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# PostgreSQL on K8S at Zalando: Two years in production

FOSDEM 2020

PostgreSQL devroom

Brussels

**ALEXANDER KUKUSHKIN**

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# ABOUT ME

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## WE BRING FASHION TO PEOPLE IN 17 COUNTRIES

**17** markets

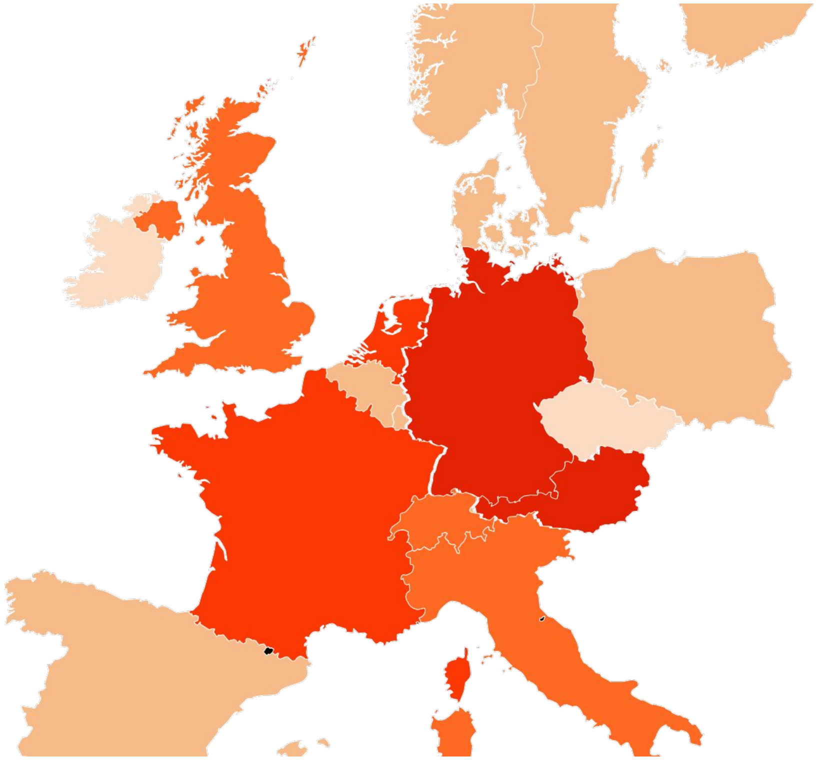
**7** fulfillment centers

**26.4 million** active customers

**5.4 billion €** net sales 2018

**250 million** visits per month

**15,000** employees in Europe



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## AGENDA

Brief introduction to Kubernetes

Spilo & Patroni

Postgres-Operator

Typical problems and horror stories

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## Kubernetes at Zalando

- > 140 Kubernetes clusters
  - 50/50 production/test
- Deployment to production only via **CI/CD**
- Access to production clusters is possible, but restricted
  - Requires the open incident ticket or approval by a colleague (4 eyes principle)

# PostgreSQL on K8s at Zalando

> 1400

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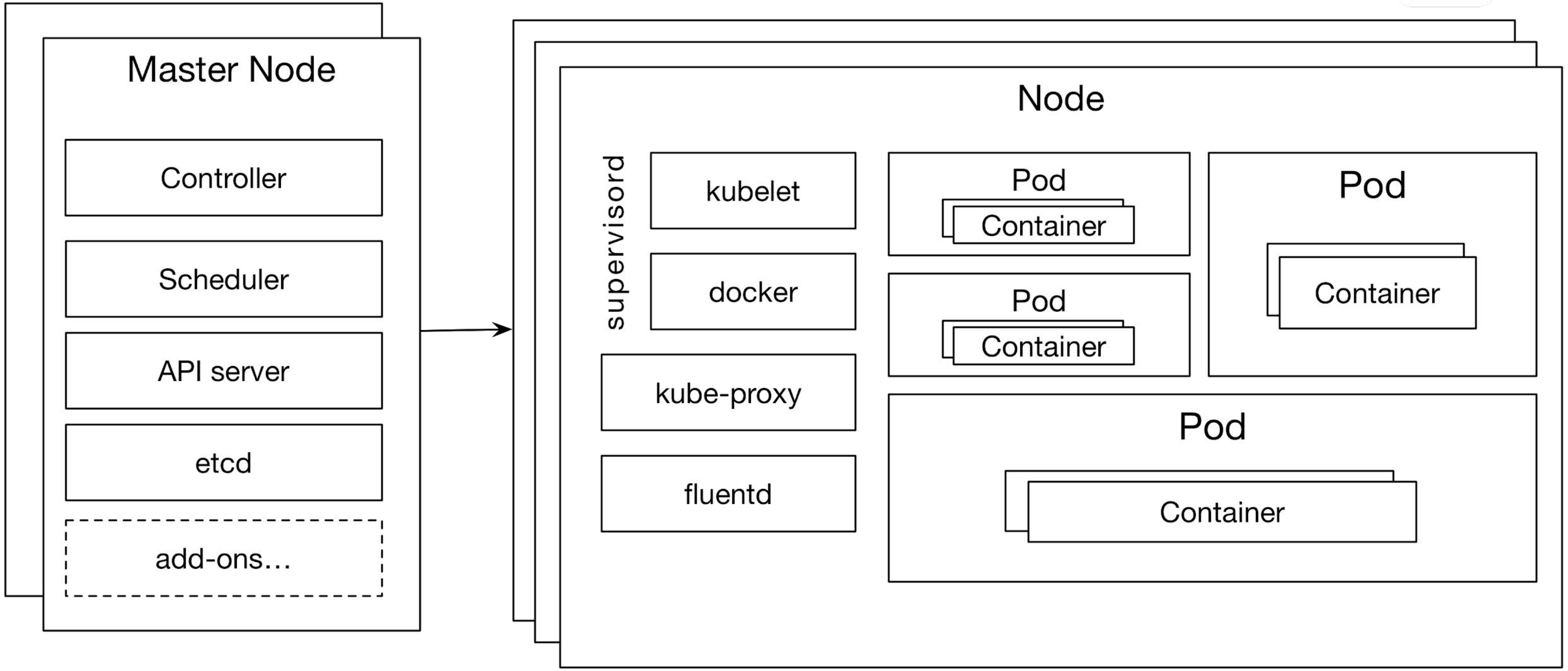
## Terminology

| Traditional infrastructure | Kubernetes |
|---|---|
| Physical server | Node |
| Virtual machine | Pod |
| Individual application | Container (typically Docker) |
| NAS/SAN | Persistent Volumes |
| Load balancer | Service/Endpoint |
| Application registry/hardware information | Labels |
| Password files, certificates | Secrets |

# Kubernetes overview



## Stateful applications on Kubernetes

- **PersistentVolumes**
  - Abstracts details how storage is provisioned
  - Supports many different storage types via plugins:
    - EBS, AzureDisk, iSCSI, NFS, CEPH, Glusterfs and so on
- **StatefulSets**
  - Guarantied number of Pods with stable (and unique) identifiers
  - Ordered deployment and scaling
  - Connecting Pods with corresponding persistent storage (**PersistentVolume+PersistentVolumeClaim**)

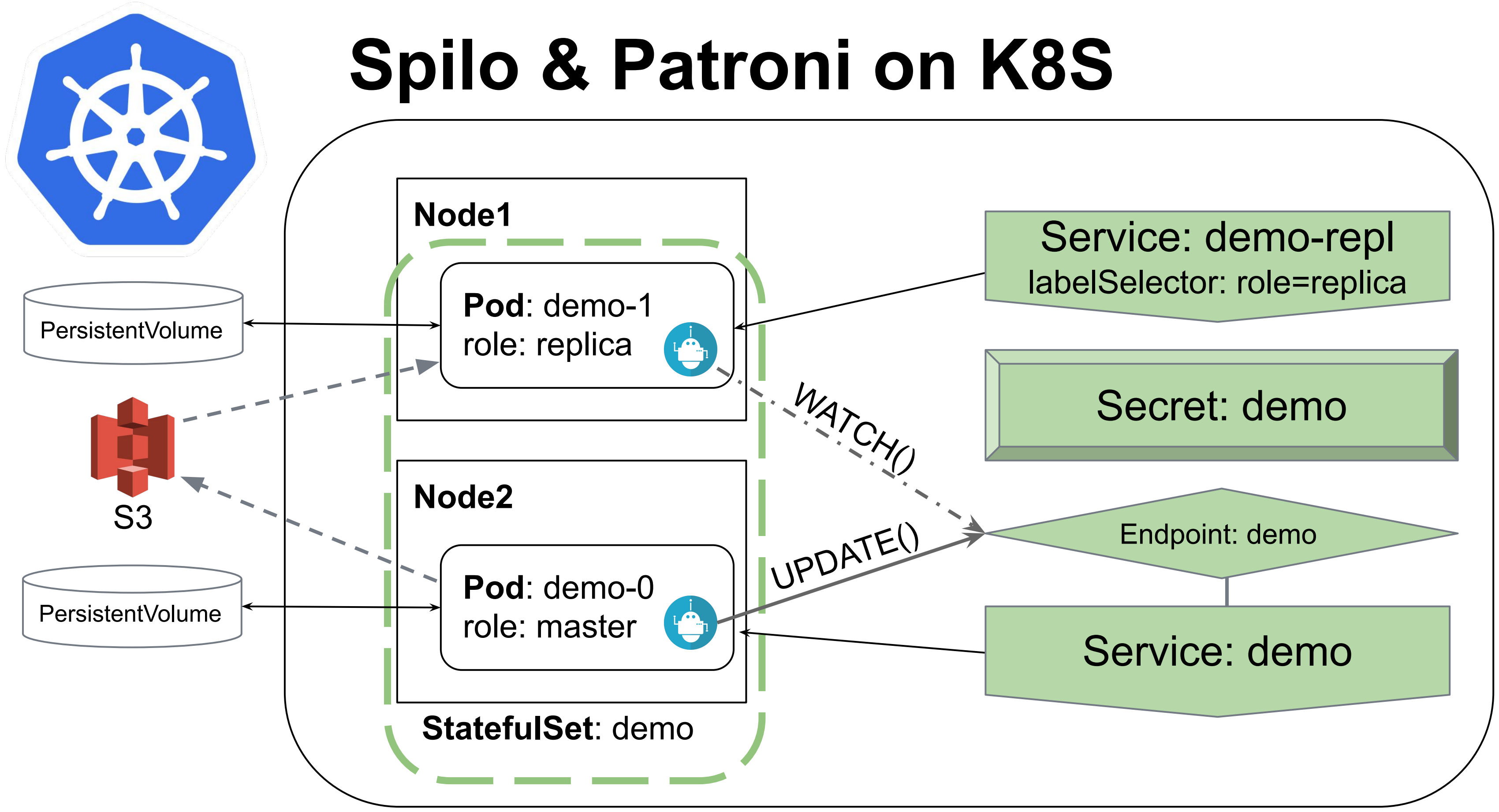
## Spilo Docker image

- All supported versions of PostgreSQL inside the single image
- Plenty of extensions (pg_partman, pg_cron, postgis, timescaledb, etc)
- Additional tools (pgq, pgbouncer, wal-e/wal-g)
- PGDATA on an external volume
- Patroni for HA
- Environment-variables based configuration

# What is Patroni

- Automatic failover solution for PostgreSQL
- A python daemon that manages one PostgreSQL instance
- Uses Kubernetes objects (Endpoint or ConfigMap) for leader elections
  - Makes PostgreSQL 1st class citizen on Kubernetes!
- Helps to automate a lot of things like:
  - A new cluster deployment
  - Scaling out and in
  - PostgreSQL configuration management

# Spilo & Patroni on K8S



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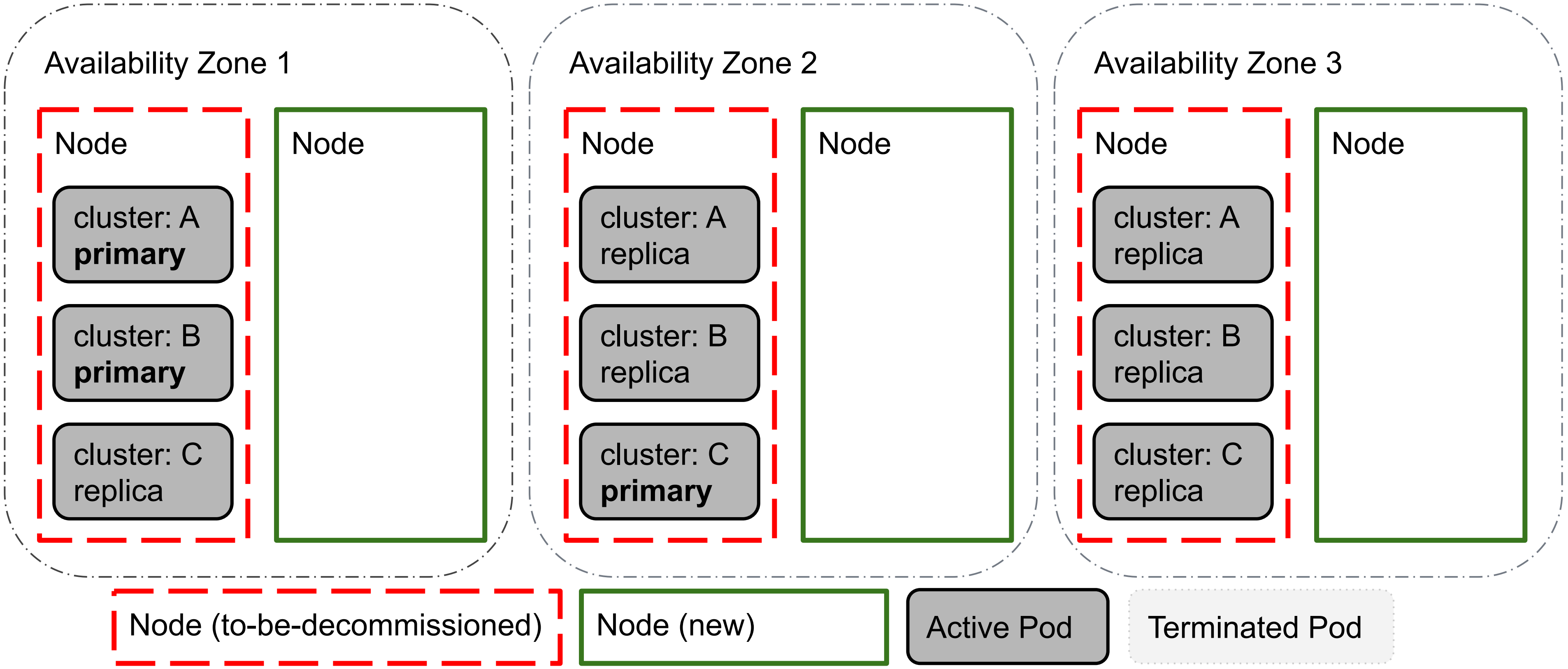
## Manual deployment to Kubernetes

- A few long YAML manifests to write
- Different parts of PostgreSQL configuration spread over multiple manifests
- No easy way to work with a cluster as a whole (update, delete)
- Manual generation of DB objects, i.e. users, and their passwords.

## Kubernetes rolling upgrade

- Rotates all worker nodes in the K8s cluster
- Does it in a rolling matter, one-by-one
- If you are unlucky, it will cause the number of failover equal number of pods in your postgres cluster

# Kubernetes rolling upgrade



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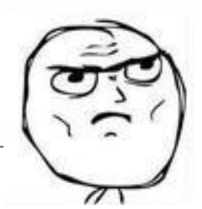
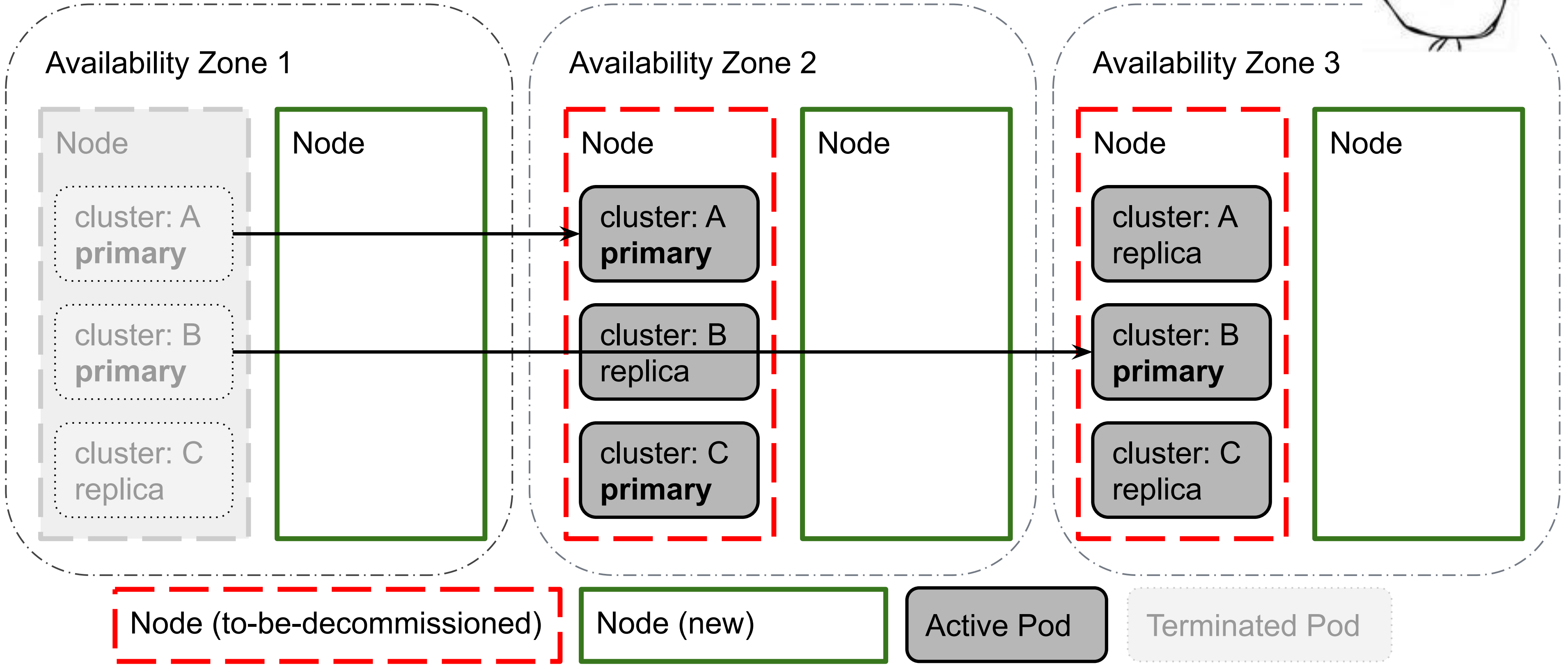
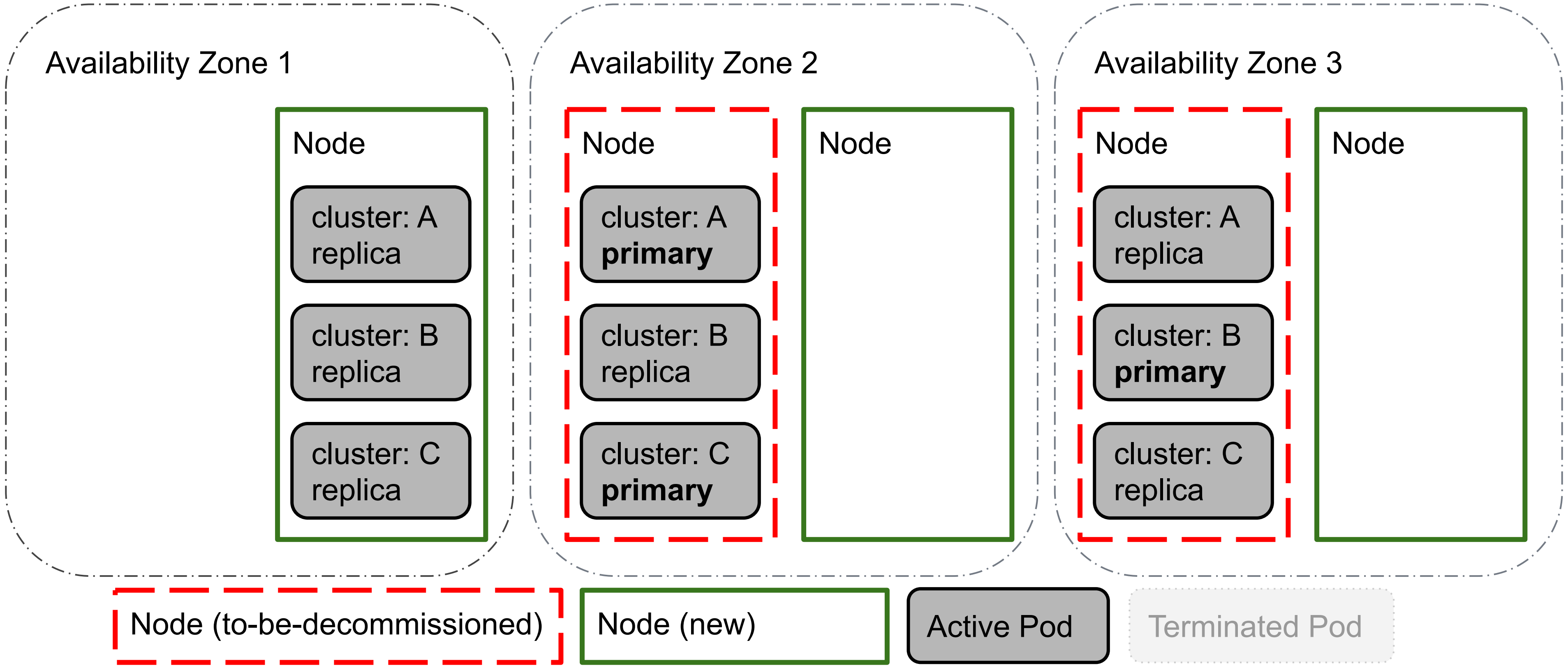
# Kubernetes rolling upgrade





# Kubernetes rolling upgrade



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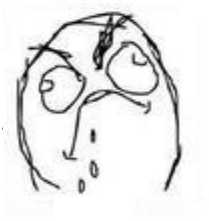
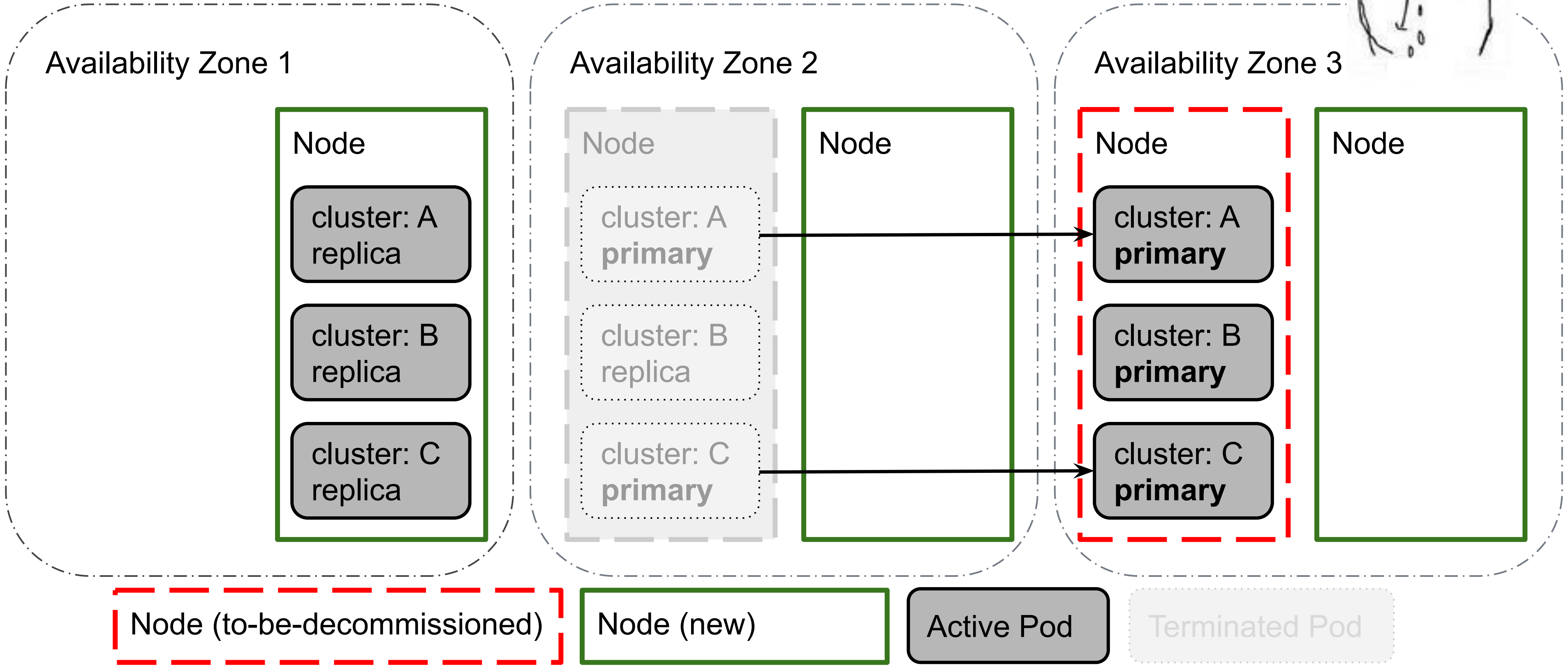
# Kubernetes rolling upgrade





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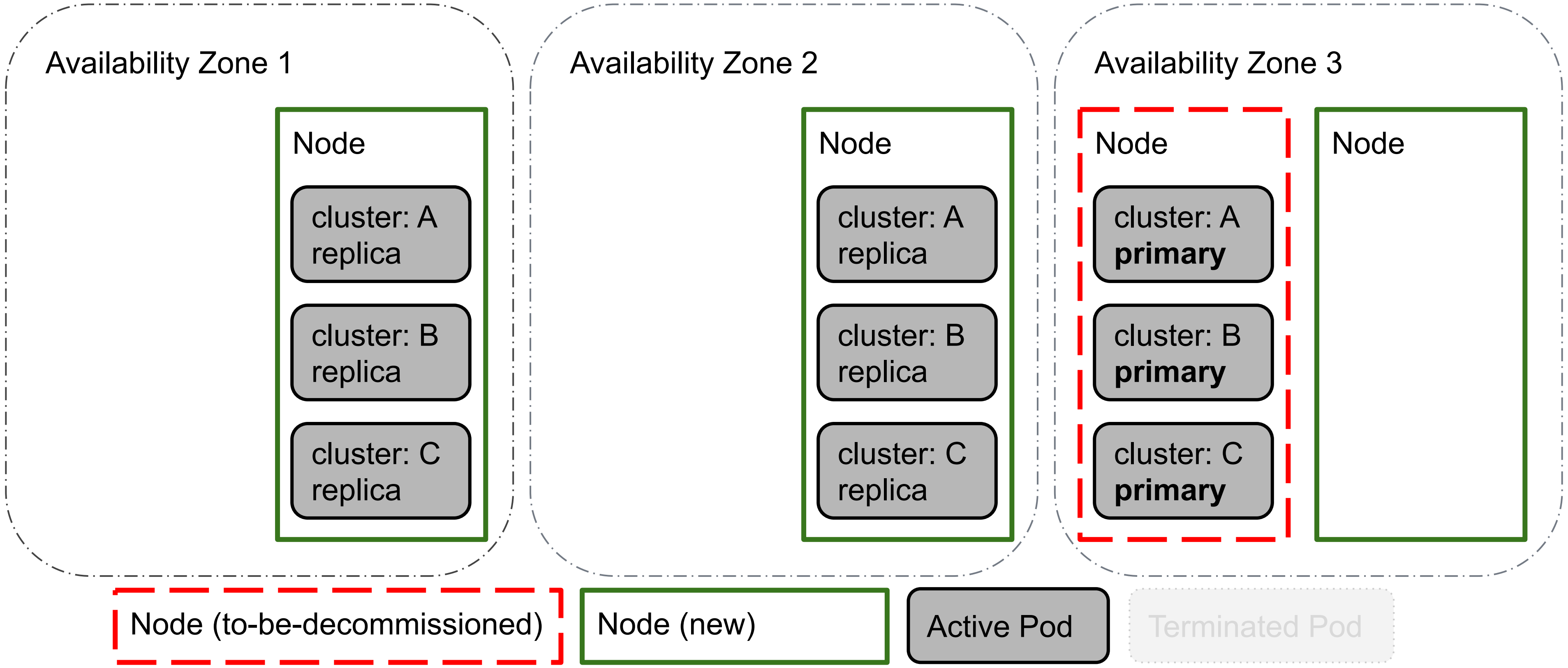
# Kubernetes rolling upgrade



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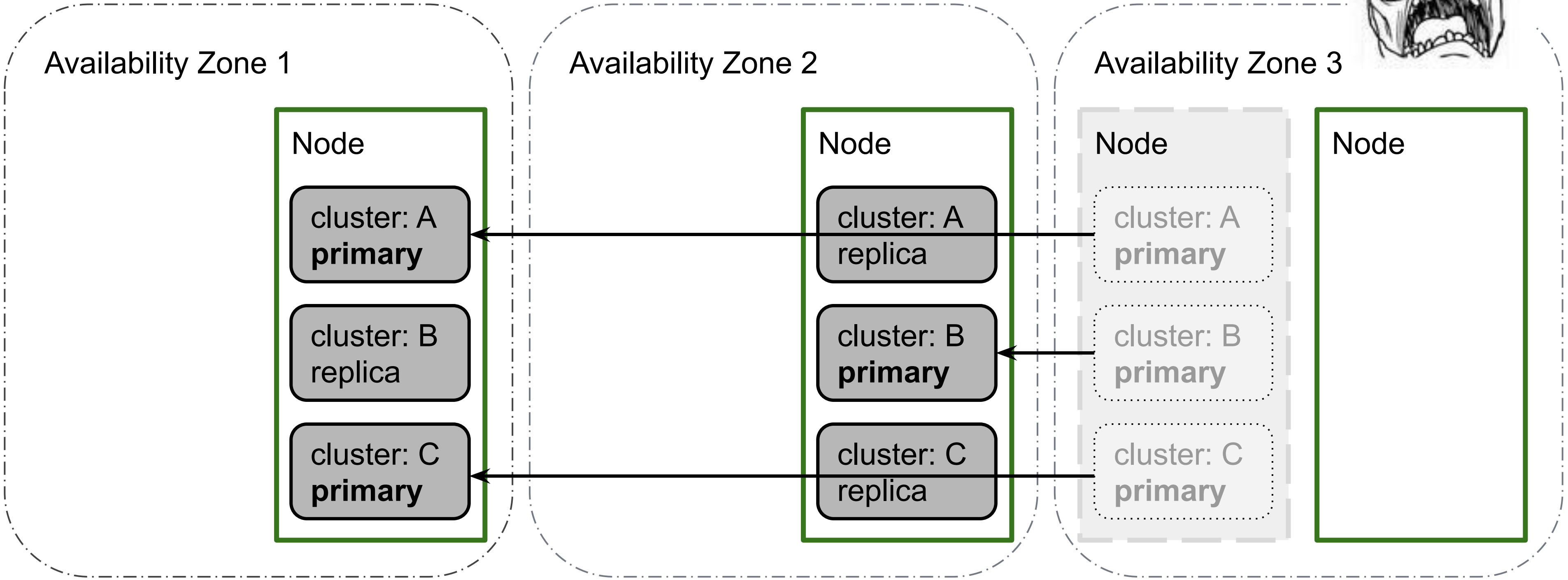
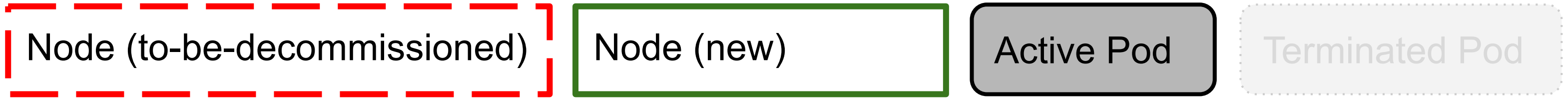
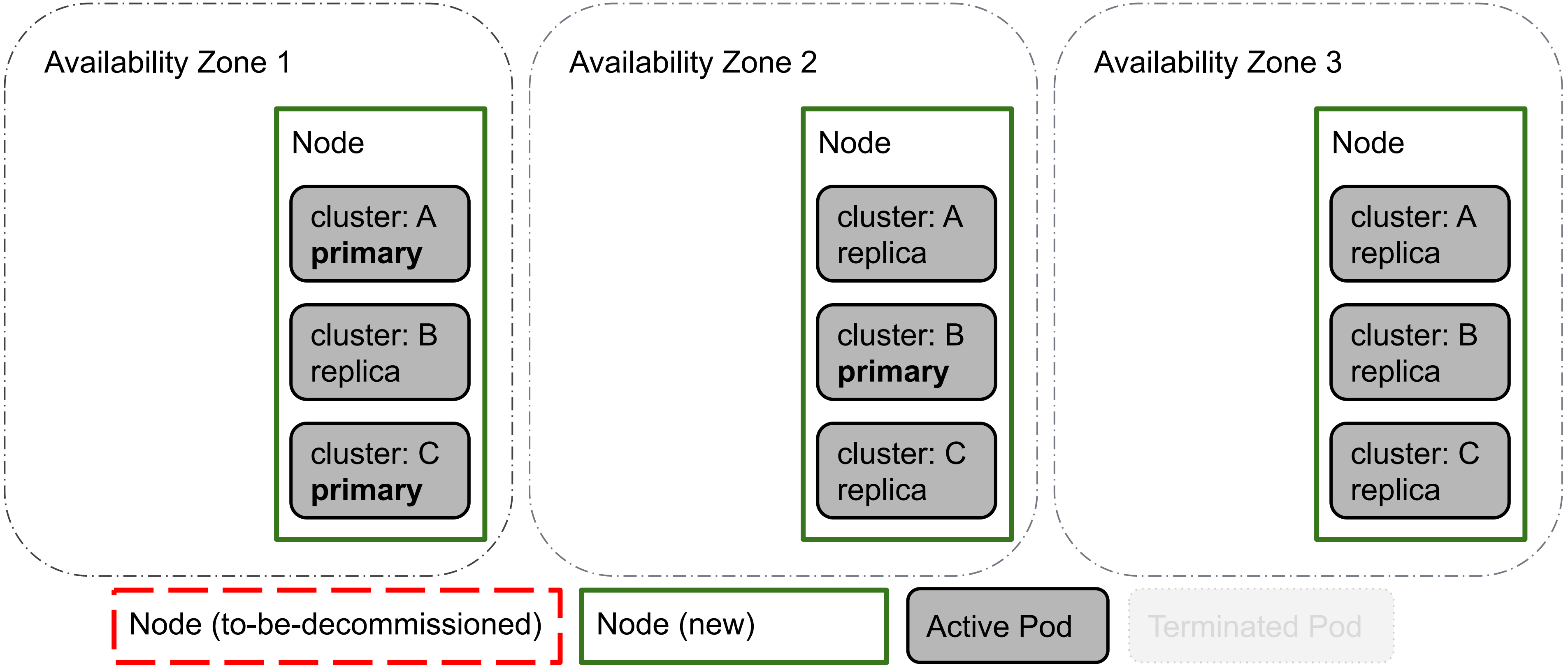
# Kubernetes rolling upgrade





# Kubernetes rolling upgrade



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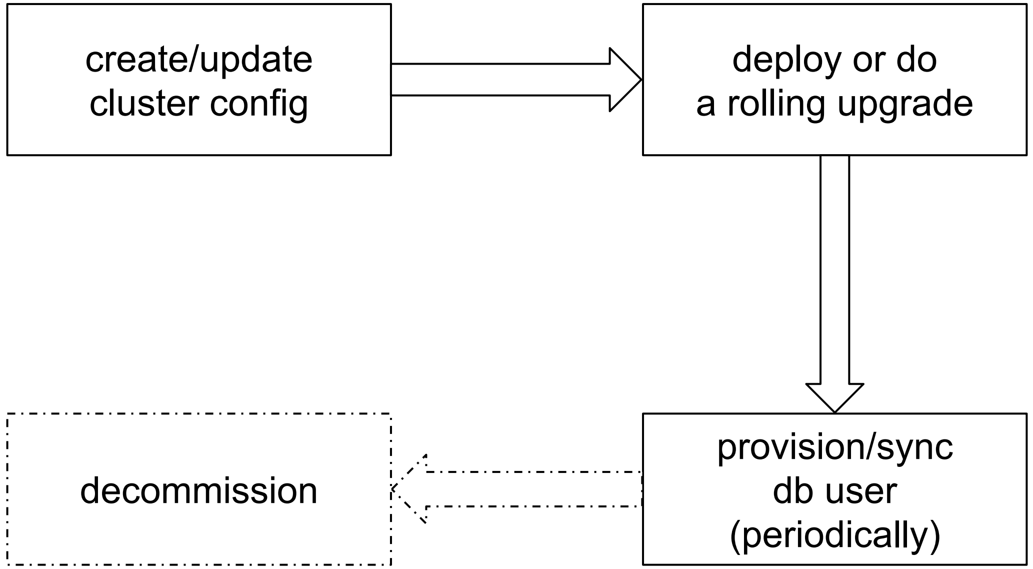
# Kubernetes rolling upgrade

| Cluster | Number of failovers |
|---|---|
| A | 3 |
| B | 2 |
| C | 2 |

## We need automation!

# PostgreSQL cluster life-cycle


create/update cluster config
deploy or do a rolling upgrade
provision/sync db user (periodically)
decommission

## Goals

- Fully automated:
    - deployments
    - cluster upgrades
    - user management
    - minimize a number of failovers

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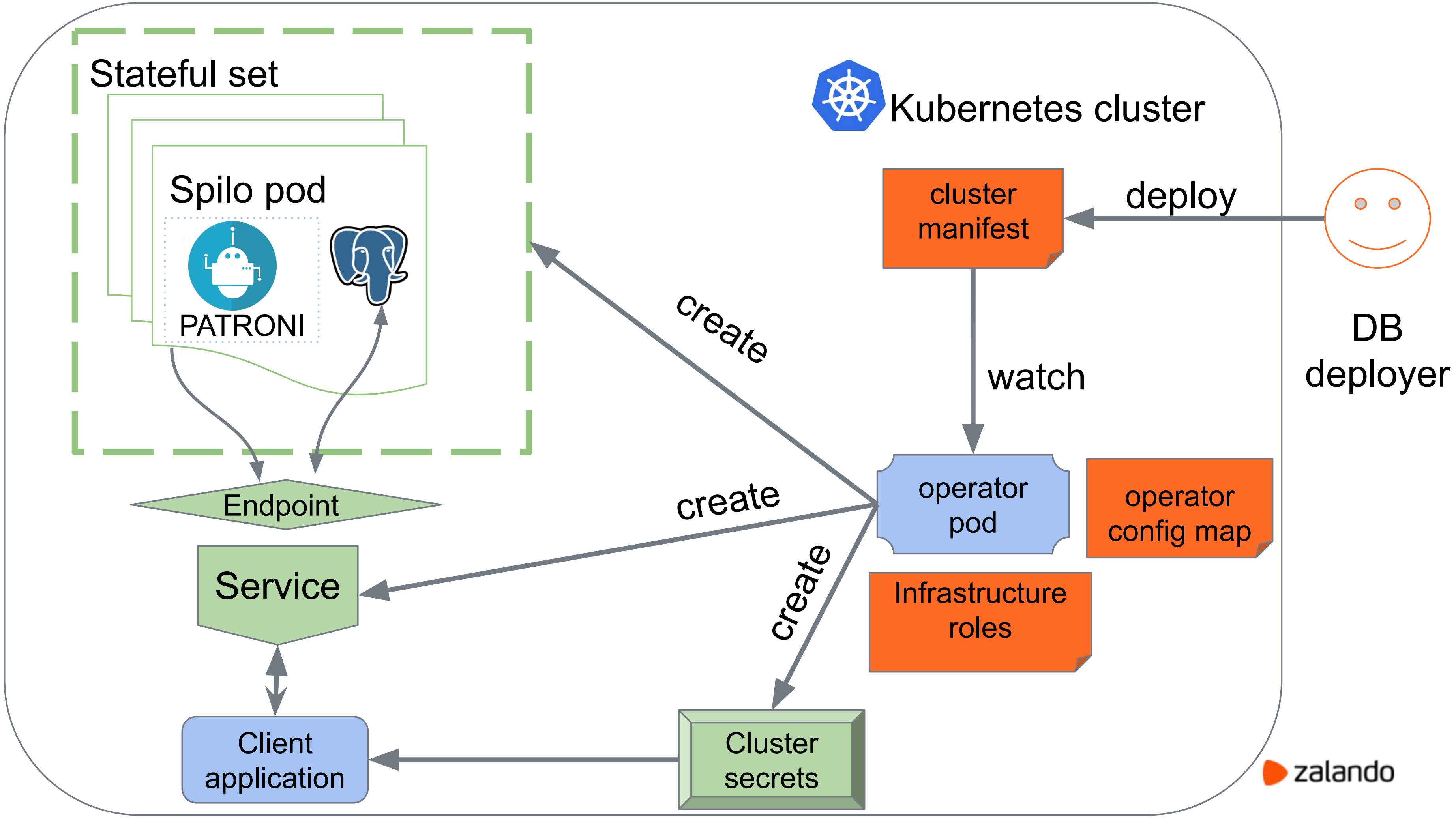
## Zalando Postgres-Operator

- Defines a custom Postgresql resource
- Watches instances of Postgresql, creates/updates/deletes corresponding Kubernetes objects
- Allows updating running-cluster resources (memory, cpu, volumes), postgres configuration
- Creates databases, users and automatically generates passwords
- Auto-repairs, smart rolling updates (switchover to replicas before updating the master)

## Postgresql manifest

```yaml
apiVersion: "acid.zalan.do/v1"
kind: postgresql
metadata:
 name: acid-minimal-cluster
spec:
 teamId: "ACID" # is used to provision human users
 volume:
   size: 1Gi
 numberOfInstances: 2
 users:
   zalando: # database owner
   - createrole
   - createdb
   foo_app_user: # role for application foo
 databases: # name->owner
   foo: zalando
 postgresql:
   version: "11"
```


Stateful set
Spilo pod
PATRONI
Kubernetes cluster
cluster manifest
deploy
DB deployer
watch
create
operator pod
operator config map
Infrastructure roles
Endpoint
create
Service
create
Client application
Cluster secrets
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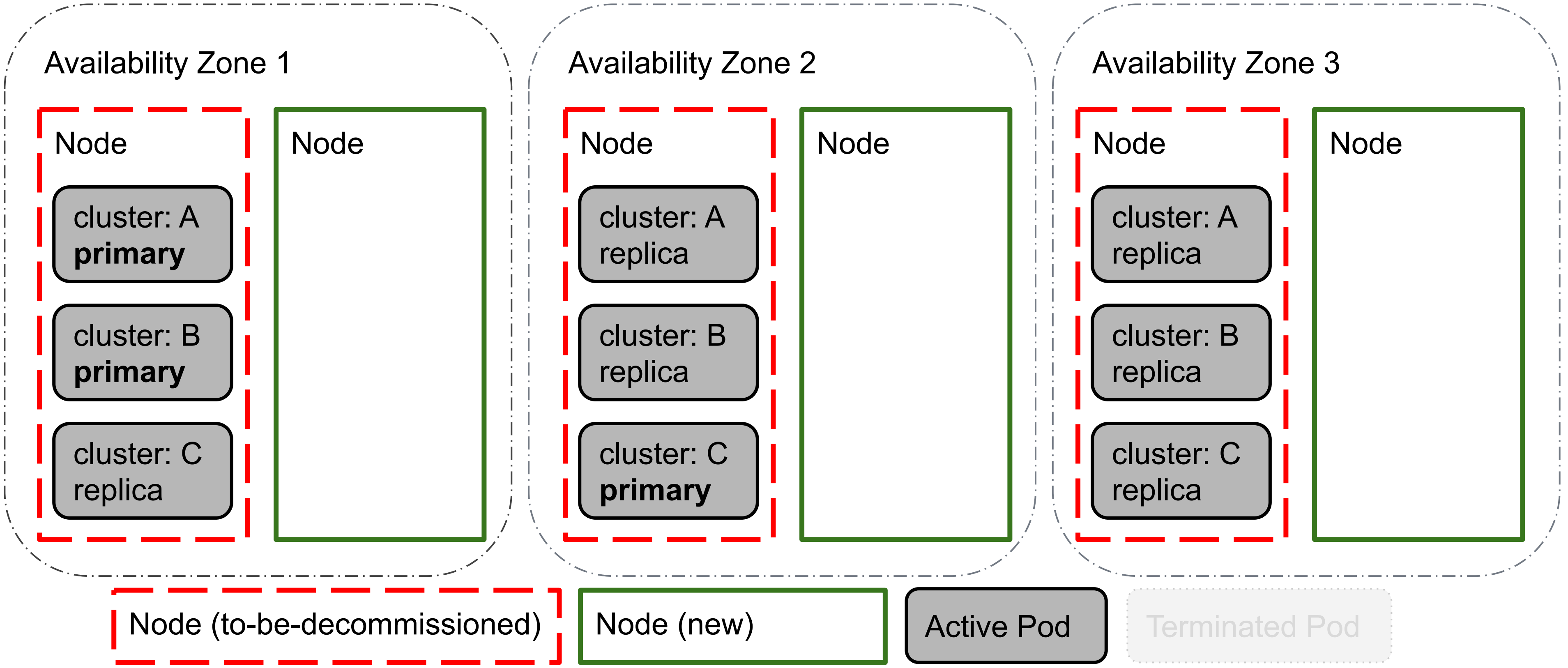
## Rolling upgrade with Postgres-Operator

- Detect the to-be-decommissioned node by lack of the ready label and SchedulingDisabled status

- Move replicas to the already updated (new) node

- Trigger switchover to those replicas

# Smart rolling upgrade (start)



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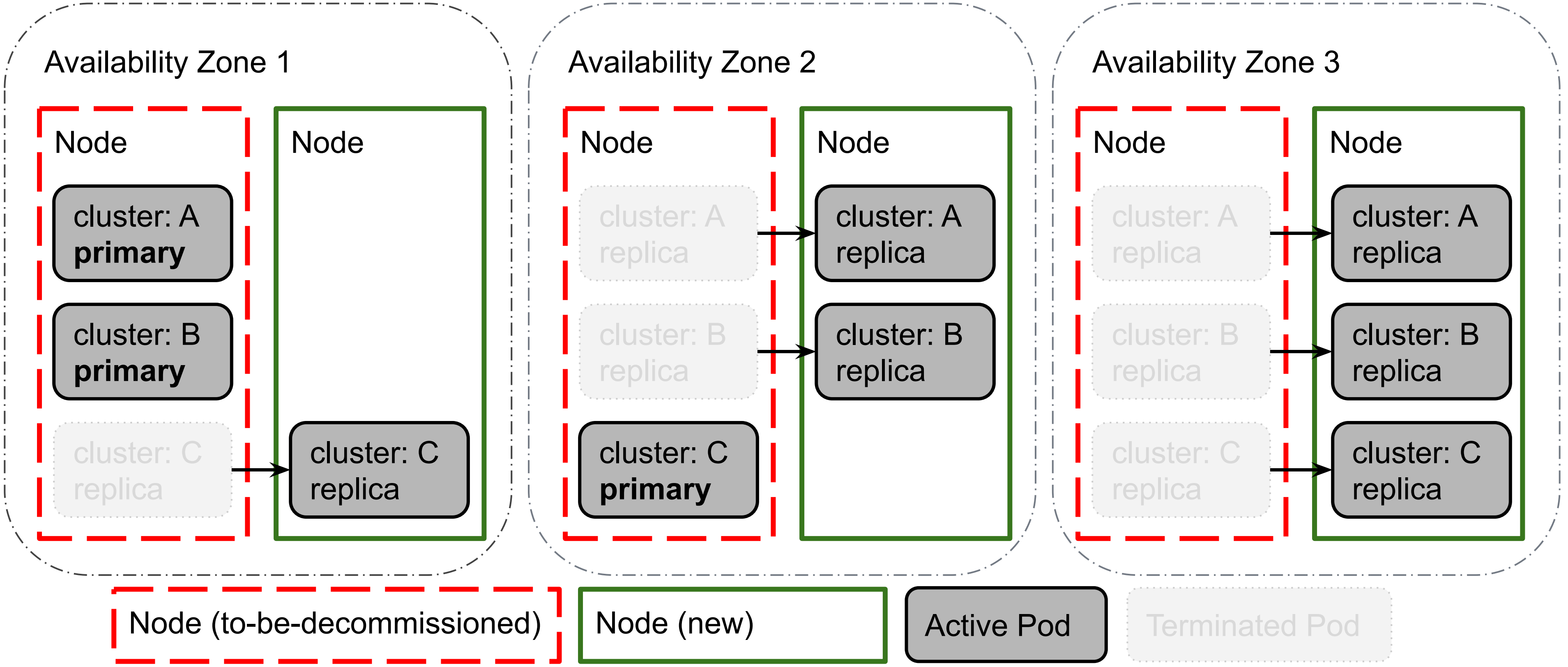
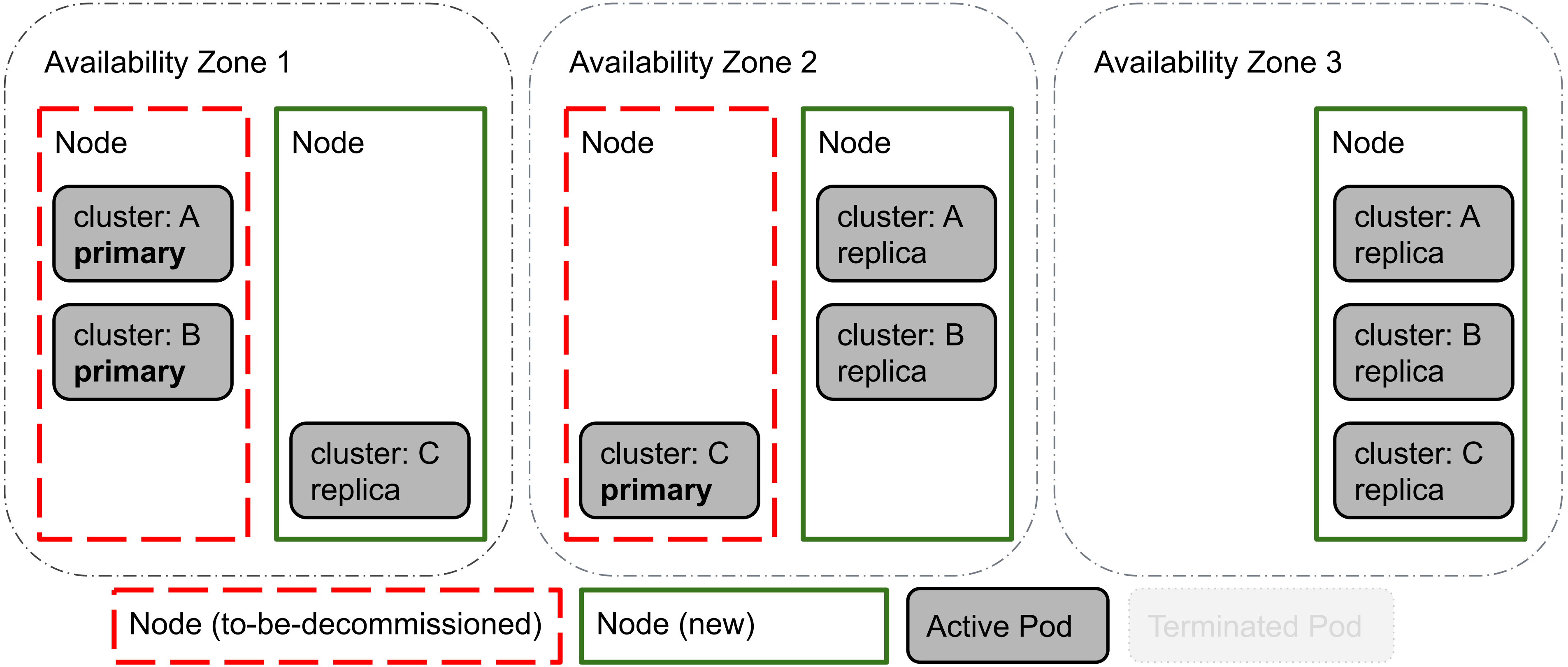
# Smart rolling upgrade (step 1)



# Smart rolling upgrade (step 1)



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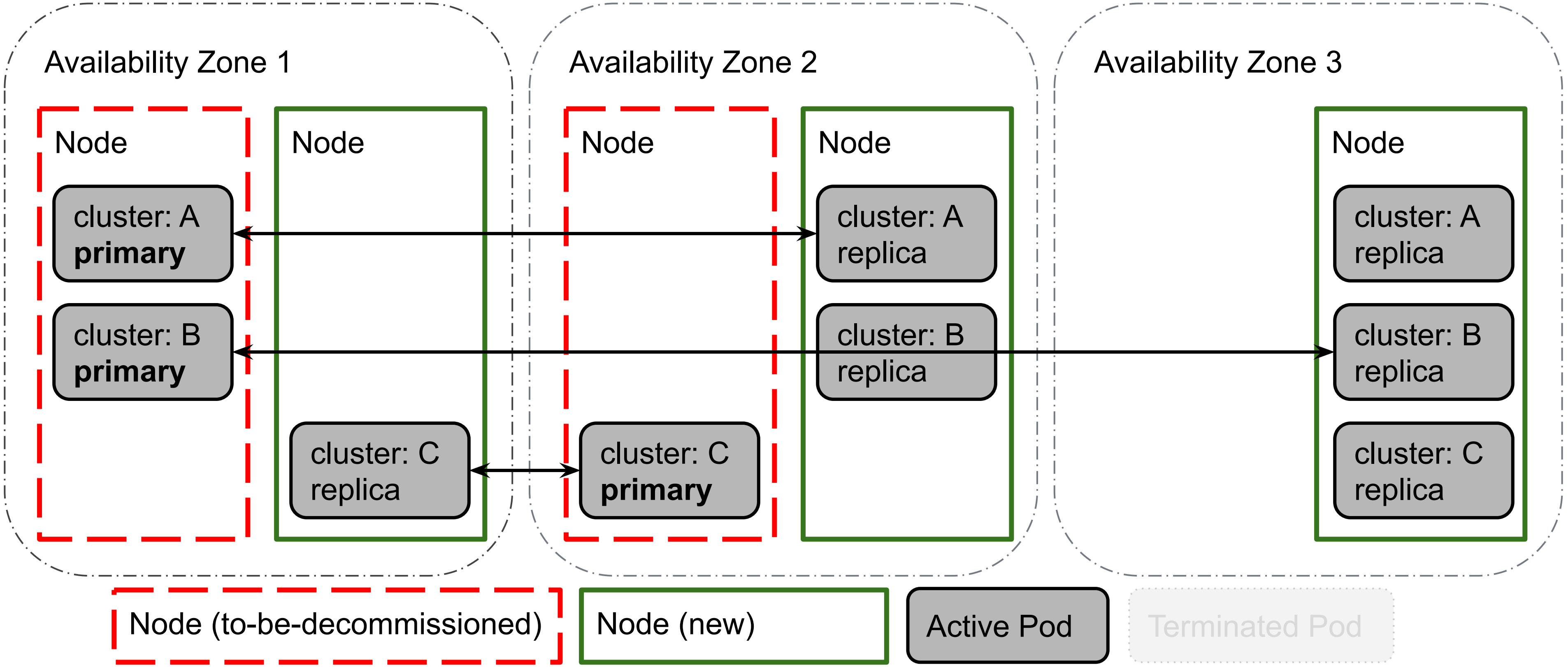
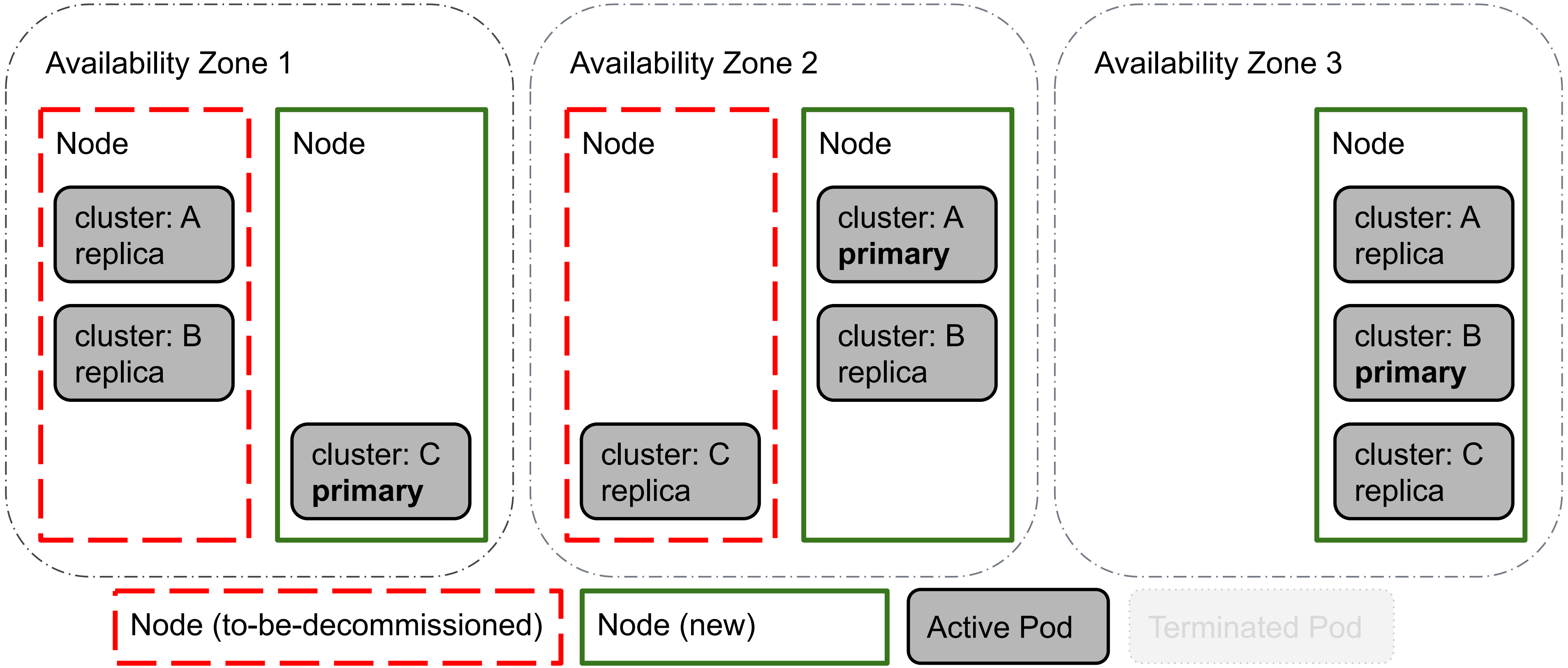
# Smart rolling upgrade (switchover)



# Smart rolling upgrade (switchover)



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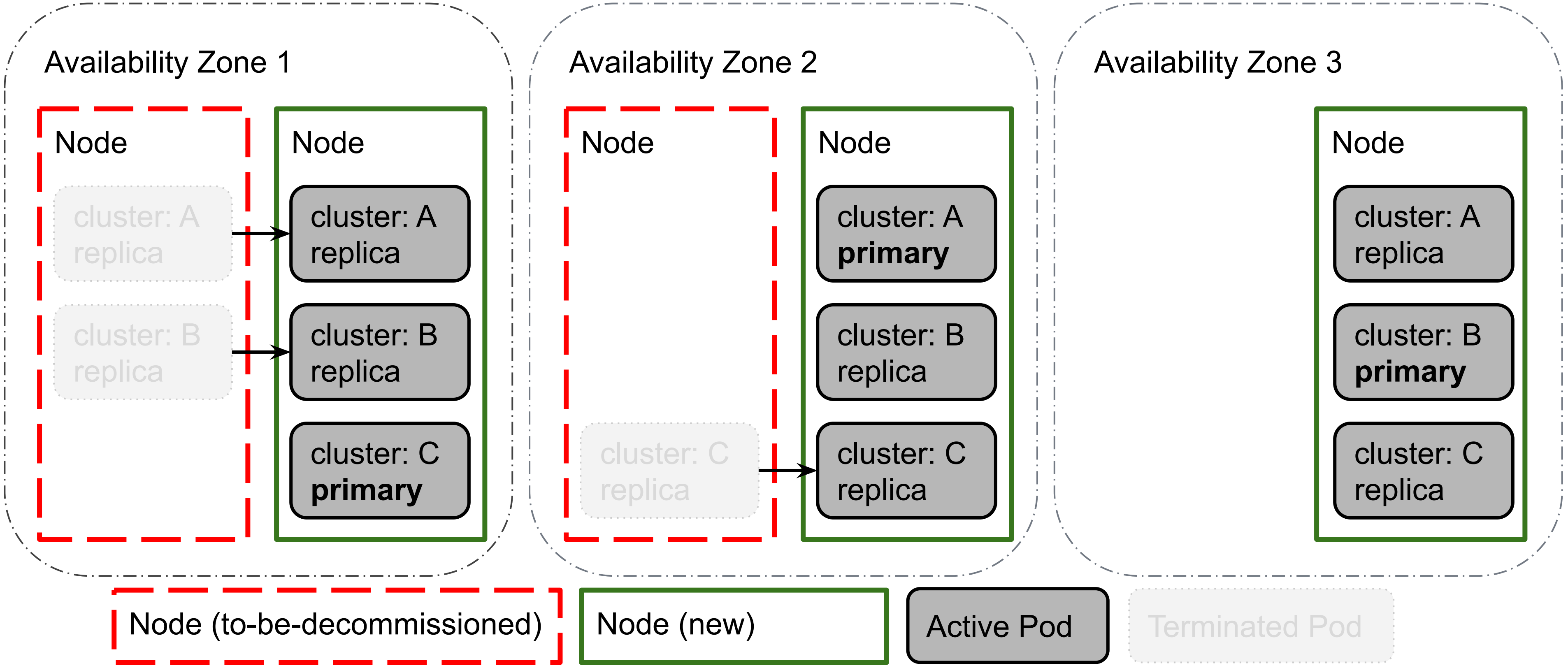
# Smart rolling upgrade (finish)



## Most common issues on K8s

## Problems with AWS infrastructure

- AWS API Rate Limit Exceeded
  - Prevents or delays attaching/detaching persistent volumes (EBS) to/from Pods
    - Delays recovery of failed Pods
  - Might delay a deployment of a new cluster
- Sometimes EC2 instances fail and being shutdown by AWS
  - Shutdown might take ages
  - All EBS volumes remain attached until instance is shutted down
    - Pods can’t be rescheduled

## Lack of Disk space

- Single volume for PGDATA, **pg_wal** and **logs**
- FATAL,53100,could not write to file "pg_wal/xlogtemp.22993": **No space left on device**
    - Usually ends up with postgres being self shutdown
- Patroni tries to recover the primary which isn’t running
    - “start->promote->No space left->shutdown” loop

**Disk space MUST be monitored!**

## Why not auto-extend volumes?

- Excessive logging
  - slow queries, human access, application errors, connections/disconnections
- pg_wal growth
  - archive_command is slow/failing
  - Unconsumed changes on the replication slot
    - Replica is not streaming? Replica is slow?
    - Logical replication slot?
  - checkpoints taking too long due to throttled IOPS
- PGDATA growth
  - Table and index bloat!
    - Useless updates of unchanged data?
    - Autovacuum tuning? Zheap?
  - Natural growth of data
    - Lack of retention policies?
    - Broken cleanup jobs?

# ORM can cause wal-e to fail!

```
wal_e.main ERROR MSG: Attempted to archive a file that is too
large. HINT: There is a file in the postgres database
directory that is larger than 1610612736 bytes. If no such
file exists, please report this as a bug. In particular,
check pg_stat/pg_stat_statements.stat.tmp, which appears to
be 2010822591 bytes
```

## Meanwhile in **pg_stat_statements**:

```
UPDATE foo SET bar = $1 WHERE id IN ($2, $3, $4, …, $10500);
UPDATE foo SET bar = $1 WHERE id IN ($2, $3, $4, …, $100500);
```

…. and so on

# Exclusive backup issues

```
PANIC,XX000,"online backup was canceled, recovery cannot
continue",,,,,,"xlog redo at D45/EB000028 for
XLOG/CHECKPOINT_SHUTDOWN: redo D45/EB000028; tli 237; prev
tli 237; fpw true; xid 0:105446371; oid 187558; multi 1;
offset 0; oldest xid 544 in DB 1; oldest multi 1 in DB 1;
oldest/newest commit timestamp xid: 0/0; oldest running xid
0; shutdown",,,,,""
```

- There is no way to join back such failed primary as a replica without rebuilding (reinitializing) it!
  - wal-g supports non-exclusive backups, but not yet stable enough

# Out-Of-Memory Killer

```
$ postgres.log:

server process (PID 10810) was terminated by signal 9: Killed
```

```
$ dmesg -T:

[Wed Jul 31 01:35:35 2019] Memory cgroup out of memory: Kill process
14208 (postgres) score 606 or sacrifice child
[Wed Jul 31 01:35:35 2019] Killed process 14208 (postgres)
total-vm:2972124kB, anon-rss:68724kB, file-rss:1304kB,
shmem-rss:2691844kB
[Wed Jul 31 01:35:35 2019] oom_reaper: reaped process 14208
(postgres), now anon-rss:0kB, file-rss:0kB, shmem-rss:2691844kB
```

## Out-Of-Memory Killer

- Pids in the container (**10810**) and on the host are different (**14208**)
  - Hard to investigate!
- **oom_score_adj** trick doesn’t really make sense in the container
  - There is only Patroni+PostgreSQL running
- It is not really clear how memory accounting in the container works:
  - memory: usage 8388392kB, limit 8388608kB, failcnt 1
  - cache:2173896KB **rss:6019692KB** rss_huge:0KB shmem:2173428KB

    mapped_file:2173512KB dirty:132KB writeback:0KB swap:0KB

    inactive_anon:15732KB active_anon:8177696KB inactive_file:320KB active_file:184KB

    unevictable:0KB

# Yet another OOM

```
$ kubectl get pods my-cluster-0
NAME            READY  STATUS    RESTARTS   AGE
my-cluster-0    1/1     Running 7          42d

$ kubectl describe pods my-cluster-0
...
Events:
Normal SandboxChanged 30m (x7 over 14d) kubelet, node1 Pod sandbox changed, it will be
killed and re-created.
Normal Killing 30m (x4 over 12d) kubelet, node1 Stopping container postgres
```

# Yet another OOM

```
$ dmesg

postgres invoked oom-killer: gfp_mask=0x14200ca(GFP_HIGHUSER_MOVABLE), nodemask=(null),
order=0, oom_score_adj=-998
[ pid ]   uid tgid    total_vm   rss   pgtables_bytes swapents oom_score_adj name
[29203]    0  29203   256        1      32768          0        -998          pause
[29308]    0  29308   1096       190    49152          0        -998          dumb-init
[29419]   101 29419   154759     5592   442368         0        -998          patroni
[29420]   101 29420   27011      784    241664         0        -998          pgqd
[29474]   101 29474   162244     7861   417792         0        -998          postgres

Memory cgroup out of memory: Kill process 29203 (pause) score 0 or sacrifice child
Killed process 29203 (pause) total-vm:1024kB, anon-rss:4kB, file-rss:0kB, shmem-rss:0kB
```

## How to mitigate Out-Of-Memory Killer?

- Reduce **shared_buffers** from 25% to 20%

- vm.dirty_background_bytes = 67108864
- vm.dirty_bytes = 134217728

Could be set only per Node :(

# Kubernetes+Docker

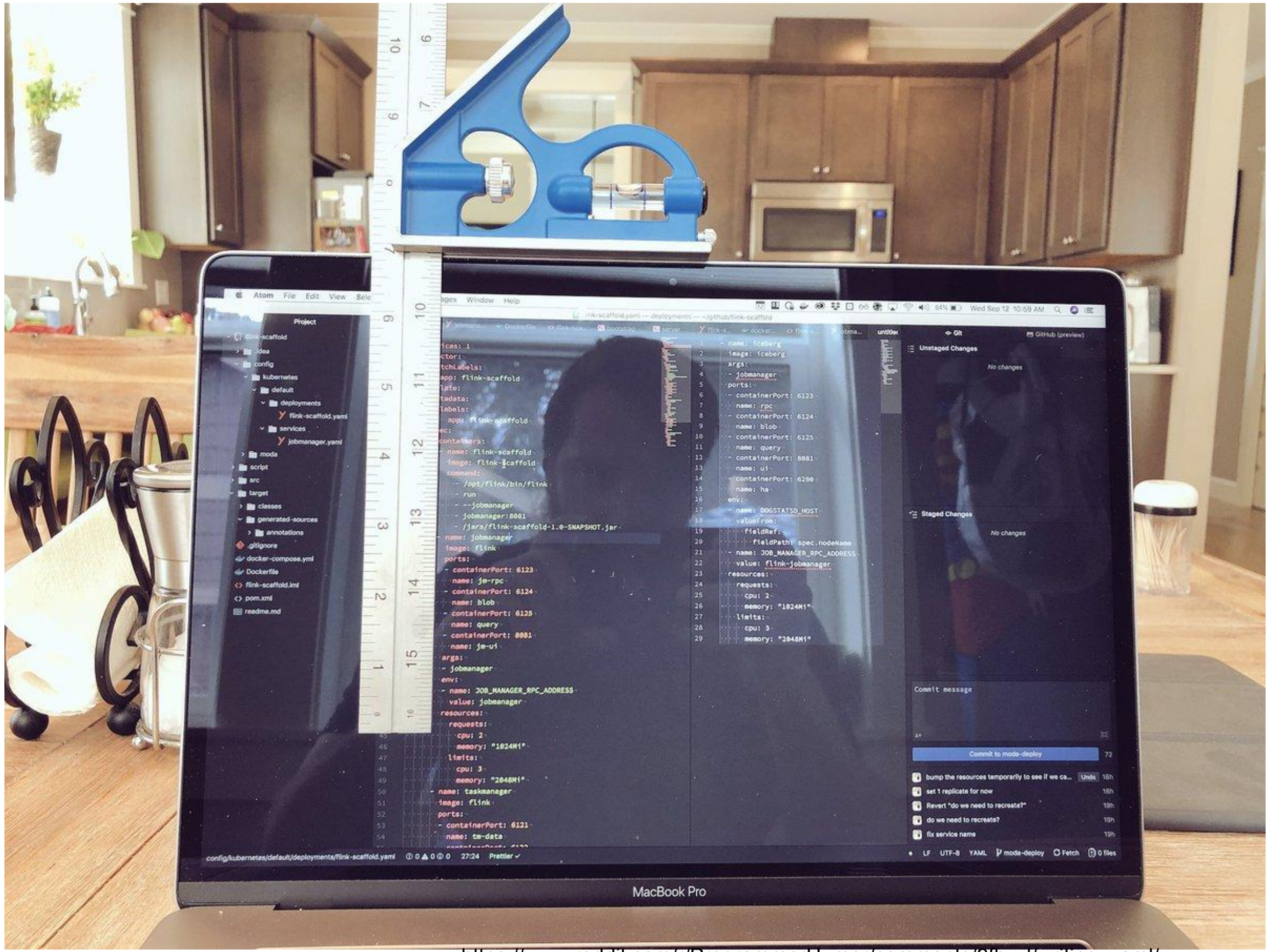
- `ERROR:  `**`could not resize shared memory segment`**` "/PostgreSQL.1384046013" to 8388608 bytes: `**`No space left on device`**
- PostgreSQL 11 (due to the “parallel hash join”)
- Docker limits **/dev/shm** to 64MB by default
- How to fix?
  - Mount custom dshm tmpfs volume to /dev/shm
    - Or set **enableShmVolume: true** in the cluster manifest

# Problems with PostgreSQL

- Logical decoding on the replica? Failover slots?
    - Patroni does sort of a hack by not allowing connections until logical slot is created.
        - Consumer might still lose some events.
- **“FATAL too many connections”**
    - Prevents replica from starting streaming
        - Solved in PostgreSQL 12 (**wal_senders** not count as part of **max_connections**)
    - Built-in connection pooler?

## Human errors

- Inadequate resource requests and limits
    - Pod can’t be scheduled due to the node weakness
    - Processes are terminated by oom-killer
- Deleted Postgres-Operator/Spilo ServiceAccount by employees
- YAML formatting :)



```
icas: 1
ctor:
tchLabels:
app: flink-scaffold
late:
tadata:
labels:
  app: flink-scaffold
ec:
containers:
- name: flink-scaffold
  image: flink-scaffold
  command:
    - /opt/flink/bin/flink
    - run
    - --jobmanager
    - jobmanager:8081
    - /jars/flink-scaffold-1.0-SNAPSHOT.jar
- name: jobmanager
  image: flink
  ports:
  - containerPort: 6123
    name: jm-rpc
  - containerPort: 6124
    name: blob
  - containerPort: 6125
    name: query
  - containerPort: 8081
    name: jm-ui
  args:
  - jobmanager
  env:
  - name: JOB_MANAGER_RPC_ADDRESS
    value: jobmanager
  resources:
    requests:
      cpu: 2
      memory: "1024Mi"
    limits:
      cpu: 3
      memory: "2048Mi"
- name: taskmanager
  image: flink
  ports:
  - containerPort: 6121
    name: tm-data
```

```
- name: iceberg
  image: iceberg
  args:
  - jobmanager
  ports:
  - containerPort: 6123
    name: rpc
  - containerPort: 6124
    name: blob
  - containerPort: 6125
    name: query
  - containerPort: 8081
    name: ui
  - containerPort: 6200
    name: ha
  env:
  - name: DOGSTATSD_HOST
    valueFrom:
      fieldRef:
        fieldPath: spec.nodeName
  - name: JOB_MANAGER_RPC_ADDRESS
    value: flink-jobmanager
  resources:
    requests:
      cpu: 2
      memory: "1024Mi"
    limits:
      cpu: 3
      memory: "2048Mi"
```

https://www.reddit.com/r/ProgrammerHumor/comments/9fhvyl/writing_yaml/

## Cluster YAML definition

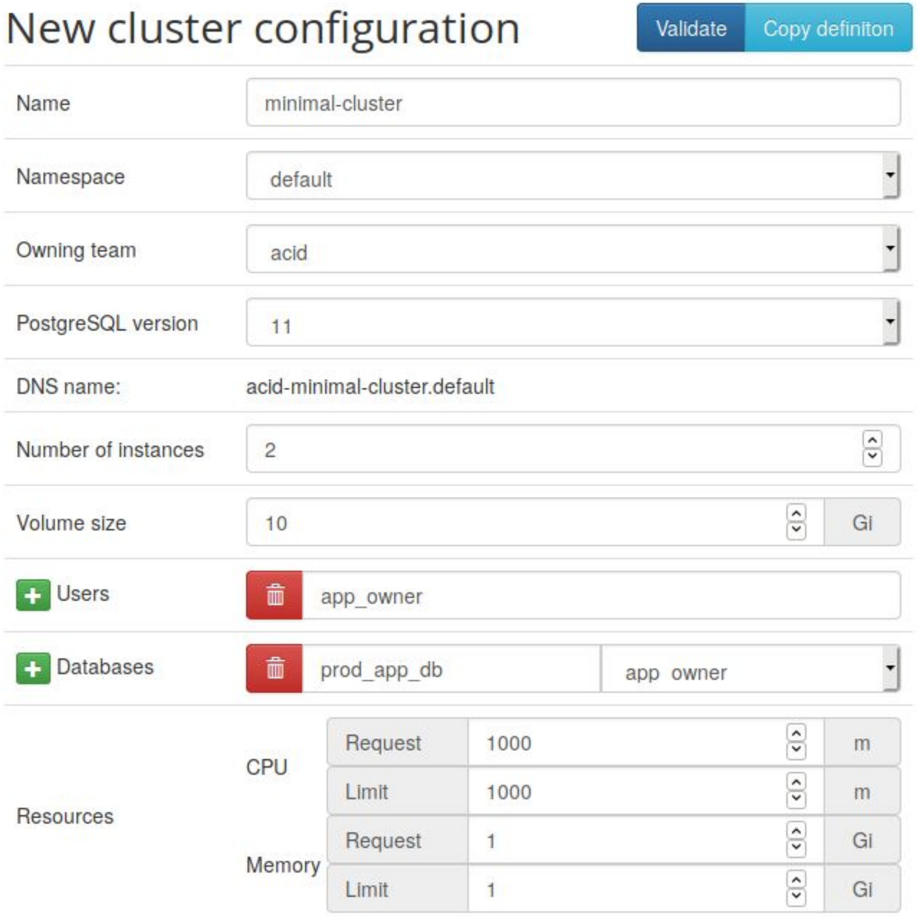
```
kind: "postgresql"
apiVersion: "acid.zalan.do/v1"

metadata:
  name: "acid-minimal-cluster"
  namespace: "default"
  labels:
    team: acid

spec:
  teamId: "acid"
  postgresql:
    version: "11"
  numberOfInstances: 2
  volume:
    size: "10Gi"
  users:
    app_owner: []
  databases:
    prod_app_db: app_owner
  allowedSourceRanges:
    # IP ranges to access your cluster go here

  resources:
    requests:
      cpu: 1000m
      memory: 1Gi
    limits:
      cpu: 1000m
      memory: 1Gi
```

## New cluster configuration



| | |
|---|---|
| Name | minimal-cluster |
| Namespace | default |
| Owning team | acid |
| PostgreSQL version | 11 |
| DNS name: | acid-minimal-cluster.default |
| Number of instances | 2 |
| Volume size | 10 Gi |
| Users | app_owner |
| Databases | prod_app_db / app_owner |
| Resources — CPU Request | 1000 m |
| Resources — CPU Limit | 1000 m |
| Resources — Memory Request | 1 Gi |
| Resources — Memory Limit | 1 Gi |

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## Conclusion

- Postgres-Operator helps us to manage more than 1500 PostgreSQL clusters distributed in 80+ K8s accounts with minimal effort.
  - It wouldn’t be possible without high level of automation
- In the cloud and on K8s you have to be ready to deal with absolutely new problems and failure scenarios
  - Find the solution and implement a permanent fix

# Open-source

- Postgres-operator: https://github.com/zalando/postgres-operator
- Patroni: https://github.com/zalando/patroni
- Spilo: https://github.com/zalando/spilo

# Thank you!

## Questions?