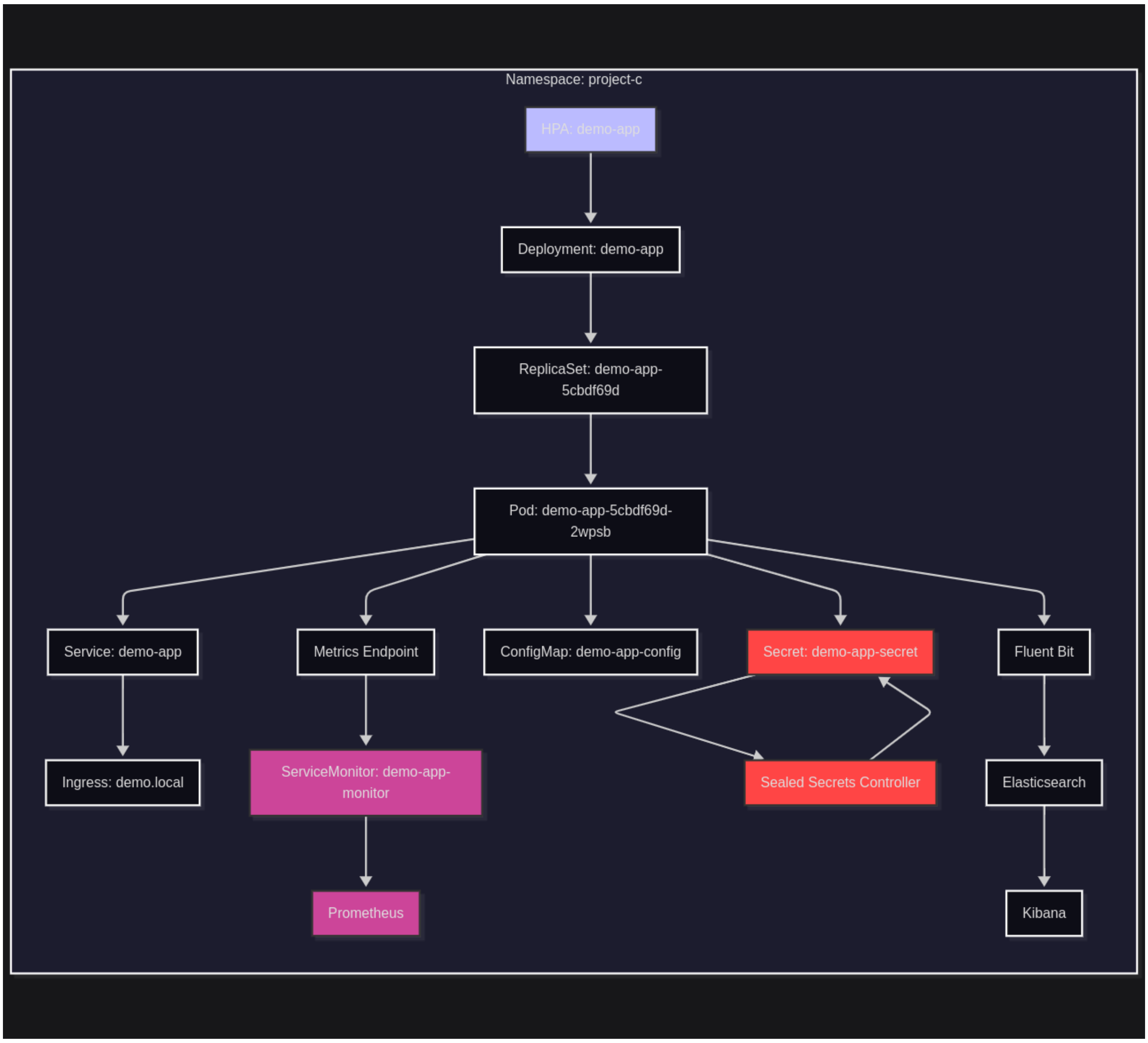
Project C: Local Kubernetes Cluster (k3s)

Overview

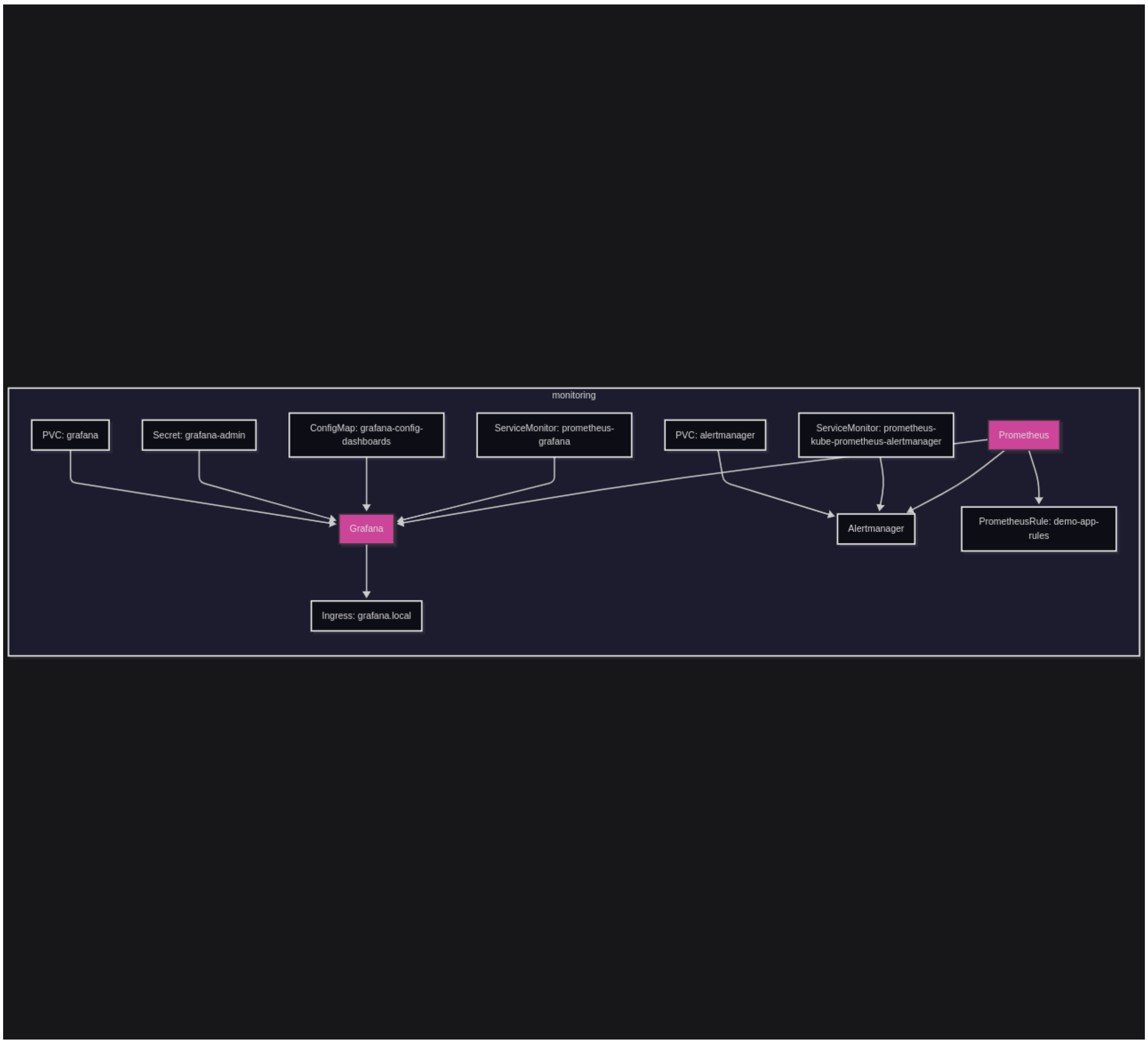
This project demonstrates deploying a containerized Flask application to a local Kubernetes cluster (k3s), with full observability using Prometheus and Grafana. The project follows the 8-week progression outlined in the TCS DevOps Internship Program. A complete end-to-end setup of a Kubernetes-based deployment using k3s, Helm, Prometheus, and Grafana to deploy and monitor a Python Flask application with custom metrics.

🗂 Contents

Architecture Diagram


Namespace: project-c
HPA: demo-app
Deployment: demo-app
ReplicaSet: demo-app-5cbdf69d
Pod: demo-app-5cbdf69d-2wpsb
Service: demo-app
Metrics Endpoint
ConfigMap: demo-app-config
Secret: demo-app-secret
Fluent Bit
Ingress: demo.local
ServiceMonitor: demo-app-monitor
Sealed Secrets Controller
Elasticsearch
Prometheus
Kibana

- Prometheus connects the 2 diagrams


monitoring
PVC: grafana
Secret: grafana-admin
ConfigMap: grafana-config-dashboards
ServiceMonitor: prometheus-grafana
PVC: alertmanager
ServiceMonitor: prometheus-kube-prometheus-alertmanager
Prometheus
Grafana
Alertmanager
PrometheusRule: demo-app-rules
Ingress: grafana.local

```
   ┌─────────────┐           ┌──────────────┐          ┌────────────┐
   │  Developer  │           │   Ingress    │          │  Grafana   │
   │   (Host)    ├──────────▶│  Controller  ├─────────▶│ Dashboards │
   └─────┬───────┘           └──────┬───────┘          └─────┬──────┘
         │                          │                        │
         ▼                          ▼                        ▼
 ┌─────────────────┐      ┌──────────────────┐    ┌──────────────────────┐
 │  demo.local +   │      │ demo-app Service │    │ Prometheus + AlertMgr│
 │  /etc/hosts     │      │  (ClusterIP)     │    │  (metrics scraping)  │
 └─────────────────┘      └──────────────────┘    └──────────────────────┘
         │                          │                        ▲
         └─────────────▶────────────┴────────────▶───────────┘
                   k3s Cluster: Deployed via Helm
```

Quick Start

```
# 1. Clone the repository
git clone https://github.com/<your-username>/<repo-name>.git && cd <repo-
name>
# 2. Install k3s
curl -sfL https://get.k3s.io | sh -
# 3. Build and import the app image
docker build -t demo-app:v1 .
docker save demo-app:v1 | sudo k3s ctr images import -
# 4. Deploy using Helm
helm upgrade --install demo-app charts/demo-app -n project-c
helm upgrade --install grafana grafana/grafana -f grafana-values.yaml -n
monitoring
# 5. Add /etc/hosts entries
echo "127.0.0.1 demo.local grafana.local prometheus.local" | sudo tee -a
/etc/hosts
```

Create GitHub repository

- went to https://github.com/new to create repository, tip: initialize with .gitignore
- Initialize Git locally: `cd ~/project-c` `git init`
- Add files and create a commit: `git add .` `git commit -m "Initial commit: Project C k3s local cluster"`
- Connected my local repo to GitHub: `git remote add origin https://github.com/<your-username>/<repo-name>.git`
- Generated a Personal Access Token
- Pushed my code to GitHub: `git branch -M main` `git push -u origin main`

Cluster Setup and Containerization (Week 1)

- Installed k3s on local machine with: `curl -sfL https://get.k3s.io | sh -`
- Verified the cluster is running with: `kubectl get nodes`
- Created a Dedicated Namespace `kubectl create namespace project-c` `kubectl config set-context --current --namespace=project-c`
- Created Dockerfile for Flask app (`demo-app`) exposing `/metrics`.
- Built and loaded Docker image into k3s using: `docker build -t demo-app:v1 .` `docker run --rm -p 8080:8080 demo-app:v1` `curl http://localhost:8080/` `docker save demo-app:v1 | sudo k3s ctr images import -`

Basic Deployment (Week 2)

- Created Kubernetes resources via Helm chart: `cd project-c/` `helm create demo-app`
- Deployment, Service, Ingress, Chart, Values, Hpa, etc. in a folder structure as below:

```
project-c/
├── charts/
│   └── demo-app/
│       ├── Chart.yaml
│       ├── values.yaml
│         └── templates/
│             └── dashboards
│                 ├── demo-app-dashboard.json
│                 └── original-dashboard.json
│             └── tests/
│                 └── test-connection.yaml
│             ├── deployment.yaml
│             ├── service.yaml
│             ├── configmap.yaml
│             ├── dashboard-provisioning-config.yaml
│             ├── ingress.yaml
│             ├── hpa.yaml
│             ├── grafana-ingress.yaml
│             ├── prometheus-ingress.yaml
│             ├── servicemonitor.yaml
│             ├── demo-app-rules.yaml
│             ├── NOTES.txt
│             ├── _helpers.tpl
│             ├── sealedsecret.yaml
│             └── serviceaccount.yaml
├── app/
│   └── app.py
├── Dockerfile
├── grafana-values.yaml
├── fluentbit-values.yaml
├── readonly.yaml
└── README.md
```

- Lint & Template-Render: `helm lint charts/demo-app` `helm template demo-app charts/demo-app --namespace project-c`
- Verified app was running: `kubectl port-forward svc/demo-app 8080:8080`

Helm Chart (Week 3)

- Developed Helm chart in `charts/demo-app/`
- Parameterized values in `values.yaml`:
  - replicaCount
  - added serviceAccount: create: false name: ""
  - image.repository/tag
  - service type/port
  - Added an autoscaling stub so the HPA template has the keys it expects.
- created configmap.yaml and sealedsecret.yaml
  - configured values.yaml, deployment.yaml to include them, then ran: `helm upgrade --install demo-app ./demo-app` `kubectl get configmap,secret,deploy,pod -n project-c` `kubectl apply -f https://github.com/bitnami-labs/sealed-secrets/releases/download/v0.25.0/controller.yaml`
  - Download the binary (version v0.27.1) `curl -LO https://github.com/bitnami-labs/sealed-secrets/releases/download/ v0.27.1/kubeseal-0.27.1-linux-amd64.tar.gz`
  - Extract the binary `tar -xzf kubeseal-0.27.1-linux-amd64.tar.gz kubeseal`

  - Make it executable and move to /usr/local/bin `chmod +x kubeseal` `sudo mv kubeseal /usr/local/bin/`
  - Confirm installation `kubeseal --version` `kubectl create secret generic demo-app-secret --from-literal=API_TOKEN=newtoken --from-literal=DB_PASSWORD=securepassword -n project-c --dry-run=client -o yaml > demo-app-secret.yaml` `kubeseal --format=yaml < demo-app-secret.yaml > demo-app-sealedsecret.yaml` `kubectl apply -f demo-app-sealedsecret.yaml` `helm upgrade --install demo-app ./charts/demo-app -n project-c`
- Verified deployment and Installed my Helm Release with: `helm install demo-app charts/demo-app -n project-c`
- Verify Kubernetes Resources `kubectl get all -n project-c`
- Komodor Helm Dashboard installation: `helm repo add komodorio https://helm-charts.komodor.io` `helm repo update` `helm install helm-dashboard komodorio/helm-dashboard -n kube-system --create-namespace`

Ingress & Scaling (Week 4)

- Installed Traefik ingress controller (already built into k3s).
- Configure Local DNS for Ingress: mapped demo.local to the k3s node’s IP. First, finding that IP: `kubectl get nodes -o wide -n project-c`
- Added `/etc/hosts` entry: 127.0.0.1 demo.local
- tested the Ingress Endpoint: `curl http://demo.local/metrics` `curl http://demo.local/` `curl http://demo.local/healthz`
- added Liveness and readiness Probe in project-c/charts/demo-app/templates/deployment.yaml `kubectl top pod -n project-c`
- Defined CPU/Memory Requests & Limits: resources: requests: cpu: 100m memory: 128Mi limits: cpu: 250m memory: 256Mi
- added labels in deployment.yaml and Verifyed After Deploy: `helm upgrade --install demo-app ./charts/demo-app -n monitoring` `helm upgrade --install demo-app ./charts/demo-app -n project-c` `kubectl get deploy demo-app -n project-c -o yaml | grep -A 10 "labels:"` `kubectl get deploy demo-app -n project-c -o jsonpath="{.metadata.annotations}"`
- Helm Upgrade with Probes: `helm upgrade demo-app charts/demo-app -n project-c`
- Additional Sanity Checks `kubectl logs deployment/demo-app -n project-c` `kubectl describe pod -l app=demo-app -n project-c`
- Running the Built-in Helm Test: `helm test demo-app -n project-c --timeout 180s --logs`
  - output of test: Phase: Succeeded POD LOGS: demo-app-test-connection Connecting to demo-app:8080 … index.html saved
- edited HPA template in templates/hpa.yaml, applied the Changes with `helm upgrade`
- Verified scaling with `replicaCount: 3`.

Monitoring Integration (Week 5)

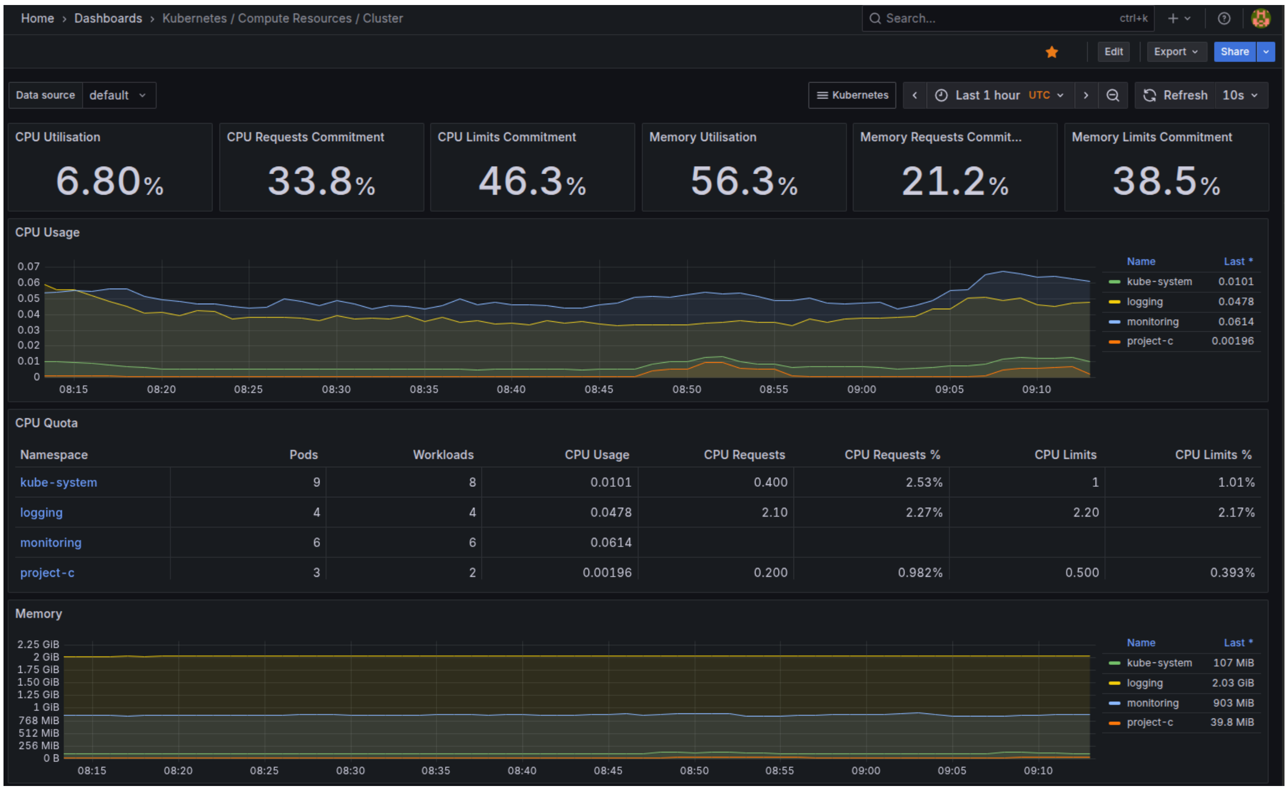
- Add the Prometheus Helm Repository: `helm repo add prometheus-community https://prometheus-community.github.io/helm-charts` `helm repo update`

- Create the Monitoring Namespace `kubectl create namespace monitoring`
- Installed Prometheus with Helm: `helm install prometheus prometheus-community/prometheus --namespace monitoring --set server.service.type=NodePort --set alertmanager.service.type=ClusterIP`
- Verify Prometheus Pods & Services: `kubectl get pods,svc -n monitoring`
- Port-Forward to Access the Prometheus UI: `kubectl port-forward -n monitoring svc/prometheus-kube-prometheus-prometheus 9090:9090`
- Edited charts/demo-app/templates/service.yaml and added under metadata: annotations: prometheus.io/scrape: "true" prometheus.io/port: "8080" prometheus.io/path: "/metrics"
- Upgraded my app chart with `helm upgrade`
- modified app.py with this: @app.route('/metrics') def metrics(): metric = 'demo_app_custom_metric 1\n' return Response(metric, mimetype='text/plain')
- reBuild the image: `docker rmi demo-app:v1` `docker build --no-cache -t demo-app:v1 .`
- Import into k3s and restart: `docker save demo-app:v1 | sudo k3s ctr images import -` `kubectl rollout restart deployment/demo-app -n project-c` `kubectl get pods -n project-c -o wide` `kubectl logs -l app=demo-app -n project-c`
- Install Grafana & Build Your Dashboard, Added the Grafana Helm Repository: `helm repo add grafana https://grafana.github.io/helm-charts` `helm repo update`
- Installed Grafana in the monitoring Namespace: `helm install grafana grafana/grafana --namespace monitoring --set service.type=NodePort --set adminUser=admin --set adminPassword=admin`
- Verify Grafana Resources: `kubectl get pods,svc -n monitoring | grep grafana`
- Port-Forward to Access Grafana: `kubectl port-forward svc/grafana -n monitoring 3000:80`
- Added Prometheus as a Data Source
- Created a Dashboard & Panel, Added a Pod CPU/Memory Panel
- Deploying Grafana with `grafana.local` Ingress.
- created new values in the values.yaml for Grafana
- Added `/etc/hosts` entry: 127.0.0.1 grafana.local
- Upgraded Grafana with the override `helm upgrade prometheus prometheus-community/kube-prometheus-stack -n monitoring -f values.yaml`
- run into issue: `ensure CRDs are installed first, resource mapping not found for name:` solution: `kubectl apply --server-side -f`

`https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_alertmanagers.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_podmonitors.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_probes.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_prometheuses.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_prometheusrules.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_servicemonitors.yaml` `kubectl apply --server-side -f https://raw.githubusercontent.com/prometheus-operator/prometheus-operator/main/example/prometheus-operator-crd/monitoring.coreos.com_thanosrulers.yaml`

- rerun `helm upgrade` command
- created grafana-ingress.yaml: `kubectl apply -f grafana-ingress.yaml`
- Exposed app metrics with ServiceMonitor: kind: ServiceMonitor namespaceSelector: matchNames: ["project-c"] selector: matchLabels: app: demo-app
- Verified `/metrics` is working in Prometheus and Grafana.
- changed to official Grafana chart: `helm repo add grafana https://grafana.github.io/helm-charts` `helm repo update` `helm upgrade --install grafana grafana/grafana -f project-c/values.yaml -n monitoring`

- Grafana showing the memory and cpu usage of k3s and my app:



CPU Utilisation	CPU Requests Commitment	CPU Limits Commitment	Memory Utilisation	Memory Requests Commit...	Memory Limits Commitment
6.80%	33.8%	46.3%	56.3%	21.2%	38.5%

CPU Usage

Name	Last *
kube-system	0.0101
logging	0.0478
monitoring	0.0614
project-c	0.00196

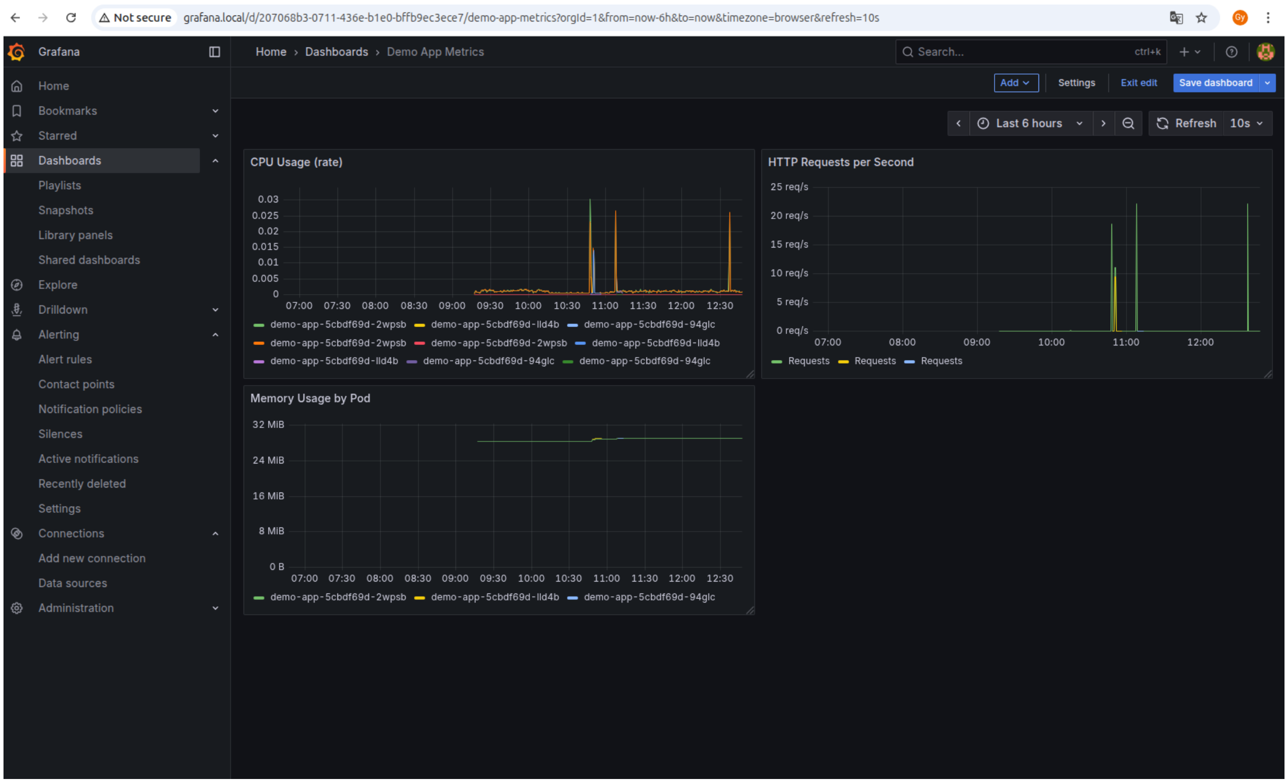
CPU Quota

Namespace	Pods	Workloads	CPU Usage	CPU Requests	CPU Requests %	CPU Limits	CPU Limits %
kube-system	9	8	0.0101	0.400	2.53%	1	1.01%
logging	4	4	0.0478	2.10	2.27%	2.20	2.17%
monitoring	6	6	0.0614				
project-c	3	2	0.00196	0.200	0.982%	0.500	0.393%

Memory

Name	Last *
kube-system	107 MiB
logging	2.03 GiB
monitoring	903 MiB
project-c	39.8 MiB

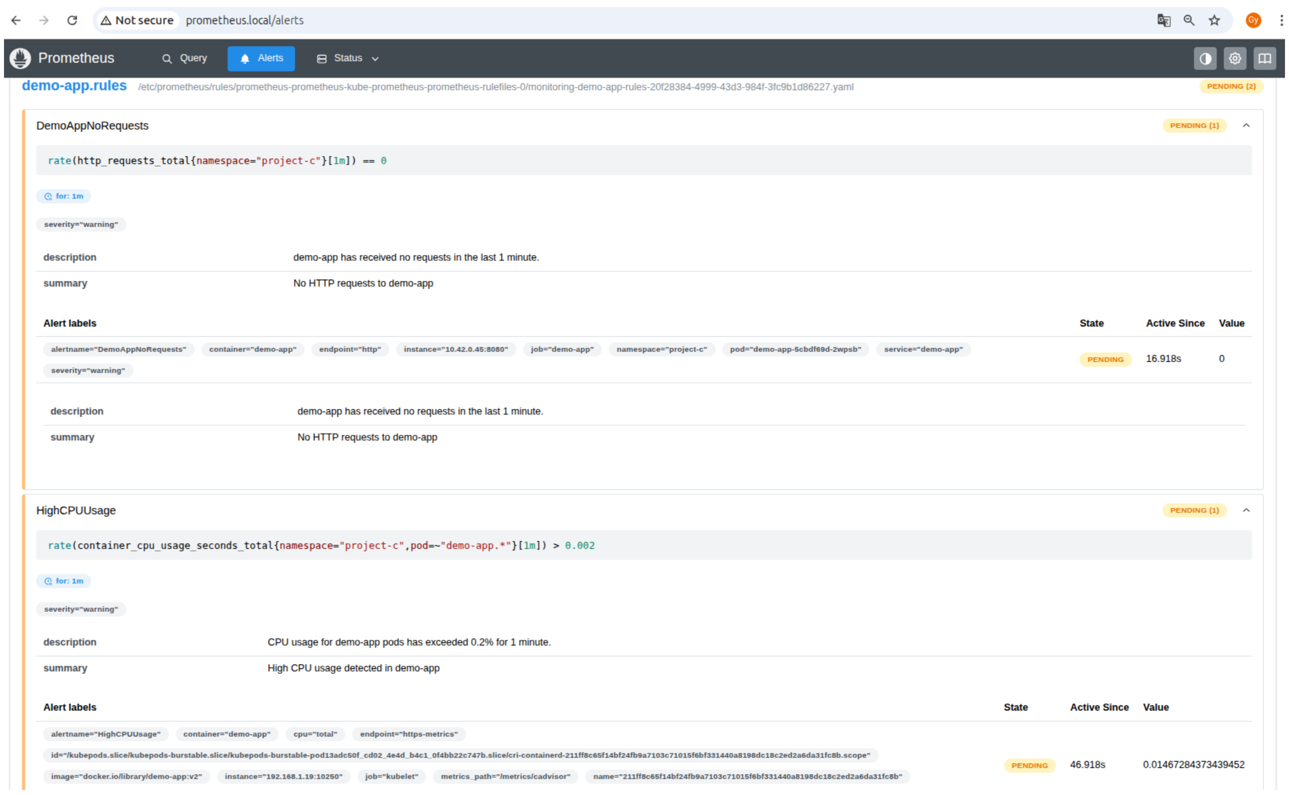
- just my app for clearer visibility:



Advanced Monitoring & Alerts (Week 6)

- created HPA: `kubectl autoscale deployment demo-app --cpu-percent=50 --min=1 --max=5 -n project-c`
- tested under load with this load script: `sudo apt install apache2-utils` `ab -n 1000 -c 50 http://demo.local/`
- checking: `kubectl get hpa -n project-c` `kubectl get pods -n project-c -w`

- created servicemonitor.yaml for /metrics endpoint so Prometheus can watch it: `kubectl apply -f servicemonitor.yaml`
- edited charts/demo-app/templates/service.yaml (name: http) so ServiceMonitor in servicemonitor.yaml can connect: ports:
  - name: http port: {{ .Values.service.port }} targetPort: {{ .Values.service.port }}
- updated prometheus data source URL to: `http://prometheus-kube-prometheus-prometheus.monitoring.svc.cluster.local:9090`
- labeled service.yaml: `kubectl label svc demo-app app=demo-app -n project-c --overwrite`
- created demo-app-rules.yaml with 2 prometheus alerts: `kubectl apply -f demo-app-rules.yaml`
- Created PrometheusRule for:
  - `/metrics` http request threshold
  - CPU/memory usage threshold
- Verified alert firing in Prometheus UI.
- Prometheus alerts in action:



demo-app.rules /etc/prometheus/rules/prometheus-prometheus-kube-prometheus-prometheus-rulefiles-0/monitoring-demo-app-rules-20f28384-4999-43d3-984f-3fc9b1d86227.yaml PENDING (2)

DemoAppNoRequests PENDING (1)

```
rate(http_requests_total{namespace="project-c"}[1m]) == 0
```

for: 1m

severity="warning"

description	demo-app has received no requests in the last 1 minute.
summary	No HTTP requests to demo-app

Alert labels	State	Active Since	Value
alertname="DemoAppNoRequests" container="demo-app" endpoint="http" instance="10.42.0.45:8080" job="demo-app" namespace="project-c" pod="demo-app-5cbdf69d-2wpsb" service="demo-app" severity="warning"	PENDING	16.918s	0

description	demo-app has received no requests in the last 1 minute.
summary	No HTTP requests to demo-app

HighCPUUsage PENDING (1)

```
rate(container_cpu_usage_seconds_total{namespace="project-c",pod=~"demo-app.*"}[1m]) > 0.002
```

for: 1m

severity="warning"

description	CPU usage for demo-app pods has exceeded 0.2% for 1 minute.
summary	High CPU usage detected in demo-app

Alert labels	State	Active Since	Value
alertname="HighCPUUsage" container="demo-app" cpu="total" endpoint="https-metrics" id="/kubepods.slice/kubepods-burstable.slice/kubepods-burstable-pod13adc50f_cd02_4e4d_b4c1_0f4bb22c747b.slice/cri-containerd-211ff8c65f14bf24fb9a7103c71015f6bf331440a8198dc18c2ed2a6da31fc8b.scope" image="docker.io/library/demo-app:v2" instance="192.168.1.19:10250" job="kubelet" metrics_path="/metrics/cadvisor" name="211ff8c65f14bf24fb9a7103c71015f6bf331440a8198dc18c2ed2a6da31fc8b"	PENDING	46.918s	0.01467284373439452

Final Refinements & Docs (Week 7)

- created grafana-values.yaml to successfully use sealedsecret.yaml and then ran: `helm upgrade --install grafana grafana/grafana -f grafana-values.yaml -n monitoring` `helm upgrade --install demo-app ./charts/demo-app -n project-c`
- Reviewed all manifests and checked all resources: `kubectl get all,ingress,configmap,secret,pvc,servicemonitor -n project-c` `kubectl get all,ingress,configmap,secret,pvc,servicemonitor -n monitoring`
- Ensured Helm chart is reusable and parameterized.
- Created and documented custom dashboards in Grafana:
  - Application metrics
  - CPU usage

- Verified `helm upgrade` works with modified values.
- Install EFK Stack `kubectl create namespace logging`
- Add Helm Repos `helm repo add elastic https://helm.elastic.co` `helm repo add fluent https://fluent.github.io/helm-charts` `helm repo update`
- Deploy Elasticsearch `helm install elasticsearch elastic/elasticsearch -n logging --set replicas=1 --set minimumMasterNodes=1 --set persistence.enabled=true --set resources.requests.memory=512Mi`
- Deploy Kibana `helm install kibana elastic/kibana -n logging --set service.type=ClusterIP --set ingress.enabled=true --set ingress.className=traefik --set ingress.hosts[0].host=kibana.local --set ingress.hosts[0].paths[0].path="/" --set ingress.hosts[0].paths[0].pathType=Prefix`
- Deploy Fluent Bit `helm install fluent-bit fluent/fluent-bit -n logging --set backend.type=es --set backend.es.host=elasticsearch-master.logging.svc.cluster.local --set backend.es.port=9200` `helm upgrade fluent-bit fluent/fluent-bit -n logging --set backend.type=es --set backend.es.host=elasticsearch-master.logging.svc.cluster.local --set backend.es.port=9200 --set backend.es.tls=yes --set backend.es.tls_verify=no --set backend.es.http_user=elastic --set backend.es.http_passwd=euQO6sLXpF2DFKG7`

Demo (Week 8)

- Option 1: Enable RBAC and create a read-only service account:

- created and applied readonly.yaml: `kubectl apply -f readonly.yaml`

- tested it to only list pods/services: `kubectl auth can-i list pods --as=system:serviceaccount:project-c:readonly-user -n project-c` `kubectl auth can-i create pods --as=system:serviceaccount:project-c:readonly-user -n project-c`

- Option 2: Run kube-bench locally for CIS benchmark scan: `docker run --rm -v /etc:/etc -v /var:/var --pid=host aquasec/kube-bench version` `docker run --rm -v /etc:/etc -v /var:/var --pid=host aquasec/kube-bench run`

- Prepared clean deployment state.

- Tested scaling and pod self-healing.

- Visualized app metrics in Grafana live.

Troubleshooting

- added Troubleshooting tips along the way in weekly work
- **Grafana panel empty**: Check `Prometheus > Targets`, and ensure metric is collected.
- **Pod not restarting**: Check `kubectl describe pod` for crash loop logs.
- **Alerts not firing**: Ensure rule syntax is valid and thresholds are crossed.

Tools and Versions

Tool / Component	Version
k3s	v1.32.6+k3s1
Go (k3s build)	go1.23.10
Helm	v3.18.4
kubeseal	0.27.1
Grafana (Helm Chart)	grafana-9.3.0
Grafana App	12.1.0
Prometheus (Helm Chart)	kube-prometheus-stack-75.13.0
Prometheus App	v0.83.0
Python	Used via Docker (`python:3.10-slim`)
Flask	Installed via Dockerfile
Prometheus Client	Installed via Dockerfile

Cleanup

```
# Delete app and monitoring
helm uninstall demo-app -n project-c
helm uninstall grafana -n monitoring
helm uninstall prometheus -n monitoring
# Delete namespaces
kubectl delete ns project-c monitoring logging
```