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Project: Kube-Snake

1. Introduction

This project is based on an assignment in the Kubernetes-course at Campus Mölndal 2025. The assignment had several core constraints:

- Containerization – Application must be run in containers
- Persistence – Data must survive pod restarts
- Cloud deployment – Utilize cloud infrastructure
- Multiple deployment methods – Implement at least two deployment strategies (ultimate goal: ArgoCD + Helm)
- Ingress configuration – Understand and implement reverse proxy patterns

Goal: Build a basic .NET-application with MongoDB, deployed in a Kubernetes cluster.

On top of these requirements, I added a critical personal constraint: *sustainability*.

The project must remain operational after completion and submission without ongoing costs. This meant avoiding expensive cloud services like Azure AKS with Load Balancers, which would incur continuous charges just to keep the system running.

1.1 Project repository at GitHub

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

1.2 Prerequisites (knowledge, accounts and software installs)

To replicate this system, you need..

Knowledge requirements:

- Basic understanding of Bash or other CLI tools
- Linux fundamentals (install and configure system files)
- Basic understanding of cloud service setup and configuration
- Container concepts (Docker)
- Kubernetes fundamentals
- CI/CD pipeline basics
- HTMX or at least HTML/CSS basics

Required accounts:

- GitHub (source control + container registry)
- Docker Hub (costs!) or GitHub Container Registry (free) – image store
- Cloud service provider (Hetzner, Azure or similar)
- Domain registrar (if you chose to configure DNS for subdomain redirection like I did)

Software and tools – local development:

- Docker Desktop (initial testing)
- IDE of choice (I used VS Code)
- Kubectl (Kubernetes CLI), Git CLI
- Helm (package manager)
- Kubeseal CLI (for Bitnami Sealed Secrets)

Software and tools – deployed to cluster (via Helm/manifests):

- ArgoCD (GitOps CD – continuously delivery)
- Redis (Bitnami Helm Chart – distributed session storage)
- Bitnami Sealed Secrets (encrypt secrets)
- MongoDB (StatefulSet with persistence)

2. Overview of the project

The project tree structure looks like this:

```
Kube-Snake                  # Project root
│
├──.github
│   └──workflows            # GitHub Actions CI/CD pipelines
│
├──apps                     # Web applications
│   ├──backend              # (Future: Snake game backend)
```

```
│   ├── frontend            # (Future: Snake game frontend)
│   ├── guestbook           # .NET 9 Minimal API guestbook app
│   │   ├── Endpoints       # API endpoints (Auth, Messages)
│   │   ├── Extensions      # Service configuration extensions
│   │   ├── Helpers         # HTML rendering, authentication helpers
│   │   ├── Models          # Data models (Message)
│   │   ├── Properties      # Project properties
│   │   └── Services        # MongoDB service
│   └── healthcheck         # System health monitoring page
│
├── argocd
│   └── applications        # ArgoCD Application manifests
│
├── docs                    # Project documentation (phases, architecture)
│
├── helm
│   └── charts              # Helm charts for deployments
│       ├── guestbook       # Guestbook application chart
│       │   └── templates   # K8s manifests (Deployment, Service, etc.)
│       ├── healthcheck     # Healthcheck application chart
│       │   └── templates
│       ├── mongodb         # MongoDB StatefulSet chart
│       │   └── templates
│       └── secrets         # SealedSecrets for credentials
│
└── k8s
    ├── cert-manager        # TLS certificate management
    ├── guestbook           # (Legacy/manual K8s manifests)
    └── traefik             # Ingress controller configuration
```

2.1 Choices, choices.. why when what how?

Choices to be made initially or during the project included the below. It is not a complete list, and in-depth explanation will be found in other sections, but to name a few:

- Why K3s instead of managed Kubernetes (AKS/ESK)
- Why Hetzner Cloud over Azure/AWS/GCP
- Why HTMX instead of React/Vue/Node etc
- Why MongoDB for persistence
- Why Redis for session storage
- Why Caddy instead of Traefik/Nginx
- Why Sealed Secrets instead of external secret managers?

2.2 General overview: Infrastructure

The infrastructure is built on minimal, cost-effective components that provide production-grade reliability without ongoing cloud expenses. The foundation is a single VM running K3s, with persistent storage and automated TLS management.

- Hetzner Cloud VM (Ubuntu 22.04, 2 vCPU, 4GB RAM) – Cost-effective cloud hosting (€4.49/month – already pre-paid by other projects so this is essentially “free”)
- K3s lightweight Kubernetes distribution – Production-ready K8s without the overhead of managed services
- Local-path provisioner – K3s built-in storage provisioner for Persistent/Volumes (uses VM disk space)
- Caddy reverse proxy – Automatic TLS certificate management via Let’s Encrypt
- Domain setup – Subdomain kube-snake.mymh.dev with external DNS provider for -a-record pointing to VM IP

2.3 General overview: Kubernetes architecture

The Kubernetes cluster follows a microservices pattern with stateless application pods and stateful data stores. All components run in the default namespace, with ArgoCD managing deployments from its own namespace. The architecture enables horizontal scaling, persistent storage, and zero-downtime deployments.

- Namespaces: default (applications), argocd (GitOps controller), kube-system (k3s components)
- StatefulSets: MongoDB (persistent database), Redis (distributed session cache)
- Deployments: Guestbook (2 replicas), Healthcheck (2 replicas)
- Services: ClusterIP for internal pod-to-pod communication
- Ingress: Path-based routing - / (healthcheck), /guestbook (guestbook API)
- Persistent storage: PVCs for MongoDB data and ASP .NET DataProtection keys

2.4 General overview: GitOps + Deployment strategy

The deployment strategy combines three complementary tools to create a fully automated GitOps workflow. While each tool serves a distinct purpose, they work together to ensure that Git is the single source of truth for both application code and infrastructure configuration. Changes pushed to the main branch trigger an automated pipeline that builds, tags, and deploys new versions without manual intervention.

- Helm - Package manager for K3s manifests (templates, versioning, reusability)
- ArgoCD - Continuous delivery via Git polling (syncs cluster state with Git repo)
- GitHub Actions - CI/CD pipeline (build Docker images, tag with commit-SHA, push to GHCR)
- Trunk-based development - All changes committed directly to main branch

- Automated rollout - SHA-tagged images trigger ArgoCD sync, which pulls new image and performs rolling deployment

Key principle: Developers push code -> CI builds image -> CI updates manifests -> ArgoCD deploys. Zero manual kubectl commands in production.

2.5 General overview: CI/CD pipeline

The CI/CD pipeline is fully automated and triggered by code changes. When a developer pushes to the repository, GitHub Actions builds a new Docker image, tags it with the commit SHA for traceability, and updates the Helm values file. This GitOps approach ensures that every deployment is traceable to a specific commit and can be rolled back if needed.

- Trigger - GitHub Actions triggers on apps/guestbook/** changes
- Build – Multi-stage Dockerfile creates optimized production image (SKD stage –> runtime stage)
- Tag - Image tagged with commit SHA (main-<sha>) for version tracking
- Push – Image pushed to GitHub Container Registry (GHCR)
- Update manifests – CI bot automatically updates values.yaml with new image tag
- Commit & push – CI commits updated values-file using Personal Access Token (PAT)
- ArgoCD sync – ArgoCD polls every 30 minutes, detects change, and triggers rolling deployment

Key principle: Git is the single source of truth. Developers never manually edit cluster resources—all changes flow through Git, ensuring auditability and repeatability.

2.6 General overview: Application stack

The application layer uses a minimal technology stack that prioritizes simplicity and maintainability. The backend is a .NET Minimal API that serves HTML partials instead of JSON, enabling the frontend to use HTMX for dynamic interactions without heavy JavaScript frameworks. Authentication and session management are handled server-side, with stateless cookies and distributed session storage enabling horizontal scaling.

- Backend - .NET 9 Minimal API (guestbook)
- Frontend - HTMX embedded in static HTML (healthcheck)
- Database - MongoDB StatefulSet with PVC (Persistent Volume Claim)
- Session Store - Redis (Bitname Helm Chart) for distributed sessions
- Authentication - Cookie-based auth with admin credentials in Sealed Secrets

Key principle: Hypermedia over JSON APIs. The server sends ready-to-render HTML instead of raw data, reducing client-side complexity and eliminating the need for state management libraries.

2.7 General overview: Security and Secrets Management

Security is implemented through multiple layers, ensuring that sensitive data is never exposed in Git repositories or transmitted insecurely. Secrets are encrypted at rest (when stored in Git) using Bitnami Sealed Secrets, which allows safe storage in version control while maintaining GitOps principles. Runtime secrets are managed by Kubernetes, session cookies are configured with security flags to prevent common web vulnerabilities, and DataProtection keys are shared across replicas to ensure consistent cookie encryption.

- Sealed Secrets - Bitnami Sealed Secrets for Git-safe encryption
- Kubernetes Secrets - MongoDB credentials, admin credentials, Redis configuration
- GitHub Secrets - Personal Access Token (PAT) for CI/CD
- Cookie security – Session cookies configured with HttpOnly (prevents XSS), Secure (HTTPS only), SameSite=None (cross-origin requested)
- DataProtection keys – ASP .NET DataProtection keys stored on PersistentVolume, ensuring all replicas use the same encryption keys for cookie consistency.

Key principle: Secrets are encrypted before committing to Git. The Sealed Secrets controller running in the cluster is the only entity that can decrypt them, ensuring that even if the Git repository is compromised, secrets remain protected.

2.8 General overview: Session persistence strategy

Stateless applications require external session storage to support horizontal scaling. The default in-memory session cache only works with a single pod—when multiple replicas exist, users would be randomly routed to different pods that don't share session state. Redis solves this by providing a distributed cache accessible by all pods, enabling seamless session persistence across the cluster.

- Problem: In-memory sessions don't work with multiple replicas
- Solution: Redis as distributed cache (Bitnami Helm chart deployment)
- Session data stored in Redis (accessible by all pods via ClusterIP)
- Cookie configuration for HTTPS (SameSite=None, Secure=true)
- Horizontal scaling enabled (any pod can serve requests, query Redis)

Key principle: Pods remain stateless. All session state lives in Redis, allowing pods to be added, removed, or restarted without disrupting user sessions. This enables true horizontal scaling and zero-downtime deployments.

2.9 The system in action

An overview of the natural flow within the system:

2.9.1 GitOps Deployment Flowchart

```
Developer Push
```

```
    ↓
GitHub Actions (build + tag image)
    ↓
Push to GHCR
    ↓
Update values.yaml (automated)
    ↓
ArgoCD polls Git (every 30 min)
    ↓
Detect change -> Sync
    ↓
K3s pulls new image
    ↓
Rolling deployment
```

2.9.2 User Interaction Flowchart

```
User Browser (HTTPS)
    ↓
Caddy Reverse Proxy (VM:443) (HTTPS)
    ↓
K3s Ingress
    ↓
Healthcheck Service -> Healthcheck Pod
    ↓ (HTMX request to /guestbook/api/*)
Guestbook Service -> Guestbook Pod (any replica)
    ↓
MongoDB (read/write messages)
    ↓
Redis (session validation)
    ↓
Response (HTML partial via HTMX)
```

2.9.3 Admin (guestbook) Interaction Flowchart

```
Admin Login Form
    ↓
POST /guestbook/api/login
    ↓
Validate credentials (env vars from SealedSecret)
    ↓
Store session in Redis
    ↓
Set cookie (HttpOnly, Secure, SameSite=None)
    ↓
Return admin panel HTML
    ↓
Subsequent requests validate cookie -> Redis lookup
```

```
    ↓
Any pod can serve authenticated requests
```

2.10 General overview: LLM in this project

LLMs have been used in a variety of ways, and different types of LLMs.

Claude 4.5 has been my primary code support, it suggested tools I asked for when I was looking to solve problems. Redis is one such tool. ChatGPT 5 has been a resource when I asked general questions, and ChatGPT 4.1 has had a few looks at the code too. Claude has been helpful to automatically document in the docs/phase_number.md when I finished a section – I tell it to record what was built in and it kept those for me as “logs”/reference.

I want to stress that I primarily asked the LLMs for tools and options, virtually using it as a guide when I am trying to figure out system architecture or what software tools I have available.

2.10.1 LLMs, reading through code suggestions and mistakes

I have used LLMs extensively to generate or review code for me, but I have also been reviewing everything it does. For example: several times the LLMs have created either public logfiles (GitHub) or files that are open in my repository – where sensitive account information has been posted in plain sight.

Since I am here to learn, and I want to verify that whatever code is generated for me, I have been reviewing their code and found at least a handful of worrying instances. I have given them strict instructions not to generate more than a few lines of code at a time, so I can read through them myself, and I always ask what something means if I do not recognize it.

I want to be transparent though with what usage there has been. The two primary sources of generation has been to convert my code into markdown (the phase_number.md documents) and to generate sections of code when I felt it either a) speeds me up without me losing control or overview, and b) it has complexity levels and I realize they read through text faster than I do.

3. In-depth: Infrastructure in-depth

The infrastructure layer consists of a single Hetzner Cloud VM running K3s, a lightweight Kubernetes distribution that includes built-in storage provisioning and ingress capabilities. Caddy serves as the reverse proxy, providing automatic HTTPS certificate management through Let's Encrypt without manual configuration.

K3s includes a local-path provisioner that automatically creates persistent storage on the VM's disk when pods request PersistentVolumeClaims. This eliminates the need for external storage solutions while maintaining data persistence across pod restarts. The

subdomain kube-snake.mymh.dev points to the VM's public IP via an A-record, allowing Caddy to handle TLS termination and route traffic to the K3s ingress controller.

This minimal infrastructure approach keeps operational costs below €5/month (actually for free, since it shares the VM) while providing production-grade features like automatic TLS renewal, persistent storage, and container orchestration. The single-VM design is suitable for low-traffic applications and educational projects where high availability is not critical.

3.1 Verification and troubleshooting: Infrastructure

Common issues and where to look:

- K3s not starting -> Check /var/log/syslog or journalctl -u k3s, verify firewall rules allow ports 6443, 80, 443
- DNS not resolving -> Run dig kube-snake.mymh.dev, verify A-record points to correct VM IP, wait 5-60 minutes for propagation
- TLS certificate fails -> Check sudo journalctl -u caddy -f, ensure ports 80/443 are open for Let's Encrypt validation, verify DNS is correct
- PVC stuck in Pending -> Run kubectl describe pvc <name>, verify local-path provisioner is running: kubectl get pods -n kube-system
- Out of disk space -> Check df -h, clean up old images: sudo k3s crictl rmi --prune, review storage usage: du -sh /var/lib/rancher/k3s/storage/*
- Caddy not routing traffic -> Verify Caddyfile syntax: sudo caddy validate --config /etc/caddy/Caddyfile, restart: sudo systemctl restart caddy
- Firewall blocking connections -> Check rules: sudo ufw status, add missing ports: sudo ufw allow <port>/tcp

4. In-depth: Kubernetes in-depth

The Kubernetes architecture separates stateful components (MongoDB, Redis) from stateless application pods (Guestbook, Healthcheck). StatefulSets provide stable network identities and persistent storage for databases, while Deployments handle stateless workloads that can be freely scaled and restarted.

Persistent storage is managed through PersistentVolumeClaims (PVCs), which request a specific amount of storage from the cluster. When a pod restarts, K3s automatically mounts the same PVC, ensuring data survives pod lifecycle events. This is critical because pods are ephemeral—they can be killed, rescheduled, or scaled down at any time.

4.1 StatefulSets vs Deployments

StatefulSets (MongoDB, Redis):

- Stable network identity (pod names stay consistent: mongodb-0, redis-0)

- Ordered deployment and scaling (pods created sequentially)
- Persistent storage automatically attached via PVCs
- Used for databases and stateful services

Deployments (Guestbook, Healthcheck):

- Random pod names with generated suffixes (e.g., guestbook-7b8f9c-xq4z2)
- Parallel scaling (all replicas start simultaneously)
- Stateless by design (any pod can serve any request)
- Used for application workloads

4.2 Persistent Storage with PVCs

How it works:

1. Pod requests storage via PersistentVolumeClaim (e.g., 5Gi)
2. K3s local-path provisioner creates a directory on VM disk
3. PVC binds to the new PersistentVolume
4. Pod mounts the volume at specified path
5. On pod restart, same PVC is mounted (data intact)

Why this matters: Pods are ephemeral and can die at any time. PVCs ensure MongoDB data and DataProtection keys persist across restarts, scaling events, and node failures.

4.3 Verification and troubleshooting: Kubernetes

- PVC stuck in Pending -> Run kubectl describe pvc <name>, check if local-path provisioner is running: kubectl get pods -n kube-system | grep local-path
- StatefulSet pods not starting -> Check kubectl describe statefulset <name>, verify PVCs are bound, ensure sufficient disk space on VM
- ImagePullBackOff errors -> Verify image exists in GHCR: kubectl describe pod <name>, check imagePullSecrets if repository is private
- CrashLoopBackOff -> View logs: kubectl logs <pod-name>, common causes: missing environment variables, database connection failures, port conflicts
- Service not routing traffic -> Check service selector matches pod labels: kubectl get svc <name> -o yaml, verify endpoints: kubectl get endpoints <name>
- Pod evicted due to disk pressure -> Check kubectl describe node, clean up old images: k3s crictl rmi --prune, review PVC usage
- Secrets not mounting -> Verify secret exists: kubectl get secret <name>, check SealedSecret is unsealed: kubectl get sealedsecret <name>
- Liveness/Readiness probes failing -> Check probe path is correct (e.g., /guestbook/api/messages), verify application is listening on correct port, review pod logs for startup errors

5. In-depth: GitOps + Deployment

GitOps treats Git as the single source of truth for both application code and infrastructure configuration. Changes are made by committing to Git, not by running manual kubectl commands. Helm packages Kubernetes manifests into reusable charts, while ArgoCD continuously monitors Git and automatically syncs changes to the cluster. This approach ensures that the cluster state always matches what's in Git, enabling auditable deployments and easy rollbacks.

5.1 Let us stay on top of things, like a HELM

Helm is to Kubernetes what apt/yum is to Linux. Instead of managing dozens of individual YAML files, Helm packages everything into a Chart. This enables templating (same chart, different values for dev/staging/prod), versioning (rollback to previous deployments), and dependency management (automatically deploy Redis when deploying Guestbook).

Analogy: 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`

5.2 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”
- statefulset.yaml then says “here’s *how* Kubernetes should deploy and run MongoDB using those settings”

5.3 Key Learnings: Do not ArgoCD with me

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 in its own namespace, argocd. It runs several components:

- Server pod – API + web server
- Controller – Watches Git, syncs to Kubernetes
- Repo server – Clones Git repositories

5.3.1 How ArgoCD replaces manual deployments

ArgoCD uses *polling*, not webhooks or triggers. Workflow:

1. Every 3 minutes (default, I set it to 30), 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 (30, in my case) 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.

6. In-depth: CI/CD pipeline

The CI/CD pipeline automates the application deployment process using GitHub Actions, which triggers on code pushes to the guestbook directory or changes to the workflow file itself. When code changes are pushed, GitHub Actions builds the .NET application inside a Docker container using a multi-stage Dockerfile, tags the image with the commit SHA for traceability, and pushes it to GitHub Container Registry (GHCR).

The workflow then automatically updates the Helm helm/charts/guestbook/values.yaml file with the new image tag and commits the change back to the repository using a Personal Access Token (PAT). ArgoCD detects this Git change during its next polling cycle and triggers a rolling deployment in the K3s cluster. This GitOps approach ensures that every deployment is traceable to a specific commit and can be rolled back if needed, while eliminating the need for manual kubectl commands in production.

6.1 Verification and Troubleshooting: CI/CD Pipeline

- GitHub Actions workflow not triggering -> Check workflow file syntax in guestbook-ci.yml, verify push events target correct paths (apps/guestbook/**), confirm workflow file is committed to main branch
- Docker build failures -> Check Dockerfile syntax, verify .NET project builds locally with dotnet build, review GitHub Actions logs for missing dependencies or build context issues
- Image push permission denied -> Verify GitHub repository has write:packages permission, check if GHCR authentication token is valid, confirm image name matches repository structure
- values.yaml not updating -> Check if CI bot has correct Personal Access Token (PAT) configured in GitHub Secrets, verify Git user email/name are set in workflow, review workflow logs for commit errors
- ArgoCD not syncing new image -> Verify image tag in values.yaml matches actual tag in GHCR, check ArgoCD sync policy is set to automated, manually trigger sync if polling interval hasn't elapsed
- Image pull timeouts -> Large images may exceed default pull timeout, consider multi-stage builds to reduce image size (SDK stage builds, runtime stage runs), review GHCR rate limits
- Workflow logs unclear -> Add echo statements in workflow steps to print variables and progress, use run: echo "Building image: $IMAGE_TAG" to create detailed logs visible in GitHub Actions tab

Pro tip: Adding log steps in the workflow file creates an excellent audit trail. If you make sure it prints out the various steps it goes through, you'll have a detailed log to dig through, easily visible in your repository's Actions tab!

I had excellent use of this, at one point I had help by our LLM friends to update the workflow file, and it did expose the login credentials so they ended up visible in the log files. But, since I have the habit of actually reading through the log files after deploy, I noticed this within seconds. Log files are not only a great bugfix tool, it also keeps your system more secure.

7. In-depth: Application stack

The application layer uses a minimal technology stack that prioritizes simplicity and maintainability. The backend is a .NET 9 Minimal API configured to return HTML fragments instead of JSON responses. This allows the frontend to use HTMX for dynamic interactions—when the user clicks "Post Message," HTMX sends a request to the .NET API, which responds with ready-to-render HTML that gets swapped directly into the page. No JavaScript framework or JSON parsing required.

The guestbook API is stateless by design: session data lives in Redis, and persistent data lives in MongoDB. This allows horizontal scaling without sticky sessions. The healthcheck page

embeds HTMX to make API calls to the guestbook service, demonstrating how microservices can communicate within a Kubernetes cluster using ClusterIP services.

Authentication is handled server-side with cookie-based sessions. Admin credentials are stored in Sealed Secrets and loaded as environment variables at runtime. DataProtection keys are persisted on a PVC to ensure cookie encryption remains consistent across pod restarts and multiple replicas.

7.1 Verification and Troubleshooting: Application Stack

- HTMX requests not working -> Check browser console for errors, verify HTMX library is loaded correctly, confirm API endpoints return HTML (not JSON)
- Admin login fails -> Verify SealedSecret is unsealed: kubectl get secret guestbook-admin-credentials, check environment variables are loaded in pod: kubectl exec <pod> -- env | grep ADMIN
- Session lost after pod restart -> Verify Redis is running and accessible: kubectl get pods | grep redis, check session configuration uses Redis (not in-memory cache)
- Messages not persisting -> Verify MongoDB connection string is correct, check MongoDB pod logs: kubectl logs <mongodb-pod>, confirm PVC is bound
- Cookie not setting -> Check cookie configuration has Secure=true for HTTPS, verify SameSite=None for cross-origin requests, ensure HttpOnly=true to prevent XSS
- DataProtection errors -> Check if PVC for DataProtection keys exists and is bound: kubectl get pvc guestbook-datakeys-pvc, verify pod mounts the volume correctly
- .NET application crashes -> View pod logs: kubectl logs <pod>, common causes: missing environment variables, MongoDB connection refused, Redis unreachable
- Port conflicts -> Verify application listens on port 8080 (not 80), check service targetPort matches container port in deployment.yaml

Three useful tools:

1. I can really recommend using both the browser console log (F12) and the Network tab. Modern browsers have a lot of built-in tools that help not only frontend developers, but also backend. Check the traffic!
2. I also had a lot of help from the kubectl exec <podname> -commands, there are times you wonder about what the status of your setup is and getting a CLI response is fast and accurate.
3. The third tool I used a lot was to use secret tabs or verifying the page in a second browser: sometimes cookies meant my page did not refresh properly even though ArgoCD had synced and I ran Ctrl + F5 to reload the page. I had to clear cookies/session multiple times.

8. In-depth: Security and Secrets Management

Security in a GitOps workflow presents a fundamental challenge: Git repositories are designed to be version-controlled and shared, but secrets must never be exposed in

plaintext. Sealed Secrets solves this by using asymmetric encryption—secrets are encrypted with a public key before committing to Git, and only the Sealed Secrets controller running in the cluster (which holds the private key) can decrypt them. This allows the entire infrastructure to be stored in Git safely while maintaining security best practices.

The security architecture uses multiple layers: Sealed Secrets for Git-safe credential storage, Kubernetes Secrets for runtime access, cookie-based authentication with security flags to prevent XSS and CSRF attacks, and DataProtection keys stored on persistent volumes to ensure consistent encryption across pod restarts.

8.1 In depths: Sealed Secrets

To handle Kubernetes Secrets and the Helm charts in a way that does not expose credentials, this project uses Bitnami 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

Installation process: SSH to the VM and run:

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

Then install the kubeseal CLI tool locally on your workstation. I downloaded kubeseal, placed the .exe in a /bin/kubeseal directory, and added it to Windows PATH. Now kubeseal commands work in Bash terminal. Workflow timeline:

1. Copy the kubeconfig from the VM to your workstation
2. Fix the server IP in K3s-config (change 127.0.0.1 to VM public IP)
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 temporary plaintext secret yaml-file stored locally, never committed to Git! In fact, add it to .gitignore too even if you delete the file in step 11
9. Encrypt it using kubeseal, which outputs the encrypted SealedSecret manifest
10. Copy the encrypted data from the kubeseal output into your Helm chart template
11. Verify the SealedSecret is encrypted (check for encryptedData field), then delete local plaintext secret
12. Commit the SealedSecret template to Git

After this, the connection and encryption are established. Charts were updated to reference the SealedSecret instead of plaintext secrets.

9. In-depth: Session persistence strategy

Session persistence is critical for stateless applications running in a distributed environment. When an application scales to multiple replicas, incoming requests are load-balanced across pods. Without shared session storage, a user authenticated by Pod A will be treated as unauthenticated when their next request lands on Pod B. Redis solves this by acting as a centralized session store accessible by all pods, ensuring users maintain their session state regardless of which pod handles their request.

This section explains how Redis enables horizontal scaling, the configuration required to make it work with HTTPS and path-based routing, and common pitfalls like middleware ordering that can break session persistence.

9.1 Key Learnings: Redis and Distributed Session Storage

Let's use a hotel analogy:

Imagine a hotel with multiple front desks (pods). A guest (user) checks in at Desk A, gets a room key (session cookie), and goes to their room. Later, they come back to ask for towels, but this time they talk to Desk B.

Without Redis (in-memory cache):

- Each desk has its own guest registry (local memory)
- Desk B says "Sorry, we don't have you in our system" because they only know about guests who checked in at Desk B
- Guest has to check in again every time they talk to a different desk

With Redis (distributed cache):

- All desks share one central guest registry (Redis server)
- Guest checks in at Desk A -> entry added to central registry
- Guest talks to Desk B -> Desk B checks central registry, sees the guest is registered, provides towels
- No matter which desk the guest talks to, their session is recognized

9.1.1 Why This Matters in Kubernetes and the Redis-solution

When you scale an application to multiple replicas (pods), Kubernetes uses a load balancer to distribute incoming requests. Without shared session storage:

- Request 1 (login) -> Pod A -> Session stored in Pod A's memory
- Request 2 (post message) -> Pod B -> Pod B has no knowledge of the session -> 401 Unauthorized

This is exactly what happened with our guestbook.

The solution / How Redis Fixes It:

Redis is a separate service that all pods can connect to:

1. User logs in -> Session data written to Redis (not pod memory)
2. User posts message -> Any pod can read session data from Redis
3. User logs out -> Session deleted from Redis

So it is a “consolidated temporary memory”, a shared cache.

9.1.2 Key configuration in .NET and session cookie configuration

```
services.AddStackExchangeRedisCache(options =>
{
    options.Configuration = "guestbook-redis-master:6379";
});
```

What this tells guestbook pods: "Store session data at this Redis address (Kubernetes service name), not in your own memory."

For cookies to work correctly in Kubernetes with HTTPS and path-based routing:

- HttpOnly = true -> JavaScript can't access the cookie (security)
- SameSite = SameSiteMode.None -> Cookie sent in cross-origin requests (required for modern browsers)
- Secure = true -> Cookie only sent over HTTPS
- Path = "/guestbook" -> Cookie only sent for requests under `/guestbook` path

Without these settings, browsers may reject cookies or session state may not persist correctly. I set the cookie settings in the session handling at ServiceExtensions.cs.

9.1.3 The Middleware Order Trap

In ASP.NET Core, middleware order is critical:

```
app.UsePathBase("/guestbook");  // 1. Set base path
app.UseSession();               // 2. Enable session BEFORE endpoints
app.MapGuestbookEndpoints();    // 3. Map endpoints
```

If you call UseSession() after endpoint mapping, session data won't be available when processing requests. Duh. 😊 But I had a challenge here actually: The issue wasn't immediately obvious because the code looked correct. UseSession() was called before endpoint mapping within the extension method.

I had set the correct order, in a sense, because I build using the Extension Method Pattern – this means instead of having a long Program.cs that initiate all mechanics, I break out segments into their own classes and methods and initiate settings there. In the case of Session, I have this:

```
// Map endpoints using extension method
app.MapGuestbookEndpoints();
```

The Endpoints were set in the MapGuestbookEndpoints.cs – EndpointExtensions class – with this method:

```
    public static WebApplication MapGuestbookEndpoints(this WebApplication
app)
    {
        // Session middleware (should be before endpoints)
        app.UseSession();

        // Map endpoint groups
        app.MapMessageEndpoints();
        app.MapAuthEndpoints();

        return app;
    }
```

This was not good enough, the Session was initialized too close to the Endpoints – and this is just me guessing but I have seen this behaviour before – many services need an initialization-time, like when you start your computer. But the process calculations can sometimes go very fast and simultaneously, so if the MapMessageEndpoints start a fraction after UseSession but it manage to finish before UseSession: you fire them up in the "wrong" order.

An easy solution that often works is to make some kind of process separation between them; in this case I simply moved the app.UseSession() into Program.cs and put it just ahead of app.MapGuestbookEndoints(). Guess what? It was enough to solve my problem. The only difference technically is that we have one process in-between them –> the redirection through the MapGuestbookEndpoints method! Silly but it works.

9.1.4 Key Takeaways

- In-memory session storage does NOT work with multiple replicas - Each pod has its own memory
- Redis (or any distributed cache) is essential for horizontal scaling. - All pods share session state.
- Cookie configuration matters. - Modern browsers enforce strict cookie policies—configure correctly for HTTPS.
- Middleware order matters. - Session middleware must run before endpoints.
- Health probes must use correct paths. - Include base path in probe configuration (e.g., `/guestbook/api/messages`).

Analogy recap: Redis is the hotel's central guest registry. Without it, each front desk (pod) only knows about guests who checked in there. With it, all desks share knowledge, and guests (users) have a seamless experience no matter which desk (pod) they interact with.

10. Where to go (system analysis and improvement possibilities)

There are quite a lot of roads leading to Rome, but let us look at a few key areas where this system could evolve.

10.1 Security

Strengths within the system:

- Sealed Secrets in Git - All credentials encrypted before committing, safe for public repositories
- Cookie security flags - HttpOnly, Secure, SameSite=None prevent XSS and CSRF attacks
- No hardcoded credentials - All secrets loaded from environment variables at runtime
- Minimal attack surface - HTMX reduces client-side JavaScript, fewer XSS vulnerabilities

Improvements that can be made:

- Network policies - Currently all pods can communicate freely. Implement Kubernetes NetworkPolicies to restrict traffic (e.g., only guestbook pods can access MongoDB). This follows the principle of least privilege.
- TLS for internal traffic - Pod-to-pod communication (guestbook → MongoDB/Redis) uses unencrypted HTTP. Add service mesh (Istio/Linkerd) or cert-manager for mTLS. Protects against potential MITM attacks within the cluster.
- RBAC for ArgoCD - ArgoCD currently has cluster-admin access. Create limited ServiceAccounts with specific permissions per application. Reduces blast radius if ArgoCD is compromised.

10.2 CI/CD analysis

Strengths:

- SHA-based image tagging - Every deployment traceable to specific Git commit, easy rollbacks
- Automated values.yaml updates - No manual kubectl commands, Git is single source of truth
- GitOps workflow - Changes flow through Git, providing audit trail and version control
- Multi-stage Docker builds - Optimized images (SDK stage builds, runtime stage runs), smaller attack surface

Improvements:

- Automated testing - Add unit tests and integration tests to GitHub Actions before building images. Currently deployments happen without test validation, risking broken releases.
- Staging environment - Deploy to staging namespace first, run smoke tests, then promote to production. Current setup deploys directly to production, no safety net for regressions.
- Image vulnerability scanning - Integrate Trivy or Snyk into CI pipeline to scan images for CVEs before pushing to GHCR. Currently no automated security scanning of dependencies.

10.3 Scalability analysis

Strengths:

- Horizontal pod autoscaling ready - Redis enables stateless pods, any replica can serve requests
- Load balancing built-in - K3s ingress distributes traffic across replicas automatically
- Separate concerns - StatefulSets for databases, Deployments for apps, clear separation of scaling strategies
- Path-based routing - Multiple services behind single domain, easy to add new microservices

Improvements:

- Horizontal Pod Autoscaler (HPA) - Currently manual replica count (2 replicas fixed). Add HPA to scale based on CPU/memory metrics. Would handle traffic spikes automatically.
- Database replication - MongoDB runs single instance. Add replica set for high availability and read scaling. Current setup has single point of failure for data layer.
- CDN for static assets - HTMX library and CSS served from VM. Use CDN (Cloudflare, jsDelivr) to reduce bandwidth and improve global load times.

10.4 Cost analysis

Current costs: €4.49/month (Hetzner VM) + domain registration. In reality, the project share VM and domain costs with other projects so this could either be argued that this project is “free”, or we could see it for what it is: several projects share the resources so we could say it is more like a quarter of that cost.

Trade-offs: Single VM means no high availability—if VM dies, entire system goes down. For production workloads requiring 99.9% uptime, consider multi-node K3s cluster or managed Kubernetes. Current setup optimized for educational projects and low-traffic applications where cost is prioritized over availability.

Potential savings: None without sacrificing features. Already using free tiers (GHCR, GitHub Actions, Let's Encrypt). Alternative: Host on free tier services (Render, Fly.io) but lose Kubernetes learning experience and control.

10.5 Logs and metrics

Strengths:

- kubectl logs - Basic debugging available, sufficient for small deployments
- ArgoCD dashboard - Visual deployment health and sync status
- Traditional logs: GitHub, F12 Dev Tools (in your browser)

Improvements:

- Centralized logging - Add Loki + Promtail to aggregate logs from all pods. Currently must run kubectl logs individually per pod, no historical search capability.
- Metrics and alerting - Deploy Prometheus + Grafana for resource usage monitoring. Set alerts for high CPU, disk space, pod crashes. Currently no proactive monitoring, issues discovered reactively. (would love to add this!)
- Distributed tracing - Add Jaeger or Tempo to trace requests across microservices (healthcheck → guestbook → MongoDB). Would help debug performance bottlenecks and failed requests.

10.6 Other areas that might be worth considering

Backup strategy - MongoDB data persists on local VM disk. Add automated backups to cloud storage (S3, Backblaze B2) with retention policy. Current setup vulnerable to VM failure or accidental deletion.

Disaster recovery - Document recovery procedures (restoring from backup, rebuilding cluster). Test recovery process at least once to validate documentation accuracy.

Rate limiting - Add Traefik middleware or nginx-ingress rate limiting to prevent abuse. Currently no protection against brute-force login attempts or API spam.

Monitoring external dependencies - Add health checks for GitHub (registry), Let's Encrypt (TLS renewal), DNS provider. System could break silently if external services fail.

11. Challenges and lessons learned

List here

11.1 Versioning funkyness

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

```yaml
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!

11.2 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:

```yaml
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

3. 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

4. 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. It will cause me more headache to set up but it is better practice.

11.3 Port Forwarding

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:

11.3.1 The Problem: Silent Port Conflicts

During local development testing, we encountered authentication failures where `mongosh` could successfully authenticate to MongoDB using credentials `user:password`, but the .NET MongoDB.Driver consistently failed with `MongoAuthenticationException: Unable to authenticate using sasl protocol mechanism SCRAM-SHA-1`.

Initially, we suspected connection string parsing issues, URL encoding problems, or SCRAM mechanism mismatches between the MongoDB server and the .NET driver. After extensive troubleshooting including creating multiple test users, trying different authentication mechanisms (SCRAM-SHA-1 vs SCRAM-SHA-256), and using `MongoClientSettings` instead of connection strings, the root cause was discovered: MongoDB's default port 27017 was already bound locally by either a local MongoDB instance or a stale `kubectl port-forward` process.

11.3.2 The Solution: Alternate Port Binding

The fix was to use an alternate local port for the port-forward tunnel: `kubectl port-forward svc/mongodb-service 27018:27017 -n default`. This ensured the tunnel actually forwarded traffic to the K3s MongoDB instance instead of routing to the conflicting local process.

The .NET application's `.env` file was updated to use `mongodb://user:password@localhost:27018/?authSource=admin` for local development, while production deployments in the cluster use `mongodb://user:password@mongodb-service:27017/?authSource=admin` for direct service-to-service communication.

Key takeaways: always verify `kubectl port-forward` shows `Forwarding from 127.0.0.1:XXXX` on startup, check for port conflicts using `netstat -ano | findstr :27017`, use non-standard ports for local development to avoid conflicts, and remember that authentication errors can sometimes indicate connectivity issues rather than credential problems.

12. 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.

12.1 Phase 1 – Let the Kube-Snake loose!

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

12.1.1 Phase 1:1 – 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)

12.1.2 Phase 1:2– 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

12.2 Phase 2, microscopic services under the hood

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

12.2.1 Phase 2:1 – 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

12.2.2 Phase 2:2 – 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
2. 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
3. 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.

12.2.3 Phase 2:3 – 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
2. 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

3. 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
4. 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.

12.2.4 Phase 2:4 – 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
3. 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

4. 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`

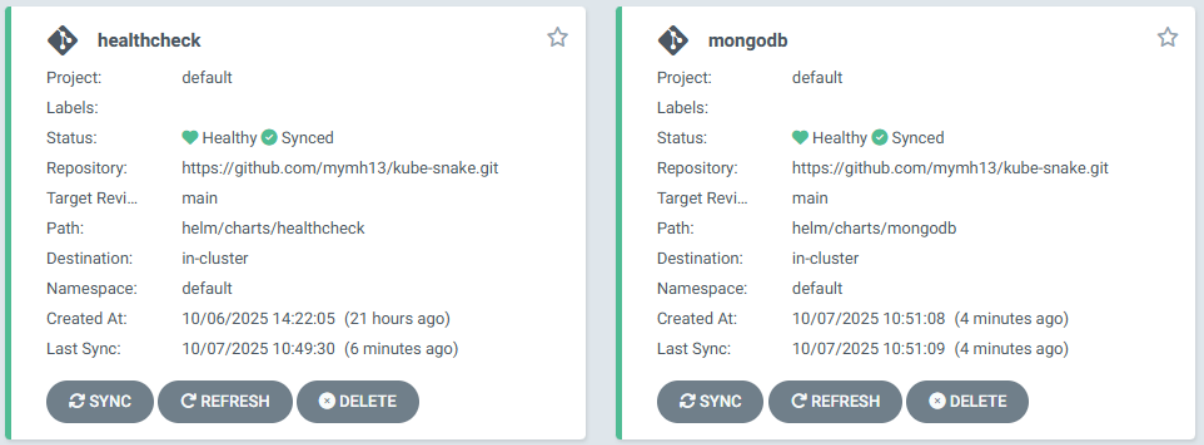
Updated Flow: MongoDB credentials encrypted locally -> SealedSecret committed to Git -> ArgoCD syncs chart -> K3s Sealed Secrets controller decrypts -> MongoDB pods start with credentials -> PVC attached to pod -> Data persists on VM disk

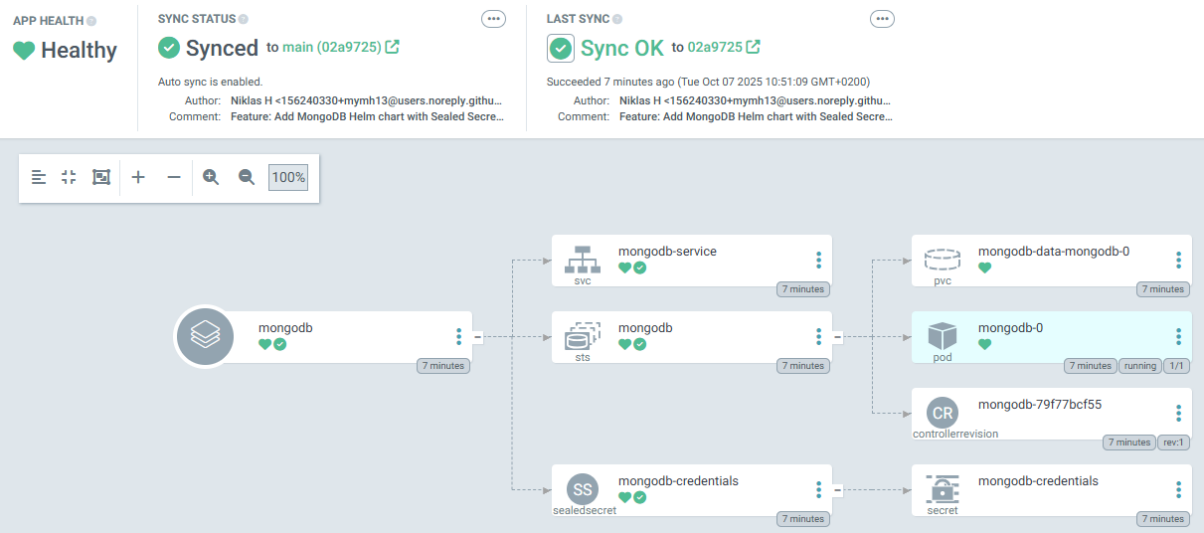
Key Learnings:

- 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.

11.2.4.1 Let us glance at ArgoCD now with the MongoDB-implementation:





Lookin' good Mister Kotter!

12.2.5 Phase 3:1 – .NET Guestbook API: Microservice Architecture

The guestbook feature was initially planned as part of the healthcheck application, but I extracted it into a standalone .NET API service following microservices architecture.

This separation provides clear boundaries between infrastructure monitoring (healthcheck) and user content management (guestbook), enables independent scaling and deployment, demonstrates technology diversity (.NET alongside Go/Python), and aligns with the GitOps architecture.

This decision creates a more realistic production setup that showcases proper service decomposition. Also, I like having a re-usable separate bit of code that suits this project.

1. Project Structure and Dependencies
   - Created .NET 9 Minimal API project in guestbook with dedicated solution
   - Added MongoDB.Driver NuGet package (v2.28.0) and DotNetEnv for configuration
   - Organized code structure: Models/, Services/, Endpoints/, Helpers/, Extensions/
   - Implemented dependency injection, services registered as singletons, endpoints mapped via extension methods, separation of concerns between data access (Services), business logic (Endpoints), and infrastructure (Program.cs)
2. MongoDB Integration and Data Models
   - Implemented Message model (Id, Text, CreatedAt, CreatedBy)
   - Created MongoDbService reading connection details from environment variables
   - Built CRUD operations: GetRecentMessagesAsync(), CreateMessageAsync(), DeleteMessageAsync()
3. API Endpoints and Authentication
   - Implemented minimal API endpoints returning HTML partials for HTMX
   - Public: GET /api/messages (last 10 messages as HTML)

- Admin: POST /api/login, POST /api/messages, DELETE /api/messages/{id}, POST /api/logout
- Configured cookie-based sessions using ASP.NET Core Session middleware

4. Security Configuration
   - Created Kubernetes Secrets for credentials (gitignored, never committed)
   - Generated .template.yaml files as safe documentation
   - Configured .env for local development (gitignored)
   - Updated .gitignore to prevent credential exposure
5. Local Development and Testing
   - Configured port-forward to K3s MongoDB (resolved port conflicts - see 10.3)
   - Tested endpoints with curl, verified MongoDB connectivity
   - Validated authentication and session management

12.2.5.1 Quick overlap into testing the guestbook

6. Containerization and Helm Chart
   - Created multi-stage Dockerfile (sdk build -> aspnet runtime, optimized image size)
   - Added .dockerignore for build optimization (exclude bin/, obj/, .env files)
   - Built and tested Docker image locally (verified app starts on port 8080)
   - Created Helm chart structure with Chart.yaml, values.yaml, and templates/
   - Configured Deployment template with environment variables from Kubernetes Secrets
   - Configured Service template (ClusterIP, port 80 -> 8080)
   - Added health probes (liveness and readiness on /api/messages endpoint)
   - Created ArgoCD Application manifest for GitOps deployment
   - Chart ready for deployment, awaiting GitHub Actions CI workflow
7. HTMX Integration with Healthcheck
   - Updated healthcheck index.html with guestbook section
   - Added HTMX script reference (CDN: htmx.org v1.9.10)
   - Implemented message list with auto-refresh (hx-get every 30s)
   - Added admin login form with session management
   - Configured HTMX to swap HTML partials from API endpoints
   - Awaiting cluster deployment to test service-to-service communication

Flow for this standalone API**:**

Local: .env -> .NET API -> Port-forward (27018:27017) -> MongoDB service -> HTML partials

Production (Pending): GitHub Actions -> GHCR -> ArgoCD -> K3s -> Sealed Secrets -> .NET pod -> mongodb-service:27017

Key Learnings**:**

- Port-forward conflict resolution during local development

Security Achievement: Zero credentials in Git - all sensitive data in gitignored .env (local) or Kubernetes Secrets (production), with templates providing documentation.

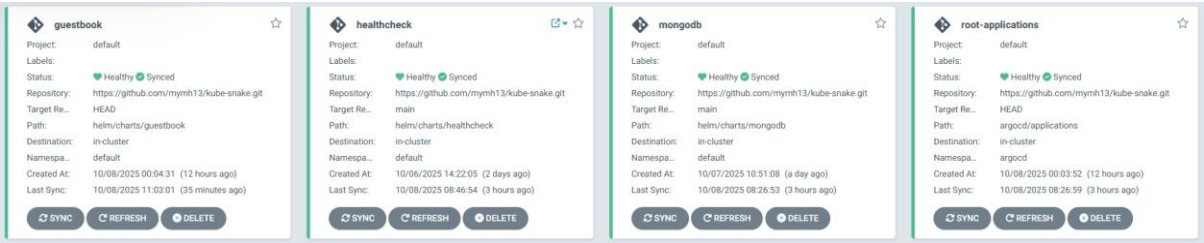
12.2.6 Phase 3:2 – Guestbook API: GitOps deployment and integration

This phase focused on securely deploying the guestbook API, integrating it with the healthcheck page, and validating the GitOps workflow in a Kubernetes environment.

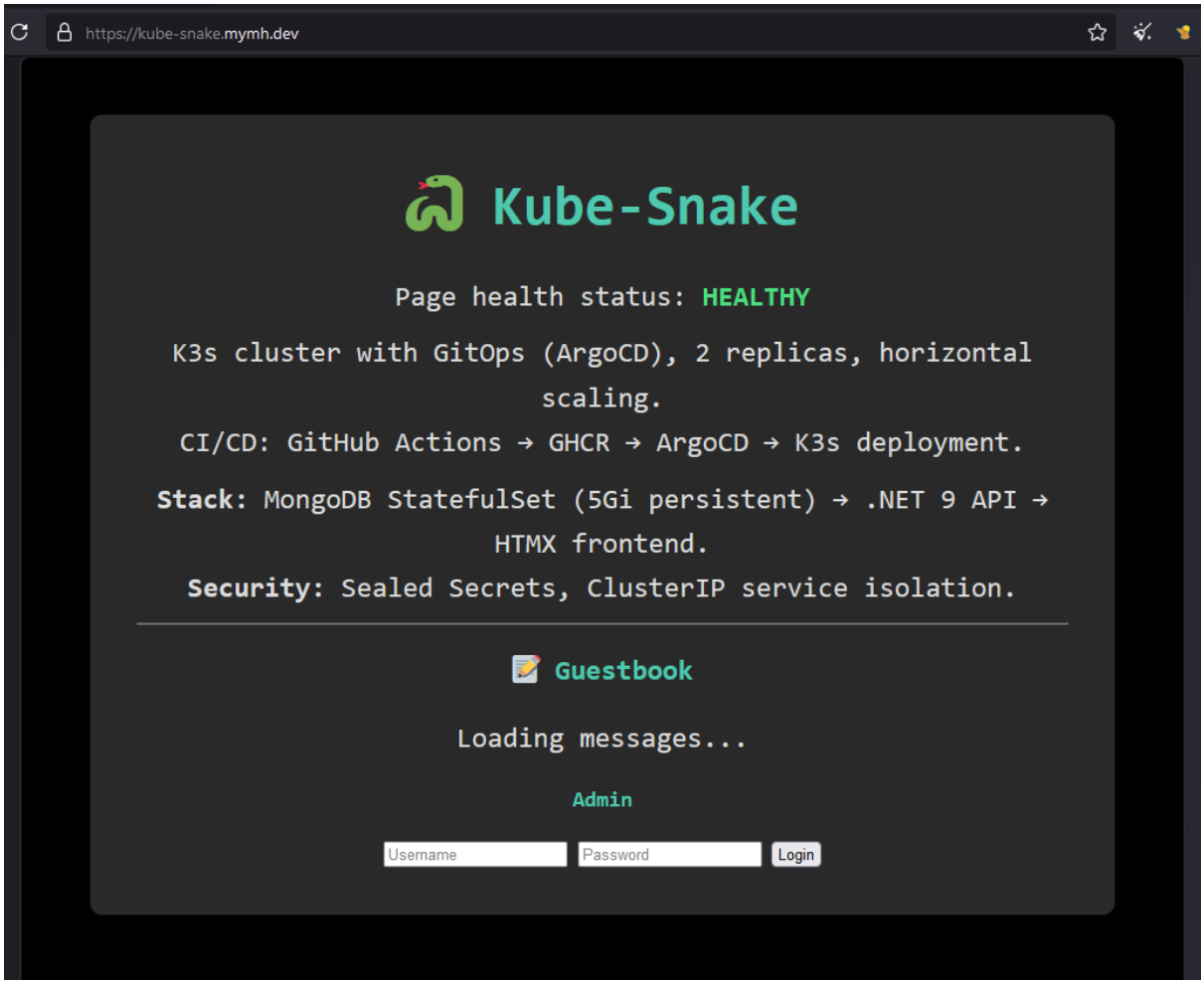
1. Helm Chart & ArgoCD Setup
   - Finalized Helm chart for guestbook API, ensuring correct environment variable and secret references.
   - Deployed guestbook service to cluster using ArgoCD, verified healthy sync and rollout.
2. Sealed Secrets & Secure Configuration
   - Used Bitnami Sealed Secrets for MongoDB credentials, referenced securely in deployment.
   - Confirmed no sensitive data in git; all secrets managed via Kubernetes.
3. Healthcheck Integration
   - Updated healthcheck index.html to embed guestbook via HTMX.
   - Verified service-to-service communication and correct routing in Ingress.
4. Troubleshooting & Validation
   - Resolved probe failures and port mismatches in deployment.
   - Fixed redirect loop by clearing browser cache and confirming ingress/app path configuration.
   - Compared healthy/unhealthy pod specs to ensure stable rollout.
5. Final Verification
   - Confirmed guestbook, healthcheck, and MongoDB apps are healthy and synced in ArgoCD.
   - Documented lessons learned and updated phase_three.md for future reference.

Key Outcome: Guestbook API is now securely deployed, integrated with healthcheck, and managed via GitOps—ready for admin features and further enhancements.

ArgoCD looks quite nice now, four nodes all green and happy!



Let us also have a look at the web front, we can see an early version of the guestbook:



12.2.7 Phase 3:3 – Multi-Replica Session Persistence & Automated Image Rollout

This phase addressed two critical production requirements: enabling session persistence across multiple replicas and automating the image deployment workflow to eliminate manual interventions.

1. Session Persistence Problem Discovery
   - Scaled guestbook deployment to 2 replicas for high availability.
   - Discovered authentication failures: login worked, but subsequent requests (posting messages, logout) returned 401 Unauthorized.
   - Root cause: Session state stored in-memory (`AddDistributedMemoryCache()`) was local to each pod.
   - When load balancer routed requests to different pods, session cookies couldn't be validated.
2. Redis Distributed Cache Implementation
   - Deployed Redis via Bitnami Helm chart: `helm install guestbook-redis bitnami/redis --set auth.enabled=false`

- Added Microsoft.Extensions.Caching.StackExchangeRedis NuGet package to .NET project.
- Replaced in-memory cache with Redis configuration in ServiceExtensions.cs:
- Session cookie configured with SameSite=None and Secure=true for HTTPS
- Cookie path set to /guestbook to match UsePathBase configuration
- Ensured app.UseSession() is called before endpoint mapping in Program.cs

3. Session Persistence Validation
   - Tested with 2 replicas: login, post message, logout—all operations successful.
   - Verified session state persists regardless of which pod handles the request.
   - Confirmed Redis stores session data accessible by all guestbook pods.
4. Automated Image Tagging & Deployment**
   - Problem: ArgoCD didn't detect new images with :latest tag, requiring manual kubectl rollout restart.
   - Solution: Implemented SHA-based image tagging in GitHub Actions workflow:
     - Build and push image with commit SHA tag (e.g., `main-78ec86c`)
     - Automatically update `helm/charts/guestbook/values.yaml` with new tag
     - Configure Git credentials for CI Bot to commit and push changes
     - ArgoCD detects manifest change and triggers automatic sync
   - Workflow step added:

```
name: Update Helm values.yaml with new image tag
run: |
SHA="main-$(echo "${{ github.sha }}" | cut -c1-7)"
sed -i "s/tag: \".*\"/tag: \"$SHA\"/" helm/charts/guestbook/values.yaml
git config --global user.email "ci-bot@example.com"
git config --global user.name "CI Bot"
git add helm/charts/guestbook/values.yaml
git commit -m "Update guestbook image tag to $SHA"
git push
```

5. Health Probe & Path Configuration
   - Fixed readiness/liveness probes to use correct path: /guestbook/api/messages
   - Resolved probe timeout errors that prevented pods from becoming ready
   - Ensured all HTMX requests use /guestbook/api/* paths consistently
6. End-to-End Workflow Validation
   - Tested complete pipeline: Git push -> image build -> values.yaml update -> ArgoCD sync -> pod rollout
   - Verified no manual intervention required for deployments
   - Confirmed image tag in values.yaml matches pushed image in GHCR
   - Validated GitOps principles: all changes tracked in Git, declarative state management

Key Outcome: Guestbook now supports horizontal scaling with session persistence via Redis, and deployments are fully automated through GitOps workflow. No manual rollouts required—ArgoCD handles everything from Git manifest changes.

12.2.8 Phase 3:4 – Admin message management and UX polish

This phase enhanced the guestbook with admin capabilities and user experience improvements, transforming it from a basic proof-of-concept into a polished, production-ready feature.

1. Bulk Delete Functionality
   - Added checkboxes next to each message for selection
   - Implemented POST /guestbook/api/messages/delete endpoint for bulk deletion
   - Wrapped message list in form element to enable proper checkbox value submission
   - Public users see disabled checkboxes (visual consistency), admin users can select and delete
2. Username & Timestamp Display
   - Stored actual username in session during login (previously hardcoded)
   - Fixed timestamp display using DateTime.Now instead of DateTime.UtcNow for correct local time
   - Messages now show: username (2025-10-15 14:32): message text
3. User Experience Improvements
   - Increased textarea size (400px width, 80px height, resizable)
   - Added auto-clear functionality using HTMX `hx-on::after-request="this.reset()"`
   - Form automatically resets after successful message post without page reload
4. Verification & Testing
   - Tested bulk delete with multiple messages selected
   - Verified admin panel shows username correctly
   - Confirmed auto-clear works seamlessly with HTMX interactions
   - Validated all UX improvements across 2 replica pods

Key Outcome: Guestbook is now a fully polished, production-ready component with admin management capabilities and smooth user experience. All interactions remain HTMX-driven with zero JavaScript dependencies.

13. Snakes, snakes, why did it have to be snakes!

Lorum ipsum

14. References and links

14.1 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.

14.2 LLM: Partners (and enemies) in crime

Claude 4.5 and ChatGPT 5, both built-in in the IDE (VS Code) as well as the web services.