Scaling Observability with Loki at Dropbox

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Engineering Manager, Storage Platform

- Master's from Carnegie Mellon University
- Prior experience: Big Switch Networks, VMware, Cisco
- Focus: Storage systems, scalable infrastructure, Telemetry
- Interested in AI/ML infrastructure challenges

Paul Shen

Software Engineer, Logging Integration Tracing (LIT) Team

- Work: Deploying Grafana stack, Traces, Profiles
- Personal: ergonomic computer interfaces - terminal apps, LLM chat and voice-to-text, XR glasses

Dropbox

- Founded in 2007
- 700+ million users
- 18+ million paying users
- 1 T+ pieces of content
- Billions of files uploaded per day

Incident Triage Workflow

- **Detection & Alerting:** Automated alerts signal anomalies.
- **Dashboard Metrics:** Review key metrics for a high-level view.
- **Log Analysis:** Dig into logs for detailed error context.
- **Distributed Tracing:** Follow request flows to pinpoint root causes.
- **Resolution:** Implement fixes and validate the remediation.

Unstructured Logs

- **Raw Data:** Logs without a defined schema.
- **Sources:** From first-party code & third-party debug files (e.g., /var/log/dropbox).
- **Contrast:** Unlike structured logs (e.g., Hive records, traces)
- **Use Case:** Real-time troubleshooting.

Problem Statement

- Unstructured logs stored in /var/logs/
- ssh individual box
- Host rotated in 7 days
- Migration from standalone hosts to containers
- Containers are ephemeral

High-Level Requirements

- Provide a secure, ergonomic interface for analyzing unstructured logs
- Replace manual, on-host SSH log analysis for production service owners
- Ingest the complete firehose of DBX production logs without modifying application code
- Lay the groundwork for future integration with logs from acquisitions and corporate assets

Reliability Requirements

- **Retention:** Maintain logs for at least 1 week
- **Throughput:** Support up to 150TB/day of log data
- **Latency:** Achieve p99 ingestion latency within 30 seconds and query latency under 10 seconds
- **Availability:** Ensure 99% of log records are reliably stored and accessible

Security Requirements

- Enforce deny-by-default mTLS across all endpoints
- Implement strict access segmentation by service ownership with audited privilege delegation
- Encrypt log storage at rest using robust key management
- Integrate PII detection, filtering, and redaction at both ingress and query stages

Non Goals

- **Log Format**: Don’t mandate changes
- **Observability**: Not going to replace structured logging/tracing/metrics
- **Analytics**: Not for batch or historical analysis
- **Enforcement**: No mandated logging practices

Evaluation Metrics for Logging Solutions

- **Cost:** Total cost of ownership (OpEx/CapEx, contract risks)
- **Performance:** Ingestion rates, query latency & scalability
- **UX & Query:** Rich query engine, familiar Grafana integration
- **Integration:** Ease of connecting with existing observability tools
- **Security:** Data protection, sensitive data exposure risk

Do Nothing (Status Quo)

- Overview: Continue existing SSH-based log analysis
- Pros: No additional investment
- Cons: Manual, non-scalable, inefficient troubleshooting
- Outcome: Inadequate for modern observability needs

Evaluation of Logging Services

Solution	Overview	Pros	Cons	Outcome
Externally Managed SaaS	Fully managed logging service by a third party	Reduces in-house management overhead	High annual cost; potential security risks	Rejected due to cost and security concerns
Managed Cloud Logging	Managed search and logging on a cloud framework	Mature, scalable technology	Higher operational costs; complex configuration affecting UX	Not cost-effective; UX challenges
Self-Hosted Enterprise	Enterprise-grade log management on-premise	Rich feature set; robust vendor support	Expensive licensing and infrastructure demands	Too costly and cumbersome for our scale
Build Your Own Logging	Custom-developed solution	Full control; tailored features	High engineering effort; slow time-to-value	Not viable given rapid open-source advances

Grafana Loki

- **Cost-effective**: Open-source, low TCO
- **High-Performance**: Optimized for DBX-scale log ingestion and querying
- **Grafana Integration**: Native, unified observability interface
- **Scalable Architecture**: Distributed components

Why did we pick Loki: Evaluating Alternatives

- Build vs Buy: Building a new log analysis engine unlikely to make sense given mature observability sector

- SaaS vs self-hosted: SaaS was hugely disadvantaged by
  - Cost
  - Security
  - Integration Challenges

- Index complexity: full text index(esearchd) vs metadata index(loki) vs no index(BFS)

- Loki: a sweet spot in the cost vs UX tradeoff

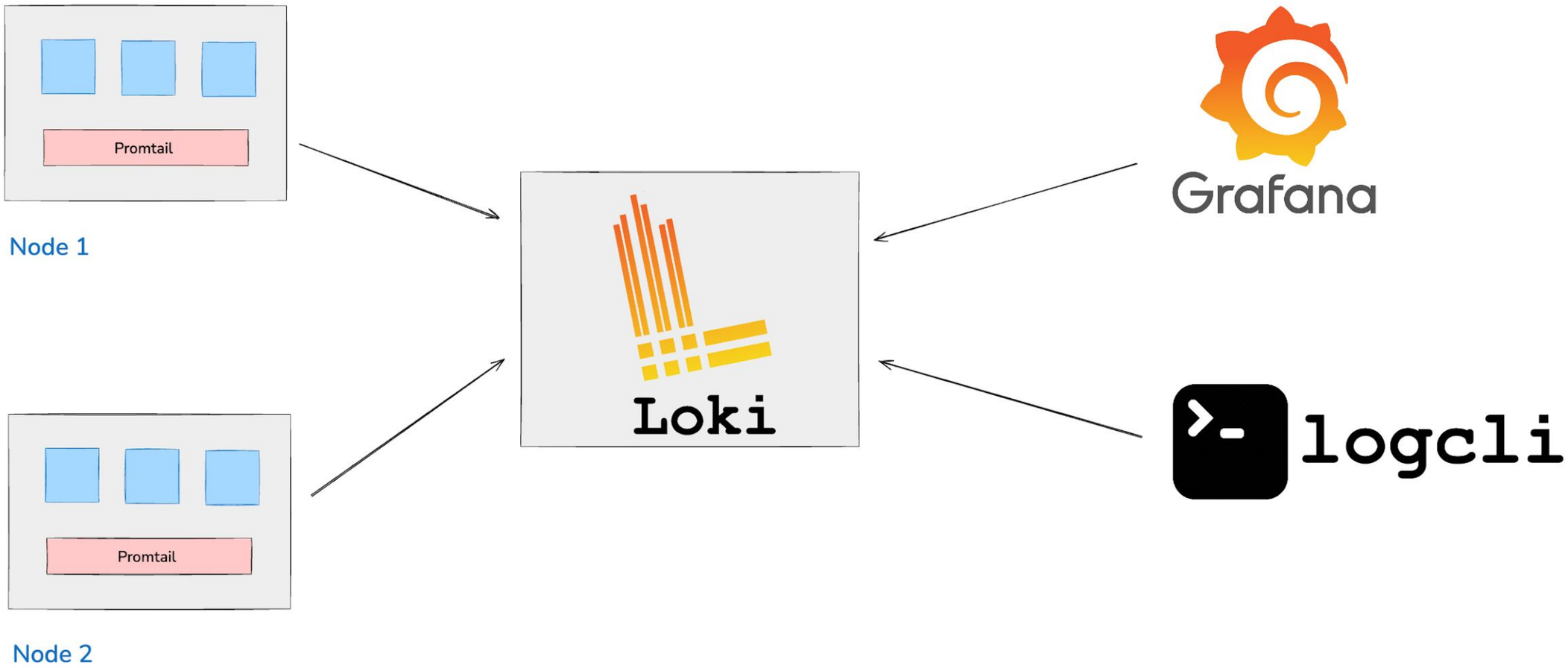
What is Loki?

- Apache 2.0 licensed
- Horizontally scalable
- Highly Available
- Multi tenant
- Prometheus inspired
- Log aggregation System

Why did we pick Loki: Other things we Liked

- Query model conceptually similar to our metrics query language V2
- Active community
- Implemented in golang so easy to patch
- Integrated/Core Grafana UX
- Backed by S3
- Scalable architecture

Architecture

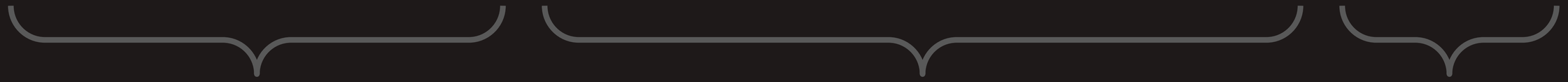


Loki Scalability

- Does not indexes the text of the log
- Loki indexes metadata
- It groups log entries into streams and indexes labels
- Faster ingestion and queries with minimal infrastructure

Logs

2025-02-01T09:02:03.123456789Z {service=”dummy_service”, node_id=”ex_node_1”} GET /about



Timestamp
With nanosecond precision

Prometheus-style **Labels**
Key-value pairs

Content
Log line

Logs - Stream

A **log stream** is stream of log entries with **exact same label set**

```
2025-02-01T09:02:03.000Z    {service=”dummy_service”, node_id=”ex_node_1”}    GET /about
2025-02-01T09:02:04.000Z    {service=”dummy_service”, node_id=”ex_node_1”}    GET /
2025-02-01T09:02:06.000Z    {service=”dummy_service”, node_id=”ex_node_1”}    GET /help
```

```
2025-02-01T09:02:03.000Z    {service=”dummy_service”, node_id=”ex_node_2”}    GET /files/1
2025-02-01T09:02:03.000Z    {service=”dummy_service”, node_id=”ex_node_2”}    GET /files/2
2025-02-01T09:02:03.000Z    {service=”dummy_service”, node_id=”ex_node_2”}    GET /files/1
```

Logs Storage - Chunks

- Streams are stored in separate chunks
- Sorted in timestamp order
- Chunks are filled till they reach a target size or timeout
- Once full, they’re compressed and flushed to Object Store

chunk #1 {service=”dummy_service”, node_id=”ex_node_1”}

2025-02-01T09:02:03.000Z GET /about
2025-02-01T09:02:04.000Z GET /
2025-02-01T09:02:06.000Z GET /help

Logs - Query

Log Stream

Chunks

{service=”dummy_service”, node_id=”ex_node_1”}

T1-T5
T6-T8
T9-T12

{service=”dummy_service”, node_id=”ex_node_2”}

T1-T3
T4-T6
T7-T12

Logs - Query

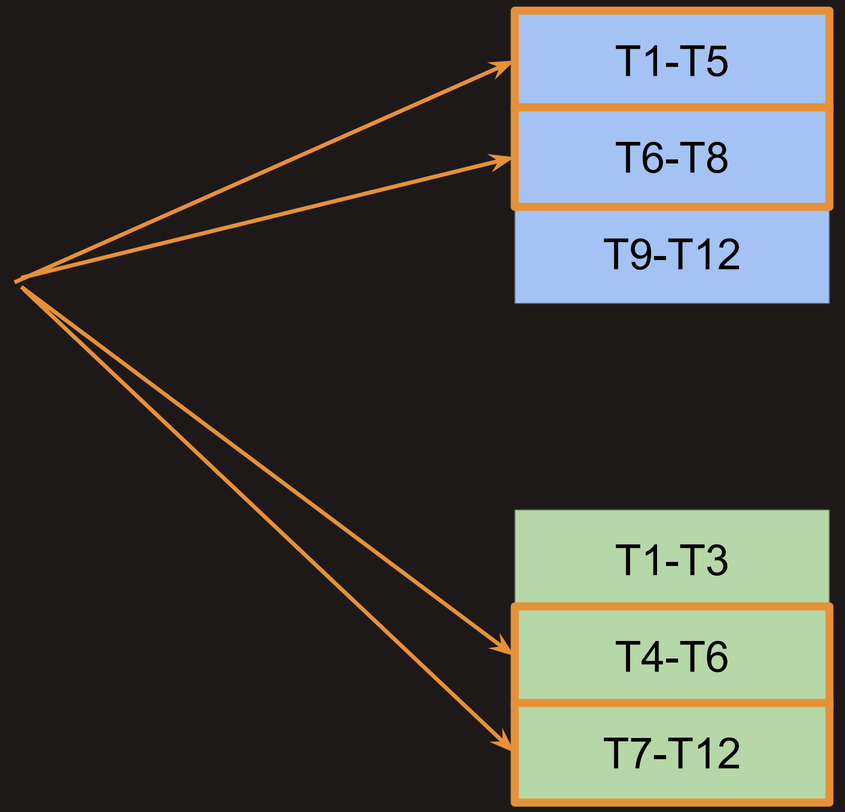
Log Stream

{service=”dummy_service”, node_id=”ex_node_1”}

Query: {service=”dummy_service”} start=T5 end=T7

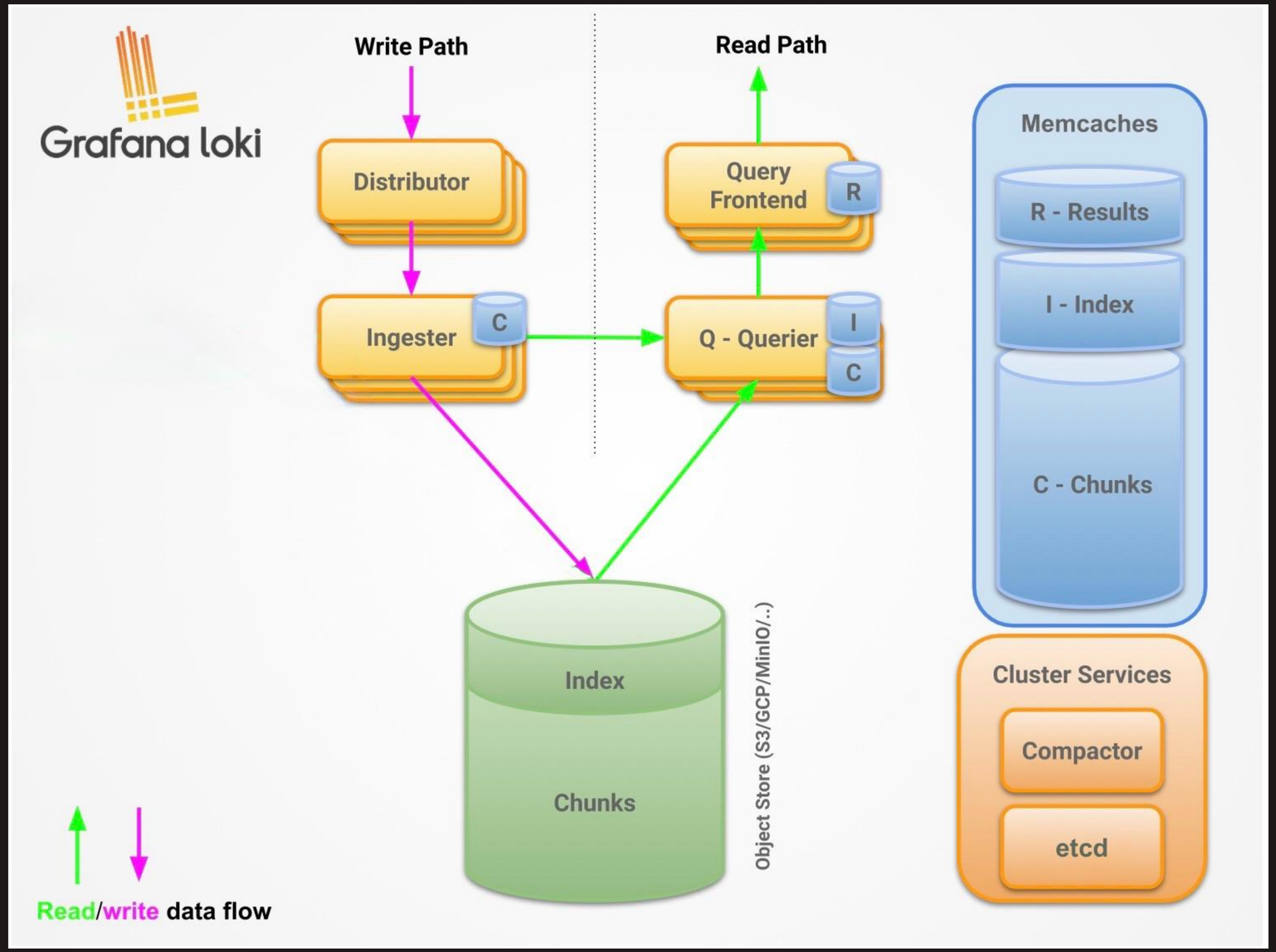
{service=”dummy_service”, node_id=”ex_node_2”}

Chunks



Dropbox-specific Loki

Loki Architecture



Loki at Dropbox: At a Glance

- ~10 GB/s logs processed
- 30 days of logs == ~10 petabytes stored in object storage
- ~1000 tenants
- <1 query per second

Multitenancy

- Loki isolates access and storage by tenant
- At Dropbox, tenant is a service (group of projects)
- One service with large log volume had to be split up by project

Auth: What?

- Before, engineers would use a production access permission for their service to SSH onto the service’s hosts to view logs
- Service == tenant aligns with previous permission model
- Some global services are accessible by everyone

Auth: Who?

- Use existing production access permission to authorize logs too
- New group permission to grant log access to a service
- Some teams have access to all logs

Auth: How?

- Custom query auth proxy that does permission lookup on user

- Grafana RBAC would’ve required a datasource per tenant/service and upgrade to enterprise

Auth: Sharing Challenges

- Team A wants to share access for their service’s logs to Team B
- Team B must request permission to the service logs for their group
- Because the permission is owned by the logging team, only we can approve
- During an incident, this delay can be costly

Auth: Breakglass

- Breakglass allows a user with a justified reason to gain temporary access to any service’s logs

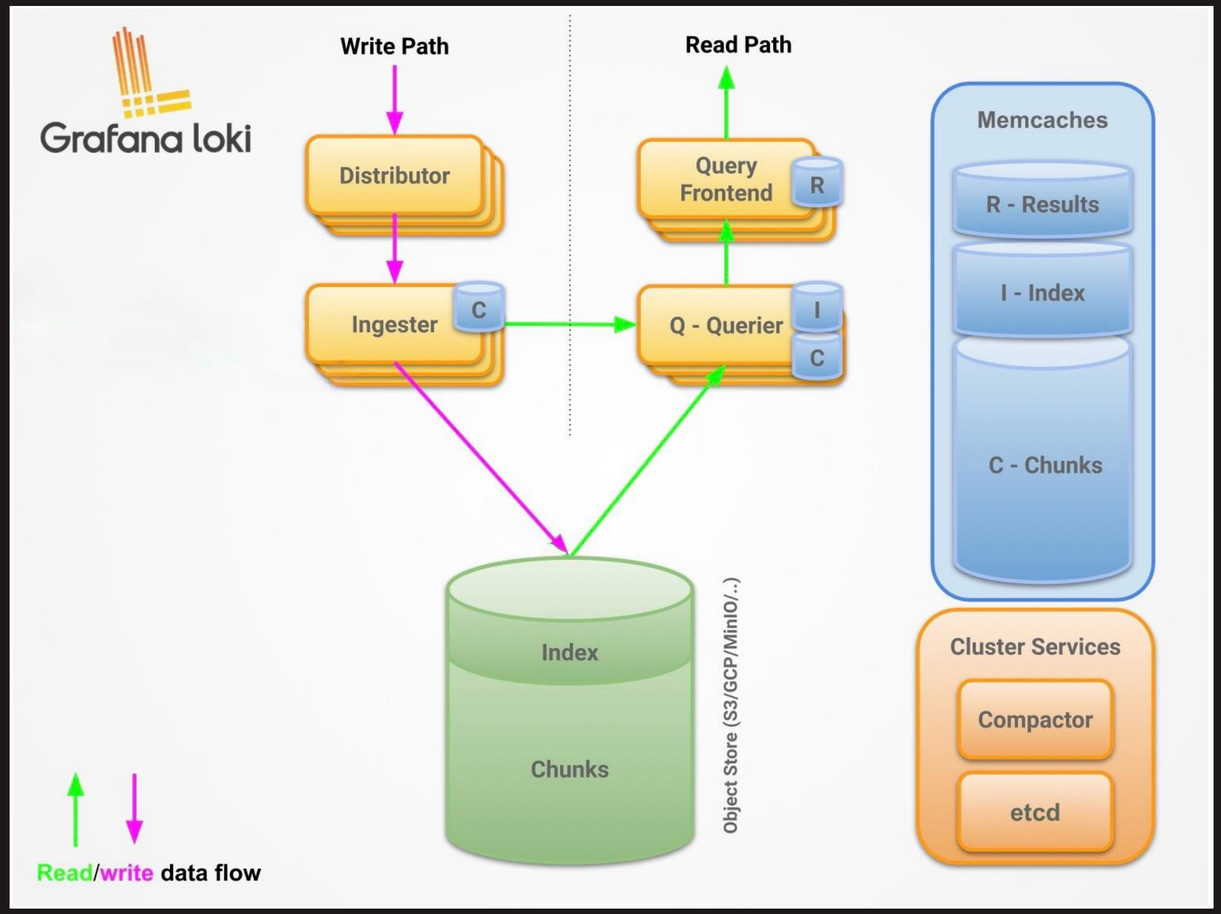
- Audit trail and safeguards in place

Multi-homing

- Run Loki in two data centers in separate geographic regions
- Same object storage is used in both regions
- Logs and queries are routed to the distributor and query frontend in the active region using a DNS server that caches Dropbox load balancer data

Multi-homing: Failover Steps

- Shift weights to the other region in load balancer global config
- After query traffic shifts to the new region, last hour of logs will be missing because they aren’t cached in new ingesters or flushed to object storage
- Restart old ingesters ASAP to flush logs to object storage
- Restart query results memcache cluster in the new region to pull in flushed logs
- Deactivate old compactor and activate compactor in new region



S3 Replacement

- Use internal object storage as drop-in replacement for S3 to save costs, especially data transfer cost
- Lower costs → Log retention increase from 1 to 4 weeks
- Performance characteristics are different
  - S3 gradually scales out reads vs. reserved capacity on-prem
  - Large index files still written to S3

Scaling Challenges

Ingester WAL

- Write Ahead Log stored on ingesters' disks
- Used to recover logs when ingester exits before flushing
- At Dropbox, disabled to prioritize availability over durability

Per-tenant Ingestion Rate Limits

- Set conservative default rate limits
- Alert notifies service owners when their service hit rate limits
- Allow tenants to override rate limits in a file
- Distribute file to Loki components using distributed KV store
- Reload Loki runtime config file with new rate limits

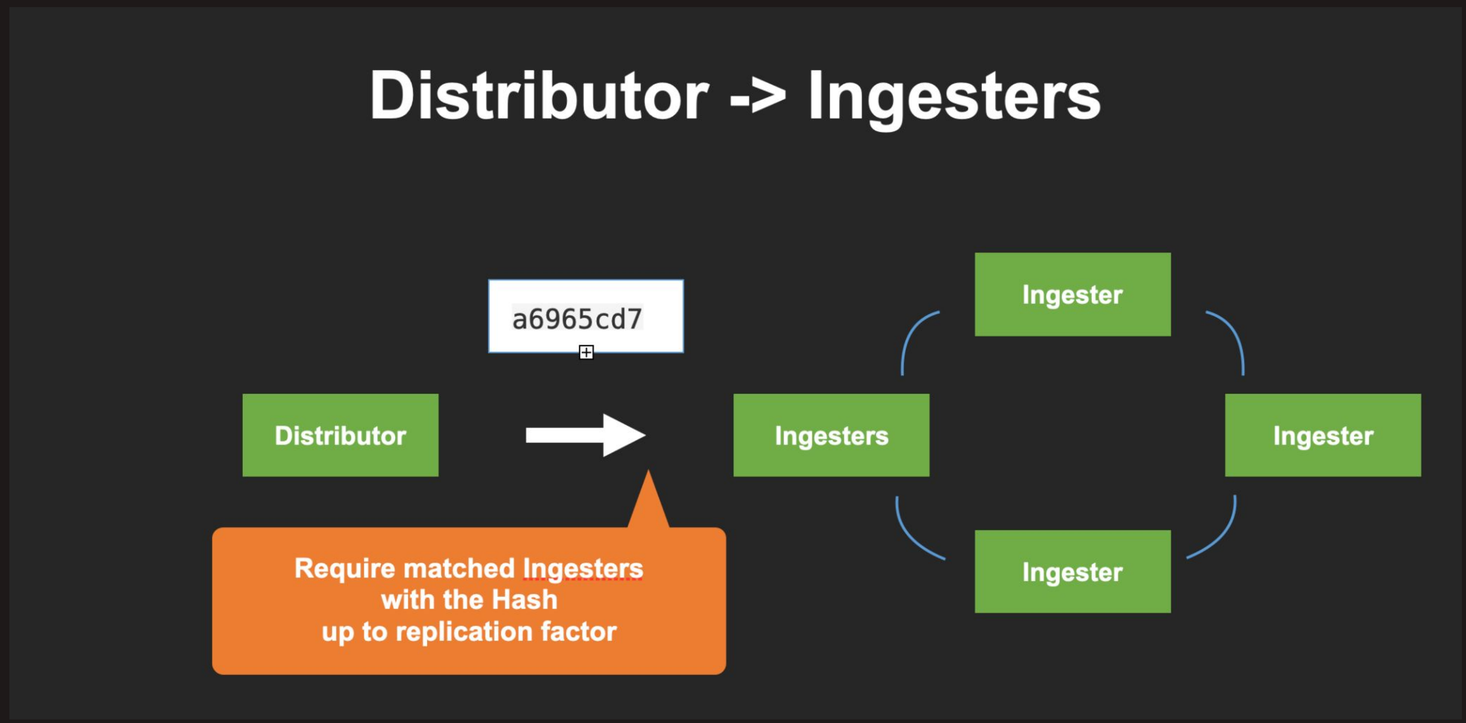
Hash Ring

- Ingesters shard log streams and own a range in the hash ring
- Ingester registers their range and health status in the ring stored in a distributed KV store
- Distributor uses ring to route log stream to ingester + replicate to other ingesters

Ingester Hash Ring Example

2025-02-01T09:02:03.000Z {service=”dummy_service”, node_id=”ex_node_1”} GET /about

a6965cd7



Hash Ring: etcd

- We original used etcd as backing KV store for Loki hash ring
- etcd: distributed, consistent KV store
- Often used for coordination and configuration, default for k8s
- Now widely used at Dropbox

Hash Ring: etcd Write Contention

- Each ingester sends a heartbeat every minute and updates the ring
- When an ingester joins/leaves the ring, it updates the ring
- etcd has a single key for the whole ring stored as a binary blob
- Each ring update is read + CAS (compare-and-swap) to replace the ring
- RF=3 and 67 ingesters for each replication factor is 201 total ingesters

Hash Ring: etcd Issues

- Deployments take hours, ingesters are pushed one at a time
- Availability alert would often trigger and fail the ingester pushes
- Single point of failure: etcd going down caused outages

Hash Ring: Migrate from etcd to memberlist

memberlist

- Now default in Loki and other Grafana projects
- Peer-to-peer gossip protocol
- Each update is only the delta, not the entire ring
- Eventually consistent

Hash Ring: memberlist Pros

- No write contention
- No single point of failure
- No issues in the last year using memberlist
- Able to scale out ingesters by 2x afterwards

Index: BoltDB → TSDB

- Log indexes determine query plan: how many log chunks to fetch
- Index format changed from BoltDB to TSDB
- TSDB based on Prometheus TSDB, ideal for labels
- Much better query performance after migration

Thank You

Alok Linkedin

Paul Linkedin