Deploying a Web Application with Kubernetes

A Cloud Native SIG Workshop

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Why Kubernetes?

- Scalability and High Availability
- Self-Healing and Reliability
- Declarative Configuration and Rolling Updates
- Resource Management
- Networking
- Security
- Extensibility and Ecosystem
- Stateful Applications
- Backup and Restore

Kubernetes Architecture

Overview

Kubernetes is a powerful container orchestration platform that automates deployment, scaling, and management of containerized applications. Its architecture is divided into two main parts:

- Control Plane
- Worker Nodes

Kubernetes Architecture

Nodes

Control plane

The **Control Plane** is the brain of the Kubernetes cluster. It manages the cluster's state and makes decisions about scheduling, scaling, and responding to events. The Control Plane has individual components running as pods on the node, each responsible for various tasks.

Worker Nodes

Worker nodes are where your application containers actually run.

Kubernetes Architecture

Control Node Key Components:

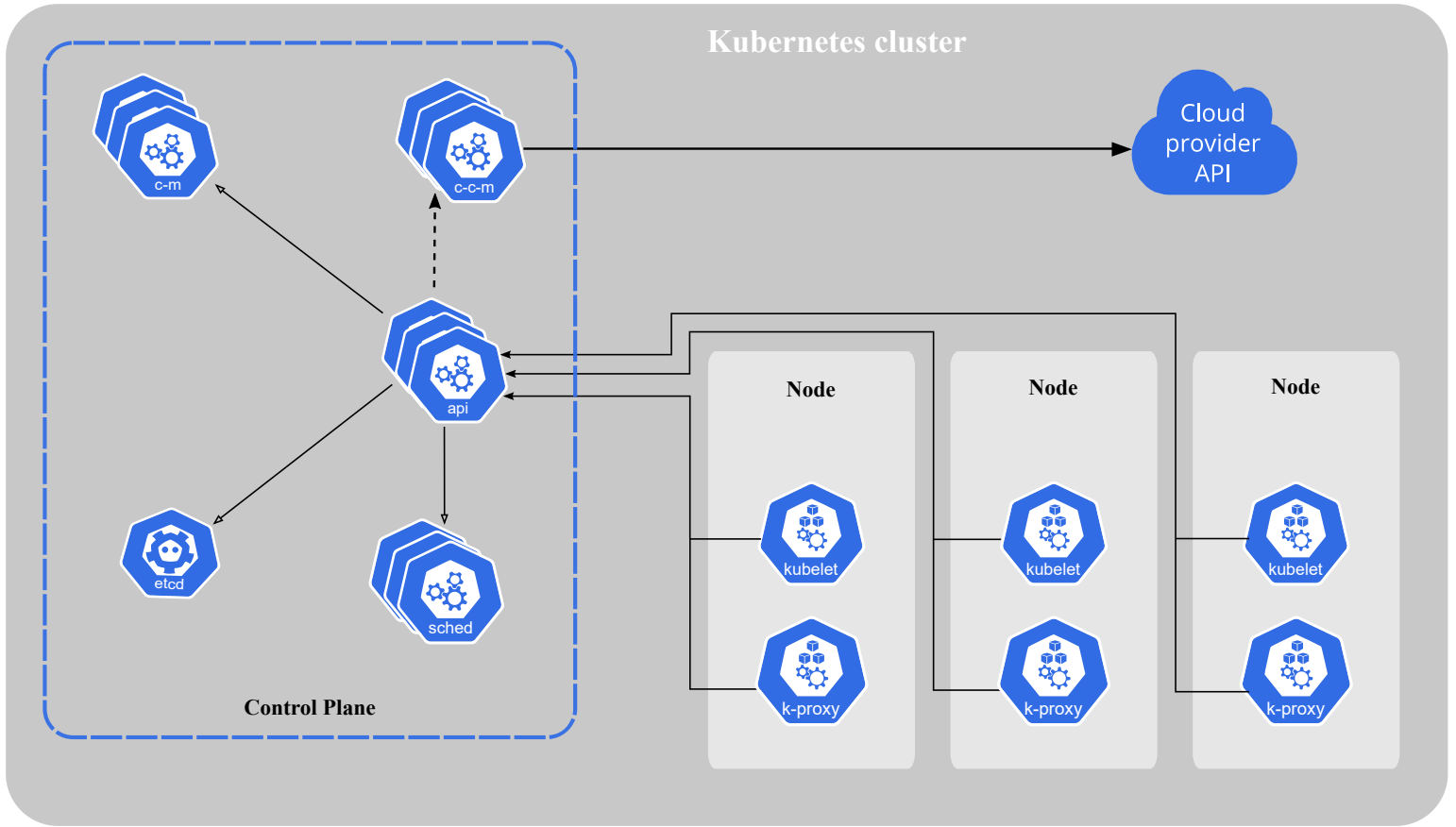
- API Server - The front-end for the Kubernetes control plane. All interactions go through this RESTful API. `kube-apiserver-<node-name>`
- Controller Manager - Runs controllers that handle routine tasks like node health checks, replication, and endpoint management. `kube-controller-manager-<node-name>`
- Scheduler - Assigns newly created pods to nodes based on resource availability and constraints. `kube-scheduler-<node-name>`
- etcd - A distributed key-value store that holds all cluster data (state, configuration, etc.). `etcd-<node-name>`

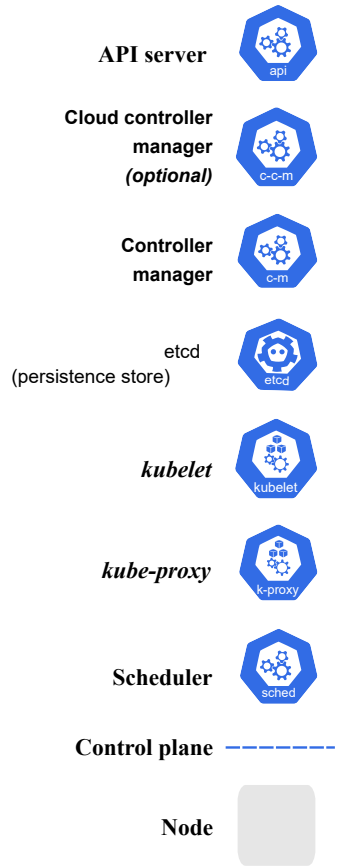
Kubernetes Architecture

Worker Node Key Components:

- Kubelet - An agent that runs on each node. It communicates with the API server and ensures containers are running as expected.
- Container Runtime - Software responsible for running containers (e.g., Docker, containerd).
- Kube-proxy - Handles network routing and load balancing for services within the cluster.

Kubernetes Architecture





https://kubernetes.io/docs/concepts/overview/components/

Kubernetes Architecture

Basic resources

Containers: The Building Blocks

A container is a lightweight, standalone, executable package that includes everything needed to run a piece of software: code, runtime, libraries, and system tools.

Why Containers?

- **Portability**: Runs the same across environments.
- **Isolation**: Each container runs independently.
- **Efficiency**: Uses fewer resources than virtual machines.

Kubernetes Architecture

Pods: The Smallest Deployable Unit in Kubernetes

A pod is a group of one or more containers that share storage, network, and a specification for how to run the containers.

Key Characteristics:

- Containers in a pod share the same IP address and port space.
- Pods are ephemeral—if a pod dies, Kubernetes can replace it.
- Typically, a pod contains a single container, but can include sidecars (e.g., logging or proxy containers).

Analogy: Think of a pod as a wrapper around containers that Kubernetes can manage.

Kubernetes Architecture

Deployments: Managing Application Lifecycle

A deployment is a Kubernetes object that manages a set of pods and ensures the desired number of replicas are running at all times.

Features:

- **Declarative updates**: You define the desired state, and Kubernetes makes it happen.
- **Rollouts and rollbacks**: Easily update your application or revert to a previous version.

Kubernetes Architecture

How could these components work together?

1. You submit a **deployment** manifest via `kubectl apply -f`.
2. The **API Server** receives the request.
3. The **Scheduler** picks a suitable node.
4. The **Controller Manager** ensures the desired state is maintained.
5. The **Kubelet** on the chosen node pulls the container image and starts the **pod**.
6. The pod creates the relevant **containers** as the manifest describes
7. **Kube-proxy** ensures networking is set up so the pod can communicate.

We will see all of this in action over the workshop

Kuberenetes architecture

Minikube

During this workshop we will be using **Minikube** to create clusters and deploy resources.

Minikube lets you run a single-node Kubernetes cluster **locally** on your machine.

It’s designed for developers and learners who want to experiment with Kubernetes without needing a full multi-node setup.

Kubernetes architecture

How standard Kubernetes architecture maps to Minikube:

Standard Kubernetes	Minikube
Control Plane	Runs inside the Minikube VM/container
Worker Node	Same VM/container acts as the worker node
Kubelet	Runs inside Minikube
API Server	Accessible via `kubectl` on your host
etcd, Scheduler, Controller Manager	All run inside the Minikube VM

Kubernetes Architecture

Minikube vs full node setup:

- **Single-node setup**: Control plane and worker node are co-located.
- **Simplified networking**: Easier to manage locally.
- **Ideal for testing**: Lightweight and fast to spin up.

Kubernetes Architecture Summary

- A Kubernetes cluster is formed of a control plane node and worker nodes
- Learnt the definitions of control plane node and worker nodes
- Learnt core concepts of Pods and Deployments (we will revisit this)
- Introduced Minikube
- Explored differences between Minikube and a multi node setup

Lesson 0: Minikube Dashboard

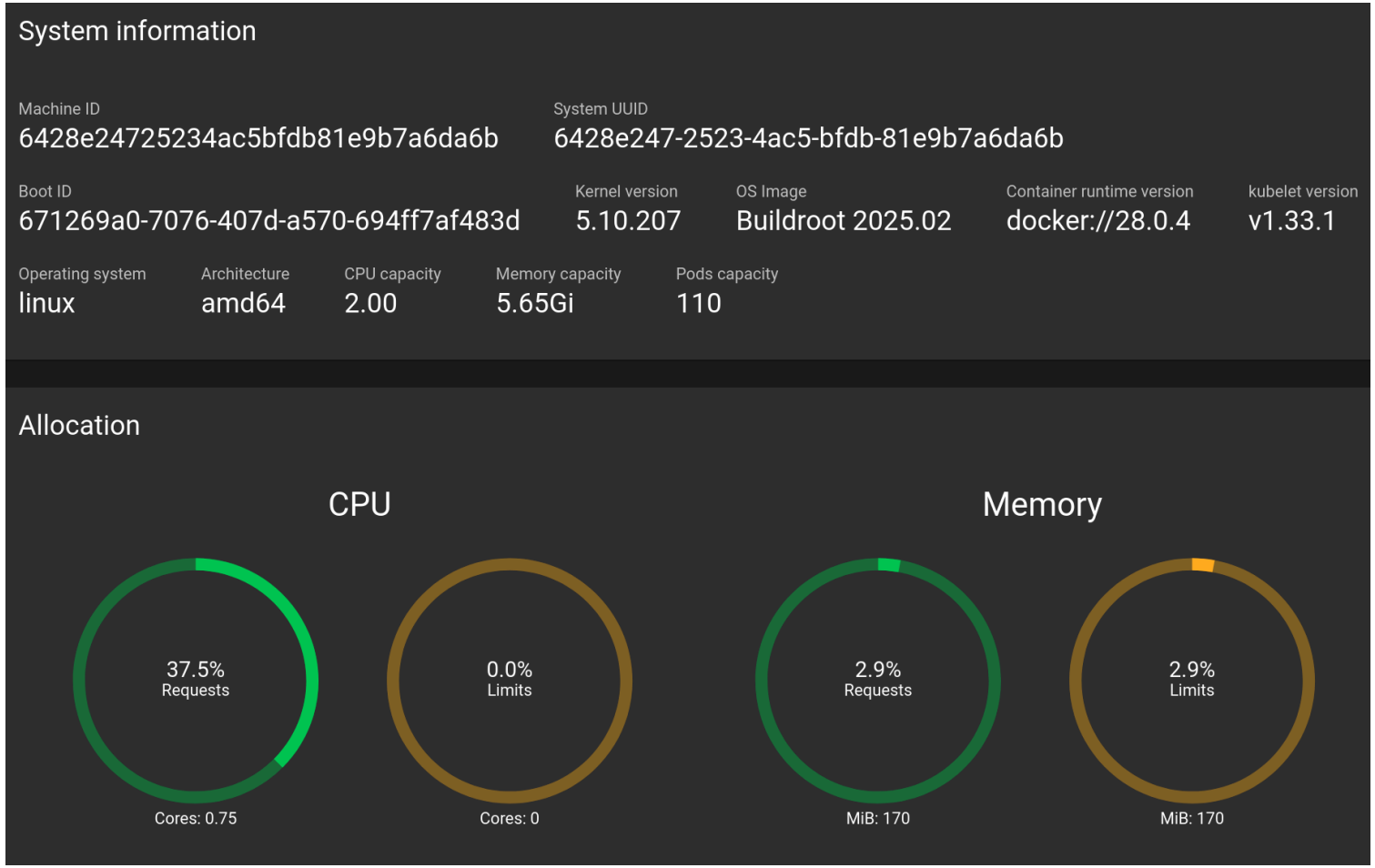
First, start a cluster if you have not already:

```
minikube start
```

Then, launch the dashboard with

```
minikube dashboard
```

Lesson 0: Minikube Dashboard



Lesson 0: Minikube Dashboard

Namespaces: provide a way to organise and isolate resources within a cluster.

Click on Namespaces in the sidebar of the minikube dashboard

- In this workshop, we will work in the *default* namespace
- In the real-world, you may want to use namespaces to divide resources (e.g., `dev`, `prod`)

Lesson 0: Minikube Dashboard

💡 Tips

- Keep the dashboard open to see the effect of `kubectl` commands in real-time
- Green typically mean healthy/running, yellow pending/updating, and red an error state
- Click on any resource name to get detailed information and logs

Lesson 1: Kubechaos

In this lesson we are going to launch our first application on Kubernetes!

Make a local clone of Kubechaos repository:

```
git clone https://github.com/rosalindfranklininstitute/rsecon25-intro-to-kubernetes.git
cd rsecon25-intro-to-kubernetes
```

Check your cluster from the previous lesson is still running(`minikube start` if it is not):

```
minikube status
```

Lesson 1: Kubechaos

Using Minikube's build tool create a Docker image (defined in `image/Dockerfile`) for the Kubechaos app:

```
minikube image build -t local/kubechaos:v1 image
```

A Kubernetes **manifest** defines the target state of resources in a cluster.
Open `deployment/manifests.yaml`, it contains definitions for:

- A Deployment (manages pods)
- A Service (provides networking)
- A ConfigMap (we'll explore that later)

The image tag `local/kubechaos:v1` in the manifest matches what we just built.

Lesson 1: Kubechaos

To deploy the app:

```
kubectl apply -f deployment/manifests.yaml
```

For large applications, it can be useful to know when a pod is ready:

```
kubectl wait --for=condition=ready pod -l app=kubechaos
```

View the app in your browser by using:

```
minikube service kubechaos-svc
```

Open the returned URL in your browser—every refresh is a new surprise 🎲

Lesson 1: Kubechaos

Pods

List the running pods (or in Minikube Dashboard under `Workloads > Pods`):

```
kubectl get pods
```

You will get output similar to:

```
NAME                          READY   STATUS    RESTARTS   AGE
kubechaos-6d7ddd9cf-lvczb     1/1     Running   0          3s
```

Pods are the **smallest unit** of Kubernetes **deployment** representing containers running together.

Lesson 1: Kubechaos

Logs

To view the pod logs:

```
kubectl logs kubechaos-<id>
```

Replace `<id>` with the unique identifier that was shown under `NAME` when you ran the `get pods` command.

You will see a record of the node.js app starting inside the container:

```
> kubechaos@1.0.0 start
> node app.js

Server running at http://localhost:3000
```

Lesson 1: Kubechaos

Deletion Experiment

Let's see what happens if we delete the pod from the cluster:

```
kubectl delete <pod-name>
```

Now run `kubectl get pods` again, what do you notice?

Lesson 1: Kubechaos

- A new pod is created with a different unique-identifier
- The cluster has *self-healed*

Why?

A *Deployment* is a Kubernetes resource that manages the desired state of an application.

Declarative approach

Declare the target state → Kubernetes figures out how to attain and then maintain.

Therefore, when you delete a pod a new one will be created in its place to maintain the state.

Lesson 1: Kubechaos

Replica Sets

Deployments don't directly manage pods. Instead, they work through *ReplicaSets* which are responsible for creating the individual pods.

Deployment → ReplicaSet → Pods

Where *Deployment* defines the target state, *ReplicaSet* ensures the correct number of replicas are alive, and *Pods* are the actual App instances.

Lesson 1: Kubechaos

Let's take a look at the Deployment section of `deployments/manifest.yaml` here we can see the definition of the Replica Set.

```
apiVersion: apps/v1
kind: Deployment
metadata: ...
spec:
  replicas: 1
  selector:
    matchLabels:
      app: kubechaos
  template:
    metadata:
      labels:
        app: kubechaos
```

Lesson 1: Kubechaos

then we have description of the application container that will be running in the pod

```
    spec:
      containers:
      - name: app
        image: local/kubechaos:v1
        ports:
        - containerPort: 3000
```

Lesson 1: Kubechaos

Scaling

We want to scale up to three replicas to support more concurrent requests or ensure better availability.
Let's set up a watch to monitor the pods in real-time:

```
kubectl get pods -w
```

Next, in a new terminal, run the following `kubectl scale` command:

```
kubectl scale deployment kubechaos --replicas=3
```

What do you see?

Lesson 1: Kubechaos

In the first terminal you will see in two additional replicas being spun up immediately!

You can verify the new state with

`kubectl get deployment`

or by reviewing the Deployments/Pods page in the Web Dashboard.

Lesson 1: Kubechaos

Summary

- Deployed a web application on Kubernetes
- Deleted a pod and watched it self-heal
- Learnt Kubernetes concepts of Pods, Deployments and Replica Sets.
- Scaled the deployment to 3 replica sets

Lesson 2: Updating the Kubechaos App

How do you update a running application without breaking it?

In this lesson, we'll explore redeployment in Kubernetes by applying changes to both the application image and specification.

Lesson 2: Updating the Kubechaos App

Open `image/app.js` and find the `suprises` variable (line 7):

```
const surprises = [
  `<h2>🎯 Click the target!</h2>
   <div style="font-size:100px;cursor:pointer;" onclick="alert('You hit it! 🎉')">🎯</div>`,

  `<h2>😂 Joke of the moment</h2>
   <p>Why did the dolphin get a job in Kubernetes?<br>Because it already knew how to work in pods.</p>`,

  // ... more entries
];
```

Lesson 2: Updating the Kubechaos App

Your tasks:

1. Add 2-3 of you own surprises with jokes or other HTML content
2. Remove the original surprise elements
3. Finally, locate the "KubeChaos @ RSECon25!" title and replace it with "<your-name> @ RSECon25!"

> ⚠️ JavaScript Array Syntax:
>
> - Each element is wrapped in backticks `\` (multi-line strings)
> - Elements are separated by commas

Lesson 2: Updating the Kubechaos App

Once you've made your changes, build a new container image with a `v2` tag:

```
minikube image build -t local/kubechaos:v2 image
```

Verify your new image was created:

```
minikube image ls
```

You should see both `local/kubechaos:v1` and `local/kubechaos:v2` listed.

Lesson 2: Updating the Kubechaos App

Open `deployment/manifests.yaml` and update the container's image tag:

```
    spec:
      containers:
      - name: app
        image: local/kubechaos:v2  # Changed from v1
```

Make sure to save the file then apply your changes to the cluster:

```
kubectl apply -f deployment/manifests.yaml
```

Check when the deployment is complete:

```
kubectl rollout status deployment kubechaos
```

Lesson 2: Updating the Kubechaos App

Return to the browser window/URL with the running application - on refresh you should now see your own jokes and custom title!

> 💡 If we had simply modified and rebuilt the `v1` image, it would have been sufficient to restart the deployment (`kubectl rollout restart deploy kubechaos`). Since we changed the manifest, however, a redeployment is necessary.

Lesson 2: Updating the Kubechaos App

Summary

- Updated the container image
- Redeployed the application with a single command
- No need to restart or rebuild systems for a re-deploy

Lesson 3: Updating with ConfigMaps

- In lesson 2 you learnt how to update the Kubechaos app by making changes to the source code and then easily redeploying the app.
- In this lesson we will update the application without modifying the code using ConfigMaps

What is a ConfigMap ?

- It is a Kubernetes API object which stores data in key-value pairs.
- Non-confidential data only

Pods can use the information in ConfigMaps either as:

- environmental variables
- mounted as a volume.

Lesson 3: Updating with ConfigMaps

Configuring the Style with Environmental variables

In web applications the style is often configured independently of the application code.

We currently have a ConfigMap running in our cluster. View it either through the Minikube dashboard or with:

```
kubectl describe configmap kubechaos-style
```

Lesson 3: Updating with ConfigMaps

```
Name:         kubechaos-style
Namespace:    default
Labels:       <none>
Annotations:  <none>

Data
====
border_color:
----
grey

border_size:
----
8px

border_style:
----
dotted

font_color:
----
white

style.css:
----
body { font-family: 'garamond';
       text-align: left;
       margin-top: 10rem;}

bg_color:
----
teal

BinaryData
====

Events:  <none>
```

Lesson 3: Updating with ConfigMaps

This ConfigMap controls the style of the website. .

Change the colors and border of the web application. To edit the ConfigMap:

```
kubectl edit configmap kubechaos-style
```

Lesson 3: Updating with ConfigMaps

Change the following variables:

```
bg_color:  white
font_color: black
border_color: black
border_size: 4px
border_style: dashed
```

> ⚠️ Note you will need to use specific variables for colors:
>
> - they can be in hex-RGB format e.g. #000000 or #0000ff
> - or they can be in css names e.g. black or blue

Refresh your web browser. What has happened?

Lesson 3: Updating with ConfigMaps

You will have noticed that your changes have not been applied, the styling remains the same.

To get the colours to change run the following:

```
kubectl rollout restart deployment kubechaos
```

Refresh your web browser, what do you see now?

Lesson 3: Updating with ConfigMaps

Explanation

The variables that you edited in the ConfigMap are applied as **environmental variables**. To get the pod to pick up on its new environment it needs to be remade. The quickest way to restart everything is to use the `kubectl rollout restart` command we used above.

Lesson 3: Updating with ConfigMaps

We will now look at `manifest.yml`. Please open up this file and scroll to the block at line 22, to line 44. In this part of the deployment we set the `env` section of the container with values from the ConfigMap.

```
    spec:
      containers:
      - name: app
        image: local/kubechaos:v1
        ports:
        - containerPort: 3000
        env:
        - name: BG_COLOR
          valueFrom:
            configMapKeyRef:
              name: kubechaos-style
              key: bg_color
     ...
```

Lesson 3: Updating with ConfigMaps

In this section we injected variables from the ConfigMap into the pod as environmental variables to make changes without having to rebuild the image:

- ideal for applications that read configuration through environment variables
- doesn't require file handling
- Requires restart for changes to take effect.

Now we will look at mounting our ConfigMap as a volume. This method is used when applications are expecting **configuration files** rather than **environmental variables**.

Lesson 3: Updating with ConfigMaps

Usually a website's style is configured through a `.css` file, rather than environmental variables.

Look at the ConfigMap either through the Minikube Dashboard or with:

`kubectl describe configmap style-kubechaos`

There is a definition of a css file :

```
style.css:
----
body { font-family: 'sans-serif';
       text-align: center;
       margin-top: 5rem;}
```

Lesson 3: Updating with ConfigMaps

Now let's edit these variables in the ConfigMap keeping the structure of the file intact:

```
kubectl edit configmap style-kubechoas
```

Refresh your browser? What happens now?

> ⚠️ Note you will need to use specific variables for `font-family and` text-align`:
>
> - `text-align` can be `center`, `right`, `left`
> - `font-family` has to belong to the web-safe fonts e.g. `serif`, `arial`, `garamond`

Lesson 3: Updating with ConfigMaps

Explanation

Here we are mounting a file as a volume into the pod. The file is being written by the values in the ConfigMap. When we change the values they are immediately picked up by the pod without it being restarted.

Lesson 3: Updating with ConfigMaps

Open the `manifest.yml` and scroll to line 44 to 54:

```
        ...
      volumeMounts:
      - name: style-env
        mountPath: "/src/public/"
        readOnly: true
    volumes:
    - name: style-env
      configMap:
        name: kubechaos-style
        items:
          - key: "style.css"
            path: "style.css"
```

This creates a volume called `style-env` and mounts it as a volume. This volume has the `style.css` file mounted on the path the application expects.

Lesson 3: Updating with ConfigMaps

To see the manifest of the original ConfigMap (before our edits) you can scroll down to line 73 in `manifests.yml`:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: kubechaos-style
data:
  bg_color:  white
  font_color: black
...

  style.css: |
    body { font-family: 'sans-serif';
   ...
           }
```

Lesson 3: Updating Config Maps

Summary:

- ConfigMaps are key-value pair API objects
- They can be used to inject environmental variables or as volumes
- You can update your application without changing the code or the deployment
- environmental variables require restarts, volumes do not
- For a production system you can version control your changes to a ConfigMap as a manifest and apply it to your cluster.

Lesson 4: Helm

Introduction

Helm is a package manager for Kubernetes that provides a convenient way to share and install community applications.

By packaging manifests into reusable 'Charts', complex projects can be installed with a single command, including any dependencies.

In this lesson, we'll deploy a community application available as
a Helm chart to our minikube cluster.

Lesson 4: Helm

> ⚠️ Security
>
> Like all code on the internet, Helm charts can contain malicious content.
> Only install Helm charts from trusted sources. Vetting charts using Helm's
> `template` and `verify` commands and other best practices
> are discussed in the `sysdig` article in Further Reading in the documentation at:
> https://rosalindfranklininstitute.github.io/rsecon25-intro-to-kubernetes/

Lesson 4: Helm

Prerequisites

On Linux/WSL, Helm can be installed as a snap package

```
sudo snap install helm --classic
```

On macOS, it is available through Homebrew

```
brew install helm
```

Other Windows users can use the Chocolately package manager:

```
choco install kubernetes-helm
```

You can verify your installation by running `helm version`.

Lesson 4: Helm

🍹 Deploying Mocktail with Helm

Mocktail, https://github.com/Huseyinnurbaki/mocktail, is a minimalist server that allows you to define and test custom API endpoints.

We'll use it to demonstrate deploying a collection of Kubernetes manifests to our cluster using a Helm chart.

Helm Charts can be found in two main ways:

- On community repositories like Artifact Hub, with many projects
- On individual repositories e.g. on GitHub for specific projects

Lesson 4: Helm

Mocktail provides its own Helm repository, which we can add to Helm with

```
helm repo add hhaluk https://huseyinnurbaki.github.io/charts/
```

> 💡 **Tip** It's a good idea to periodically get Helm to check for updates from added repositories:
>
> ```
> helm repo update
> ```

Lesson 4: Helm

Deploying Mocktail

Having added the Mocktail helm repository, the application can be deployed to our Minikube cluster with

```
helm install mocktail hhaluk/mocktail -n mocktail --create-namespace
```

That's it! In the background, Helm organised:

- Downloading the chart and generating all necessary manifests
- Creating a namespace for the manifests to be deployed to
- Creating deployments and services
- Starting the application

Lesson 4: Helm

Query the service

```
minikube service mocktail-svc --url -n mocktail
```

The URL should take you to the Mocktail dashboard.

> **Extra** You can also use your Minikube dashboard or the `kubectl` commands you have learned to explore the pods and deployments associated with >Mocktail.

Lesson 4: Helm

Optional: Try creating a custom endpoint in the dashboard:

1. Add a new GET endpoint: `/surprise`
2. Set the response:

```
{
      "message": "Hello from Kubernetes!",
      "pod": "mocktail-pod",
      "surprise": "🎲"
}
```

3. Test it with curl from a Terminal:

```
curl <mocktail-dashboard-url:PORT>/mocktail/surprise
```

Lesson 4: Helm

Customising Charts with Values

A powerful feature of Helm is the ability to customise applications with your own parameters.
First, view available configuration options for Mocktail:

```
helm show values hhaluk/mocktail
```

Let's override the default `replicaCount: 1` to have three replicas
for the service:

```
helm upgrade mocktail hhaluk/mocktail --set replicaCount=3 -n mocktail
```

Lesson 4: Helm

For larger number of changes, you can write a `custom-values.yaml`.
We have provided a file at helm/custom-values.yaml for updating the existing helm release with an ingress.

```
helm upgrade -i my-mocktail hhaluk/mocktail -n my-mocktail --create-namespace -f helm/custom-values.yaml
```

The above command can be used for a first time install of a helm release or to upgrade an existing release due to the `-i` flag.

This upgrade has changed the container port that the service listens on.

Lesson 4: Helm

There are numerous community charts covering thousands of web and infrastructure projects.
Charts on Artifact Hub https://artifacthub.io/ may be searched directly from the command line with:

```
helm search hub <search-term>
```

Lesson 4: Helm

You can also search in any repositories you have added. For example, first adding the popular Bitnami
Library https://github.com/team-maravi/bitnami-charts:

```
helm repo add bitnami https://charts.bitnami.com/bitnami
helm repo update
```

Then:

```
helm search repo <search-term>
```

Lesson 4: Helm

Cleaning up

We can clean up everything we deployed during this lesson using:

```
helm uninstall mocktail -n mocktail
helm uninstall my-mocktail -n my-mocktail
```

You can check that the resources have been removed by using `kubectl` :

```
helm list -n mocktail
helm list -n my-mocktail
```

> ⚠️ Note: This will not remove the namespace itself for that you need to separately run `kubectl delete namespace mocktail my-mocktail

Lesson 4: Helm

Summary

- Helm is a package manager for Kubernetes that provides a convenient way to share and install community applications.
- Installed an example application via Helm
- Configuring the Helm chart through adding `custom-values`
- How to explore repos and Artifact Hub
- Cleaning up the application

Using Kubernetes in your work

Everything you have learned today can be used in your own work. For further reading on the requirements to scale to production please see:

https://rosalindfranklininstitute.github.io/rsecon25-intro-to-kubernetes/

Cloud-Native SIG

Was brought to you with support for the **Software Sustainability Institute**

Join us:

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