Macroarea di Ingegneria
Dipartimento di Ingegneria Civile e Ingegneria Informatica

NewSQL Databases
and Time Series Databases

Corso di Sistemi e Architetture per Big Data

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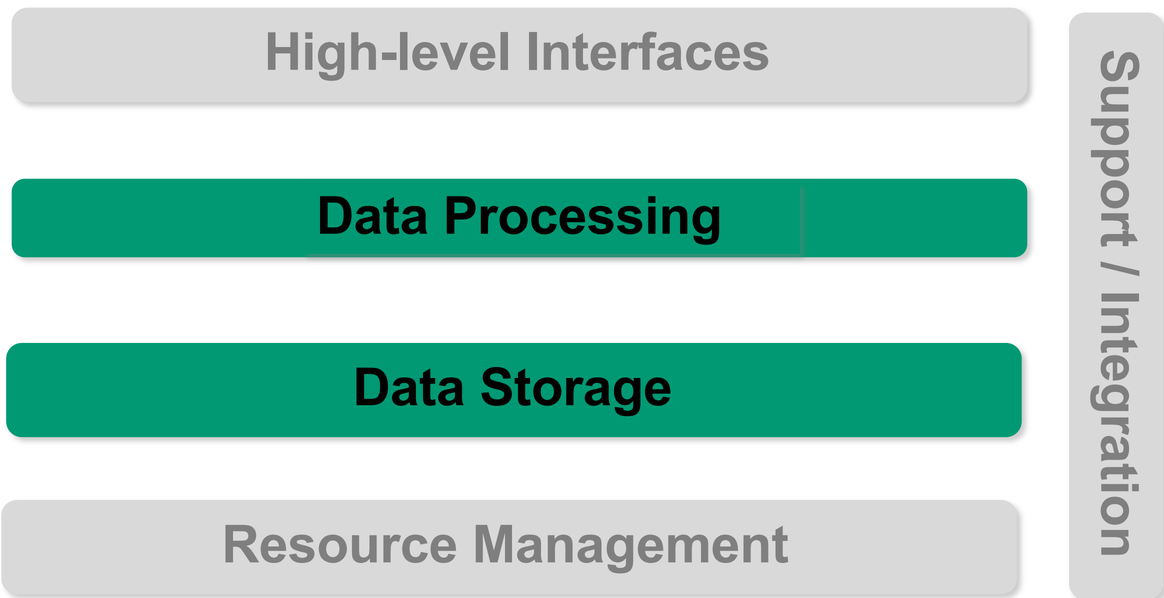
The reference Big Data stack



Relational database systems

- RDBMS pros:
  - ACID transactions
  - Relational schemas (and schema changes without downtime)
  - SQL queries
  - Strong consistency
- RDBMS cons:
  - Lack of horizontal scalability (to 100s or 1000s of servers)

NewSQL databases

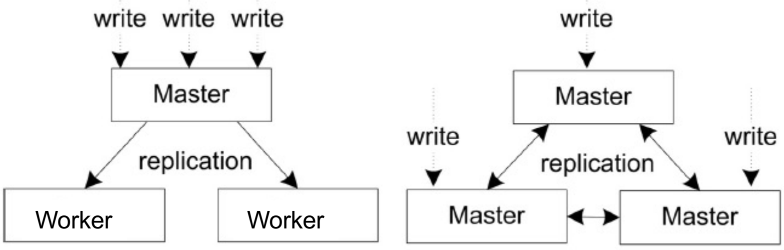
- How to build a relational database system that is both ACID compliant and horizontally scalable?
  - i.e., how to make ACID scale?
- **NewSQL**: a class of modern RDBMS
- Goals
  - Provide scalability of NoSQL systems for OLTP workloads, while maintaining ACID support of traditional RDBMS
  - Support SQL

NewSQL examples

- **Google's Spanner**
  - Also available as cloud service in Google Cloud Platform: Cloud Spanner https://cloud.google.com/spanner/
- CockroachDB
  - Open-source, born as Spanner clone, then evolved differently https://www.cockroachlabs.com/
- Google's F1 Query
  - Relational distributed transactional DB built on top of Spanner
- **VoltDB** https://www.voltdb.com/
- Clustrix (now MariaDB Xpand)
- NuoDB
- Note: most of them closed source

Replication in NewSQL

- Hot to scale? Multi-master (or master-less) schemes
  - Any node can receive data update statements



Primary-based replication Multi-master replication

- Google Spanner
  - Uses Paxos state machine replication to guarantee that a sequence of commands is executed in the same order by all the replicas
- VoltDB
  - A transaction/session manager receives the updates, which are forwarded to all replicas and executed in parallel

Spanner: why

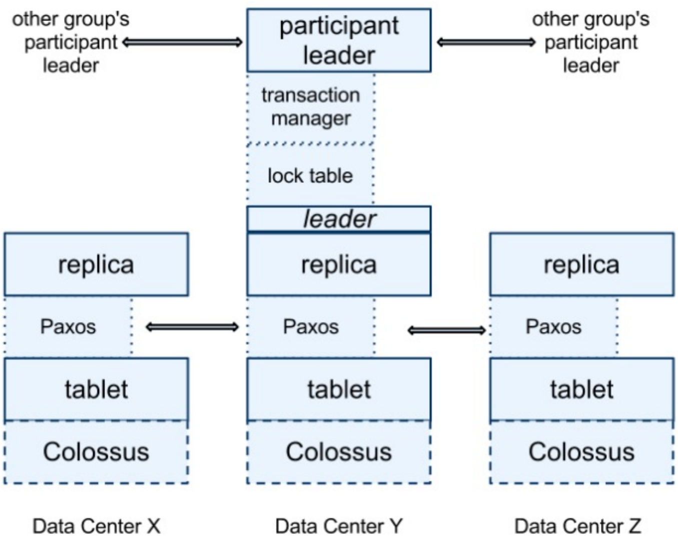
- Google's motivations:
  - "Even though many projects happily use Bigtable, we have also consistently received complaints from users that Bigtable can be difficult to use for some kinds of applications: those that have complex, evolving schemas, or those that want strong consistency in the presence of wide-area replication"
  - We provide a "temporal multi-version database instead of a Bigtable-like versioned key-value store" to make it easier for programmers to write their applications

Spanner

- Wide-area distributed multi-version database
  - Support for ACID transactions
  - Strong consistency and high availability
  - SQL-based query language
  - Multi-version data
    - Each version of data is automatically timestamped with its commit time
  - "At the highest level of abstraction, it is a database that shards data across many sets of Paxos state machines in data-centers spread all over the world"
- Running in production
  - E.g., storage layer for Google's ads data

Spanner: software stack

- Based on Paxos and Colossus (GFS successor)



Spanner: overview

- Feature: lock-free distributed read-only transactions
  - Lock-free: no need of locking to read any data item
  - But of course lock on read/write transactions!
- Property: external consistency of distributed transactions
  - External consistency: strictest concurrency-control guarantees for transactions (more than linearizability)
    - System behaves as if all transactions were executed sequentially
  - In a globally distributed system
- Implementation: integration of concurrency control, replication, and 2PC
  - Correctness and performance
- Enabling technology: a new API Time called TrueTime
  - Used to generate monotonically increasing timestamps and assign them to transactions

Spanner: Google's TrueTime (TT)

- Distributed synchronized clock with bounded non-zero error
  – Returns a time interval that is guaranteed to contain the clock's actual time for some time during the call's execution
  – Relies on a well engineered tight clock synchronization available at all servers thanks to GPS clocks and atomic clocks
  – *Cons*: TT requires special hardware and a custom-build tight clock synchronization protocol, which is infeasible for many systems
    - Spanner is run over Google's private global network (not over public Internet), which is very high throughput, global fiber optic network linking its data centers

Spanner: concurrency control

- Hybrid approach
  – Read-write transactions are implemented through read-write locks, but read-only transactions are lock-free
- Why is it possible?
  – To read without blocking writes, Spanner (and other DB systems) keep multiple immutable versions of data: this concurrency control mechanism is called multi-version concurrency control (MVCC)
    - Each write creates a new immutable version of data whose timestamp is that of the write's transaction, such that concurrent readers can still see the old version while the update transaction proceeds concurrently
    - A read at a timestamp returns the value of the most recent version prior to that timestamp, and does not need to block writes
  – Spanner stores multiple versions of data, and a read transaction is basically a read at a "safe" timestamp
  – Proper timestamping is achieved by using TrueTime

Cloud Spanner

- Spanner as Cloud service on GCP
- Globally distributed, ACID-compliant database that automatically handles replicas, sharding, and transaction processing
- High availability: up to 99.999%

- Note: Spanner (and Cloud Spanner) are both strongly consistent and high available on a wide-area scale: CAP theorem?
  - Short answer: technically CP
  - If you are curious: [Spanner, TrueTime and the CAP Theorem]()

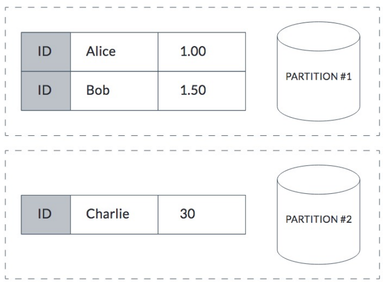
VoltDB

- In-memory, partitioned, single-threaded, distributed, ACID-compliant database
  - In-memory: data is held in RAM rather than on disk
  - Partitioned and distributed: database tables are partitioned across multiple servers so to achieve high concurrency and high throughput
  - Single-threaded: serialized processing on data within a single partition thus avoiding locking overhead
  - ACID-compliant: to ensure data consistency, integrity and accurate query results
- Other features
  - Based on shared nothing architecture at per-core level
  - Horizontal scale-out on commodity hardware
  - Durability and high availability through async and sync command logging, database snapshot, replication
  - Open-source community edition

VoltDB

- How it began
  - Open source RDBMs ran on memory-based file system
    - Over 80% of time spent on page buffer management, index management, and concurrency management
      - Index management: indexing schemes (e.g., B-tree, hashing) require significant CPU and I/O
      - Locking operations are overhead-intensive
    - Only 12% of time spent doing the real work
  - Lead to H-Store http://hstore.cs.brown.edu
  - Developed by M. Stonebraker (2015 ACM Turing award)

VoltDB: partitioning



- Tables are automatically partitioned over multiple servers, and clients can call any server
  - Transparent distribution, but the user can choose how to partition the table by specifying the partitioning column
  - If a table is partitioned, each time you insert a row into that table, VoltDB decides which partition the row goes into based on the value of the partitioning column
- Selected tables can be replicated over servers, e.g. for fast access to read-mostly data

VoltDB: concurrency control

- Alternative design with respect to Spanner, not using clock-based scheme but based on two assumptions
  1. Total available memory is large enough to store entire data store
  2. All user transactions are short-lived and can be very efficiently executed over in-memory data
- Transactions that involve a single partition are executed sequentially (from beginning to end) in a single-threaded, lock-free environment
- Transactions that span multiple partitions are sent to a special global controller, which is responsible for deciding a serial order

Time series data base (TSDB)

- How to analyze DevOps monitoring, application metrics, sensor data from smart factories, smart cities, or smart vehicles?

  Time series databases (**TSDBs**)
  - A possible solution, not the only one!
- Optimized for handling high-volume time series data
  - *Time series*: sequence of data points (arrays of numbers) indexed by time (a date time or a date time range), e.g.:
    - Stock prices (price curve)
    - Energy consumption (load profile)
    - Temperature values (temperature trace)
- Optimized for providing complex logic to analyze time series data
  - Queries for historical data, replete with time ranges and roll ups and arbitrary time zone conversions are difficult in DBMS

TSDB: overview

- Create, enumerate, update and destroy various time series and organize them in some fashion
  - Series may be organized hierarchically and have companion metadata
  - Provide basic calculations on a series as a whole (e.g., multiplying, adding, or combining various time series into a new time series)
  - Filter on arbitrary patterns (e.g., day of the week, low value, high value)
  - Provide statistical functions that are targeted to time series data
    - mean, mode, stddev, percentile, exponential moving average, …

TSDB: some products

- Some open-source products
  - CrateDB https://crate.io
  - Chronix http://www.chronix.io
  - Graphite https://graphiteapp.org
    - Stores numeric time-series data and renders graphs on demand
  - InfluxDB https://www.influxdata.com
  - KairosDB https://kairosdb.github.io
    - Stores its time series in Cassandra
  - OpenTSDB http://opentsdb.net
    - Stores its time series in HBase
  - Riak TS http://basho.com/products/riak-ts/
    - NoSQL key-value store optimized for time series data with masterless architecture (similar to Riak KV)

InfluxDB

- Written in Go
- Supports high write loads and large data set storage
- Conserves space through downsampling
  - By automatically expiring and deleting unwanted data as well as backup and restore
- Provides easy-to-use SQL-like query language for interacting with data
- Provides simple, high performing write and query HTTP(S) APIs, e.g.:
  - To create a database

```
curl -i -XPOST http://localhost:8086/query --data-urlencode
"q=CREATE DATABASE mydb”
```

  - To write data

```
curl -i -XPOST 'http://localhost:8086/write?db=mydb' --data-binary
'cpu_load_short,host=server01,region=us-west value=0.64
1434055562000000000'
```


InfluxDB: time series

- Data organized by time series, which contain a measured value, like “cpu_load” or “temperature”
- Time series have zero to many points, one for each discrete sample of the metric
- Points consist of:
  - time (a timestamp)
  - measurement (e.g., “cpu_load”)
  - at least one key-value field (the measured value itself, e.g. “value=0.64”, or “temperature=21.2”)
  - and 0 to many key-value tags containing any metadata about the value (e.g. “host=server01”, “region=EMEA”, “dc=Frankfurt”)

InfluxDB: time series

- General format of points:

  `<measurement>[,<tag-key>=<tag-value>...] <field-key>=<field-value>[,<field2-key>=<field2-value>...] [unix-nano-timestamp]`

  – Timestamp is optional: InfluxDB uses the server's local nanosecond timestamp in UTC if the timestamp is not included with the point
- Examples of points:

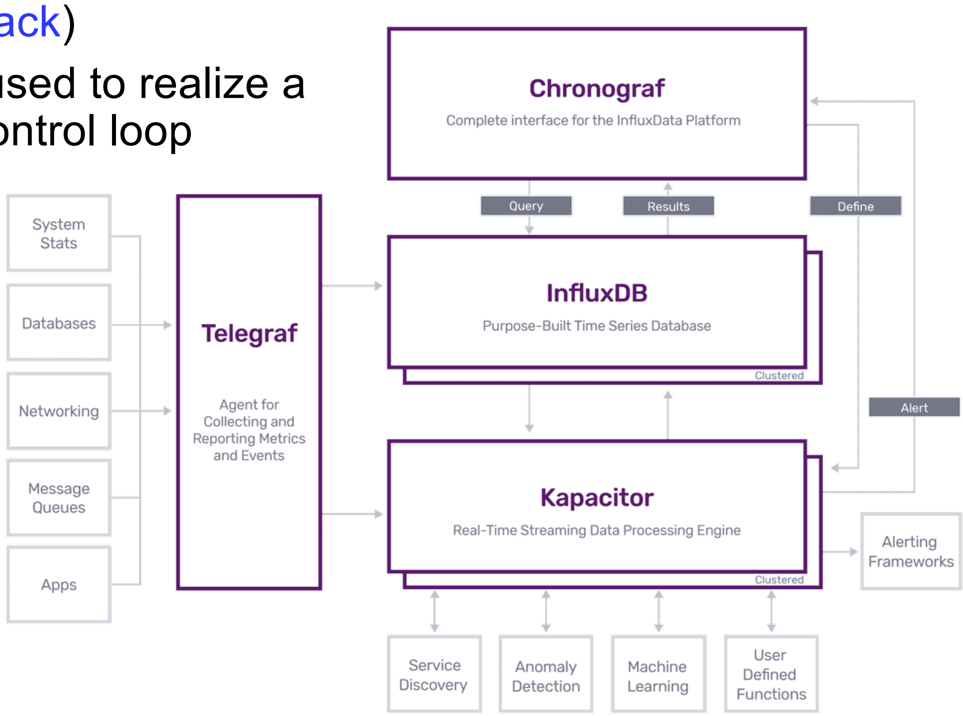
```
cpu,host=serverA,region=us_west value=0.64
payment,device=mobile,product=Notepad,method=credit billed=33,licenses=3i 1434067467100293230
stock,symbol=AAPL bid=127.46,ask=127.48
temperature,machine=unit42,type=assembly external=25,internal=37 1434067467000000000
```


InfluxDB: data store

- A measurement is like a SQL table, where the primary index is time
- With respect to DBMS:
  – No need to define schemas up-front
  – Null values are not stored
- InfluxDB limitation
  – Horizontal scalability: clustered installation available only as enterprise product

InfluxDB: TICK stack

- Integrated with Telegraph, Chronograf and Kapacitor (TICK stack)
- Can be used to realize a MAPE control loop



See https://www.influxdata.com/time-series-platform/

InfluxDB: TICK stack

- Telegraf: plugin-driven server agent for collecting and reporting metrics and events
  – Input plugins or integrations to source a variety of metrics
  – Output plugins to send metrics to other data stores, services, and message queues (InfluxDB, Graphite, OpenTSDB, Kafka, MQTT, …)
- Chronograf: administrative user interface and visualization engine
  – To build dashboards with real-time visualizations of data and to create alerting and automation rules
- Kapacitor: native data processing engine
  – To process both stream and batch data from InfluxDB
  – E.g., to perform specific actions (e.g., dynamic load balancing) based on alerts (e.g., above load threshold)

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