The Snowflake Elastic Data Warehouse
SIGMOD 2016 and beyond

Ashish Motivala, Jiaqi Yan

Our Product

- The Snowflake Elastic Data Warehouse, or "Snowflake"
    - Built for the cloud
    - Multi-tenant, transactional, secure, highly scalable, elastic
    - Implemented from scratch (no Hadoop, Postgres etc.)
- Currently runs on AWS and Azure
- Serves tens of millions of queries per day over hundreds petabytes of data
- 1000+ active customers, growing fast

Talk Outline

- Motivation and Vision
- Storage vs. Compute or the Perils of Shared-Nothing
- Architecture
- Feature Highlights
- Lessons Learned

Why Cloud?

- Amazing platform for building distributed systems
  - Virtually unlimited, elastic compute and storage
  - Pay-per-use model (with strong economies of scale)
  - Efficient access from anywhere

- Software as a Service (SaaS)
  - No need for complex IT organization and infrastructure
  - Pay-per-use model
  - Radically simplified software delivery, update, and user support
    - See "Lessons Learned"

Data Warehousing in the Cloud

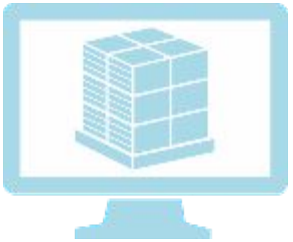
- Traditional DW systems pre-date the cloud
  - Designed for small, fixed clusters of machines
  - But to reap benefits of the cloud, *software* needs to be elastic!

- Traditional DW systems rely on complex ETL (extract-transform-load) pipelines and physical tuning
  - Fundamentally assume predictable, slow-moving, easily categorized data from internal sources (OLTP, ERP, CRM…)
  - Cloud data increasingly stems from changing, external sources
    - Logs, click streams, mobile devices, social media, sensor data
    - Often arrives in schema-less, semi-structured form (JSON, XML, Avro)

What about Big Data?

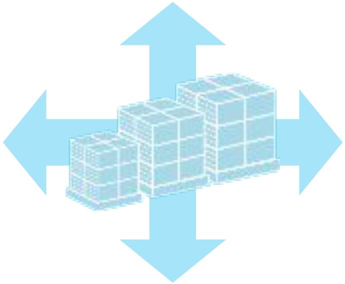
- Hive, Spark, BigQuery, Impala, Blink…
- Batch and/or stream processing at datacenter scale
  - Various SQL'esque front-ends
  - Increasingly popular alternative for high-end use cases
- Drawbacks
  - Lack efficiency and feature set of traditional DW technology
    - Security? Backups? Transactions? …
  - Require significant engineering effort to roll out and use

Our Vision for a Cloud Data Warehouse



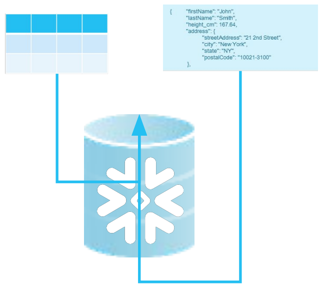
Data warehouse as a service

No infrastructure to manage, no knobs to tune



Multidimensional elasticity

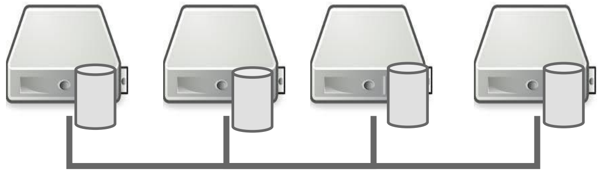
On-demand scalability data, queries, users



All business data

Native support for relational + semi-structured data

Shared-nothing Architecture

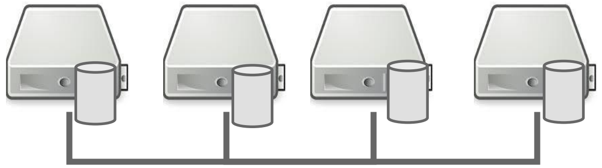


- Tables are horizontally partitioned across nodes
- Every node has its own local storage
- Every node is only responsible for its local table partitions

- Elegant and easy to reason about
- Scales well for star-schema queries

- Dominant architecture in data warehousing
  - Teradata, Vertica, Netezza…

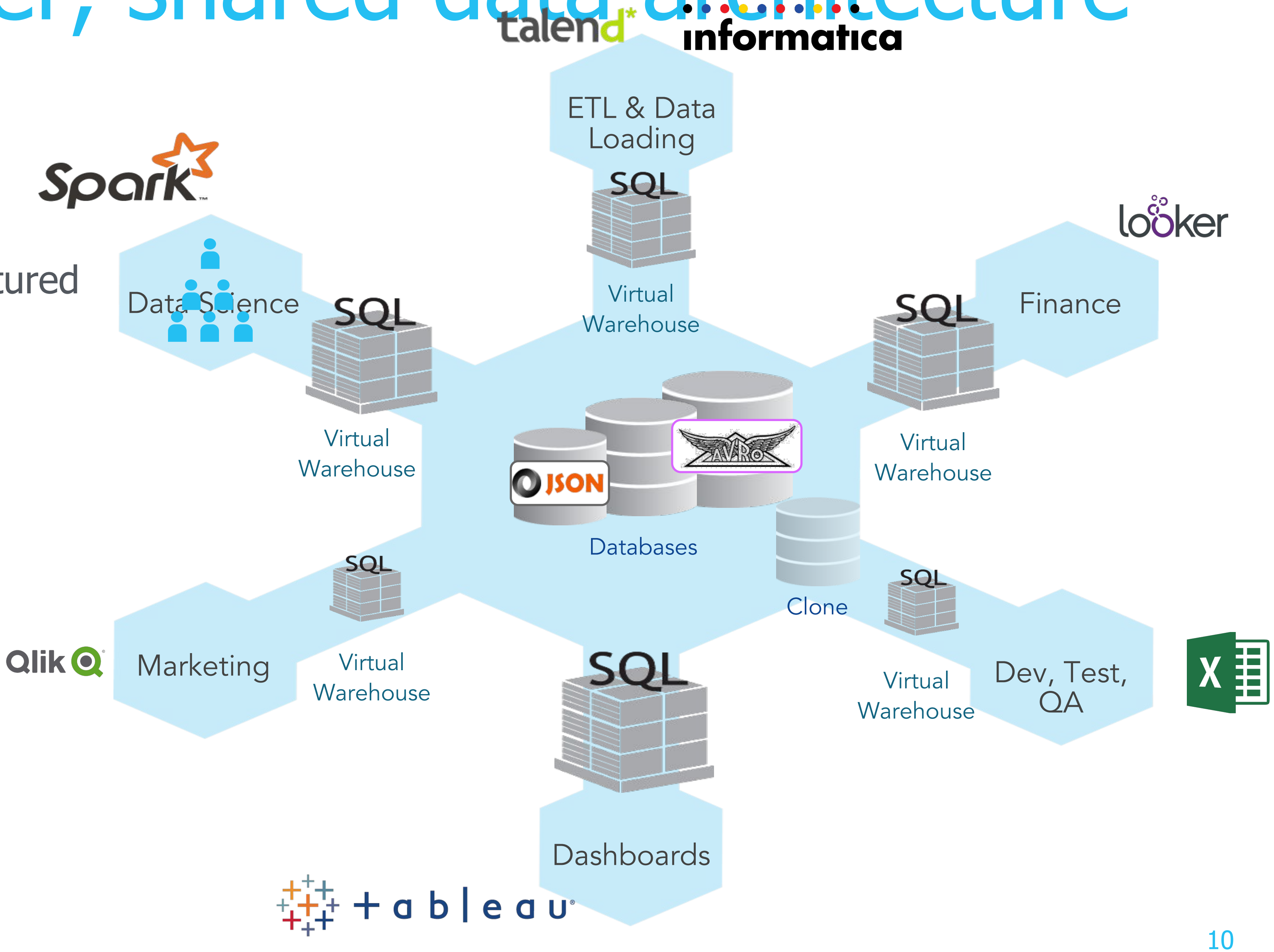
The Perils of Coupling



- Shared-nothing *couples* compute and storage resources
- Elasticity
  - Resizing compute cluster requires redistributing (lots of) data
  - Cannot simply shut off unused compute resources → no pay-per-use
- Limited availability
  - Membership changes (failures, upgrades) significantly impact performance and may cause downtime
- Homogeneous resources vs. heterogeneous workload
  - Bulk loading, reporting, exploratory analysis

Multi-cluster, shared data architecture

- **No data silos**
  Storage decoupled from compute
- **Any data**
  Native for structured & semi-structured
- **Unlimited scalability**
  Along many dimensions
- **Low cost**
  Compute on demand
- **Instantly cloning**
  Isolate production from DEV & QA
- **Highly available**
  11 9's durability, 4 9's availability



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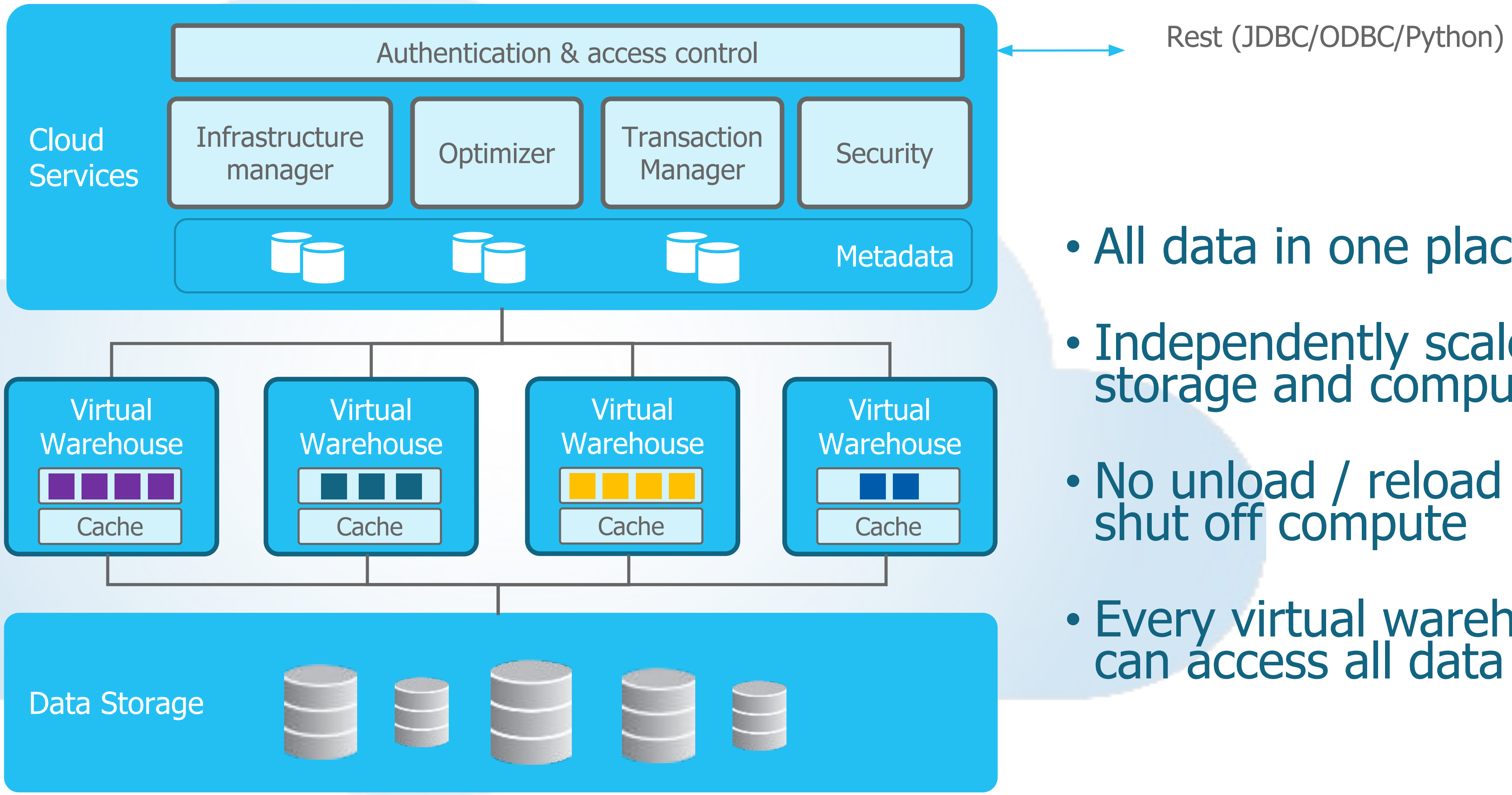
Multi-cluster Shared-data Architecture



- All data in one place
- Independently scale storage and compute
- No unload / reload to shut off compute
- Every virtual warehouse can access all data

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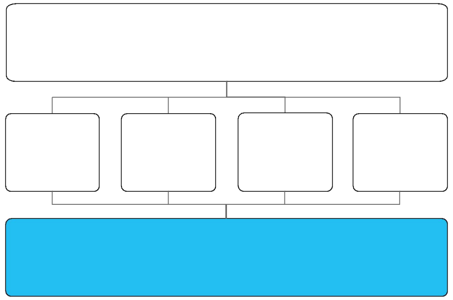
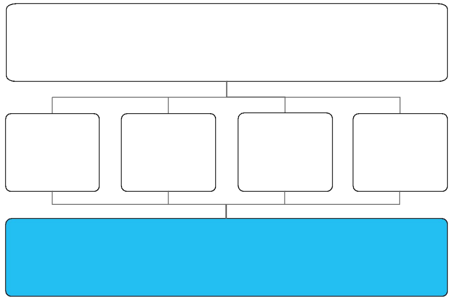
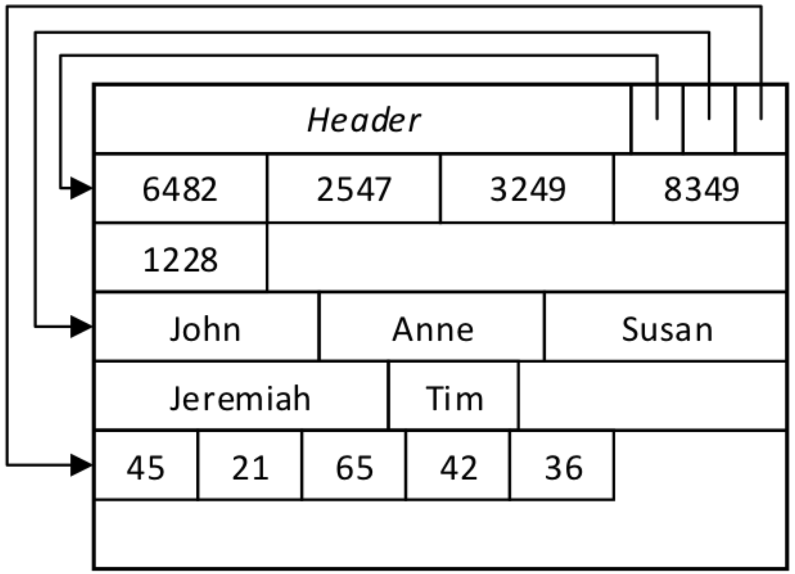
Data Storage Layer



- Stores table data and query results
  - Table is a set of immutable micro-partitions
- Uses tiered storage with Amazon S3 at the bottom
  - Object store (key-value) with HTTP(S) PUT/GET/DELETE interface
  - High availability, extreme durability (11-9)
- Some important differences w.r.t. local disks
  - Performance (sure…)
  - No update-in-place, objects must be written in full
  - But: can read parts (byte ranges) of objects
- Strong influence on table micro-partition format and concurrency control

Table Files

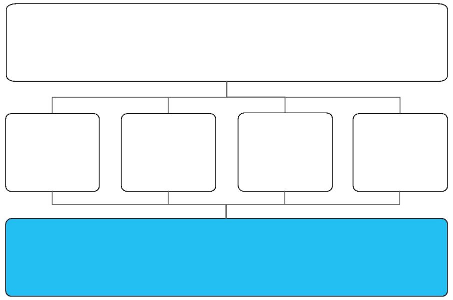




- Snowflake uses PAX [Ailamaki01] aka hybrid columnar storage

- Tables horizontally partitioned into immutable mirco-partitions (~16 MB)
    - Updates add or remove entire files
    - Values of each column grouped together and compressed
    - Queries read header + columns they need

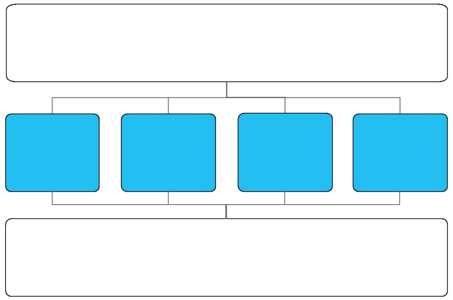
Other Data



- Tiered storage also used for temp data and query results
  - Arbitrarily large queries, never run out of disk
  - New forms of client interaction
    - No server-side cursors
    - Retrieve and reuse previous query results

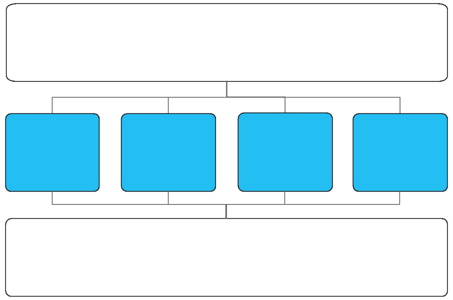
- Metadata stored in a transactional key-value store (not S3)
  - Which table consists of which S3 objects
  - Optimizer statistics, lock tables, transaction logs etc.
  - Part of Cloud Services layer (see later)

Virtual Warehouse



- warehouse = Cluster of EC2 instances called worker nodes
- Pure compute resources
  - Created, destroyed, resized on demand
  - Users may run multiple warehouses at same time
  - Each warehouse has access to all data but isolated performance
  - Users may shut down *all* warehouses when they have nothing to run
- T-Shirt sizes: XS to 4XL
  - Users do not know which type or how many EC2 instances
  - Service and pricing can evolve independent of cloud platform

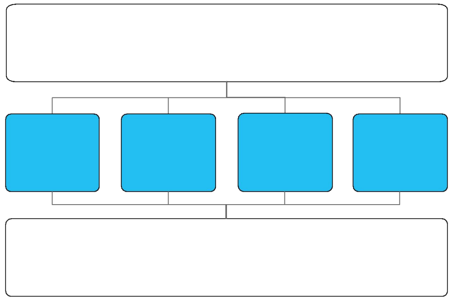
Worker Nodes



- Worker processes are ephemeral and idempotent
  - Worker node forks new worker process when query arrives
  - Do not modify micro-partitions directly but queue removal or addition of micro-partitions

- Each worker node maintains local table cache
  - Collection of table files i.e. S3 objects accessed in past
  - Shared across concurrent and subsequent worker processes
  - Assignment of micro-partitions to nodes using consistent hashing, with deterministic stealing.

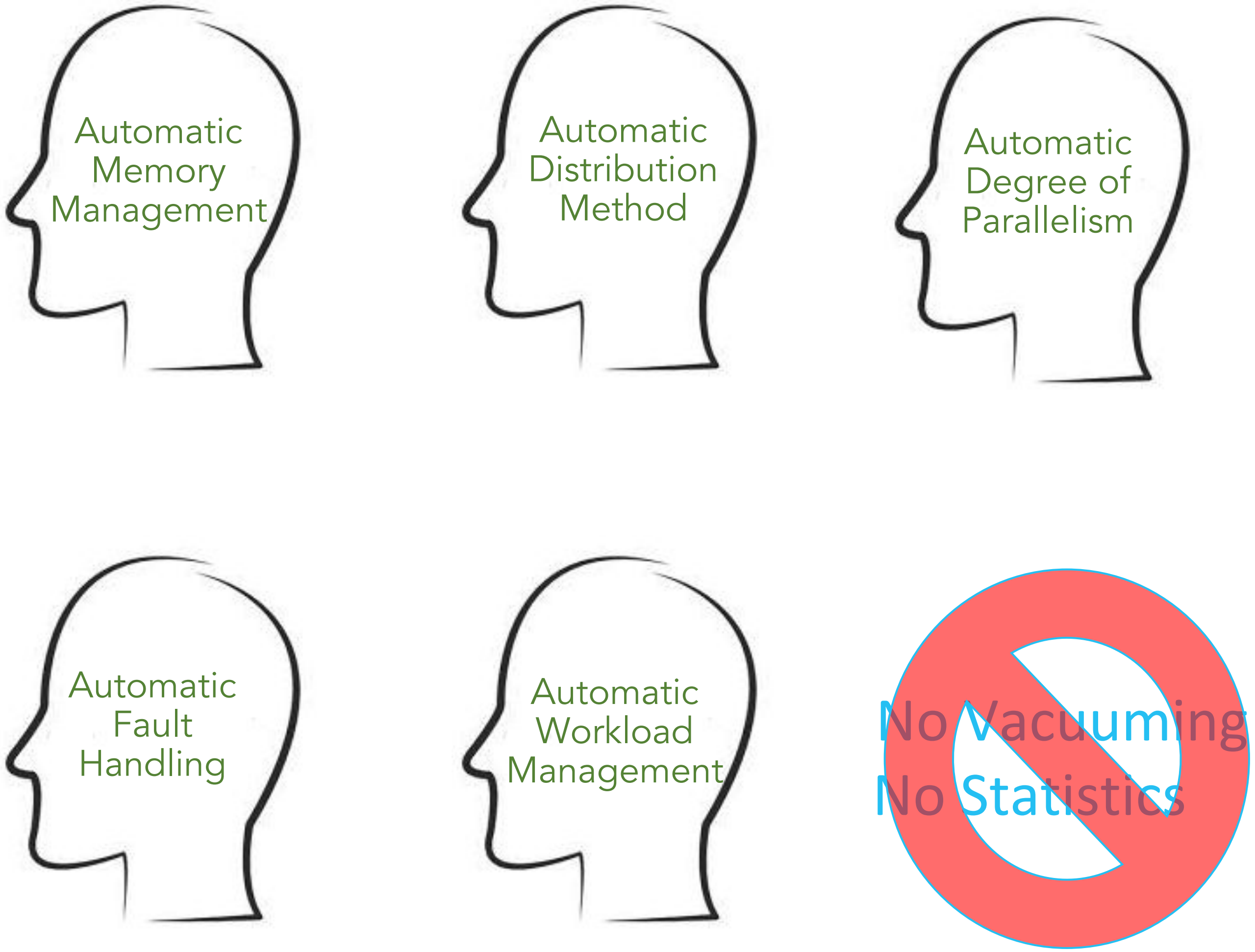
Execution Engine



- Columnar [MonetDB, C-Store, many more]
  - Effective use of CPU caches, SIMD instructions, and compression
- Vectorized [Zukowski05]
  - Operators handle batches of a few thousand rows in columnar format
  - Avoids materialization of intermediate results
- Push-based [Neumann11 and many before that]
  - Operators push results to downstream operators (no Volcano iterators)
  - Removes control logic from tight loops
  - Works well with DAG-shaped plans
- No transaction management, no buffer pool
  - But: most operators (join, group by, sort) can spill to disk and recurse

Self Tuning & Self Healing

- Adaptive
- Self-tuning
- Do no harm!
- Automatic
- Default



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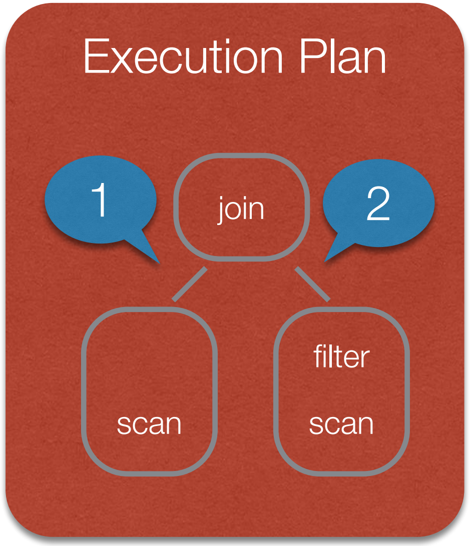
Example: Automatic Skew Avoidance

1

2

Detect popular values on the build side of the join
Use broadcast for those and directed join for the others

- Adaptive → popular values detected at runtime
- Self-tuning → number of values
- Transparent → no performance degradation
- Automatic → kicks in when needed
- Default → enabled by default for all joins



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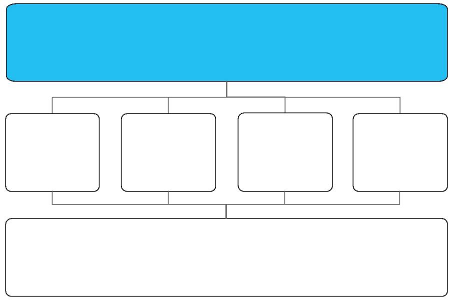
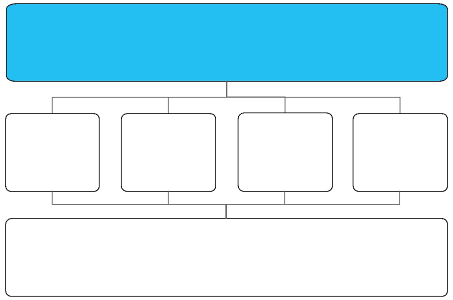
Cloud Services



- Collection of services
  - Access control, query optimizer, transaction manager etc.
- Heavily multi-tenant (shared among users) and always on
  - Improves utilization and reduces administration
- Each service replicated for availability and scalability
  - Hard state stored in transactional key-value store

Concurrency Control



- Designed for analytic workloads
  - Large reads, bulk or trickle inserts, bulk updates
- Snapshot Isolation (SI) [Berenson95]
- SI based on multi-version concurrency control (MVCC)
  - DML statements (insert, update, delete, merge) produce new table versions of tables by adding or removing whole files
  - Natural choice because table files on S3 are immutable
  - Additions and removals tracked in metadata (key-value store)
- Versioned snapshots used also for time travel and cloning

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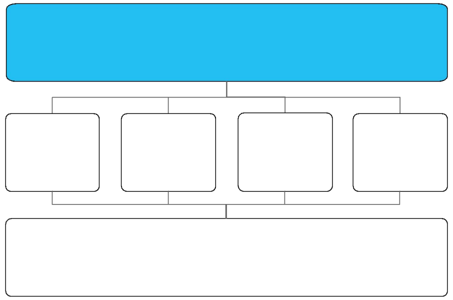
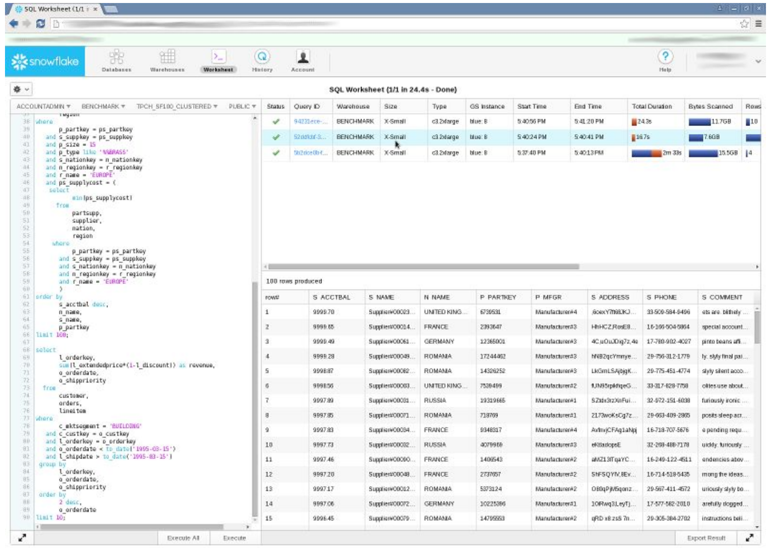
Pruning



- Database adage: The fastest way to process data? Don't.
  - Limiting access only to relevant data is key aspect of query processing
- Traditional solution: B^+-trees and other indices
  - Poor fit for us: random accesses, high load time, manual tuning
- Snowflake approach: pruning
  - AKA small materialized aggregates [Moerkotte98], zone maps [Netezza], data skipping [IBM]
  - Per file min/max values, #distinct values, #nulls, bloom filters etc.
  - Use metadata to decide which files are relevant for a given query
  - Smaller than indices, more load-friendly, no user input required

Pure SaaS Experience

- Support for various standard interfaces and third-party tools
  - ODBC, JDBC, Python PEP-0249
  - Tableau, Informatica, Looker
- Feature-rich web UI
  - Worksheet, monitoring, user management, usage information etc.
  - Dramatically reduces time to onboard users
- Focus on ease-of-use and service exp.
  - No tuning knobs
  - No physical design
  - No storage grooming



Continuous Availability

- Storage and cloud services replicated across datacenters
  - Snowflake remains available even if a whole datacenter fails
- Weekly Online Upgrade
  - No downtime, no performance degradation!
  - Tremendous effect on pace of development and bug resolution time
- Magic sauce: stateless services
  - All state is versioned and stored in common key-value store
  - Multiple versions of a service can run concurrently
  - Load balancing layer routes new queries to new service version, until old version finished all its queries

Semi-Structured and Schema-Less Data

- Three new data types: `VARIANT`, `ARRAY`, `OBJECT`
  - `VARIANT`: holds values of any standard SQL type + `ARRAY` + `OBJECT`
  - `ARRAY`: offset-addressable collection of `VARIANT` values
  - `OBJECT`: dictionary that maps strings to `VARIANT` values
    - Like JavaScript objects or MongoDB documents
- Self-describing, compact binary serialization
  - Designed for fast key-value lookup, comparison, and hashing
- Supported by all SQL operators (joins, group by, sort…)

Post-relational Operations

- Extraction from `VARIANT`s using path syntax

```
SELECT sensor.measure.value, sensor.measure.unit
FROM sensor_events
WHERE sensor.type = ‘THERMOMETER’;
```

- Flattening (pivoting) a single `OBJECT` or `ARRAY` into multiple rows

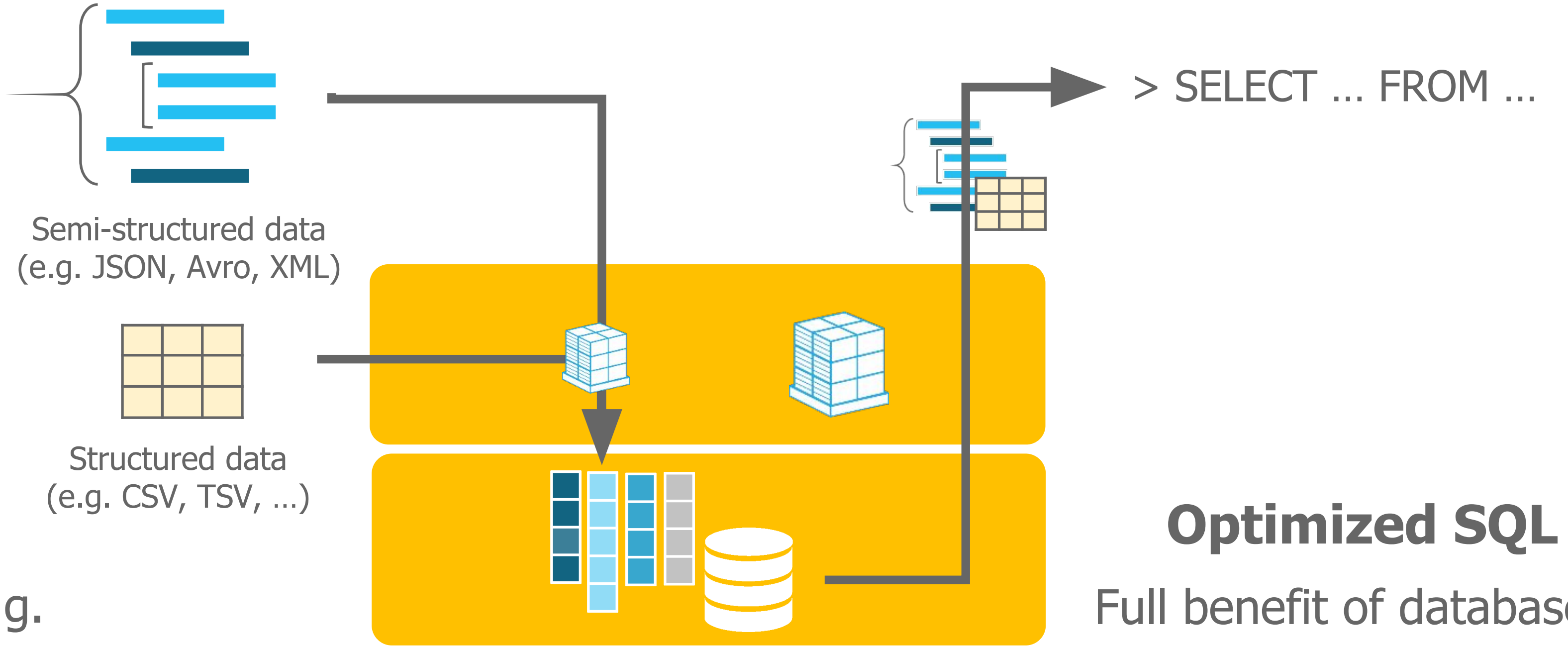
```
SELECT p.contact.name.first AS "first_name",
       p.contact.name.last AS "last_name",
       (f.value.type || ': ' || f.value.contact) AS "contact"
FROM person p,
     LATERAL FLATTEN(input => p.contact) f;

------------+-----------+---------------------+
 first_name | last_name |       contact       |
------------+-----------+---------------------+
 “John"     | “Doe"     | email: john@doe.xyz |
 “John"     | “Doe"     | phone: 555-123-4567 |
 “John"     | “Doe"     | phone: 555-666-7777 |
------------+-----------+---------------------+
```

Schema-Less Data

- Cloudera Impala, Google BigQuery/Dremel
  - Columnar storage and processing of semi-structured data
  - But: full schema required up front!

- Snowflake introduces *automatic* type inference and columnar storage for *schema-less* data (`VARIANT`)
  - Frequently common paths are detected, projected out, and stored in separate (typed and compressed) columns in table file
  - Collect metadata on these columns for use by optimizer → pruning
  - Independent for each micro-partition → schema evolution

Automatic Columnarization of semi-structured data

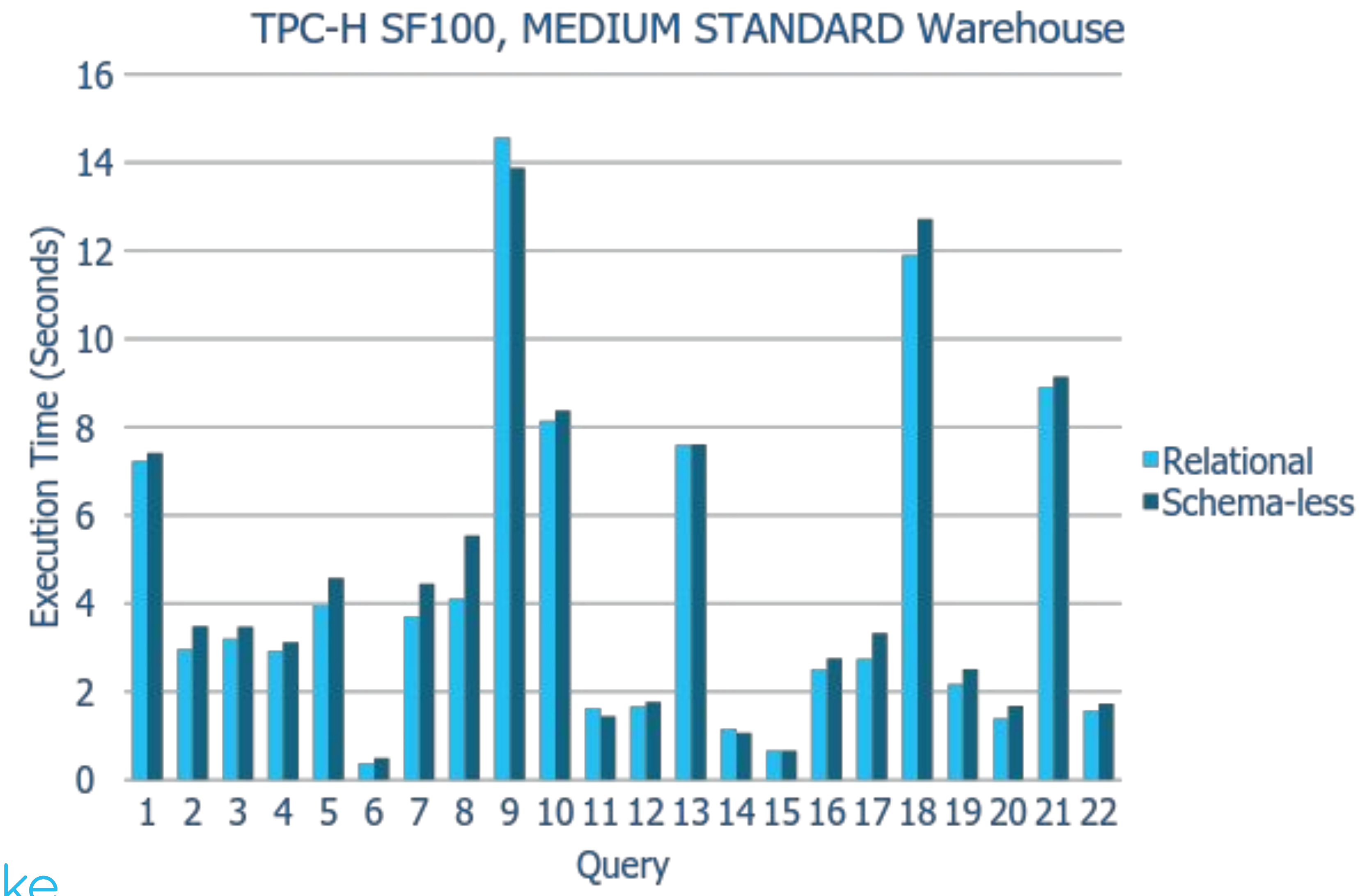


Native support
Loaded in raw form (e.g. JSON, Avro, XML)

Optimized storage
Optimized data type, no fixed schema or transformation required

Optimized SQL querying
Full benefit of database optimizations (pruning, filtering, …)

Schema-Less Performance



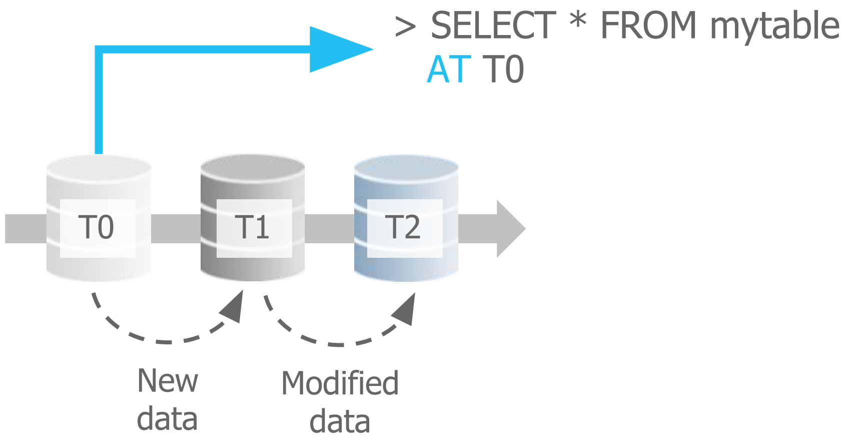
ETL vs. ELT

- ETL = Extract-Transform-Load
  - Classic approach: extract from source systems, run through some transformations (perhaps using Hadoop), then load into relational DW
- ELT = Extract-Load-Transform
  - Schema-later or schema-never: extract from source systems, leave in or convert to JSON or XML, load into DW, transform there if desired
  - Decouples information producers from information consumers

- Snowflake: ELT with speed and expressiveness of RDBMS

Time Travel and Cloning

- Previous versions of data automatically retained
  - Same metadata as Snapshot Isolation
- Accessed via SQL extensions
  - UNDROP recovers from accidental deletion
  - SELECT AT for point-in-time selection
  - CLONE [AT] to recreate past versions



Security

- Encrypted data import and export
- Encryption of table data using NIST 800-57 compliant hierarchical key management and key lifecycle
    - Root keys stored in hardware security module (HSM)
- Integration of S3 access policies
- Role-based access control (RBAC) within SQL
- Two-factor authentication and federated authentication

Post-SIGMOD '16 Features

- Data sharing
- Serverless ingestion of data
- Reclustering of data
- Spark connector with pushdown
- Support for Azure Cloud
- Lots more connectors

Lessons Learned

- Building a relational DW was a controversial decision in 2012
  - But turned out correct; Hadoop did not replace RDBMSs
- Multi-cluster, shared-data architecture game changer for org
  - Business units can provision warehouses on-demand
  - Fewer data silos
  - Dramatically lower load times and higher load frequency
- Semi-structured extensions were a bigger hit than expected
  - People use Snowflake to replace Hadoop clusters

Lessons Learned (2)

- SaaS model dramatically helped speed of development
  - Only one platform to develop for
  - Every user running the same version
  - Bugs can be analyzed, reproduced, and fixed very quickly
- Users love “no tuning” aspect
  - But creates continuous stream of hard engineering challenges…
- Core performance less important than anticipated
  - Elasticity matters more in practice

Ongoing Challenges

- SaaS and multi-tenancy are big challenges
  - Support tens of thousands of concurrent users, some of which do *weird* things, and need protection for themselves.
  - Metadata layer has become huge
  - Categorizing and handling failures automatically is hard, but
  - *Automation* is key to keeping operations lean
- Lots of work left to do
  - SQL performance improvements, better skew handling etc.
  - Cloud platform enables a slew of new classes of features.

Future work

- Advisors
- Materialized Views
- Stored procedures
- Data Lake support
- Streaming
- Time series
- Multi-cloud
- Global Snowflake
- Replication

Who We Are

- Founded: August 2012
- Mission in 2012: Build an enterprise data warehouse as a cloud service
- HQ in downtown San Mateo (south of San Francisco), Engr Office #2 in Seattle
- 400+ employees, 80 engrs and hiring…
    - Founders: Benoit Dageville, Thierry Cruanes, Marcin Zukowski
    - CEO: Bob Muglia
- Raised $283M in 2018

Summary

- Snowflake is an enterprise-ready data warehouse as a service
    - Novel multi-cluster, shared-data architecture
    - Highly elastic and available
    - Semi-structured and schema-less data at the speed of relational data
    - Pure SaaS experience
- Rapidly growing user base and data volume
- Lots of challenging work left to do