CLO24 -- Kubernetes -- Niklas Häll (2025)

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# Project: Description here

# 1. Introduction

Lorum Ipsum

## 1.1 The entire project can be found at GitHub

Made you look! <https://github.com/mymh13/kube-snake>

## 1.2 Prerequisites (knowledge, accounts and software installs)

To replicate this system, you are expected to know and have:

* Point 1
* Point 2
* Point 3

# 2. Overview of the project

Lorum Ipsum overview-um

## 2.1 Choices, choices.. why when what how?

A rough overview would be this: Lorum Ipsum

## 2.2 General overview: Infrastructure

choices

## 2.3 General overview: Kubernetes

Choices

## 2.4 General overview: DevOps, GitOps, CI/CD, IaC

We elaborate about the various DevOps-concepts in the in-depth section below, but we really should what is mutual and what is different across these concepts.

## 2.5 General overview: .NET

choices

## 2.6 General overview: LLM in this project

Explanation here

## 2.7 The system in action

An overview of the natural flow within the system:

### 2.7.1 bla bla flowchart

1. List 1
2. List 2
3. List 3
4. List 4

### 2.7.2 blu blu flowchart

1. Further listing
2. Further listing 2

### 2.7.3 User interaction flowchart

1. More lists
2. More lists 2

Example below: can look like this

# 3. Infrastructure in-depth

Intro text

## 3.1 Verification and troubleshooting: Infrastructure

Common issues and where to look:

* list

# 4. Kubernetes in-depth

Text

Explain concepts like StatefulSet and -pvc (Persistent Volume Claim), how PVC “claims”/requests a specific storage (i.e 10 GB) and how the StatefulSet then uses the PVC to give pods stable network identity and ordered deployment. A restart of Kubernetes will mount the same PVC, which means the data is intact. This is vital since pods are ephemeral (can die).

Explain Helm – make an analogy – maybe compare it to a package manager (like apt/yum for Linux). Instead of managing individual YAML files with kubectl apply, we package everything into a Helm Chart. Elaborate how (why should be kind of self-explainable: after all we want to automate our infrastructure, no? 😊 haha). Still though: Resuability (same chart but different values for dev/staging/prod), templating, versioning, dependencies etc.

# X. Section Number?: Sealed Secrets

To handle [Kubernetes Secrets and the Helm charts](#_10.2_Kubernetes_secrets) in a way that does not expose credentials, I decided to use Sealed Secrets. What is it?

* A Kubernetes controller that runs in your cluster
* You encrypt secrets locally with a public key
* Only the controller (with the private key) can decrypt them
* You commit the encrypted SealedSecret to Git safely
* The controller automatically creates the actual Secret in K3s

The process of working with this is simply to SSH to the VM and run this:

kubectl apply -f https://github.com/bitnami-labs/sealed-secrets/releases/download/v0.24.5/controller.yaml

Then we need a kubeseal CLI tool locally on our workstation. I downloaded kubeseal, set the .exe in a /bin/kubeseal directory behind the user and added it to Windows PATH. Now I can use kubeseal commands in my Bash terminal. There is a flurry of commands after this, but the timeline is roughly:

1. Copy the kubeconfig from the VM to your workstation
2. Fix the server IP in K3s-config
3. Verify it changed (grep "server:" ~/.kube/k3s-config)
4. Backup current config, then merge the local and VM-K3s-configs
5. See available contexts (should see docker-desktop and default = K3s)
6. Switch to K3s (kubectl config use-context default)
7. Verify (kubectl get nodes)
8. Create a secret yaml-file hidden locally
9. Encrypt it so only the K3s-cluster can decrypt it
10. Verify (I cat’d the secret, noticed the SealedSecret tag + encrypted string, then deleted the cat’d file)

That was it, now there is a connection and encryption running. At this strage I updated the charts to reflect these changes too.

# X. Section number?: HELM and ArgoCD in-depth

Some intro here

## X.1 Let us stay on top of things, like a HELM

The structure in Helm is like building a house from a blueprint:

* Chart.yaml - The blueprint cover sheet (metadata: name, version, description)
* values.yaml - The customization form (configurable settings like replica count,

image tags, ports - default values that can be overridden, similar to properties

in a .NET class)

* templates/deployment.yaml - Construction instructions for the application

(creates the pods/containers that run your code, using Chart + values to generate

the actual Kubernetes manifest)

* templates/service.yaml - Utility hookup instructions (creates the network endpoint

that exposes your application and routes traffic to the pods, also uses Chart +

values for configuration)

The deployment creates the workers (pods), the service creates the front door (network routing).

As I am running the Helm CLI locally, I can use verify syntax locally by typing this: helm lint ./helm/charts/healthcheck

### X.1.1 Further down the road, we got to StatefulSet

..which we defined in statefulset.yaml. This literally works like a config file (for the deployment, it is a Kubernetes configuration for running MongoDB – MongoDB has its own config files), a general understanding of the symbiosis between them could be this:

Chart.yaml says “this is a MongoDB chart, version x.x.x”. values.yaml then says “here are the default settings, username, password, storage size etc”. Then statefulset.yaml says “here’s *how* Kubernetes should deploy and run MongoDB using those settings”.

## X.2 Do not ArgoCD with me

Let us keep the house building analogy:

ArgoCD is the logistics operator. We update the blueprint (Git), then ArgoCD delivers the material and make sure the construction matches the blueprint. If someone manually changes something on-site, ArgoCD says “that is not in the blueprint!” and fixes it back.

ArgoCD is installed locally on the VM, gets its own namespace within the cluster, I install its files and then I have a backend running a server pod (API + web server), a controller (watches Git, syncs to Kubernetes), a repo server (clones Git repos) and it all runs in the namespace within the cluster.

It also has a frontend, which is a web dashboard we can access via a browser. It shows all our applications, sync status, health. It lets us manually trigger syncs, view logs, etc:

* Your Browser (anywhere on internet) –>
* <https://argocd.kube-snake.mymh.dev> ->
* Caddy reverse proxy (VM, port 443) ->
* ArgoCD server service (K8s ClusterIP 10.43.247.196:443) ->
* ArgoCD server pod (running in argocd namespace)

### X.2.1 How does ArgoCD replace GitHub Actions workflow?

ArgoCD uses POLLING, not webhooks or triggers.

1. Every 3 minutes (default), ArgoCD makes a Git request to GitHub
2. It checks: "Is the commit SHA different from what I last deployed?"
3. If YES -> Triggers a sync (pulls the new code, applies it)
4. If NO –> Does nothing, waits another 3 minutes

This means: No GitHub runners, no webhooks, no triggers. Just ArgoCD constantly checking. The polling interval can be configured, or set up webhooks for instant syncs, but polling is a good way to handle traffic and costs.

# 9. Where to go (improvement possibilities)

There are quite a lot of roads leading to Rome, but let us look at a few..

## 9.1 Security

Strengths: strengths listed

Improvements: improvements listed

## 9.2 CI/CD analysis

Strengths: strengths listed

Improvements: improvements listed

## 9.3 Scalability analysis

Strengths: strengths listed

Improvements: improvements listed

## 9.4 Cost analysis

Thoughts on the topic here

## 9.5 Logs and metrics

Strengths: strengths listed

Improvements: improvements listed

## 9.6 Other areas that might be worth considering

Lorum ipsum

# 10. Challenges and lessons learned

List here

## 10.1 Versioning funkyness

There are multiple ways of writing “versions” as I notice early on. An example from a basic Helm chart template:

apiVersion: v2

name: healthcheck

description: A Helm chart for the Kube-Snake healthcheck page

type: application

version: 0.1.0

appVersion: "1.0"

apiVersion in this case means what Chart-format we are using: v1 is the old Helm 2-format, it is now deprecated, and v2 is the Helm 3 format which is the current standard. Yes, Helm 3 is v2, but it gets more confusing:

the “version” on line 5 there is our version number for the chart itself. We increment it following a standard:

* 0.1.0 – Initial version
* 0.1.1 – Bug fix
* 0.2.0 – New feature added
* 1.0.0 – First stable release

We must follow this semantic versioning (major – minor – patch).

Then we also have the “api-version” in the Kubernetes manifests itself, for example apps/v1. This tells Kubernetes which API version to use for the specific resource type. Kubernetes has different APIs that evolve over time:

* apps/v1 – Stable API for Deployments, StatefulSets, DaemonSets
* v1 – Core API for Pods, Services, ConfigMaps
* batch/v1 – For Jobs, Cronjobs

Not the very least confusing and easy to mix up.. :rolleyes: but important lesson!

## 10.2 Kubernetes secrets handling and automation

This one is causing some interesting problems. In the Helm chart values.yaml, we set the credentials for (among other things) MongoDB. We could set the secrets like this:

auth:

  rootUsername: admin

  rootPassword: changeme123  # CHANGE THIS in production!

  database: snake\_game

But that would mean our secrets would be exposed in our GitHub repo. Not good. We also need to make sure we do not put template values here that we override, because that would mean if the override ever failed, then our real credentials will be overwritten by the template values!

There are multiple solutions:

1. Sealed Secrets
   * Encrypt secrets before committing to Git
   * Only K3s can decrypt them
   * Tool example: Bitnami Sealed Secrets
2. External Secrets Operator:

* Store secrets in a vault (Azure Key Vault, AWS Secrets Manager, etc.)
* K3s pulls them at runtime
* Git only contains references, not actual secrets

1. Manual Secret creation (Simple):

* Remove secret.yaml from Helm chart
* Manually create the Secret in K3s once via SSH
* Never commit it to Git
* Helm chart just references it

1. values.yaml override (Quick fix):
   * Keep placeholder values in Git (changeme123)
   * Override with real values during deployment using --set flags
   * Not ideal solution

My choice of solution:

Normally I would want the most robust and long-term solution. Since this is a small project, I am tempted to do option #3 here, but since option #1 is more robust and better in the long run, I will choose [Sealed Secrets](#_X.__Section). It will cause me more headache to set up but it is better practice.

# 11. Build timeline

The GitHub repository will provide a more detailed history, which I also outline more specifically in modules in the markdown-documents inside the project (/docs/phase\_<phase-number>). But this serves as a rough outline of progression, to show how the system came to life.

## 11.1 Phase one – Let the Kube-Snake loose!

Goal: Establish K3s infrastructure and CI/CD pipeline with automated healthcheck deploy.

### 11.1.1 Phase one, step one – Local Development & Remote Infrastructure

Rudimentary infrastructure and a landing page:

1. Project Planning & Setup

* Laid down the general architecture and plan for the project
* Created GitHub repository and local project structure with pre-set directories
* Created architecture documentation (architecture.md)

2. Local K3s Testing (Docker Desktop)

* Verified K3s cluster working in Docker Desktop environment
* Created nginx-health-check-page.yaml deployment manifest
* Tested basic kubectl commands and internal cluster networking

3. Remote Infrastructure Preparation (Hetzner VM)

* Updated VM: apt update && apt upgrade && reboot
* Installed K3s with Traefik disabled: curl -sfL https://get.k3s.io | sh -s - --disable=traefik
* Configured kubectl access: set user permissions on kubeconfig, added KUBECONFIG to .bashrc

4. Deploy Healthcheck to Remote Cluster

* Deployed nginx healthcheck directly to VM via SSH using kubectl apply
* Verified internal service running (ClusterIP: 10.43.39.44:80)

5. External Access Configuration

* Configured Caddy reverse proxy: edited /etc/caddy/Caddyfile with subdomain block
* Added DNS A record pointing subdomain to VM IP
* Verified SSL certificate auto-provisioned by Caddy
* Confirmed external access at https://kube-snake.mymh.dev

Flow: Internet > Caddy (VM) > K3s Service > nginx container (pod)

### 11.1.2 Phase one, step two – CI/CD Pipeline Implementation

Automated deployment workflow using GitHub Actions

1. Custom Healthcheck Container

* Created custom index.html landing page with status information
* Created Dockerfile using nginx:alpine base image
* Added styles.css for consistent styling and favicon.ico

2. GitHub Actions Workflow Setup

* Created deploy-healthcheck.yml with build and deploy jobs
* Configured workflow to build Docker image and push to GitHub Container Registry (GHCR)
* Updated nginx-health-check-page.yaml to use custom GHCR image

3. Secrets & Authentication Configuration

* Added GitHub repository secrets: SSH\_HOST, SSH\_USER, SSH\_PRIVATE\_KEY
* Cloned repository to VM for kubectl access during deployment
* Resolved SSH authentication issues (key format, passphrase handling)

4. Deployment Automation & Testing

* Implemented automated deployment: Git push > Docker build > GHCR push > kubectl deploy
* Fixed image caching issue: added imagePullPolicy: Always and SHA-based tagging
* Modified workflow to use kubectl set image with commit SHA tags for reliable updates
* Verified end-to-end CI/CD pipeline working successfully

Updated Flow**:** Git Push > GitHub Actions > Build Image > GHCR > SSH to VM > kubectl set image > Pod Update

## 11.2 Phase two, microscopic services under the hood

### Goal: Implement GitOps tooling (Helm + ArgoCD) and deploy MongoDB as first stateful workload.

### 11.2.1 Phase two, step one – who’s at the HELM anyway?

Converting from raw manifests to reusable Helm charts:

1. Helm installation and Chart structure

* Installed Helm v3.19.0 on local machine and VM
* Created Helm chart structure in /helm/charts/healthcheck
* Created Chart.yaml with metadata (name, version, description)
* Created values.yaml with configureable parameters (image, replicas: 2, service conf)

2. Template Creation

* Templated deployment.yaml using {{ .Chart.Name }} and {{ .Values.\* }} syntax
* Templated service.yaml with dynamic naming and port configuration
* Validated chart with helm lint (passed with no errors)
* Tested template output with helm template to verify YAML generation

3. GitHub Actions workflow migration

* Updated workflow trigger paths to watch helm/charts/healthcheck/\*\*
* Replaced kubectl set image with helm upgrade –install
* Added --set image.tag=${IMAGE\_TAG} to override tag with commit SHA
* Added --wait and --timeout=2m for deployment verification

4. Security and Deployment

* Fixed SSH key exposure: added log-public-key: false to webfactory/ssh-agent
* Rotated compromised SSH key immediately
* Successfully deployed healthcheck with 2 replicas via Helm
* Verified both pods running and load-balanced by ClusterIP service

Updated Flow**:** Git Push > GitHub Actions > Build Image > GHCR > SSH to VM > helm upgrade –install with SHA tag 2 Pods running

Key differences from kubectl approach:

* Configurable via values.yaml instead of hardcoded manifests
* Single command deploys/updates everything
* Version-controlled chart can be reused across environments
* Foundation ready for ArgoCD GitOps automation

### 11.2.2 Phase two, step two – ArgoCD: GitOps in Action(s)

Installing and configuring continuous deployment automation:

1. ArgoCD Installation and Access

* Deployed ArgoCD v3.19.0 to K3s cluster in dedicated argocd namespace
* Created DNS A record for argocd.kube-snake.mymh.dev pointing to VM IP
* Configured Caddy reverse proxy with ClusterIP 10.43.247.196:443
* Added security headers (HSTS, X-Content-Type-Options, X-Frame-Options)
* Retrieved initial admin password from argocd-initial-admin-secret
* Successfully accessed ArgoCD UI via HTTPS

1. DNS and Network Configuration

* Discovered Caddy (running outside K8s) cannot resolve .svc.cluster.local DNS names
* Solution: Used ClusterIP addresses directly in Caddy configuration
* Applied same fix to healthcheck service (10.43.101.38:80)
* Learned: Kubernetes internal DNS only works from within the cluster

1. ArgoCD Architecture Understanding

* ArgoCD uses polling (default every 3 minutes) to check Git for changes
* No webhooks or GitHub runners required - ArgoCD actively queries GitHub
* Compares commit SHA to detect new changes
* Self-contained CD system running entirely within K8s cluster

Key Learning: ArgoCD provides GitOps without external dependencies - it polls Git, detects changes, and syncs automatically.

### 11.2.3 Phase two, step three – GitOps Workflow Integration

Transitioning from GitHub Actions deployment to ArgoCD-managed deployments:

1. ArgoCD Application Configuration

* Created Application manifest in healthcheck.yaml
* Configured source: GitHub repo mymh13/kube-snake, branch main, path healthcheck
* Configured destination: same cluster, default namespace
* Enabled automated sync policy with prune: true and selfHeal: true
* Applied manifest: kubectl apply -f argocd/applications/healthcheck.yaml

1. Self-Healing Verification

* Tested manual intervention: scaled deployment from 2 to 1 replica
* ArgoCD detected drift within seconds
* Automatically restored to 2 replicas (Git state)
* Confirmed: Git is the single source of truth, manual changes are reverted

1. GitHub Actions Workflow Refactor

* Renamed workflow: "Build and Deploy" -> "Build Healthcheck Image"
* Removed entire deploy job (SSH, Helm install steps)
* Removed helm/charts/healthcheck/\*\* from trigger paths
* Workflow now only: builds Docker image -> pushes to GHCR
* Added success message explaining ArgoCD handles deployment

1. Separation of Concerns Achieved
   * CI (GitHub Actions): Builds container images on code changes
   * CD (ArgoCD): Deploys Helm charts on Git changes
   * ArgoCD polls Git every 3 minutes for chart updates
   * Clean separation: code changes trigger builds, config changes trigger deploys

Updated Flow: Git Push -> GitHub Actions (build image only) -> GHCR | Git Push (Helm chart changes) -> ArgoCD polls -> detects change -> syncs deployment

Key Achievement: Full GitOps implementation - all deployments managed declaratively through Git, with automatic synchronization and self-healing.

### 11.2.4 Phase two, step four – MongDB: Stateful workloads

First database deployment with persistent storage:

1. MongoDB Helm Chart Creation
   * Created Helm chart structure in mongodb
   * Configured StatefulSet (not Deployment) for stable pod identity
   * Created Chart.yaml with metadata (MongoDB v0.1.0, app version 7.0)
   * Created values.yaml with configurable parameters (1 replica, 5Gi storage, resource limits)
   * Templated statefulset.yaml, service.yaml, and sealedsecret.yaml
   * Validated chart with helm lint (passed) and helm template (verified output)
2. Sealed Secrets Implementation

* Installed Bitnami Sealed Secrets controller (v0.24.5) in K3s cluster
* Installed kubeseal CLI tool (v0.24.5) locally on Windows machine
* Configured local kubectl to connect to K3s cluster from local machine (merged kubeconfig)
* Created plain Secret with MongoDB credentials (username, password, database)
* Encrypted Secret using kubeseal with cluster's public key
* Generated SealedSecret with encrypted data safe for public Git repository
* Removed plaintext credentials from values.yaml and temporary files

1. StatefulSet and Storage Configuration

* StatefulSet provides stable network identity: mongodb-0.mongodb-service.default.svc.cluster.local
* VolumeClaimTemplate automatically creates PersistentVolumeClaim per pod
* 5Gi storage using K3s local-path storage class with ReadWriteOnce access
* Headless Service (clusterIP: None) for StatefulSet DNS resolution

1. ArgoCD Application Manifest

* Created Application manifest in mongodb.yaml
* Configured source and destination
* Enabled automated sync policy with prune: true and selfHeal: true
* Ready for deployment via kubectl apply -f argocd/applications/mongodb.yaml

Updated Flow: MongoDB credentials encrypted locally -> SealedSecret committed to Git -> ArgoCD syncs chart -> K3s Sealed Secrets controller decrypts -> MongoDB pods start with credentials -> PVC attached to pod -> Data persists on VM disk

Key Learnings:

* StatefulSets vs Deployments: StatefulSets provide stable pod identities (mongodb-0, mongodb-1) required for databases, while Deployments treat pods as interchangeable
* Persistent Storage: VolumeClaimTemplates auto-create PVCs that survive pod deletion/recreation, ensuring data persistence
* Sealed Secrets Security: Credentials encrypted with cluster's public key before Git commit; only cluster's private key can decrypt them
* Headless Services: Required for StatefulSets to provide direct pod DNS resolution without load balancing

Security Achievement: MongoDB credentials encrypted end-to-end - safe to store in public GitHub repository, only K3s cluster can decrypt and use them.

### 11.2.5 Phase two, step five – .NET API Integration

Testing the full stack with a simple backend service:

1. First
2. Second

# 12. References and links

## 11.1 Our class’ studyguide/tutorial

<https://cloud-developer.educ8.se/clo/4.-run-cloud-applications/3.-kubernetes/index.html>

That webpage and the content is the property of Lars Appel, I am just referring to it.

## 11.2 LLM: Partners (and enemies) in crime

Claude 4.5 and ChatGPT 5

## 11.3 More references?

Provided here