## Our System in a Nutshell

Distributed (p2p) file system for recipes, written in Golang.

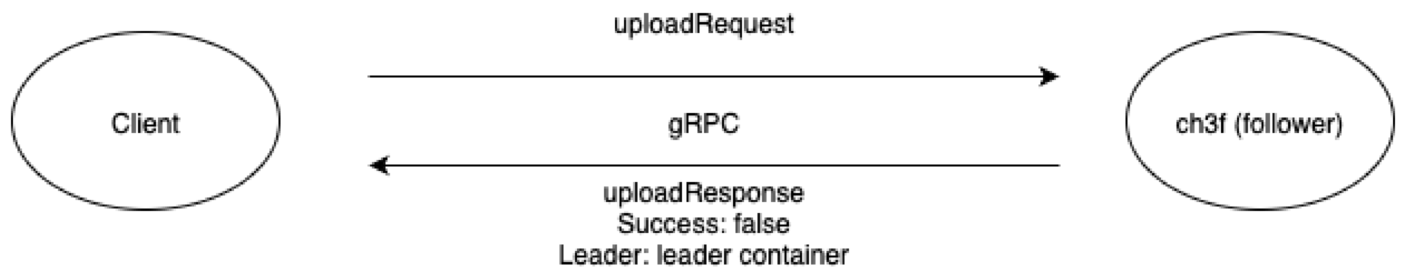
Clients can upload or download recipes.

Using leader election, all uploads are managed by the leader.

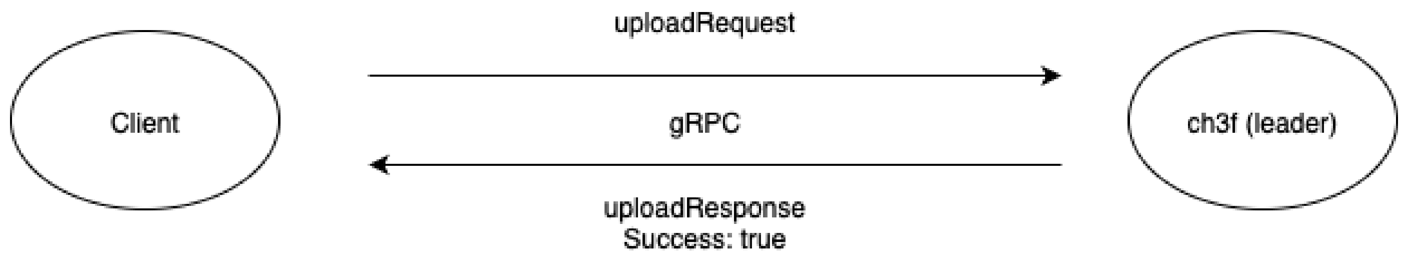
Downloading is possible on all nodes, including followers.

# Uploading a Recipe

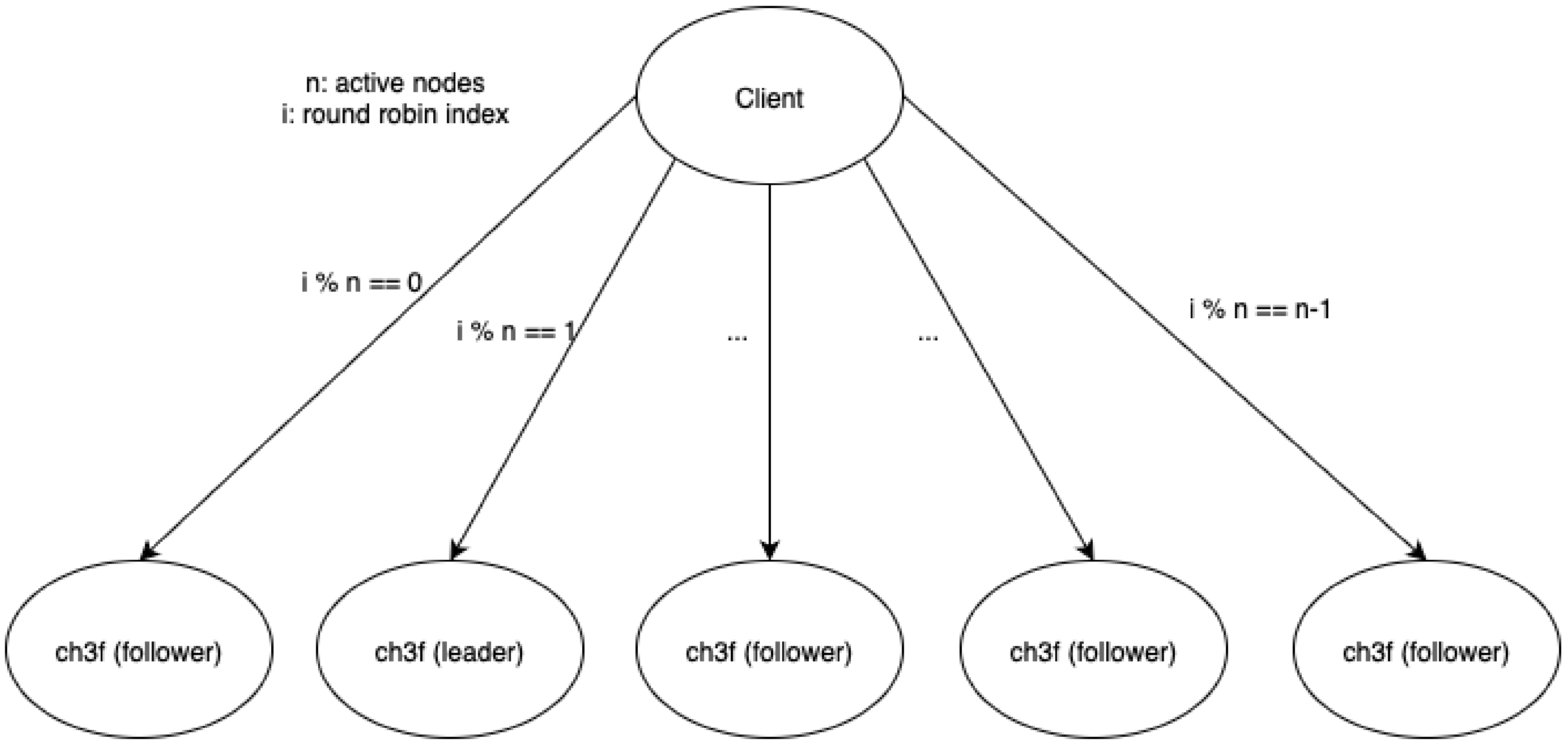
Request a random node (round robin), not the leader in this case:



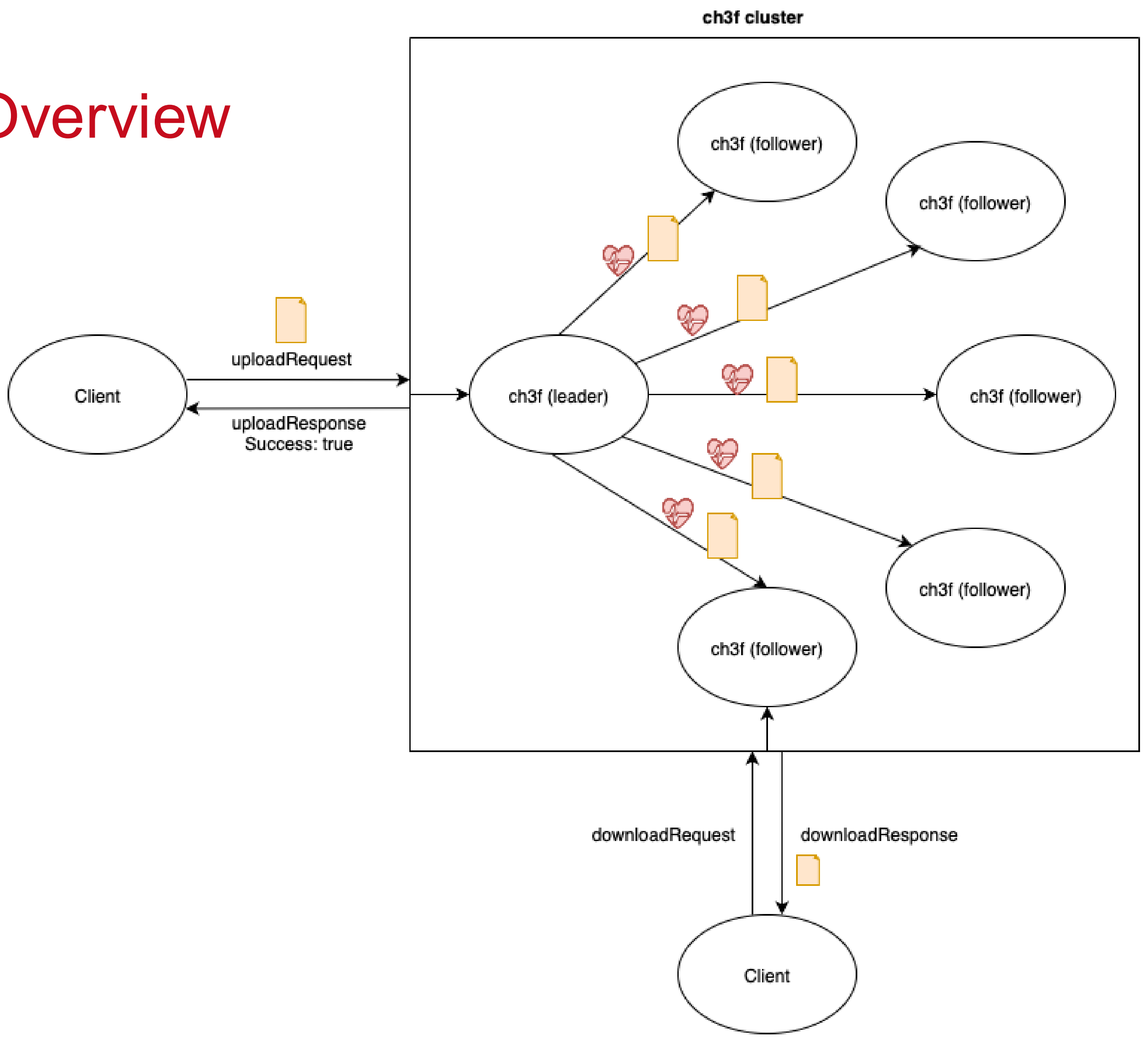
Retry to the leader:



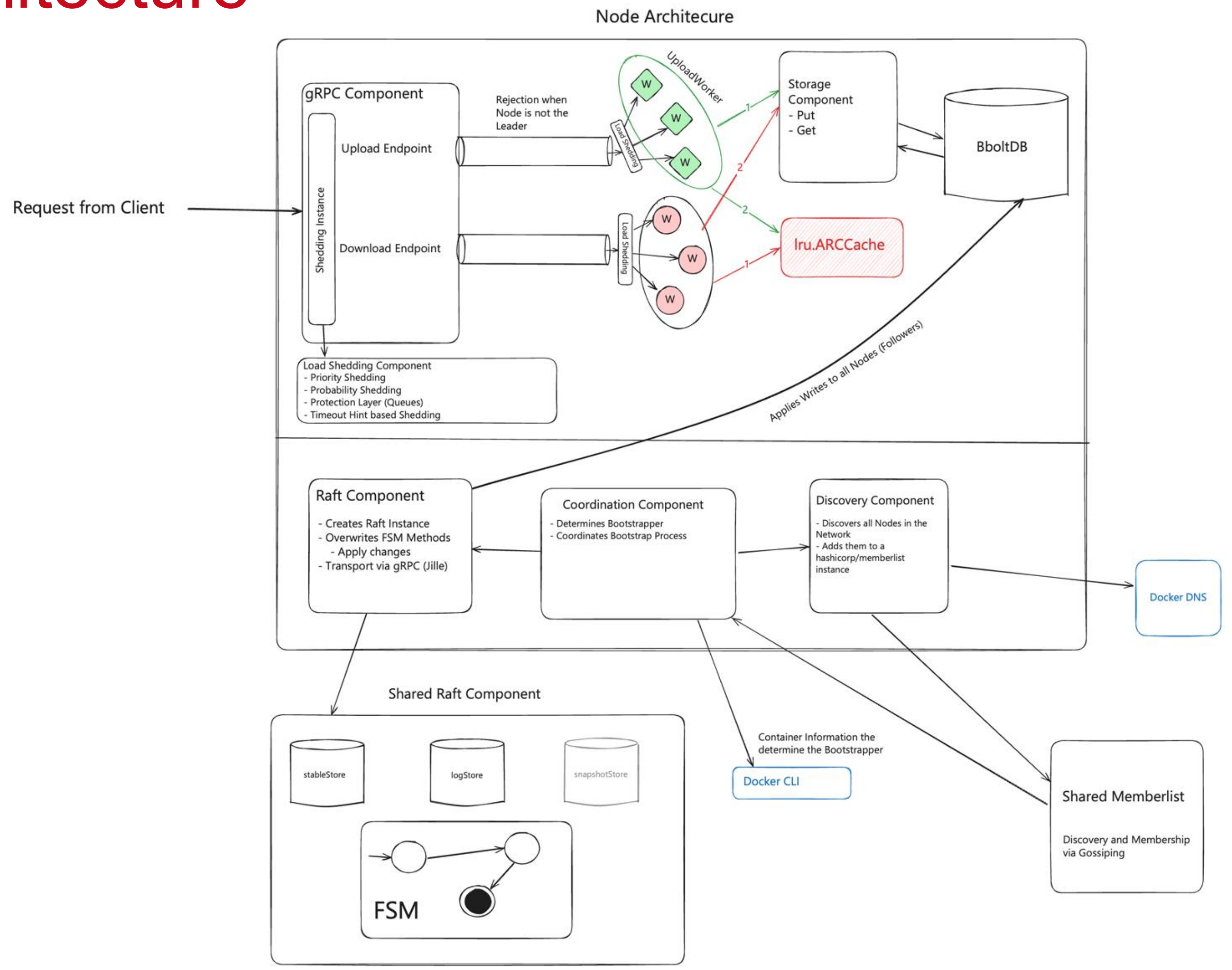
# Downloading a Recipe – Round Robin Algorithm



## Cluster Overview



# Node Architecture



## Requirements: Overview

1. The shared state consists of **persistently stored recipes**, raft logs and a member list.
2. Scaling out is possible, since the number of nodes can be specified in the .env file.
3. We combined several **load shedding** strategies and retries with backoff.
4. Two other strategies implemented from the Amazon Builder’s Library or lecture are **leader election** and **caching**.

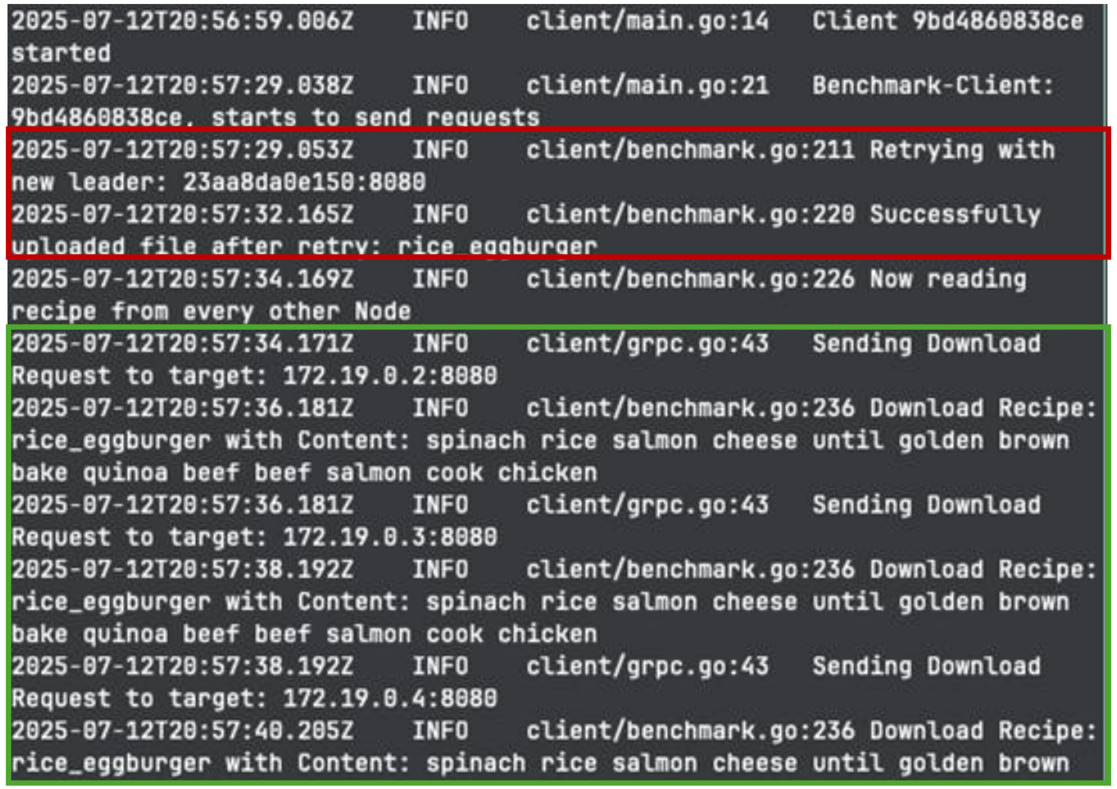
## The Workflow of the Simulation

1. Nodes of our “`ch3f`” service are discovered via Docker DNS (`cluster/discovery.go`, `cluster/coordinator.go`)
2. A leader is elected using Hashicorp’s Raft library `(cluster/raft.go)`
3. Clients initially upload 10 recipes each by calling the gRPC endpoints of the nodes `(client/benchmark.go, client/grpc.go)`
4. Subsequent requests are ~ 99.5% downloads and, ~0.5% uploads. Correlated request spikes around ~15s, 25s, 45s and 50s cause sharp RPS increases.

## Shared State, Horizontal Scalability

Single Client and 3 Nodes:

1. Client uploads to a random node
2. Not successful – Retry on Leader
3. Downloading from the 3 nodes

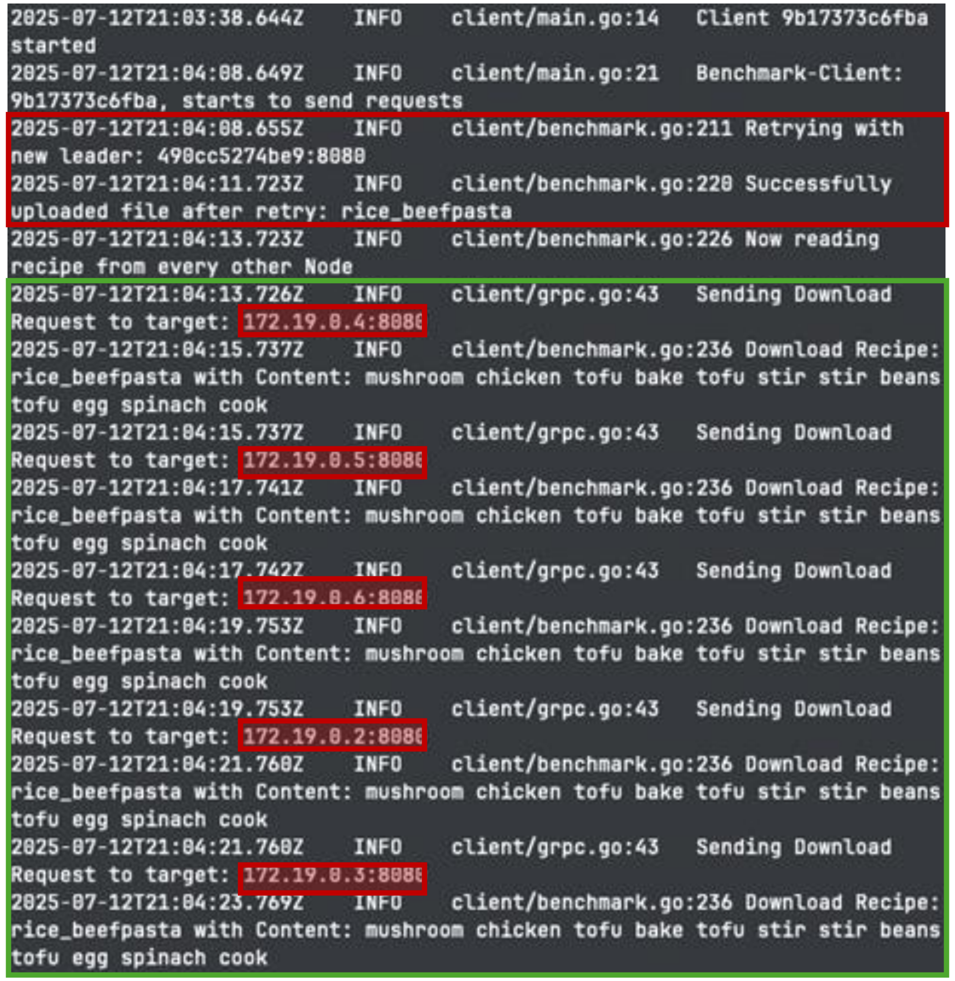


```
2025-07-12T20:56:59.006Z    INFO    client/main.go:14   Client 9bd4860838ce
started
2025-07-12T20:57:29.038Z    INFO    client/main.go:21   Benchmark-Client:
9bd4860838ce, starts to send requests
2025-07-12T20:57:29.053Z    INFO    client/benchmark.go:211 Retrying with
new leader: 23aa8da0e150:8080
2025-07-12T20:57:32.165Z    INFO    client/benchmark.go:220 Successfully
uploaded file after retry: rice_eggburger
2025-07-12T20:57:34.169Z    INFO    client/benchmark.go:226 Now reading
recipe from every other Node
2025-07-12T20:57:34.171Z    INFO    client/grpc.go:43   Sending Download
Request to target: 172.19.0.2:8080
2025-07-12T20:57:36.181Z    INFO    client/benchmark.go:236 Download Recipe:
rice_eggburger with Content: spinach rice salmon cheese until golden brown
bake quinoa beef beef salmon cook chicken
2025-07-12T20:57:36.181Z    INFO    client/grpc.go:43   Sending Download
Request to target: 172.19.0.3:8080
2025-07-12T20:57:38.192Z    INFO    client/benchmark.go:236 Download Recipe:
rice_eggburger with Content: spinach rice salmon cheese until golden brown
bake quinoa beef beef salmon cook chicken
2025-07-12T20:57:38.192Z    INFO    client/grpc.go:43   Sending Download
Request to target: 172.19.0.4:8080
2025-07-12T20:57:40.205Z    INFO    client/benchmark.go:236 Download Recipe:
rice_eggburger with Content: spinach rice salmon cheese until golden brown
```

## Shared State, Horizontal Scalability

Single Client and 5 Nodes:

All 5 Nodes return the same recipe



```
2025-07-12T21:03:38.644Z    INFO    client/main.go:14    Client 9b17373c6fba
started
2025-07-12T21:04:08.649Z    INFO    client/main.go:21    Benchmark-Client:
9b17373c6fba, starts to send requests
2025-07-12T21:04:08.655Z    INFO    client/benchmark.go:211 Retrying with
new leader: 490cc5274be9:8080
2025-07-12T21:04:11.723Z    INFO    client/benchmark.go:220 Successfully
uploaded file after retry: rice_beefpasta
2025-07-12T21:04:13.723Z    INFO    client/benchmark.go:226 Now reading
recipe from every other Node
2025-07-12T21:04:13.726Z    INFO    client/grpc.go:43    Sending Download
Request to target: 172.19.0.4:808
2025-07-12T21:04:15.737Z    INFO    client/benchmark.go:236 Download Recipe:
rice_beefpasta with Content: mushroom chicken tofu bake tofu stir stir beans
tofu egg spinach cook
2025-07-12T21:04:15.737Z    INFO    client/grpc.go:43    Sending Download
Request to target: 172.19.0.5:808
2025-07-12T21:04:17.741Z    INFO    client/benchmark.go:236 Download Recipe:
rice_beefpasta with Content: mushroom chicken tofu bake tofu stir stir beans
tofu egg spinach cook
2025-07-12T21:04:17.742Z    INFO    client/grpc.go:43    Sending Download
Request to target: 172.19.0.6:808
2025-07-12T21:04:19.753Z    INFO    client/benchmark.go:236 Download Recipe:
rice_beefpasta with Content: mushroom chicken tofu bake tofu stir stir beans
tofu egg spinach cook
2025-07-12T21:04:19.753Z    INFO    client/grpc.go:43    Sending Download
Request to target: 172.19.0.2:808
2025-07-12T21:04:21.760Z    INFO    client/benchmark.go:236 Download Recipe:
rice_beefpasta with Content: mushroom chicken tofu bake tofu stir stir beans
tofu egg spinach cook
2025-07-12T21:04:21.760Z    INFO    client/grpc.go:43    Sending Download
Request to target: 172.19.0.3:808
2025-07-12T21:04:23.769Z    INFO    client/benchmark.go:236 Download Recipe:
rice_beefpasta with Content: mushroom chicken tofu bake tofu stir stir beans
tofu egg spinach cook
```

## Mitigation Strategies: Jitter and Queuing

All requests, that a node receives, are stored in two separate queues: one for uploads (pkg/upload/) and one for downloads (pkg/download/).

To avoid running out of memory, we shed requests, if the virtual memory usage exceeds 90%

Queues help to deal with high low spikes, allowing to serve requests asynchronously.

Nodes retry to join the memberlist, until successful, using a random exponential backoff for better distribution (pkg/cluster/raft/discovery.go)

## Mitigation Strategies: Load Shedding

The load shedding is based on the cpu usage of the container and the fact that we **prioritize downloads over uploads**. (pkg/cluster/loadshed):

1. Priority Load shedding: shed only **uploads** if the cpu usage is >90%

2. Probabilistic Load shedding: shed only a percent of requests (see next slide)

3. Timeout shedding: shed all requests, if the timeout is expected to exceed before finished

## Probabilistic Load Shedding - Policies

Downloads: Uploads:

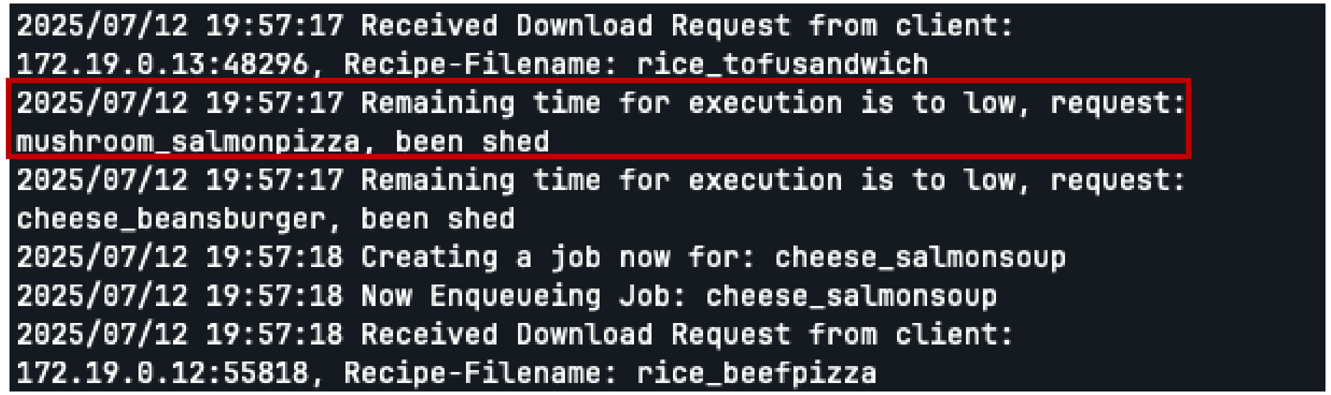
| CPU Usage in % | Shedded requests | CPU Usage in % | Shedded requests |
|---|---|---|---|
| [95, 100] | 25% | [80, 100] | 25% |
| [90, 95) | 10% | [75, 80) | 10% |
| [85, 90) | 5% | (70, 75) | 5% |
| [0, 85) | 0% | [0, 70] | 0% |

## Mitigation Strategies: Load Shedding

It was hard to show load shedding – the machine must be under heavy pressure.

The other strategies are found in: `pkg/cluster/loadshed`

This case: Load Shedding based on Timeout Hints



```
2025/07/12 19:57:17 Received Download Request from client:
172.19.0.13:48296, Recipe-Filename: rice_tofusandwich
2025/07/12 19:57:17 Remaining time for execution is to low, request:
mushroom_salmonpizza, been shed
2025/07/12 19:57:17 Remaining time for execution is to low, request:
cheese_beansburger, been shed
2025/07/12 19:57:18 Creating a job now for: cheese_salmonsoup
2025/07/12 19:57:18 Now Enqueueing Job: cheese_salmonsoup
2025/07/12 19:57:18 Received Download Request from client:
172.19.0.12:55818, Recipe-Filename: rice_beefpizza
```

## Further Strategies: Leader Election

1. builds a cluster of nodes: nodes can be followers, candidates or the leader.
2. no conflicting concurrent writes: leader serializes all writes to a log.
3. replication: broadcasts log entries to all available follower nodes.
4. keeps data consistent: if a node fails, all missing log entries will be sent to it, to catch up.
5. In our implementation, initially, the first node that starts is designated to perform the bootstrap process and start the cluster as the leader.

## Further Strategies: Leader Election

If the leader fails – detected by its peers due to missing heartbeats – a new election starts:

1. Nodes that have not received a heartbeat put themselves into candidate state.
2. To prevent that every node puts itself into candidate state and votes itself simultaneously, each node has a randomized but bounded heartbeat timeout.
3. Remaining followers will vote for a candidate whose log is at least as up-to-date as their own, ensuring that the leader has all necessary log entries.
4. The candidate that receives a majority of votes becomes the new leader.

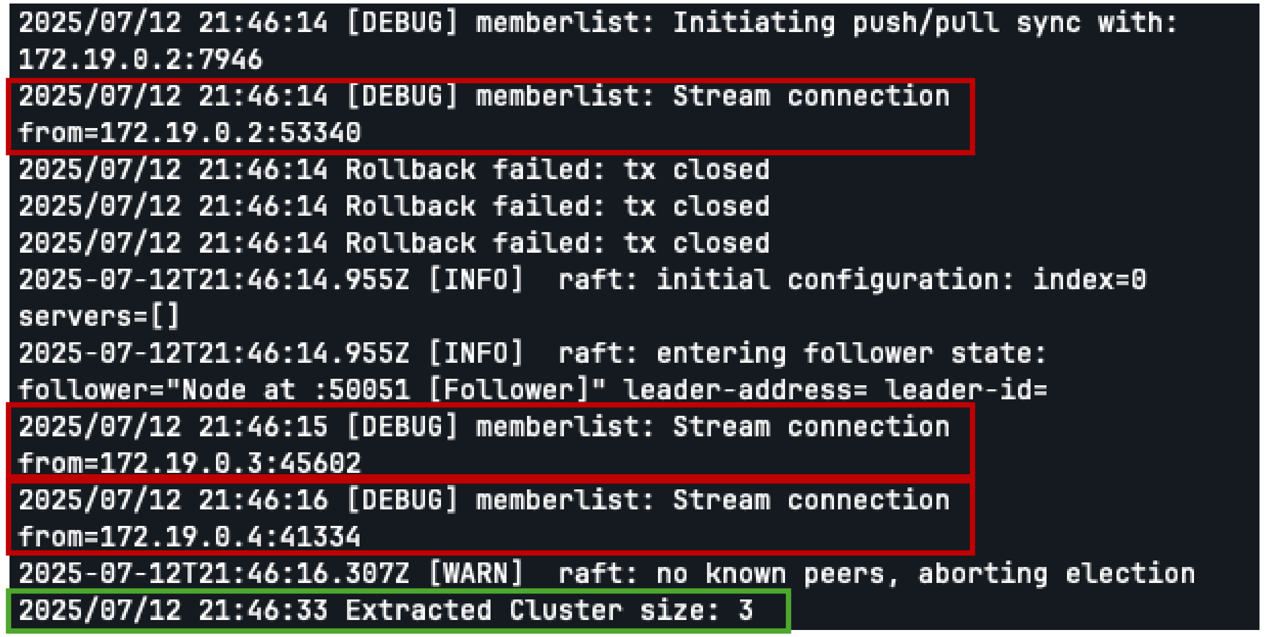
## Further Strategies: Leader Election – Discovery

Node discovers both other nodes

`pkg/cluster/raft/discovery.go`

Retry till cluster has ist expected size

(Defined in .env)



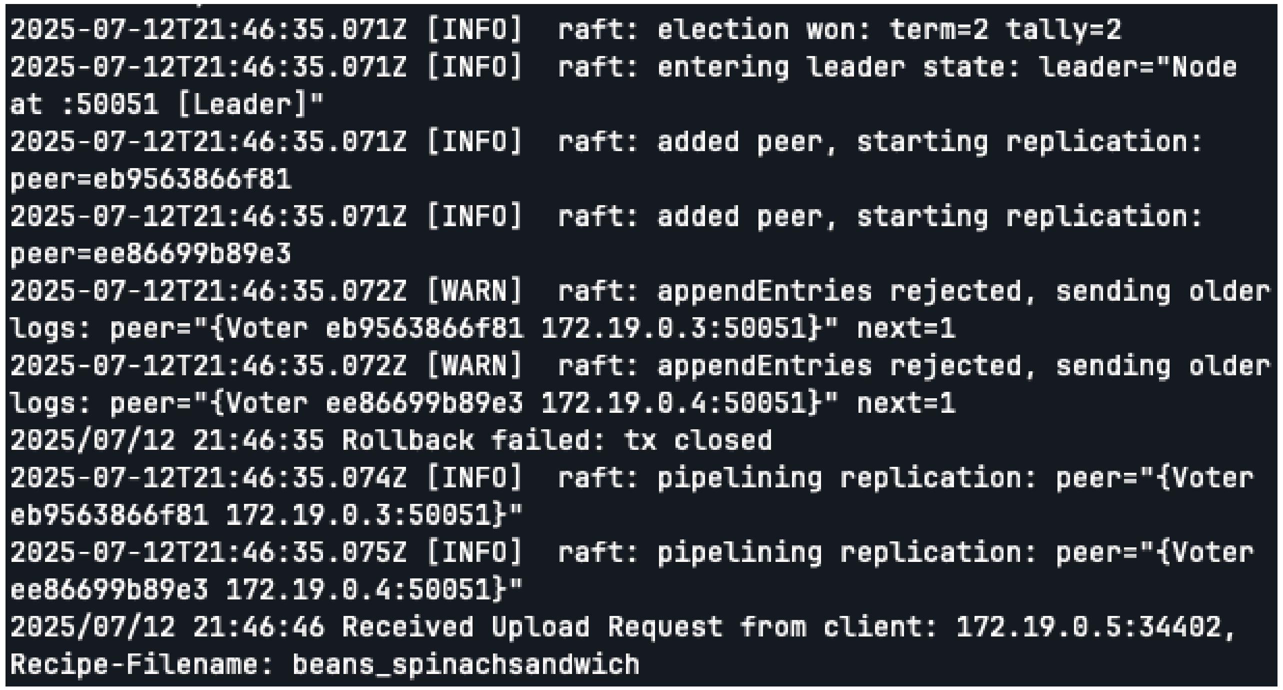
```
2025/07/12 21:46:14 [DEBUG] memberlist: Initiating push/pull sync with:
172.19.0.2:7946
2025/07/12 21:46:14 [DEBUG] memberlist: Stream connection
from=172.19.0.2:53340
2025/07/12 21:46:14 Rollback failed: tx closed
2025/07/12 21:46:14 Rollback failed: tx closed
2025/07/12 21:46:14 Rollback failed: tx closed
2025-07-12T21:46:14.955Z [INFO]  raft: initial configuration: index=0
servers=[]
2025-07-12T21:46:14.955Z [INFO]  raft: entering follower state:
follower="Node at :50051 [Follower]" leader-address= leader-id=
2025/07/12 21:46:15 [DEBUG] memberlist: Stream connection
from=172.19.0.3:45602
2025/07/12 21:46:16 [DEBUG] memberlist: Stream connection
from=172.19.0.4:41334
2025-07-12T21:46:16.307Z [WARN]  raft: no known peers, aborting election
2025/07/12 21:46:33 Extracted Cluster size: 3
```

## Further Strategies: Leader Election - Consensus

This node won the election, with 2 votes

Starts with log replication

Can serve uploads after election



```
2025-07-12T21:46:35.071Z [INFO]  raft: election won: term=2 tally=2
2025-07-12T21:46:35.071Z [INFO]  raft: entering leader state: leader="Node
at :50051 [Leader]"
2025-07-12T21:46:35.071Z [INFO]  raft: added peer, starting replication:
peer=eb9563866f81
2025-07-12T21:46:35.071Z [INFO]  raft: added peer, starting replication:
peer=ee86699b89e3
2025-07-12T21:46:35.072Z [WARN]  raft: appendEntries rejected, sending older
logs: peer="{Voter eb9563866f81 172.19.0.3:50051}" next=1
2025-07-12T21:46:35.072Z [WARN]  raft: appendEntries rejected, sending older
logs: peer="{Voter ee86699b89e3 172.19.0.4:50051}" next=1
2025/07/12 21:46:35 Rollback failed: tx closed
2025-07-12T21:46:35.074Z [INFO]  raft: pipelining replication: peer="{Voter
eb9563866f81 172.19.0.3:50051}"
2025-07-12T21:46:35.075Z [INFO]  raft: pipelining replication: peer="{Voter
ee86699b89e3 172.19.0.4:50051}"
2025/07/12 21:46:46 Received Upload Request from client: 172.19.0.5:34402,
Recipe-Filename: beans_spinachsandwich
```

## Further strategies: Caching

To increase performance, each node maintains a ARC (Adaptive Replacement Cache) – a fixed-sized key-value store

On each download request, the cache is checked first

Each recipe is added to the cache when it is uploaded or downloaded

If the cache is full, it replaces the least frequently used recipe.

## Dependencies

**BboltDB:** *(go.etcd.io/bbolt)*

**Member list:** *(github.com/hashicorp/memberlist)*

**Raft:** *(github.com/hashicorp/raft)*

**CPU, disk and memory metrics:** *(github.com/shirou/gopsutil/v3/)*

**ARC Cache:** *(github.com/hashicorp/golang-lru)*

**Logging:** *(go.uber.org/zap)*

**Env-Utils (Linus Gustafsson):** *(github.com/linusgith/goutils/pkg/env_utils)*

**Raft Transport Management:** *(github.com/Jille/raft-grpc-transport)*