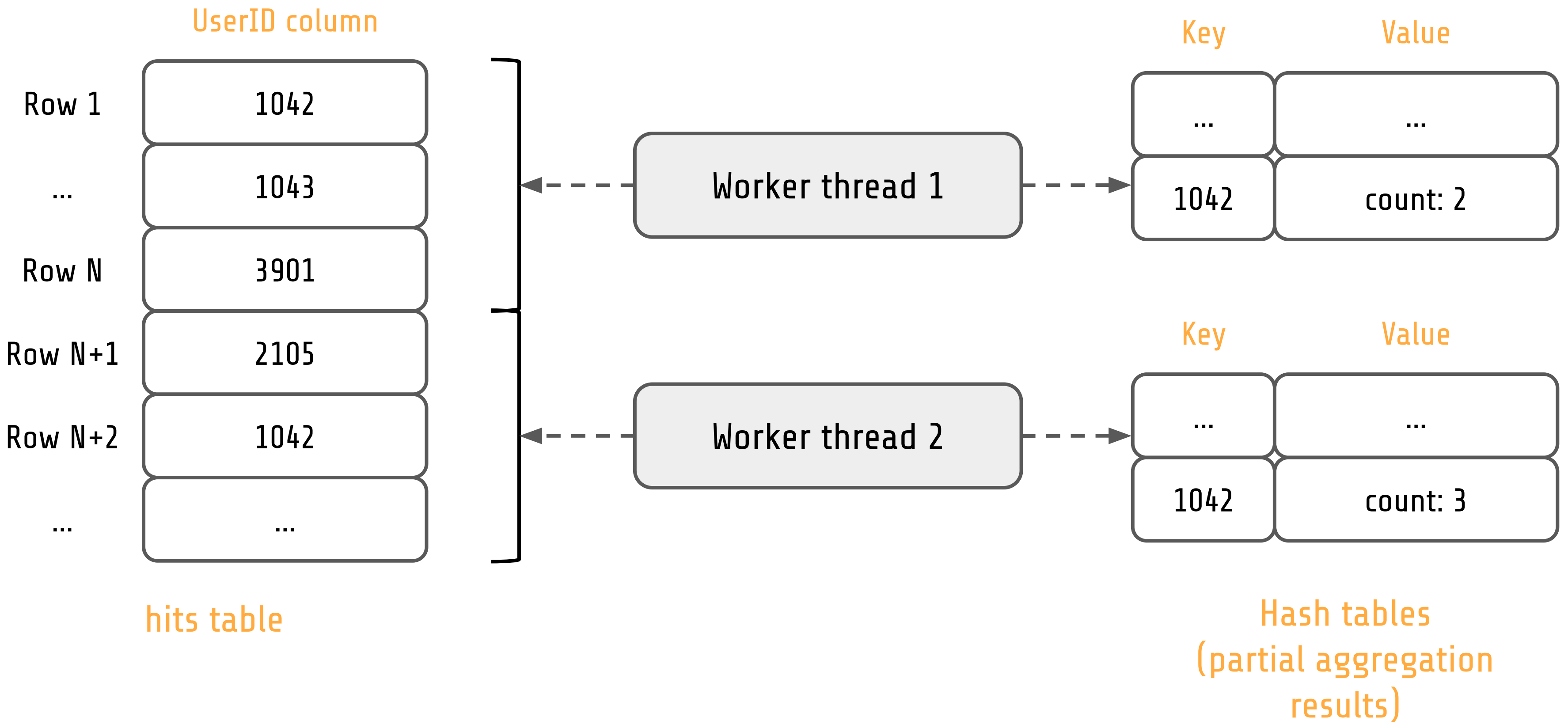
```sql
SELECT sum(AdvEngineID), count(*), avg(ResolutionWidth) FROM hits;

SELECT avg(UserID) FROM hits;

SELECT min(EventDate), max(EventDate) FROM hits;

SELECT sum(ResolutionWidth), sum(ResolutionWidth + 1), -- many more sums…
FROM hits;
```

How do you implement a GROUP BY?

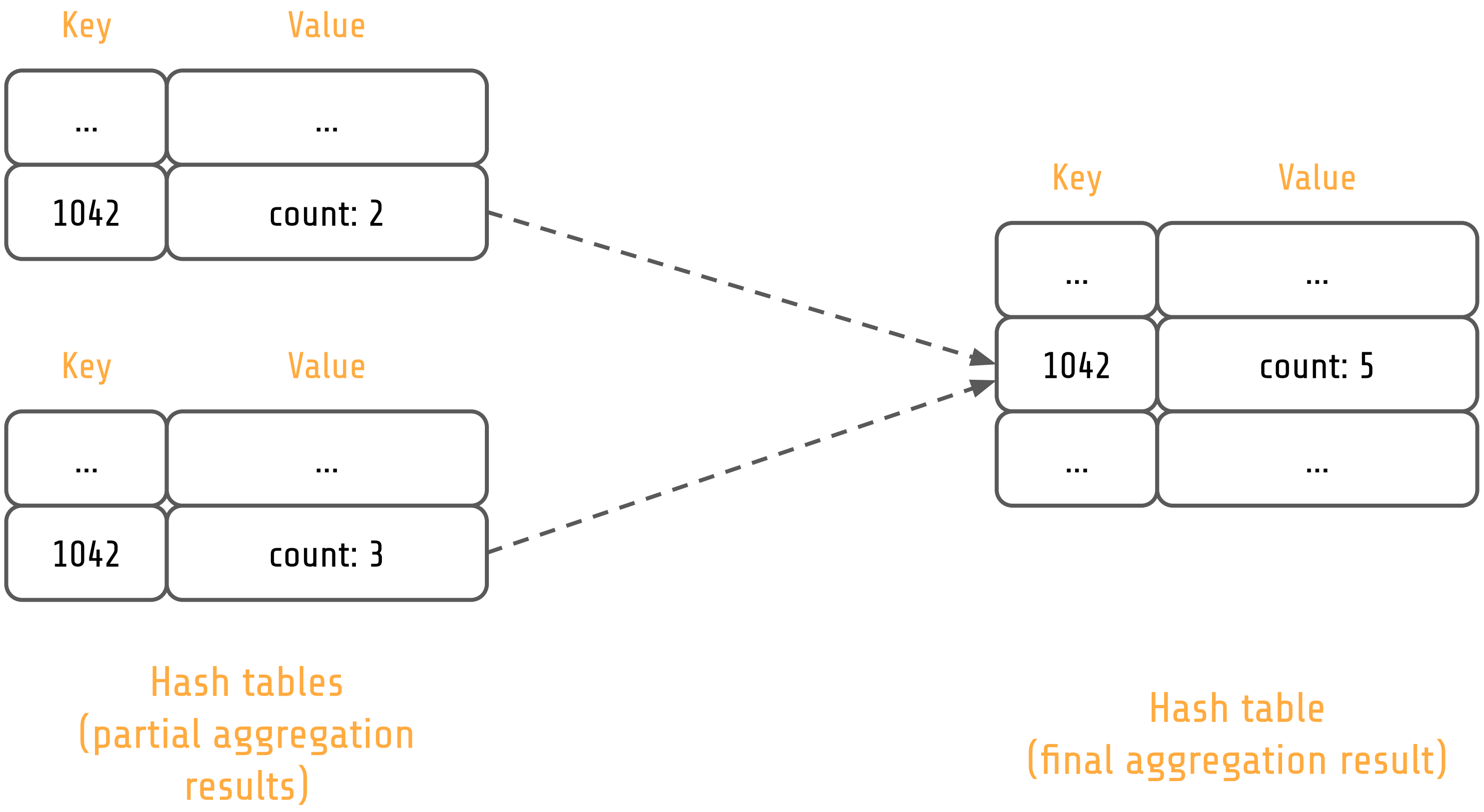
```sql
SELECT UserID, count(*) AS c
FROM hits
GROUP BY UserID;
```



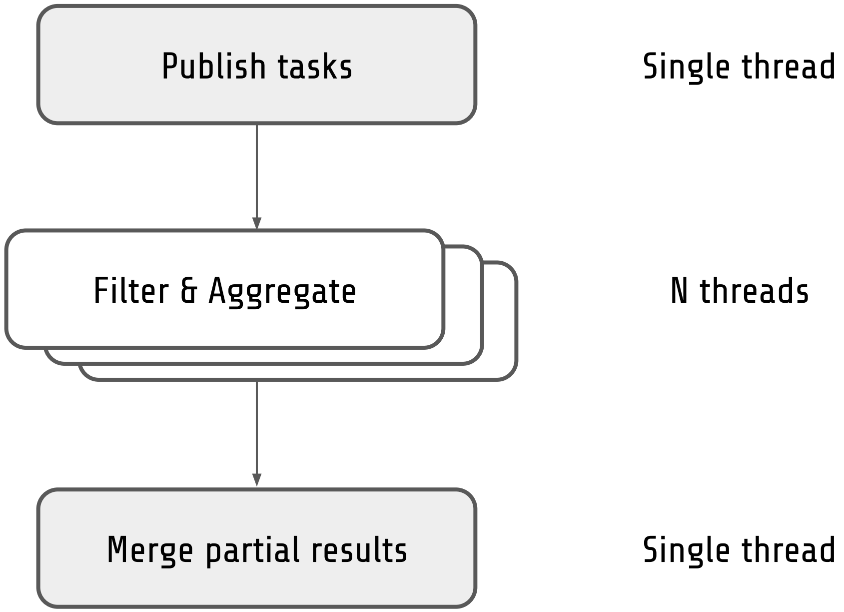
Single-threaded GROUP BY



Multi-threaded GROUP BY: aggregation



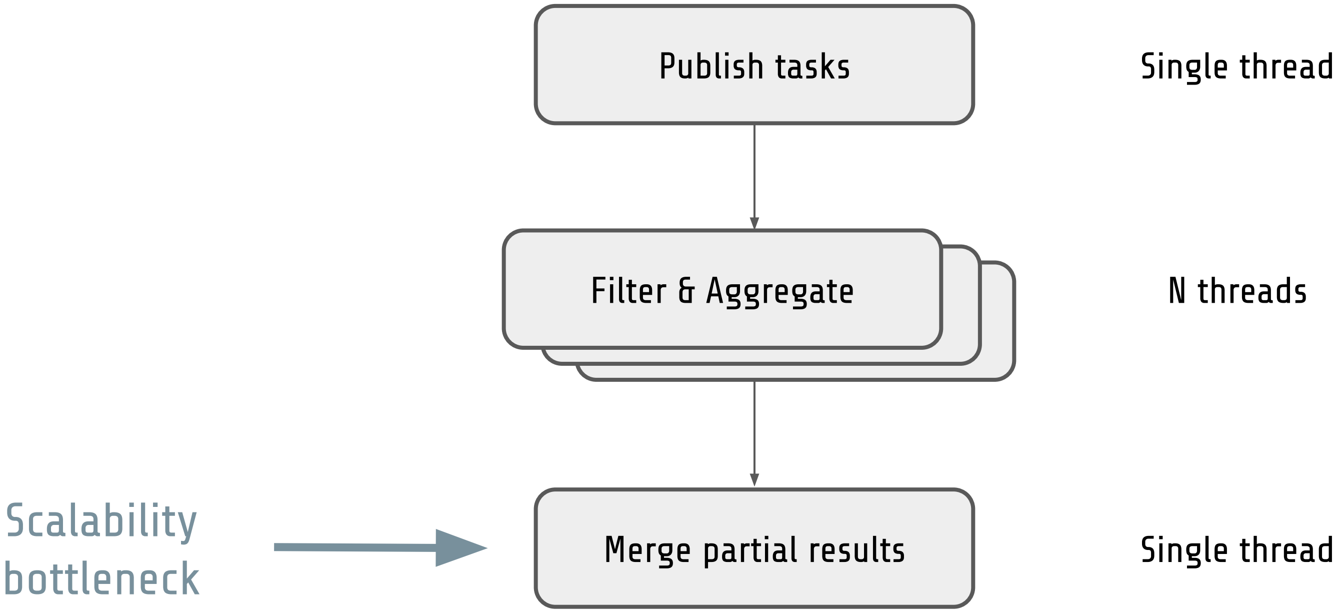
Multi-threaded GROUP BY: merge



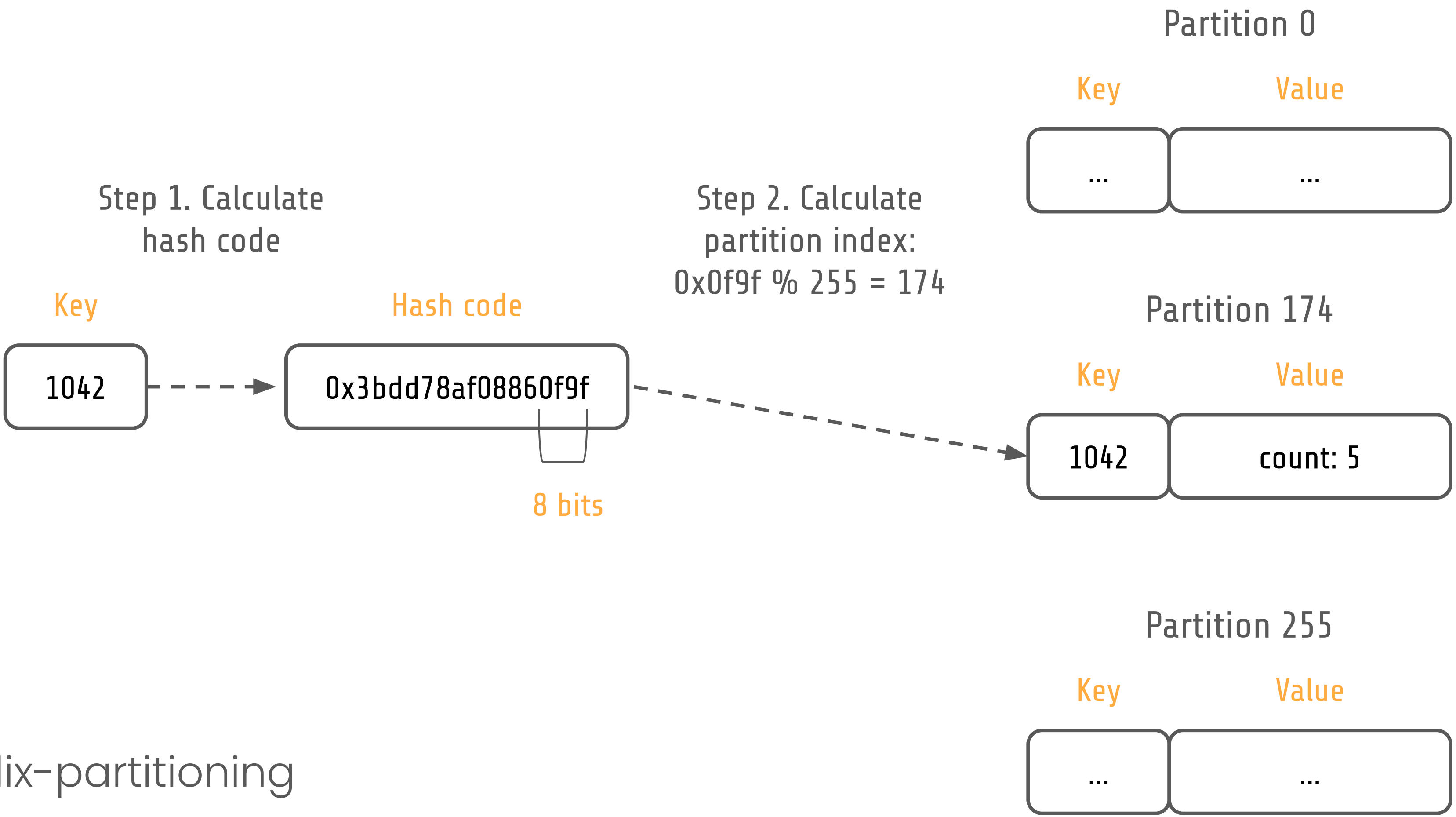
Multi-threaded GROUP BY pipeline

Parallel GROUP BY v1: any good?

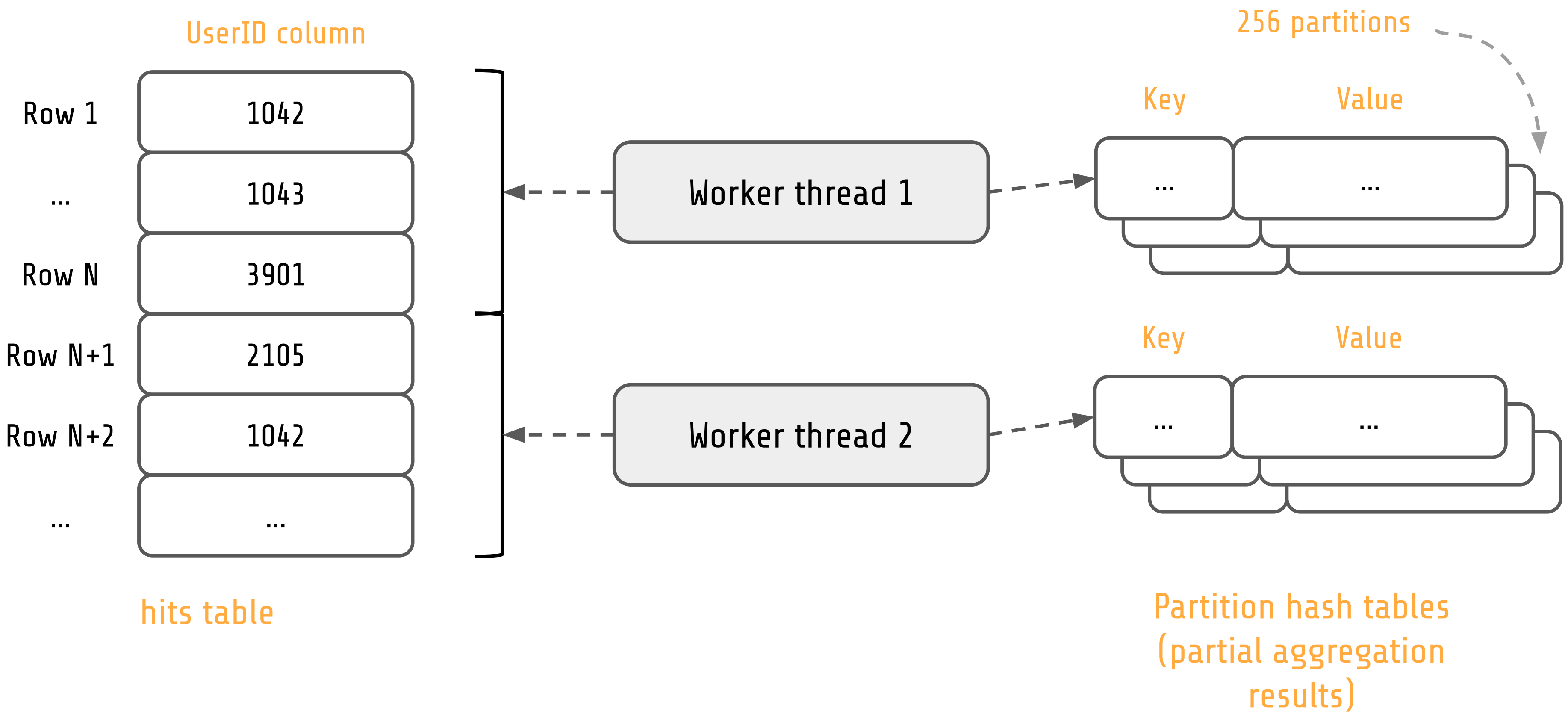
- Simple pipeline, easy to implement
- Scales nicely when there are not so many groups (distinct UserID values)
- Yet, high cardinality (>= 100K groups) is a problem



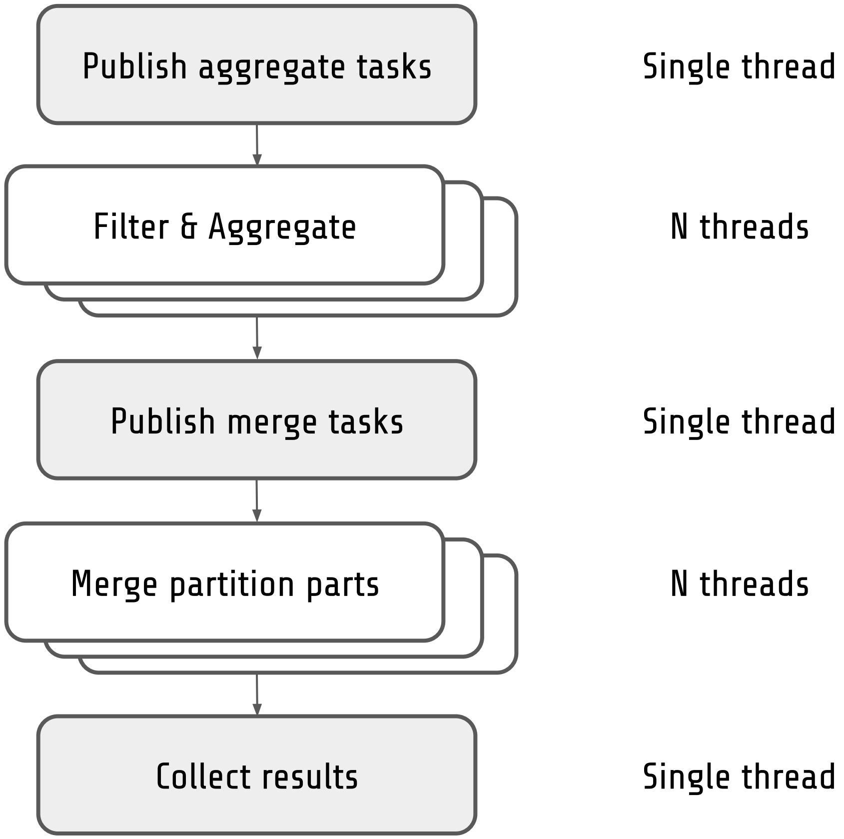
Multi-threaded GROUP BY pipeline: the cardinality problem



Radix-partitioning



High-cardinality multi-threaded GROUP BY



High-cardinality multi-threaded GROUP BY pipeline

Parallel GROUP BY v2

- More complex pipeline, a bit harder to implement
- Scales nicely for any cardinality
- Potentially parallel ORDER BY + LIMIT when the cardinality is high
- Used for multi-threaded GROUP BY and SAMPLE BY

```
SELECT RegionID, count_distinct(UserID) AS u FROM hits GROUP BY RegionID
ORDER BY u DESC LIMIT 10;
```

The more hash tables, the merrier

- Introduced a number of specialized hash tables
- All use open addressing with linear probing
- Some preserve insertion order

So far, we have:

- A "general purpose" hash table for variable-size keys
- Hash tables with small fixed-size keys (32-bit and 64-bit integers)
- A lookup table for 16-bit keys
- A hash table for single VARCHAR key

Lessons learned

- A fast time-series database must be a good analytical database
- Benchmarks made by 3rd-parties help when deciding what to optimize
- Improving query engine efficiency requires discipline
- As a nice side effect, we made SAMPLE BY run parallel
- We have lots of plans for the next steps.

https://github.com/questdb/questdb
https://questdb.io
https://demo.questdb.io
https://slack.questdb.io/
https://github.com/questdb/time-series-streaming-analytics-template

THANKS!

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