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# 10 Years of Automating PostgreSQL. A Recap.

# Introduction



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# 10 Years

🥳🎂🎉

# 15 actually!

# This Talk

# This Talk

- Chronological summary
- Different stages of automating PostgreSQL
- How the technological zeitgeist impacted automation over time
- Learnings (as an individual as well as an organization)
- How to scale-out operations from dozens to thousands of machines



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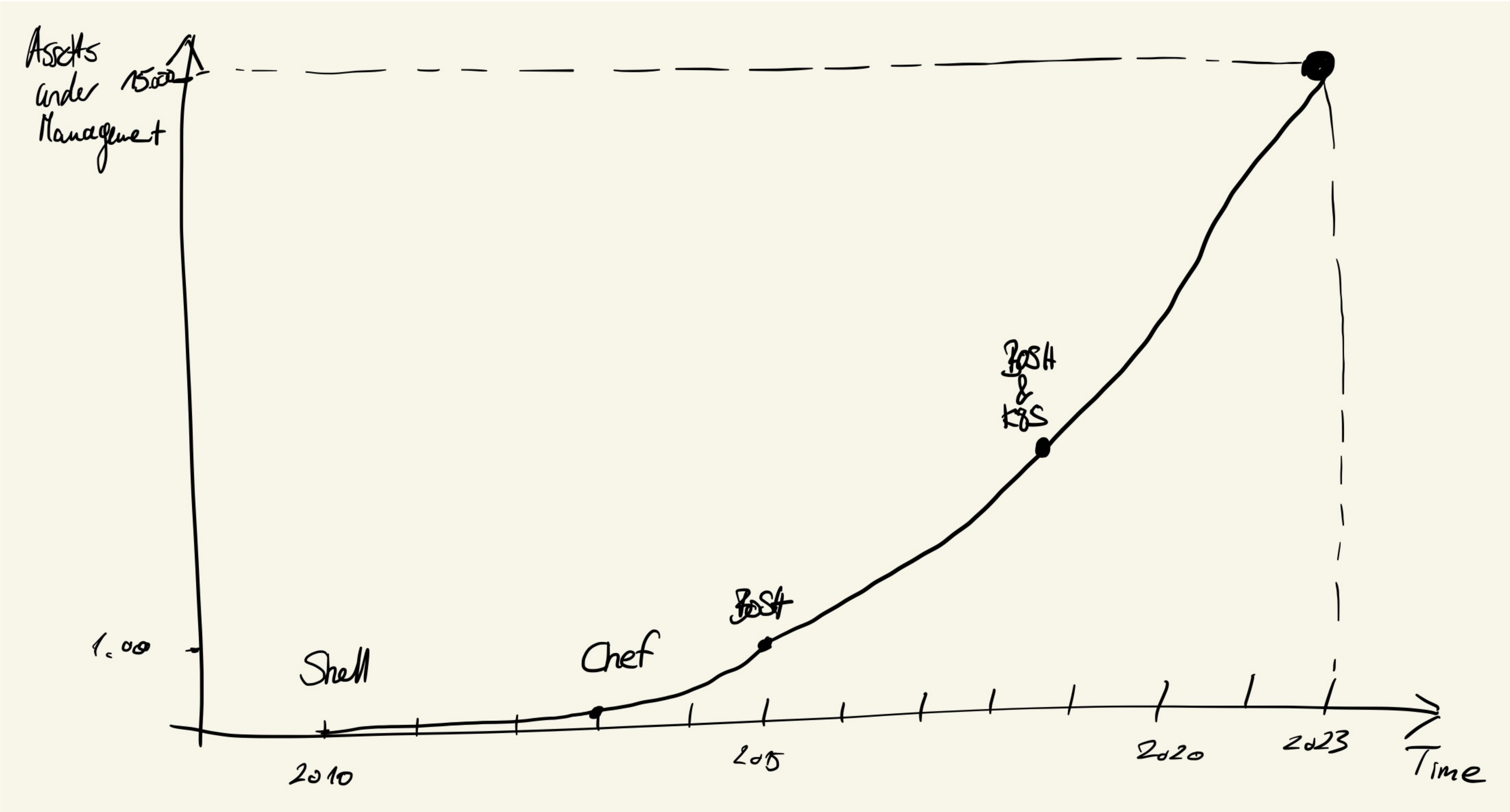
# The Perspective

# Aspects of Interest

- **Infrastructure**: physical, VM-hosts, virtual infrastructures.
- **Automation technology**: imperative, declarative.
- **Lifecycle mgmt. coverage of automation**: CRUD service instances, service bindings, backups & restore, configuration, upgrades, high-availabilty, etc.
- **Assets under management**: Physical / virtual machines && Pods / containers.
- **Operational responsibility**: Platform operator &&|| Application developer
- **PostgreSQL at the time**: HA & cluster management, upgrades, security, …


Assets under Management
1500
Shell
Chef
BOSH
BOSH & K8S
2010
2015
2020
2023
Time

# Imperative Automation

**Stage 1**: Physical servers
~2008-2009

# Physical Machines

# (Physical) Servers & Shell Scripts

- Best performance per €/$?
- Servers are dimensioned with respect to peak loads and are idle 90% of the time.
- Building clusters requires flexible data centers allowing the wiring of private networking.
- Often servers have contract lifetimes of several years (off-the-shelf DCs often not flexible enough) .
- Dependency to the data center staff for some tasks → Delays


# Shell Scripts

# (Physical) Servers & Shell Scripts

- Shell scripts
- **Coverage**: Supporting repetitive tasks
- Mostly manually managed OS
- OS provided software packages

# (Physical) Servers & Shell Scripts

- Striving for a maximum uptime as fixing failed servers requires manual intervention and takes hours to fully recover.
- Failures have strong impact on the Sysop's sleep.
    - Long TTR
- Manually executed tasks come with a human error rate

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# (Physical) Servers & Shell Scripts

- PostgreSQL
  - Looking for ways to make PostgreSQL highly available
    - Blocklevel || filesystem level replication, e.g. GlusterFS
    - Sync and async replication
    - Pacemaker
    - …

# **Stage 2**: Virtual servers
# ~2009-2011

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# Virtual Machines

# (Physical) Servers & Shell Scripts

- Automanually managed Xen & XVM hosts
- Increased hardware utilization
- Lower barrier of entry: virtual clusters
- VMs ➞ More machines to manage ➞ More automation needed



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# Chef

# (Physical) Servers & Shell Scripts

- Configuration management
- Centralized cookbooks
  - Better reusability of code
  - Less code duplicity
- More efficient that shell scripts

# (Physical) Servers & Shell Scripts

- PostgreSQL
  - Async replication has proven to be the best all-round approach.
  - Pacemaker and, later, repmgr
  - Shared HA-PostgreSQL cluster to lower the barrier of entry (VM app servers + shared virtual or physical DB server) vs. dedicated virtual DB-servers.



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# (Physical) Servers & Shell Scripts

- Limitations
  - **State drift!** Manual intervention necessary although (theoretically) covered by automation.
  - Increasing efforts for maintenance, refactoring and network management become limiting factors.
  - The team's utilization increased.
  - Training new team members was hard as, despite of the cookbooks, still a lot of knowledge was necessary to operate the application systems.



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# The Game Changer

On-demand provisioning of dedicated PostgreSQL instances based on declarative automation.

# Declarative Automation



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CLOUD FOUNDRY BOSH™

Kubernetes

OPEN SERVICE BROKER API™

# Shift in operational responsibility: App devs operate their own databases.

OPEN SERVICE BROKER API™

Kubernetes CRDs

# **Stage 3**: Virtual infrastructures ~2012-2023

# Virtual Infrastructures

The programmable data center

# Dealing with State

# Where to store state?

🔑

Store state on a **remotely attached block device** = persistent disk.

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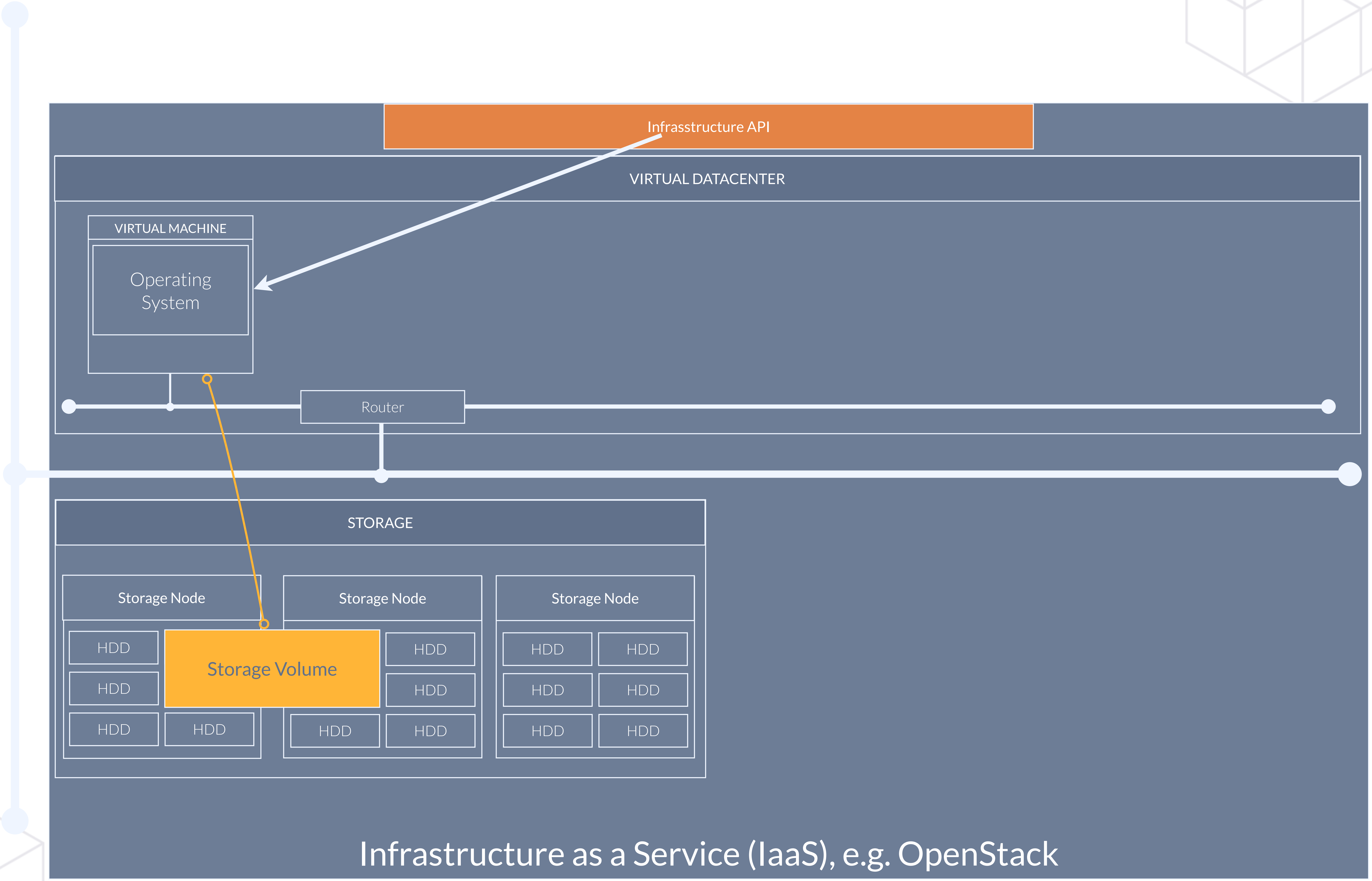

Infrasstructure API
VIRTUAL DATACENTER
VIRTUAL MACHINE
Operating System
Router
STORAGE
Storage Node
Storage Node
Storage Node
HDD
HDD
HDD
HDD
Storage Volume
HDD
HDD
HDD
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HDD
Infrastructure as a Service (IaaS), e.g. OpenStack


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The data lifecycle has been decoupled from the VM lifecycle
⇒ The VM becomes disposable.

# Ephemeral VM, persistent disk.

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BOSH™

# Predictable & repeatable deployments. No state-drift.

# Virtual Infrastructures

- PostgreSQL
  - Sync and Async Streaming replication
  - Repmgr and Patroni
  - Logic backups and PITR backups

# **Stage 4**: Container infrastructures ~2015-2023

# Kubernetes

# Kubernetes

- Declarative automation
- ~ Infrastructure abstraction API
- API standardization & Open framework for automation
- Container isolation & Noisy neighbor issues
- Often: VM automation underneath.

# Container Infrastructures

- PostgreSQL
  - Sync and Async Streaming replication
  - Patroni as a cluster manager

# The Future



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# Summary & Conclusion



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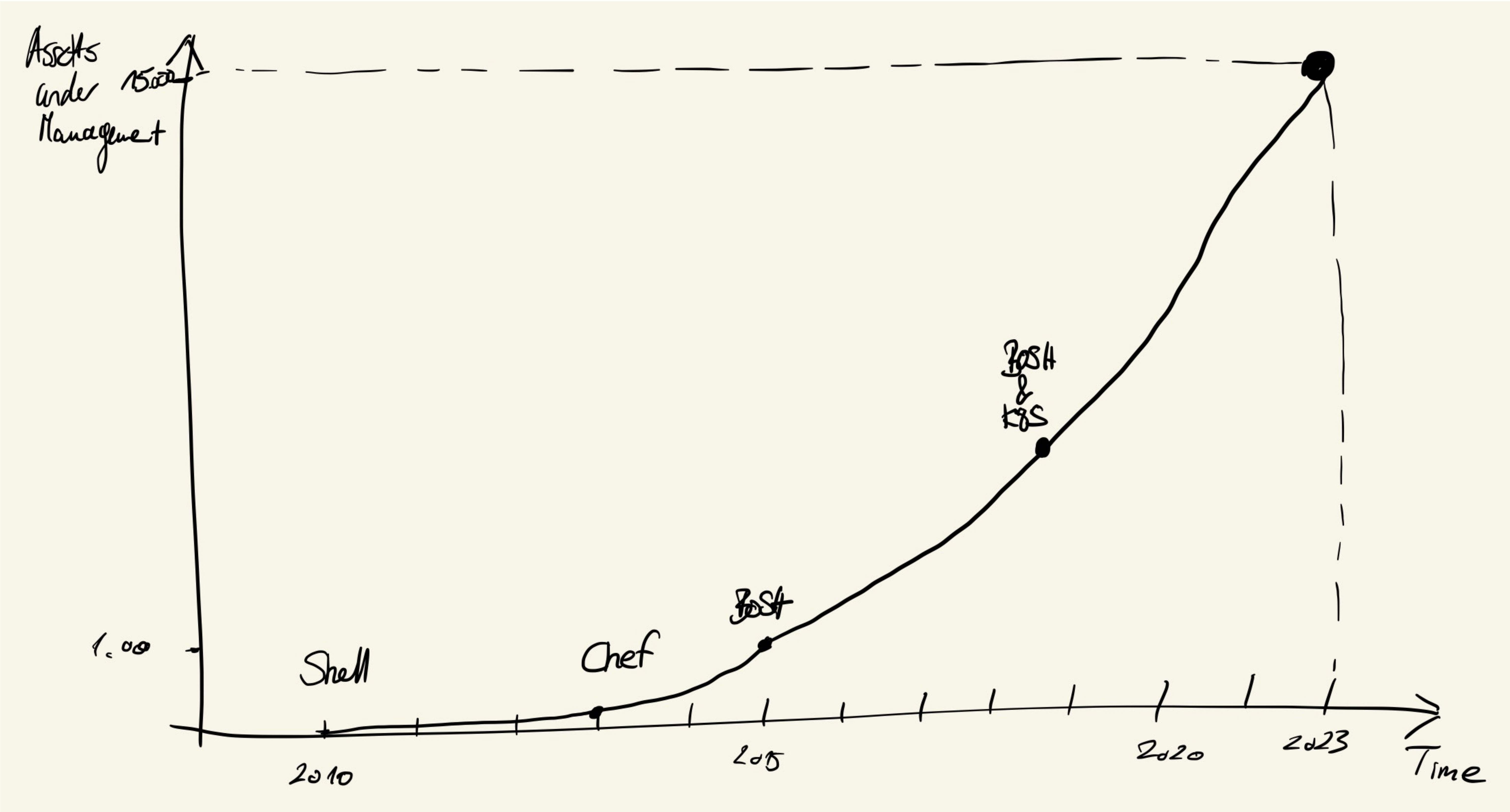
| Infrastructure | Automation Paradigm | Automation Technology | Operated by | Coverage | Machines / Devop |
|---|---|---|---|---|---|
| Physical machines | Imperative | Shell scripts | Sysop | Simple repetitive tasks | A few dozen |
| (Semi-) Manually Managed VM Hosts | Imperative | Chef | Devop | Parts of the lifecycle. Devops centric. | A few hundred |
| Virtual Infrastructure | Declarative | BOSH | Automation: Devop Database: App Dev | Full lifecycle management | Thousands to ten thousands |
| Virtual or Physical Infrastructure | Declarative | Kubernetes & K8s Add-ons | Automation: Devop Database: App Dev | Full lifecycle management | Thousands to ten thousands |


Assets under Management
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2010
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Time

# Summary

- Virtualization, EVM-PD
- Declarative automation
- Increased automation friendliness of PG



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# Thank You

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a9s Data Services

a9s Elasticsearch

a9s LogMe

# Questions?
# @anynines
# @fischerjulian

a9s Redis

a9s MySQL

a9s MongoDB

a9s PostgreSQL

a9s RabbitMQ

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# Thank You!

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# Data Service Automation



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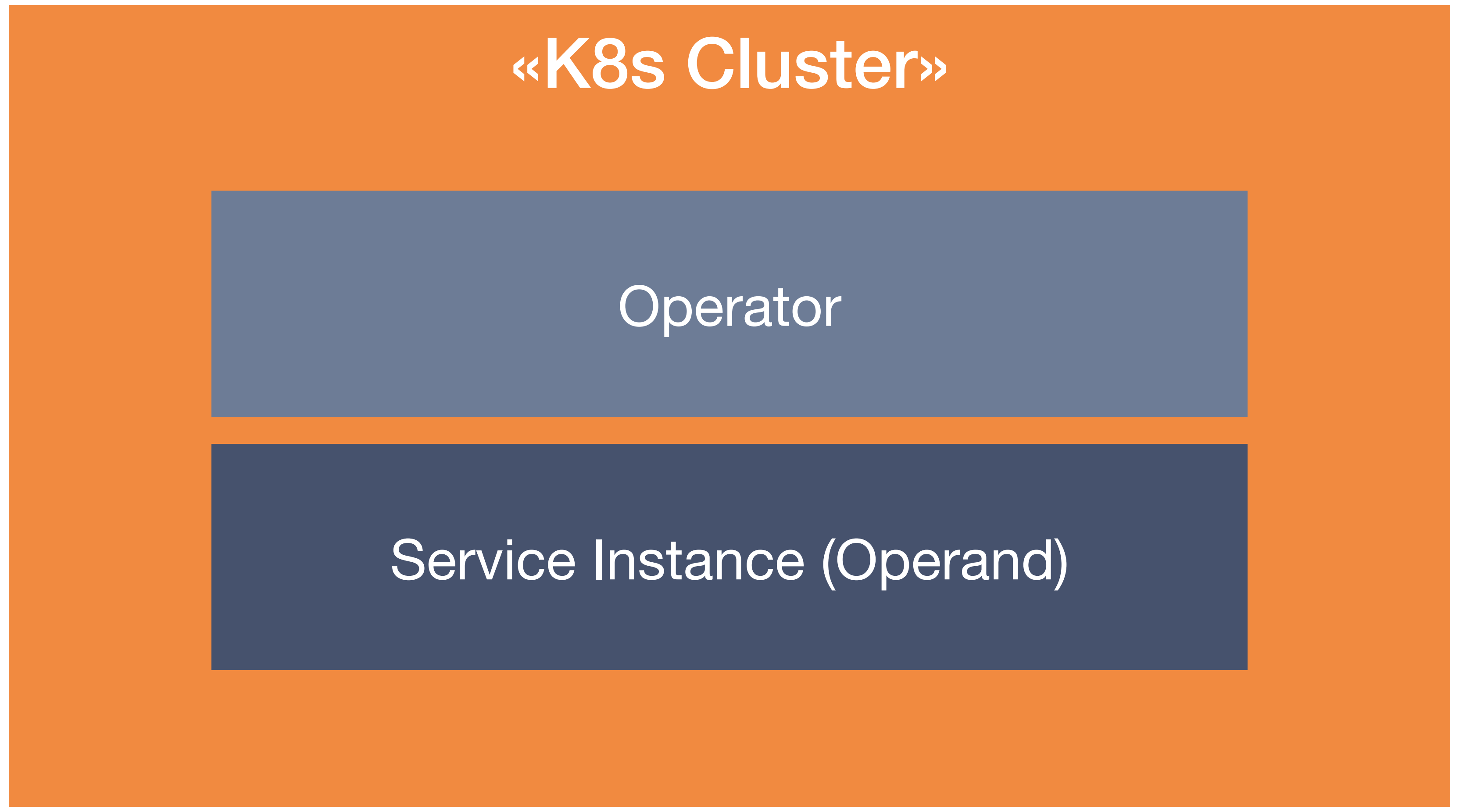
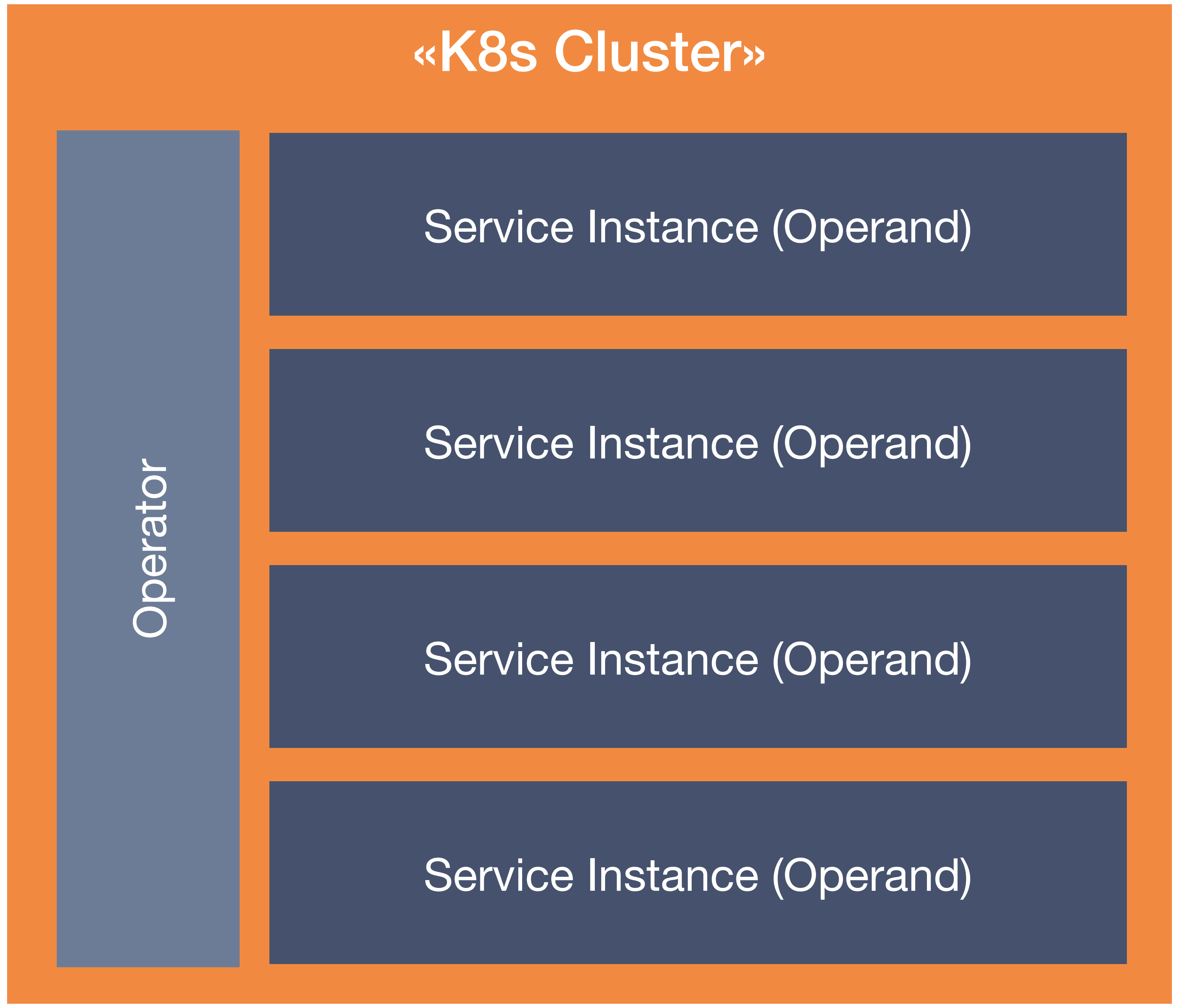
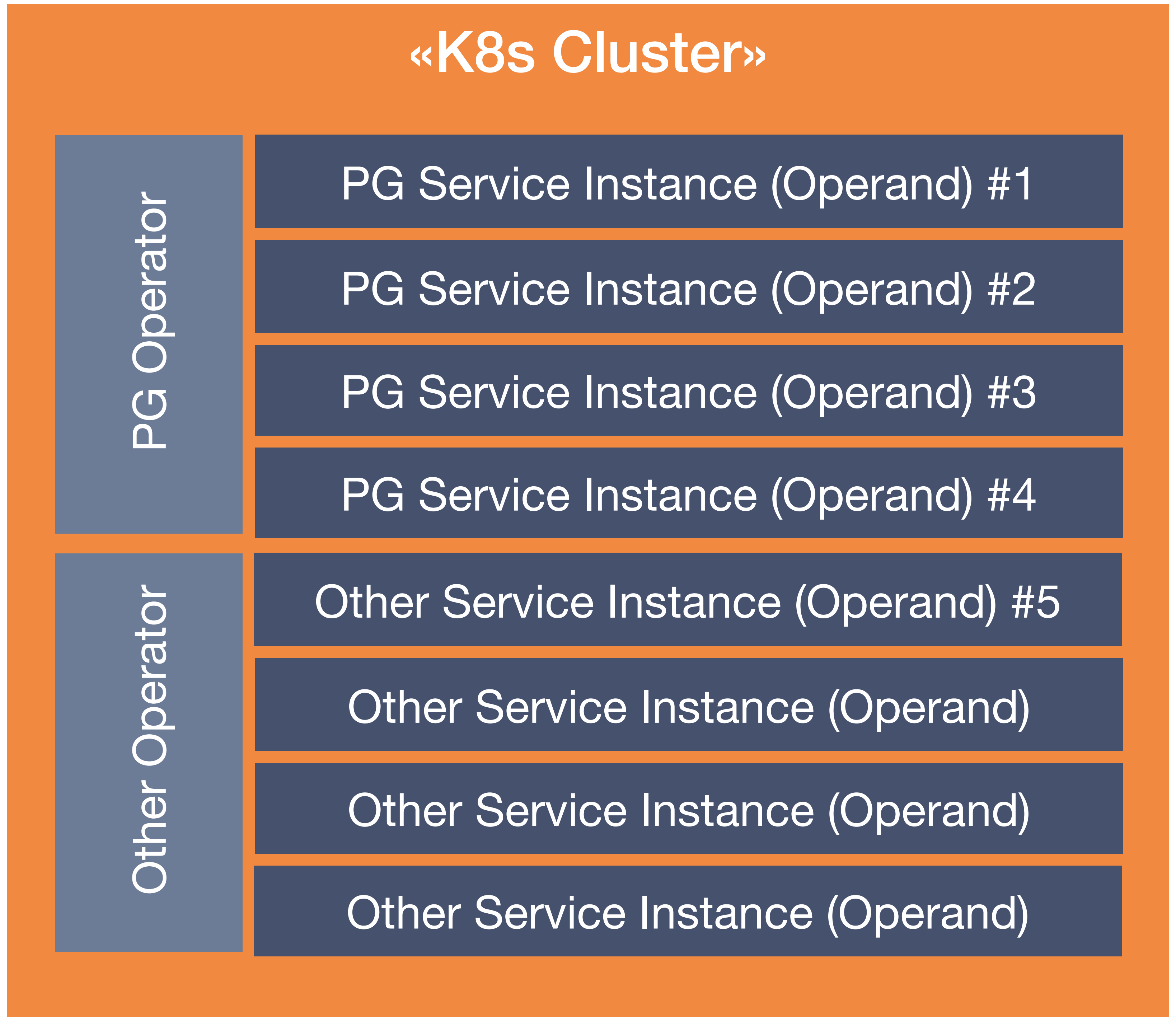
"Fully **automating** the entire **lifecycle** of a wide range of **data services** to run on cloud-native **platforms** across **infrastructures** at **scale**."



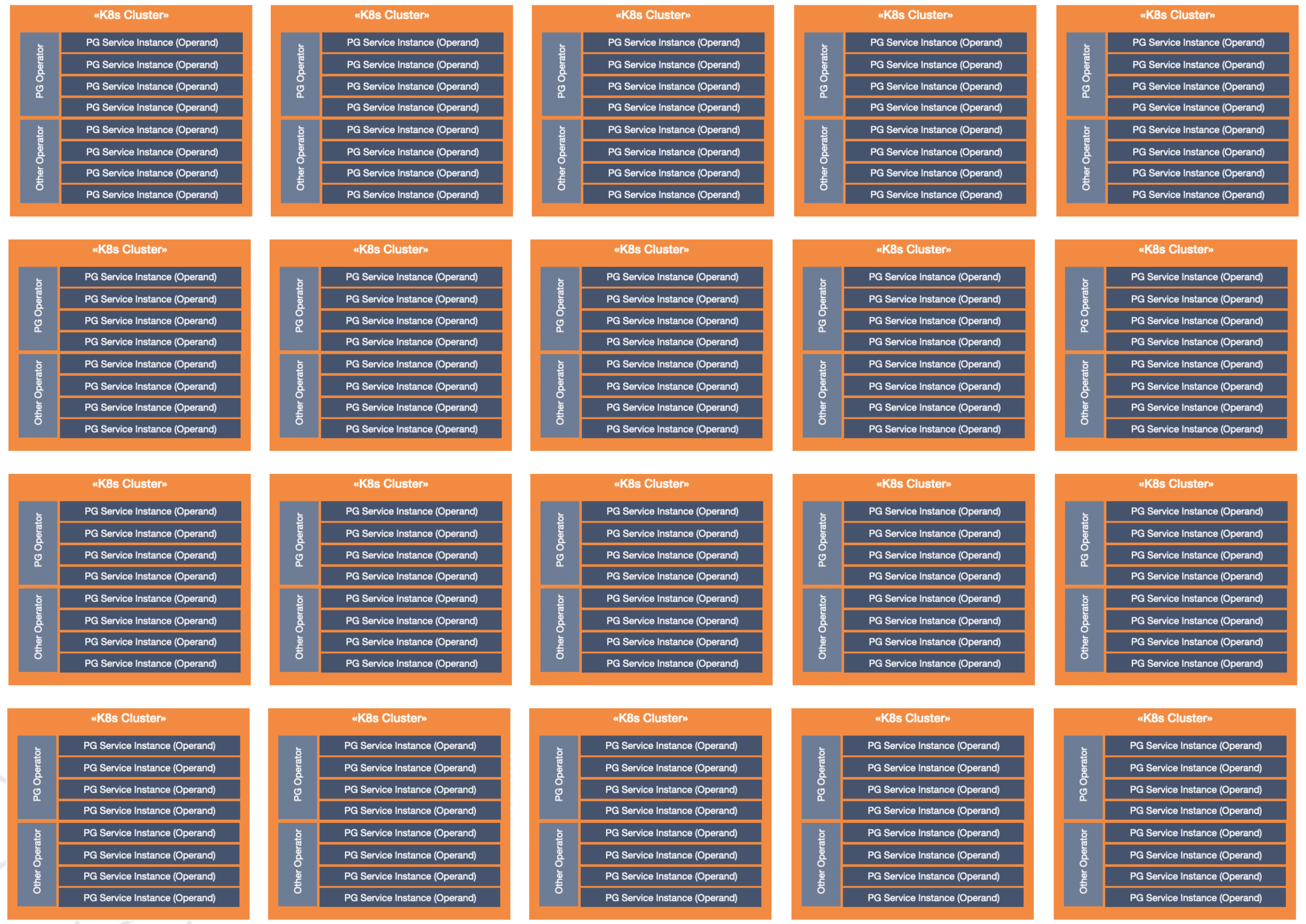

A single K8s cluster
with a single service instance
managed by a single Operator.




A single K8s cluster
with multiple service-instances
managed by a single Operator.




A single K8s cluster
with multiple service-instances
managed by a multiple Operators.




# Many K8s clusters each with multiple service-instances managed by a multiple Operators.

# 100s or 1000s of data service instances!



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# Scale Matters!




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# Each data service instance matters!



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# Methodology



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# Principles

# Principles

- Know your target audience. **Requirements** and desired **qualities**.
- Choose your data services, wisely. Be aware of open source licenses.
- Strive for full lifecycle automation.
- On-demand provisioning of dedicated service instances.
- **Rebuild failed instances instead of fixing them**.
- Design for scalability.

# Principles

- Operational model first, automation second.
- Be a **backup**/**restore** hero.
- Solve issues on the **framework** level, fine-tune data service specifically.
- **Test** code. **Test** service instances. **Test** desired and undesired behavior.
- Provide meaningful default configuration values. Except custom config parameters.

# Principles

- Don't touch upstream code, except for …
- Master **release management**
- **Deliver releases** into target environments quickly
- Collect feedback from users (e.g. through support)
- Provide meaningful documentation. Better documentation, less support.

# Data Service Automation with Kubernetes



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# Ways to Implement an „Operator“



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# Data Service Automation with K8s

- Kubernetes CRDs + Custom Controllers
- Operator SDK
- KUDO

# Stages of Development



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# Data Service Automation with K8s

- Operational Model - Level 1: What a sysop/DBA would do.
- Operational Model - Level 2: Containerization, YAML + `kubectl`
- Operational Model - Level 3: Operator
- Operational Model - Level 4: Operator Lifecycle Management



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# CRDs

```yaml
apiVersion: apiextensions.k8s.io/v1
kind: CustomResourceDefinition
metadata:
  # name must match the spec fields below, and be in the form: <plural>.<group>
  name: pgs.ds.a9s.io
spec:
  # group name to use for REST API: /apis/<group>/<version>
  group: ds.a9s.io
  # list of versions supported by this CustomResourceDefinition
  versions:
    - name: v1
      # Each version can be enabled/disabled by Served flag.
      served: true
      # One and only one version must be marked as the storage version.
      storage: true
      schema:
        openAPIV3Schema:
          type: object
          description: Yeah! Science!
          properties:
            spec:
              type: object
              required: ["replicas"]
              properties:
                postgresVersion:
                  type: string
                  # pattern: major.minor.patchlevel or major.minor > determine patchlevel automatically
                  default: "12.2"
                # postgresPlugins:
                #   type: array
                replicas:
                  type: integer
                  # pattern: 2n+1
                  minimum: 1
                  default: 1
  # either Namespaced or Cluster. Namespaced as data service instances should belong to a namespace.
  scope: Namespaced
  names:
    # plural name to be used in the URL: /apis/<group>/<version>/<plural>
    plural: pgs
    # singular name to be used as an alias on the CLI and for display
    singular: pg
    # kind is normally the CamelCased singular type. Your resource manifests use this.
    kind: PostgreSQL
    # shortNames allow shorter string to match your resource on the CLI
    shortNames:
      - pg
      - pgs
```



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```yaml
apiVersion: ds.a9s.io/v1
kind: PostgreSQL
metadata:
  name: pg-1
spec:
  postgresVersion: "12.2"
  replicas: 3
```

# K8s CRDs

- CRD = Custom Resource Definition
- Introduce custom data structures to Kubernetes
- Kubernetes provides an endpoint for managing these objects
- Kubernetes provides persistency by storing them in its etcd.

# Controllers

```go
// [...]

// add adds a new Controller to mgr with r as the reconcile.Reconciler
func add(mgr manager.Manager, r reconcile.Reconciler) error {

  // Create a new controller
  // [...]

  // Watch for changes to primary resource Memcached
  err = c.Watch(&source.Kind{Type: &cachev1alpha1.Memcached{}}, &handler.EnqueueRequestForObject{})
  if err != nil {
    return err
  }

  // TODO(user): Modify this to be the types you create that are owned by the primary resource
  // Watch for changes to secondary resource Pods and requeue the owner Memcached
  err = c.Watch(&source.Kind{Type: &corev1.Pod{}}, &handler.EnqueueRequestForOwner{
    IsController: true,
    OwnerType:    &cachev1alpha1.Memcached{},
  })

  // [...]
}
```



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```go
func (r *ReconcileMemcached) Reconcile(request reconcile.Request)
(reconcile.Result, error) {
  reqLogger := log.WithValues("Request.Namespace", request.Namespace,
"Request.Name", request.Name)
  reqLogger.Info("Reconciling Memcached")

  // Fetch the Memcached instance
  instance := &cachev1alpha1.Memcached{}

 err := r.client.Get(context.TODO(), request.NamespacedName, instance) //
Retrieve the object

  if err != nil {
    if errors.IsNotFound(err) {
      // Request object not found, could have been deleted after reconcile
request.
      // Owned objects are automatically garbage collected. For additional
cleanup logic use finalizers.
      // Return and don't requeue
      return reconcile.Result{}, nil
    }
    // Error reading the object - requeue the request.
    return reconcile.Result{}, err
  }

  // Define a new Pod object (similar to a YAML Spec)
  pod := newPodForCR(instance)

  if err := controllerutil.SetControllerReference(instance, pod, r.scheme);
err != nil {
    return reconcile.Result{}, err
  }
```

```go
  // Check if this Pod already exists
  found := &corev1.Pod{} // Empty Pod object

  err = r.client.Get(context.TODO(), types.NamespacedName{Name: pod.Name,
Namespace: pod.Namespace}, found)

  // If an error occurs and in particular the error is of the type NotFound then
we know the Pod doesn't exist.
  if err != nil && errors.IsNotFound(err) {
    reqLogger.Info("Creating a new Pod", "Pod.Namespace", pod.Namespace,
"Pod.Name", pod.Name)

    // Create the secondary objects ... in this case a single pod.
    err = r.client.Create(context.TODO(), pod)
    if err != nil {
      return reconcile.Result{}, err
    }

    // Pod created successfully - don't requeue
    return reconcile.Result{}, nil
  } else if err != nil {
    return reconcile.Result{}, err
  }

  // Pod already exists - don't requeue
  reqLogger.Info("Skip reconcile: Pod already exists", "Pod.Namespace",
found.Namespace, "Pod.Name", found.Name)
  return reconcile.Result{}, nil
}
```

# K8s Controllers

- Read custom resource object specifications
- Translate **primary resources** into a set of **secondary resources**.
- E.g. a **PostgreSQL** resource into a **Service** and a **StatefulSet**.
- Watches the primary spec for changes.
- Ensures secondary resources to comply to the desired state of the primary's spec.



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# Common Pitfalls

- Underestimate complexity and effort
- Insufficient coverage of essential lifecycle operations
- Too little robustness, observability and predictability
- Applying automation that doesn’t fit the context

# What Organizations Want

- Expose lifecycle operations using Kubernetes Custom Resources (CRDs)
- **On-Demand Provisioning of Dedicated Service-Instances**
- Allow **configuration updates**
- Provide **monitoring** of health and status
- Infrastructure-agnostic
- Runs on different Kubernetes flavors.
- Authentication with dedicated user for each application accessing the DSI



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- **Horizontal** 2n+1 DSI **scalability**: 1, 3, 5 ….
- Automatic failure detection and **fail-over**. Self-healing to recover degraded clustered service instances.
- Host-anti-affinity. Support for **multiple AZs**.
- **Vertical** DSI **scalability**: replace small pods with larger pods with even larger pods, …
- Provide **backup and restore** capabilities with the ability to create backup schedules.



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- Stream backups to external object stores.
- Allow **choosing data service versions**.
- Documentation.
- **Encryption at rest and encryption at transit**.
- …

# The Long Life of a Service Instance

# Data Service Automation

Install Operator

Update Operator

Update Operator Configuration

Delete Operator

Create Service Instance

Delete Service Instance

Add log sink

Add metrics sink

Add alerting rule

Vertical scale-up

Horizontal scale-out

Patch-level upgrade

Minor upgrade

Major upgrade

Change configuration setting

**Create service-binding**

**Delete service-binding**

Create a backup schedule

Create backup

Restore backup

Enable (Postgresql) extension

Disable (Postgresql) extension

Network Delay Fluctuation

Network Bandwidth Fluctuation

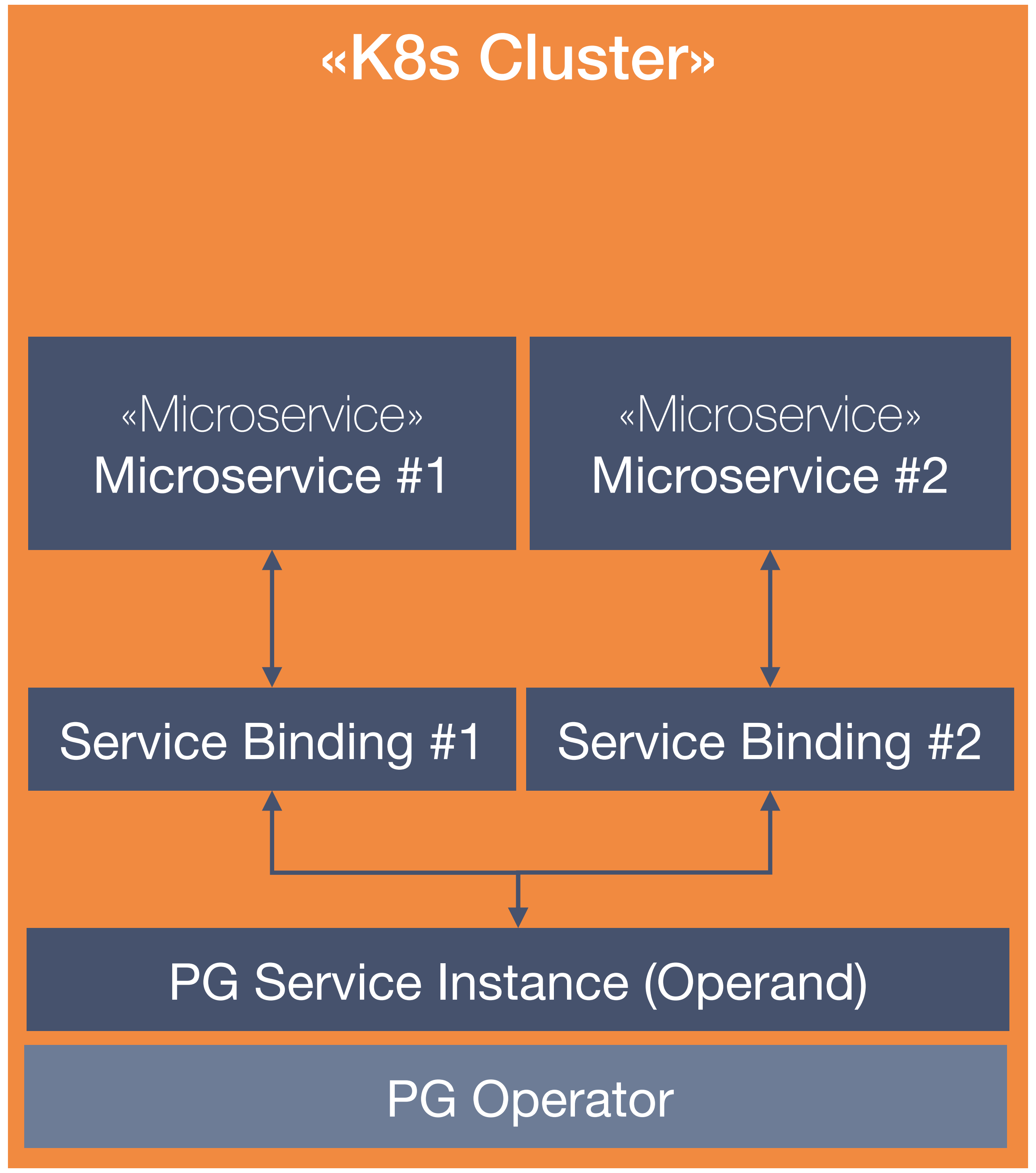
Network Partitioning

Availability Zone Failure

Kubernetes Node Failure

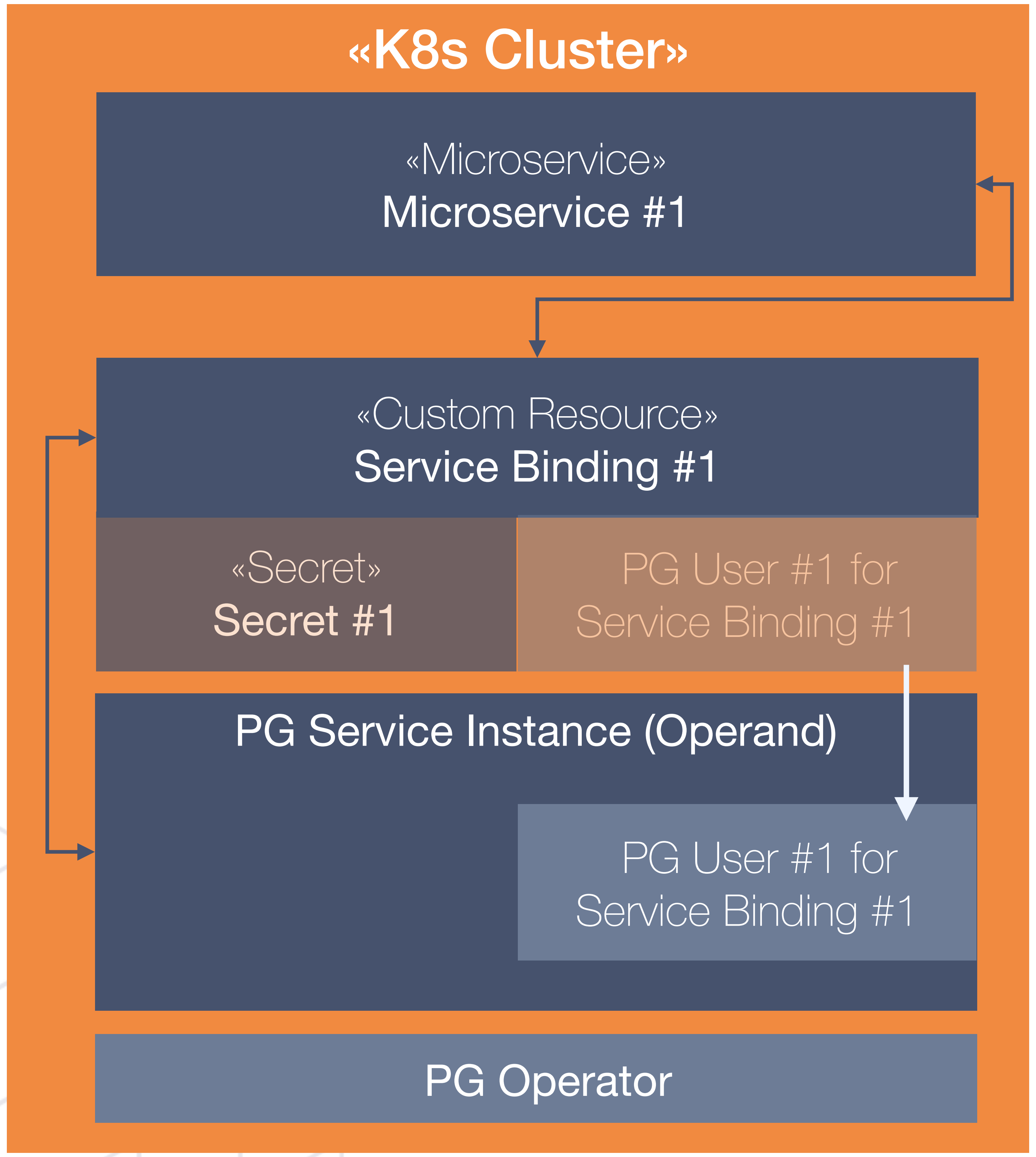
# Service Bindings

# Service Bindings




A Service Binding represents the connection between an app and a data service instance.

# Service Bindings




A Service Binding comprises a Kubernetes Secret as well as a user in the managed data service, e.g. a PostgreSQL user.

Both user and secret are unique to a particular Service Binding.



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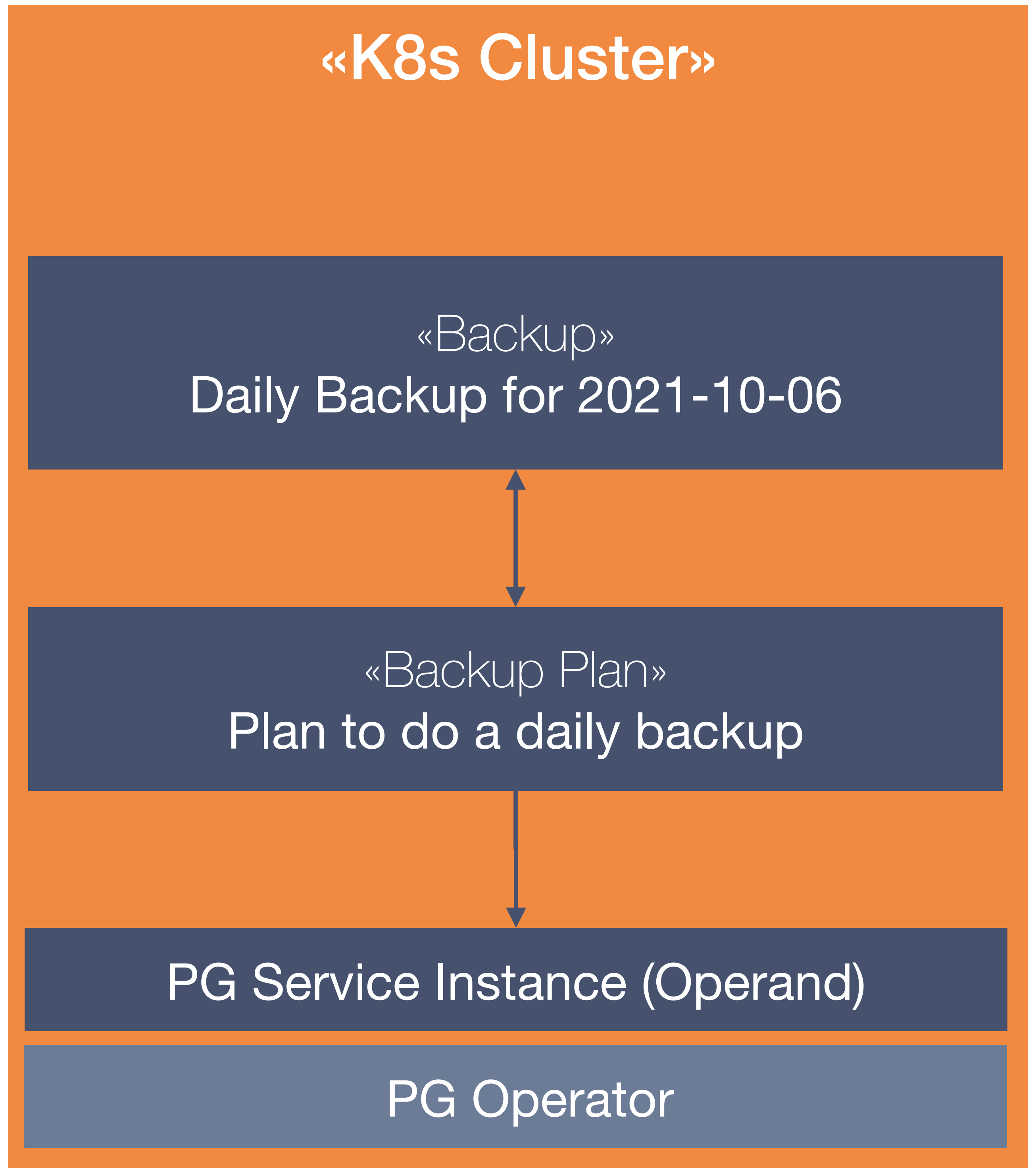
# Backups

# Backups




A single K8s cluster
with multiple service-instances
managed by a multiple Operators.

# Technology

# Writing Controllers

# Reconciling External Resources



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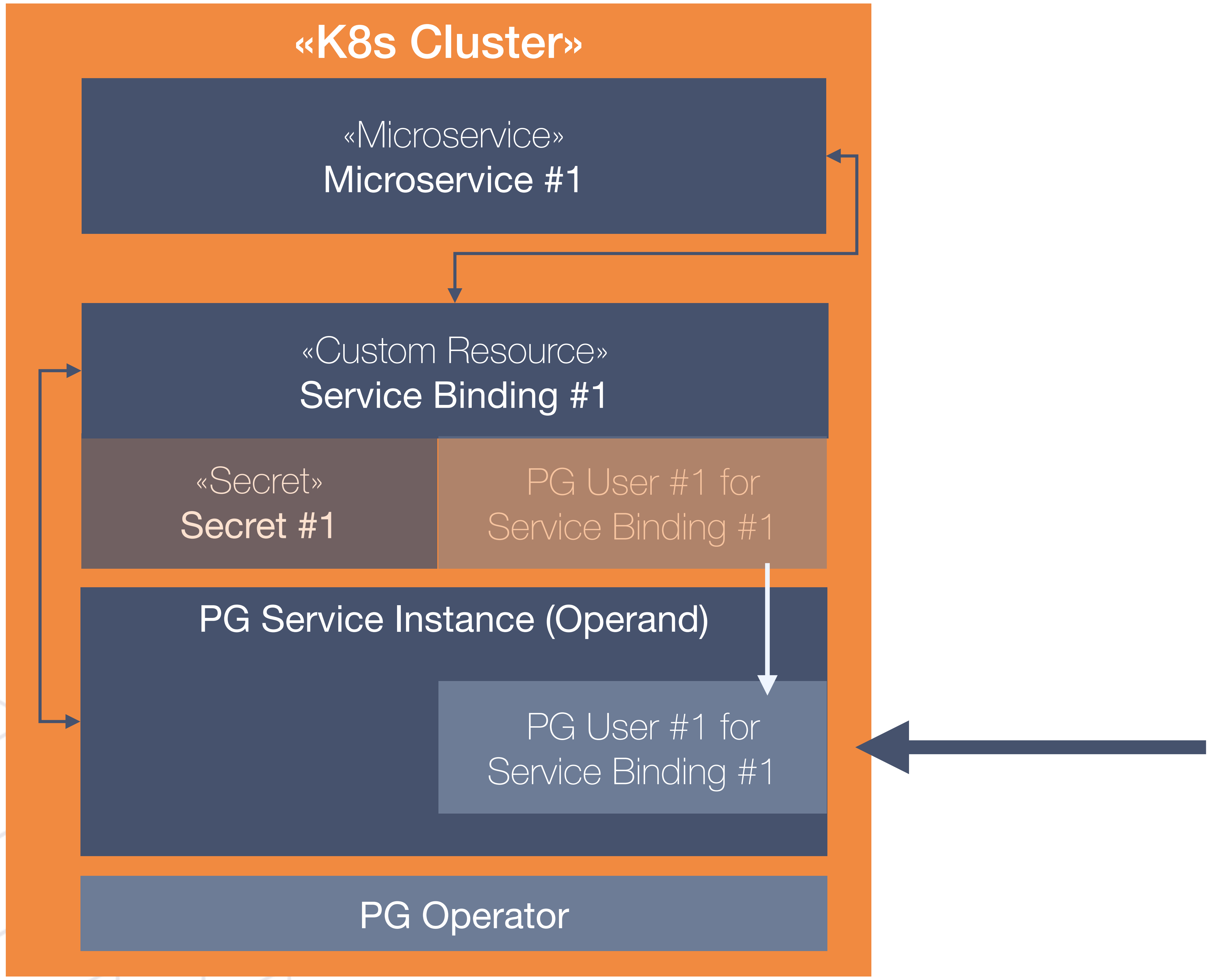
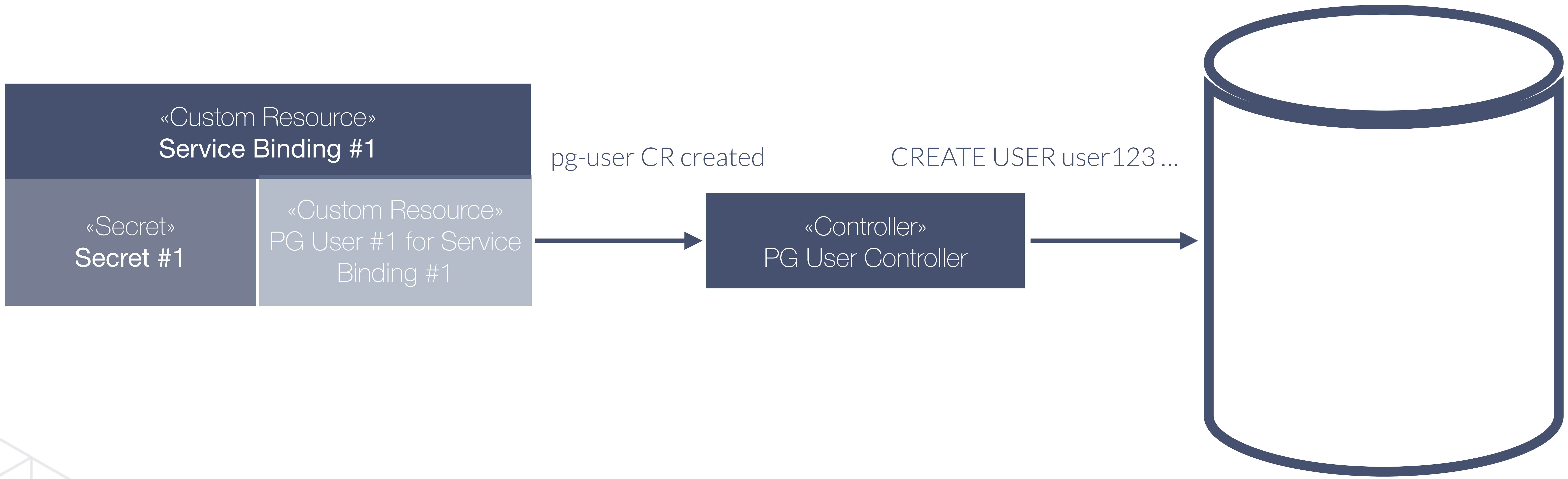



How to reconcile the postgres user?



«Custom Resource»
Service Binding #1
«Secret»
Secret #1
«Custom Resource»
PG User #1 for Service Binding #1
pg-user CR created
«Controller»
PG User Controller
CREATE USER user123 ...

# CREATE USER



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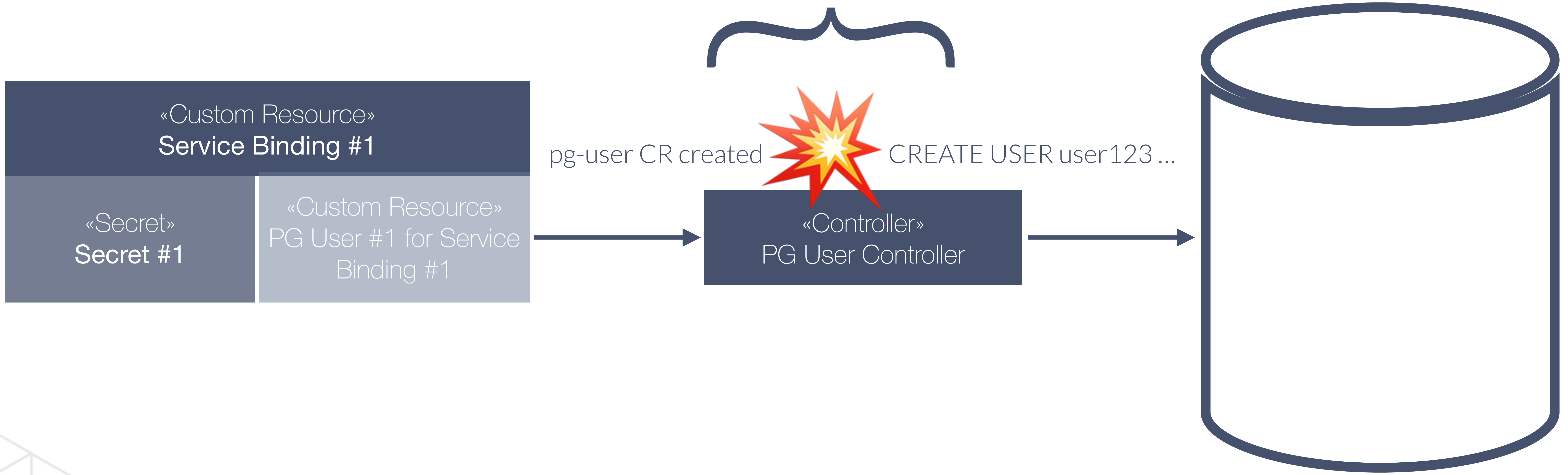
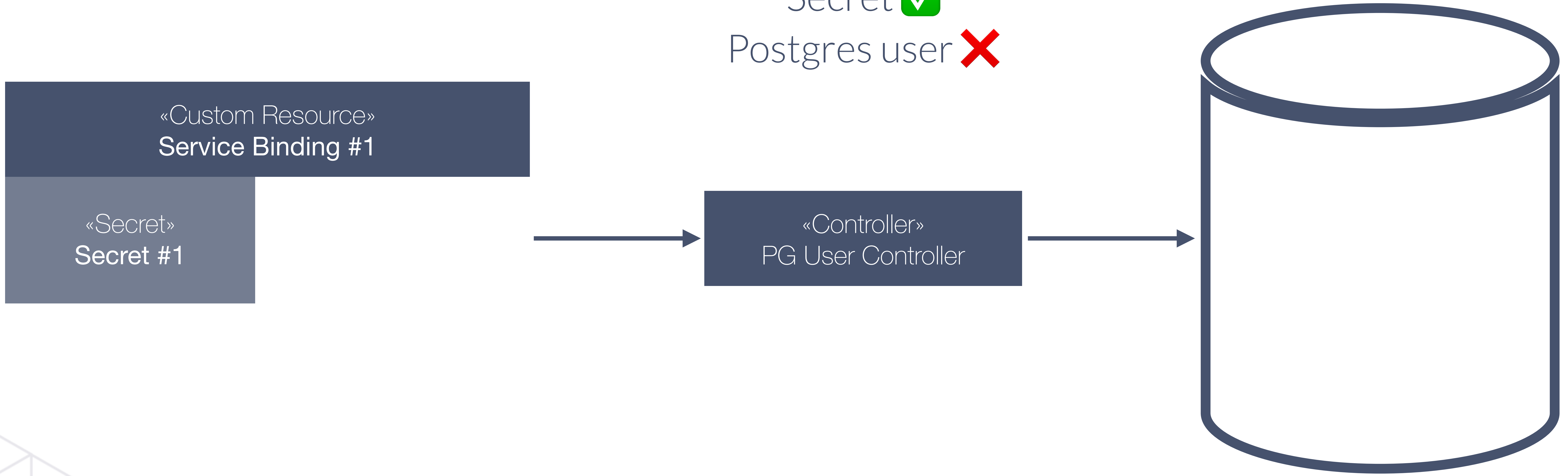
Careful ⚠️ This is not a transaction.
Atomicity is not guaranteed.



## Inconsistent state.

Secret ✅
Postgres user ❌



Be prepared to
re-reconcile by making
actions idempotent.



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# CREATE USER
# IF NOT EXISTS



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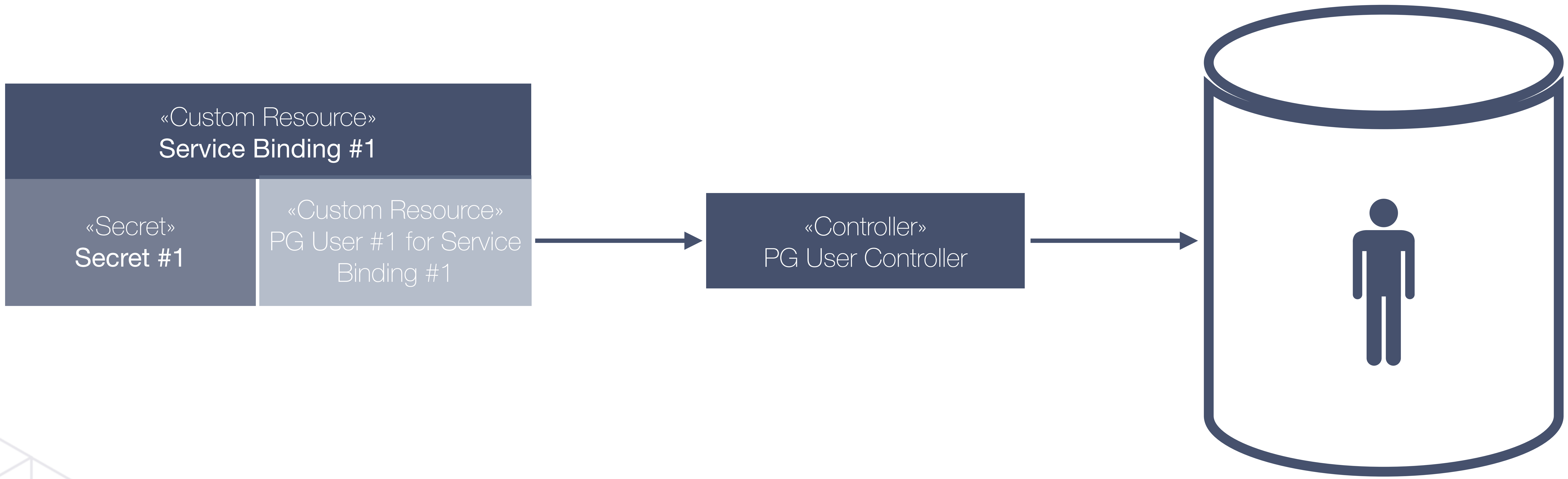

«Custom Resource»
Service Binding #1
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Secret #1
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PG User #1 for Service Binding #1
«Controller»
PG User Controller

# Summary

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a9s LogMe

# Questions?
# @anynines
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# Thank You!


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