Designing and building a distributed data store in Go

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Who am I?

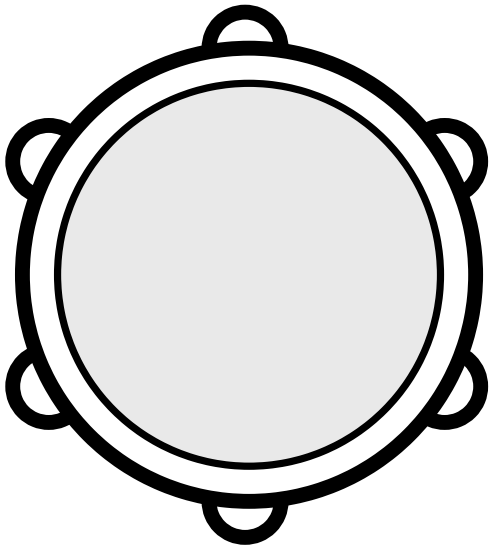
Platform Engineer working for Cloudflare in London.

Interested in distributed systems and performance.

Bulding and designing a distributed data store

What I will (and won't) cover in this talk

MSc Computer Science final project



TIMBALA

DURABLE TIME-SERIES DATABASE

It ain't production-ready

Please, please, don't use it yet in Production if you care about your data.

What's 'distributed'?

"A distributed system is a model in which components located on networked computers communicate and coordinate their actions by passing messages."

-- Wikipedia

Why distributed?

Survive the failure of individual servers

Add more servers to meet demand

Fallacies of distributed computing

The network is reliable.
Latency is zero.
Bandwidth is infinite.
The network is secure.
Topology doesn't change.
There is one administrator.
Transport cost is zero.
The network is homogeneous.

Use case

Durable long-term storage for metrics

Why not use 'the Cloud'?

- On-premise, mid-sized deployments
- High performance, low latency
- Ease of operation

Requirements

Sharding

The database must be able to store more data than could fit on a single node.

Replication

The system must replicate data across multiple nodes to prevent data loss when individual nodes fail.

High availability and throughput for data ingestion

Must be able to store a lot of data, reliably

Operational simplicity

Interoperability with Prometheus

Reuse Prometheus' best features

Avoid writing my own query language and designing my own APIs

Focus on the 'distributed' part

By the numbers

Cloudflare's OpenTSDB installation (mid-2017):

- 700k data points per second
- 70M unique timeseries

Minimum Viable Product (MVP)?

How to reduce the scope?

Reuse third-party code wherever possible

Milestone 1: Single-node implementation

Ingestion API

Query API

Local, single node, storage

Milestone 2: Clustered implementation

1. Shard data between nodes (no replication yet)

2. Replicate shards

3. Replication rebalancing using manual intervention

Beyond a minimum viable product

Read repair

Hinted handoff

Active anti-entropy

To the research!

NUMA
Data/cache locality
SSDs
Write amplification
Alignment with disk storage, memory pages
mmap(2)
Jepsen testing
Formal verification methods
Bitmap indices
xxHash, City hash, Murmur hash, Farm hash, Highway hash

Back to the essentials

Coordination

Indexing

On-disk storage format

Cluster membership

Data placement (replication/sharding)

Failure modes

Traits (or assumptions) of time-series data

Immutable data

No updates to existing data!

No need to worry about managing multiple versions of the same value and copying (replicating) them between servers

Simple data types; compress well

Don't need to worry about arrays or strings

Double-delta compression for floats

> Gorilla: A Fast, Scalable, In-Memory Time Series Database (http://www.vldb.org/pvldb/vol8/p1816-teller.pdf)

Tension between write and read patterns

Continous writes across majority of individual time-series

Occasional reads for small subsets of time-series across historical data

Writing a Time Series Database from Scratch (https://fabxc.org/tsdb/)

Prior art

Amazon's Dynamo paper

Apache Cassandra

Basho Riak

Google BigTable

Other time-series databases

Coordination

Keep coordination to a minimum

Avoid coordination bottlenecks

Cluster membership

Need to know which nodes are in the cluster at any given time

Could be static, dynamic is preferable

Need to know when a node is dead so we can stop using it

Memberlist library

I used Hashicorp's Memberlist library

Used by Serf and Consul

SWIM gossip protocol

Indexing

Could use a centralised index

Consistent view; knows where each piece of data should reside

Index needs to be replicated in case a node fails

Likely to become a bottleneck at high ingestion volumes

Needs coordination, possibly consensus

Could use a local index

Each node knows what data it has

Data placement (replication/sharding)

Consistent hashing

Hashing uses maths to put items into buckets

Consistent hashing aims to keep disruption to a minimum when the number of buckets changes

Consistent hashing: example

n = nodes in the cluster

1/n of data should be displaced/relocated when a single node fails

Example:

- 5 nodes
- 1 node fails
- one fifth of data needs to move

Consistent hashing algorithms

Decision record for determining consistent hashing algorithm (https://github.com/mattbostock/timbala/issues/27)

Consistent hashing algorithms

First attempt: Karger et al (Akamai) algorithm

Karger et al paper (https://www.akamai.com/es/es/multimedia/documents/technical-publication/consistent-hashing-and-random-trees-distributed-caching-protocols-for-relieving-hot-spots-on-the-world-wide-web-technical-publication.pdf)

github.com/golang/groupcache/blob/master/consistenthash/consistenthash.go (https://github.com/golang/groupcache/blob/master/consistenthash/consistenthash.go)

Second attempt: Jump hash

Jump hash paper (https://arxiv.org/abs/1406.2294)

github.com/dgryski/go-jump/blob/master/jump.go (https://github.com/dgryski/go-jump/blob/master/jump.go)

Jump hash implementation

```
func Hash(key uint64, numBuckets int) int32 {
        var b int64 = -1
        var j int64

        for j < int64(numBuckets) {
                b = j
                key = key*2862933555777941757 + 1
                j = int64(float64(b+1) * (float64(int64(1)<<31) / float64((key>>33)+1)))
        }

        return int32(b)
}
```

github.com/dgryski/go-jump/blob/master/jump.go (https://github.com/dgryski/go-jump/blob/master/jump.go)

Partition key

The hash function needs some input

The partition key influences which bucket data is placed in

Decision record for partition key (https://github.com/mattbostock/timbala/issues/12)

Replicas

3 replicas (copies) of each shard

Achieved by prepending the replica number to the partition key

On-disk storage format

Log-structured merge
LevelDB
RocksDB
LMDB
B-trees and b-tries (bitwise trie structure) for indexes
Locality-preserving hashes

Use an existing library

- Prometheus TSDB library (https://github.com/prometheus/tsdb)

Cleaner interface than previous Prometheus storage engine

Intended to be used as a library

- Writing a Time Series Database from Scratch (https://fabxc.org/tsdb/)

Architecture

No centralised index (only shared state is node metadata)

Each node has the same role

Any node can receive a query

Any node can receive new data

No centralised index, data placement is determined by consistent hash

Testing

- Unit tests
- Acceptance tests
- Integration tests
- Benchmarking

Unit tests

Data distribution tests

How even is the distribution of samples across nodes in the cluster?

Are replicas of the same data stored on separate nodes?

```
=== RUN TestHashringDistribution/3_replicas_across_5_nodes
Distribution of samples when replication factor is 3 across a cluster of 5 nodes:
Node 0 : #########                                                 19.96%; 59891 samples
Node 1 : #########                                                 19.99%; 59967 samples
Node 2 : ##########                                                20.19%; 60558 samples
Node 3 : #########                                                 19.74%; 59212 samples
Node 4 : ##########                                                20.12%; 60372 samples
Summary:
Min: 59212
Max: 60558
Mean: 60000.00
Median: 59967
Standard deviation: 465.55
Total samples: 300000

Distribution of 3 replicas across 5 nodes:
0 nodes:                                                           0.00%; 0 samples
1 nodes:                                                           0.00%; 0 samples
2 nodes:                                                           0.00%; 0 samples
3 nodes: ################################################## 100.00%; 100000 samples

Replication summary:
Min nodes samples are spread over: 3
Max nodes samples are spread over: 3
Mode nodes samples are spread over: [3]
Mean nodes samples are spread over: 3.00
```

Data displacement tests

If I change the cluster size, how much data needs to move servers?

```
=== RUN   TestHashringDisplacement
293976 unique samples
At most 19598 samples should change node
15477 samples changed node

293976 unique samples
At most 21776 samples should change node
16199 samples changed node
--- PASS: TestHashringDisplacement (4.33s)
```

Data displacement failure

Too much data was being moved because I was sorting the list of nodes alphabetically

Jump hash gotcha

"Its main limitation is that the buckets must be numbered sequentially, which makes it more suitable for data storage applications than for distributed web caching."

Jump hash works on buckets, not server names

Conclusion: Each node needs to remember the order in which it joined the cluster

Acceptance tests

Verify core functionality from a user perspective

Integration tests

Most effective, least brittle tests at this stage in the project

Some cross-over with acceptance tests

Docker compose for portability, easy to define

Benchmarking

Benchmarking harness using Docker Compose

pprof

```
go tool pprof
```

or

```
go get github.com/google/pprof
```

Go Diagnostics (https://tip.golang.org/doc/diagnostics.html)

pprof CPU profile

```
pprof --dot http://localhost:9080/debug/pprof/profile | dot -T png | open -f -a /Applications/Preview.ap
```

Gauging the impact of garbage collection

```
GOGC=off
```

golang.org/pkg/runtime/ (https://golang.org/pkg/runtime/)

Microbenchmarks

```
$ go test -benchmem -bench BenchmarkHashringDistribution -run none ./internal/cluster
goos: darwin
goarch: amd64
pkg: github.com/mattbostock/timbala/internal/cluster
BenchmarkHashringDistribution-4        2000000           954 ns/op         544 B/op          3 allocs/o
PASS
ok      github.com/mattbostock/timbala/internal/cluster    3.303s
```

golang.org/pkg/testing/#hdr-Benchmarks (https://golang.org/pkg/testing/#hdr-Benchmarks)

Failure injection

Stop nodes

Packet loss, re-ordering, latency using tc (Traffic Control)

www.qualimente.com/2016/04/26/introduction-to-failure-testing-with-docker/

(https://www.qualimente.com/2016/04/26/introduction-to-failure-testing-with-docker/)

Conclusions

- Greatest challenge in distribution systems is anticipating how they will fail and lose data
- Make sure you understand the tradeoffs your Production systems are making

Use dep, it's awesome 🤘

github.com/golang/dep (https://github.com/golang/dep)

More information

- Timbala architecture documentation (https://github.com/mattbostock/timbala/blob/master/docs/architecture.md)
- Designing Data-Intensive Systems (https://dataintensive.net/)
- OK Log blog post (https://peter.bourgon.org/ok-log/)
- Notes on Distributed Systems for Young Bloods (https://www.somethingsimilar.com/2013/01/14/notes-on-distributed-systems-for-young-bloods/)
- Achieving Rapid Response Times in Large Online Services (https://www.youtube.com/watch?v=1-3Ahy7Fxsc)
- Jepsen distributed systems safety research (https://jepsen.io/talks)
- Writing a Time Series Database from Scratch (https://fabxc.org/tsdb/)
- Failure testing with Docker (https://www.qualimente.com/2016/04/26/introduction-to-failure-testing-with-docker/)
- Gorilla: A Fast, Scalable, In-Memory Time Series Database (http://www.vldb.org/pvldb/vol8/p1816-teller.pdf)
- SWIM gossip protocol paper (https://www.cs.cornell.edu/~asdas/research/dsn02-swim.pdf)

Jump hash paper (https://arxiv.org/abs/1406.2294)

Thank you

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