Containers and Kubernetes
Security is not an afterthought

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Who am I?

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13 years in IT

Very interested in the benefits containers can offer, but aware of the security concerns

My wife knows I do “cloud security” and my kids know I do something for IBM, “in the office”

Agenda

The world of containers, Kubernetes (K8s) and the challenges of developing, deploying and managing secure applications in this environment.

- Introduction to containers and the role of Kubernetes.
- Some of the common security challenges.
- Strategies for securing containerised applications at the various stages of a DevSecOps pipeline.
- Best practices for addressing run-time security concerns for containerised applications and Kubernetes environments.

Part 1

An introduction to containers and the role of Kubernetes. Having set the scene, the focus will move onto some of the common security challenges.

Containers: How are they possible?

- Building blocks for containers:
  - **Namespaces:** kernel level isolation of processes
  - **Cgroups:** Control resource (CPU, memory, network, disk I/O) accessed/used by process/set of processes

What actually is a container?

In a nutshell …

App code + Binaries and libraries = Container

…Containers are created from container images

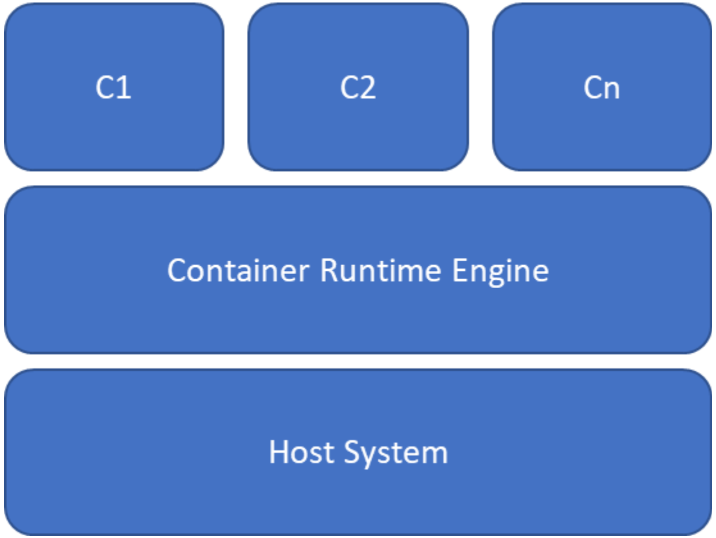
Building a Container Image

- A container image can be created from a Dockerfile/Containerfile
- Various build tools available (Docker, Buildah, Kaniko)
- Be aware of image size (e.g., layers and bloating)
- Store it in local or remote image registry

Running Containers

To execute a container, we use a container runtime engine. Commonly used ones are:

- CRI-O (used in Kubernetes)
- Containerd (from Docker)
- rkt



The need for Container Orchestration

- Why Kubernetes came about…container orchestration
- Kubernetes is an open-source system for automating deployment, scaling, and management of containerised applications.

Common Security Challenges

- Containers share the underlying host's kernel
- A container doesn't have security built in by default
- Using containers can help speed up our development lifecycle – security must keep up
- It's easy to take shortcuts to "just make it work"
- Container orchestration security doesn't just happen, we must get involved…

Summary

- Namespaces and cgroups make containers possible
- A container image is the template from which a container is created & run
- A container image can be built from a configuration file – consider layers
- Container runtime engines abstract the complexity of creating and running containers
- Container Orchestrators bring scale and management of containers
- There are security challenges and we must proactively tackle them

Part 2

Some strategies for securing containerised applications at the various stages of a DevSecOps pipeline.

Key Lifecycle Phases for Container Security

Plan

Code

Build

Deploy

Run

…Throughout the lifecycle!

Key things to shout about…

- Educate your team
- Consider your Host OS
- Deploy Kubernetes in a secure manner
- Separate and control image registries
- Configure the image securely
- Configure the workload object (deployment, statefulset etc) securely
- Check for vulnerabilities and weak configuration in pipeline
- Implement robust admission control for workloads
    - Get everything running with minimal privilege and permissions
- Monitor the runtime

Plan

NIST SP 800-190

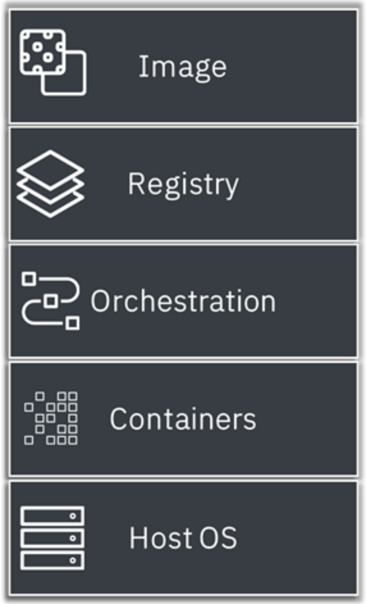
- Title: “Application Container Security Guide”
- Contents includes:
  - Introduction to application containers
  - Major risks for core components of container technologies
  - Countermeasures for major risks
  - Container threat scenario examples
  - Container technology life cycle security considerations

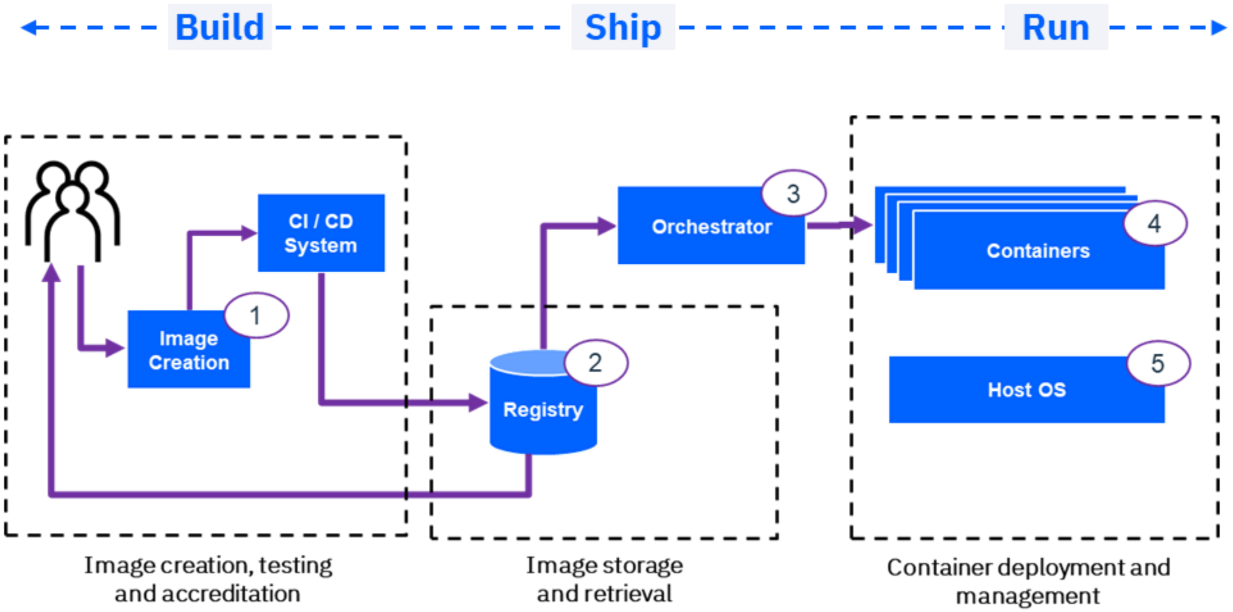
NSA & CISA Kubernetes Hardening Guidance

The National Security Agency (NSA) and Cybersecurity and Infrastructure Security Agency (CISA) have put together a hardening guide for Kubernetes. It covers:

- Threat Model
- Pod Security
- Network separation and hardening
- Authentication and Authorisation
- Log Auditing
- Upgrading and application security practices

Key Areas of Container Security





HostOS Security

- Running a full blown OS vs a container-optimised distribution…
- Benefits of the latter:
  - Minimal OS image; only includes tools needed to run containers
  - Immutable filesystems (eliminate a lot of vulnerabilities)
  - Automated atomic upgrades
- For the former:
  - Consider why you are using it
  - Remove anything you don’t need
  - Perform hardening!

Orchestration: Things to consider…

- Secure cluster configuration
- Account use
- Authentication
- Authorisation
- Admission Control
- Resource Management
- Secrets Management (and encryption)
- Audit
- Workload placement (Taints & Tolerations)
- Exposing services
- Network Policies & Microsegmentation

Secure Cluster Configuration

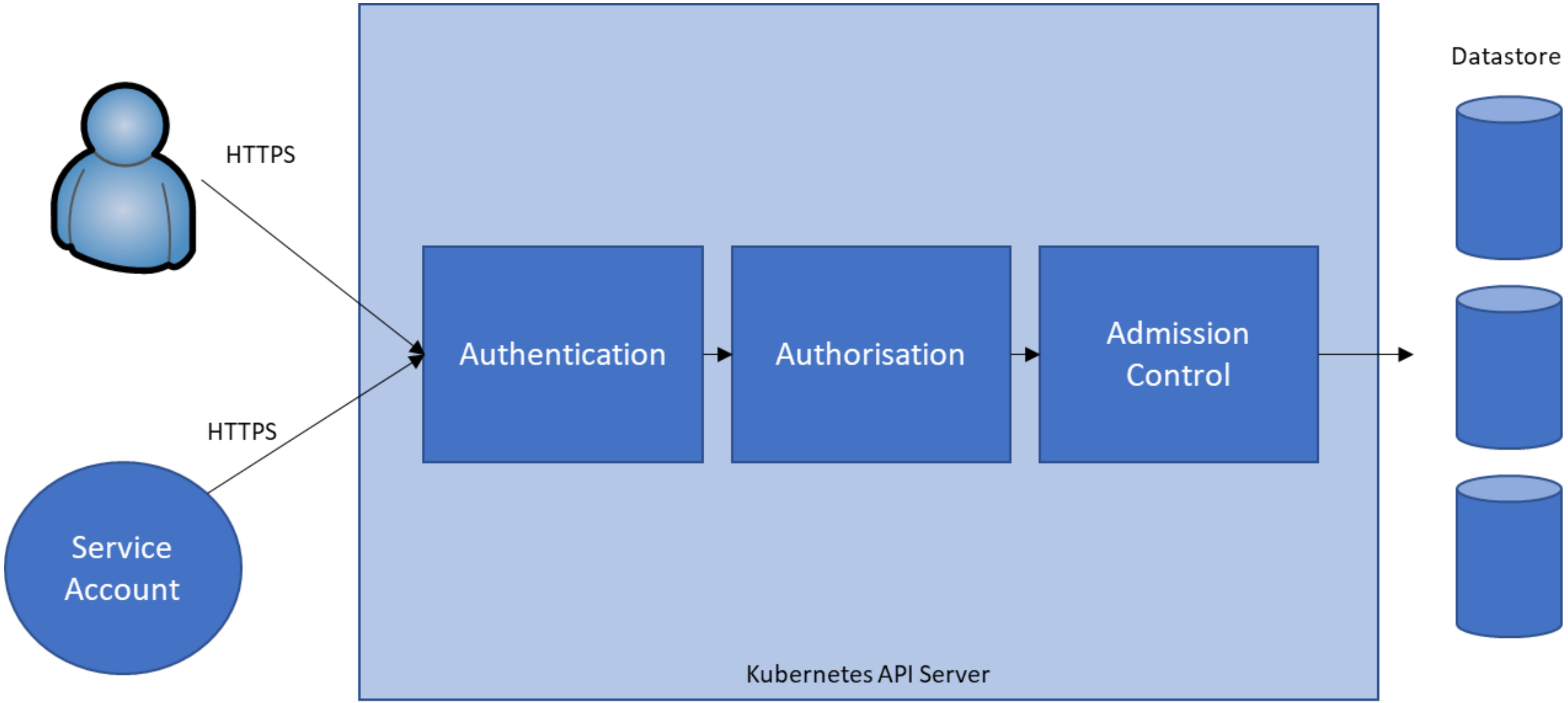
CIS Kubernetes Benchmark v1.6.1 is available from Center for Internet Security, has sections on:

- Control Plane Components
- Etcd
- Control Plane Configuration
- Worker Nodes
- Policies

Kubernetes Accounts

When you (a human) access the cluster (for example, using kubectl), you are authenticated by the apiserver as a particular User Account. Processes in containers inside pods can also contact the apiserver. When they do, they are authenticated as a particular Service Account (for example, default).

Orchestration



Default ClusterRoles

Kubernetes provides some ClusterRoles that are intended to be user-facing roles:

- **Cluster-admin:** do anything on any resource, cluster-wide
- **Admin:** do anything on any resource within a namespace
- **Edit:** read/write to most objects in a namespace (can’t modify roles or role bindings)
- **View:** read-only access to see most objects in a namespace (can’t view roles or role bindings)

…Use these where possible. Base access on namespaces too.

What are Admission Controllers?

Kubernetes admission controllers are plugins that govern and enforce how the cluster is used. They can be thought of as a gatekeeper that intercept (authenticated) API requests and may change the request object or deny the request altogether.

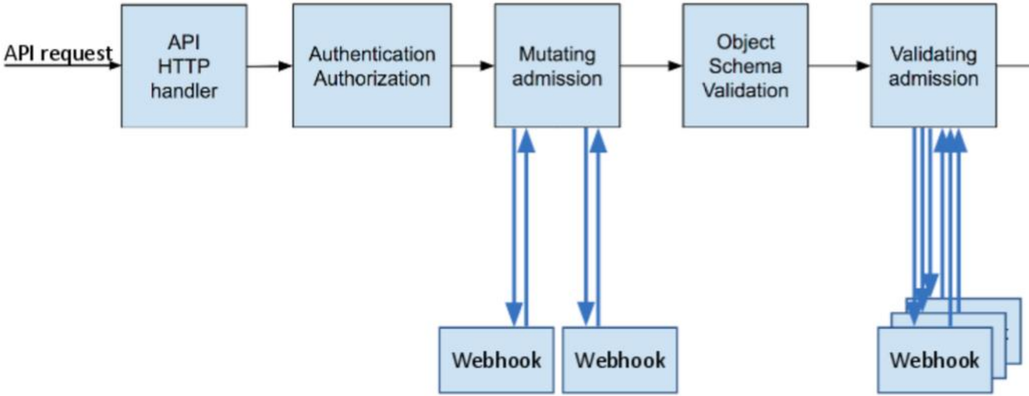


Image source: https://kubernetes.io/blog/2019/03/21/a-guide-to-kubernetes-admission-controllers/

Admission Controller – Security Interest

- Pod Security Policies
- LimitRange
- ResourceQuota

Pod Security

- PodSecurityPolicy – deprecated in v1.21 (1.22 is latest version)
- Being replaced: KEP-2579: Pod Security Admission Control
- "Replace PodSecurityPolicy with a new built-in admission controller that enforces the Pod Security Standards."

Profile	Description
Privileged	Unrestricted policy, providing the widest possible level of permissions. This policy allows for known privilege escalations.
Baseline	Minimally restrictive policy which prevents known privilege escalations. Allows the default (minimally specified) Pod configuration.
Restricted	Heavily restricted policy, following current Pod hardening best practices.

Pod Security

Has settings for:

- Access to host namespaces
- Running as privileged
- Running as root/non-root users and groups
- Kernel capabilities
- HostPath volumes
- Use of AppArmor and SELinux (access control)
- Seccomp profile (controlling syscalls)
- Sysctls (changing kernel parameters)

Resource Control

- LimitRange:
  - Enforce minimum and maximum compute resource per pod or container
  - Set default/limit for compute resources in a namespace and automatically inject them to containers at runtime
- ResourceQuota:
  - Restrict resource consumption on a namespace basis

Secrets Management

- Secret: An object that contains a small amount of sensitive data such as a password, a token, or a key
- Some potential gotchas:
  - Stored unencrypted by default
  - Anyone with API access and permission can view a secret
  - Anyone authorised to create a pod in a namespace can use that access to read any secret in the namespace
- So… RBAC, enable encryption at rest for secrets and consider use of a secrets vault.

Audit

Auditing allows cluster administrators to answer the following questions:

- what happened?
- when did it happen?
- who initiated it?
- on what did it happen?
- where was it observed?
- from where was it initiated?
- to where was it going?

So, get it configured!

Workload Placement

As per NIST SP 800-190 guidance:

“*Orchestrators should be configured to isolate deployments to specific sets of hosts by sensitivity levels.*”

Node selector: affects a single pod template and is useful when the pod needs something from the node, e.g., a kernel parameter setting.

Taints and tolerations: will affect all pods. Taints allow a node to repel a set of pods. Tolerations are applied to pods and allow (but do not require) the pods to schedule onto nodes with matching taints.

Exposing Services

- By default, pods and their services are not exposed outside the cluster; it is a conscious decision to do so.
- Consider:
  - Who are you exposing it to?
  - Why are you exposing it? Does anything outside the cluster need it?
  - Have you secured the application being exposed?
  - Could port-forwarding be of use?
  - Use TLS

Network Policies

- By default, pods are non-isolated; they accept traffic from any source.
- Network policies are additive
- Good ideas:
  - Block all traffic from outside the namespace
  - Permit the traffic that is actually required
- Consider a Service Mesh for production:
  - Facilities deployment strategies based on diverting traffic
  - Application layer aware
  - Additional controls and insights

Code

Securing Container Images: Best Practices

- Define and implement process for trusted base images
- Use minimal base image
- Reference base image by version tag or even better, its digest
- Don’t run as root
- Only install required packages
- Don’t run upgrades of packages
- Don’t include secrets in configuration file
- Use COPY not ADD
- Don’t open port 22 or include SSH unless required
- Remove set userID or set groupID permissions unless required

Securing Container Images

Spot the difference…

```
FROM python:3.9.7-alpine3.14

ARG USER=myuser
ARG UID=1000
ARG GID=1000

COPY requirements.txt /tmp
RUN pip install --no-cache-dir -r /tmp/requirements.txt && \
    addgroup -S -g ${GID} ${USER} && \
    adduser -S -D -u ${UID} -G ${USER} ${USER}

COPY --chown=${UID}:0 my_app/the_api /my_app/my_api
COPY --chown=${UID}:0 my_app/ci_cd/ci_cd.py /my_app/
COPY --chown=${UID}:0 myscript.sh /my_app/

RUN chmod -R g=u /my_app/

USER ${UID}
```

```
FROM python:latest

COPY requirements.txt /tmp
RUN pip install --no-cache-dir -r /tmp/requirements.txt

COPY my_app/the_api /my_app/my_api
COPY my_app/ci_cd/ci_cd.py /my_app/
COPY myscript.sh /my_app/
```

Securing Container Images

Multi-stage

```
####### This is a multi-stage build ######
####### Below is for building app ########
FROM node:12.22.6 as installer
COPY ./nodejs /simple-page
WORKDIR /simple-page
RUN npm install --production --unsafe-perm && \
    npm dedupe

####### Below is for building image ########
FROM node:12.22.6-alpine3.13

# Arguments for use in image build
ARG USER=simple
ARG UID=1001
ARG GID=1001

WORKDIR /simple-page

RUN addgroup --system --gid ${GID} ${USER} && \
    adduser ${USER} --system --uid ${UID} --ingroup ${USER}

COPY --from=installer --chown=${USER} /simple-page .

# Remove any setuid or setgid bits from files to avoid permission elevation
RUN find / -xdev -perm /6000 -type f -exec chmod a-s {} \; || true

USER ${UID}
EXPOSE 8080
CMD ["npm", "start"]
```

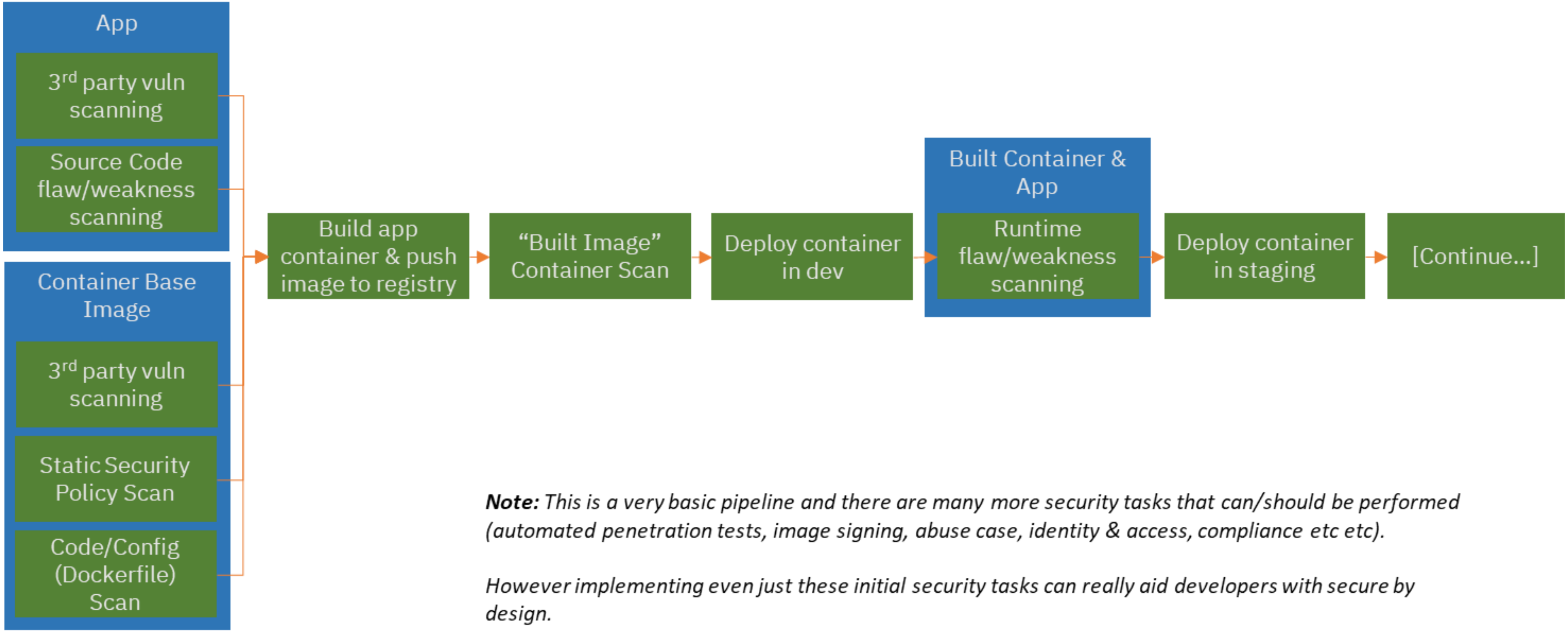
Securing Container Workloads

- Specify securityContexts!
- Some can be specified at both pod and container level (container level takes precedence)

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: <deployment-name>
...
...
      containers:
      - name: "<container-name>"
        image: "<trusted-registry>/<trusted-image>:<explicit-tag-or-hash>"
        imagePullPolicy: "IfNotPresent"
        resources:
          limits:
            cpu: <number>
            memory: <number>
          requests:
            cpu: <number>
            memory: <number>
        env:
        - name: <env-variable-name>
          value: <env-variable-value>
        securityContext:
          privileged: <false|true>
          allowPrivilegeEscalation: <false|true>
          runAsUser: <number>
          runAsGroup: <number>
          supplementalGroups: <number>
          fsGroup: <number>
          capabilities:
            add: ["<cap-1>", "<cap-n>"]
            drop: ["ALL"|"NET_RAW"]
          seccompProfile:
            type: RuntimeDefault
          seLinuxOptions:
            level: "<labels>"
          readOnlyRootFilesystem: <false|true>
...
...
```

Build

Basic Pipeline



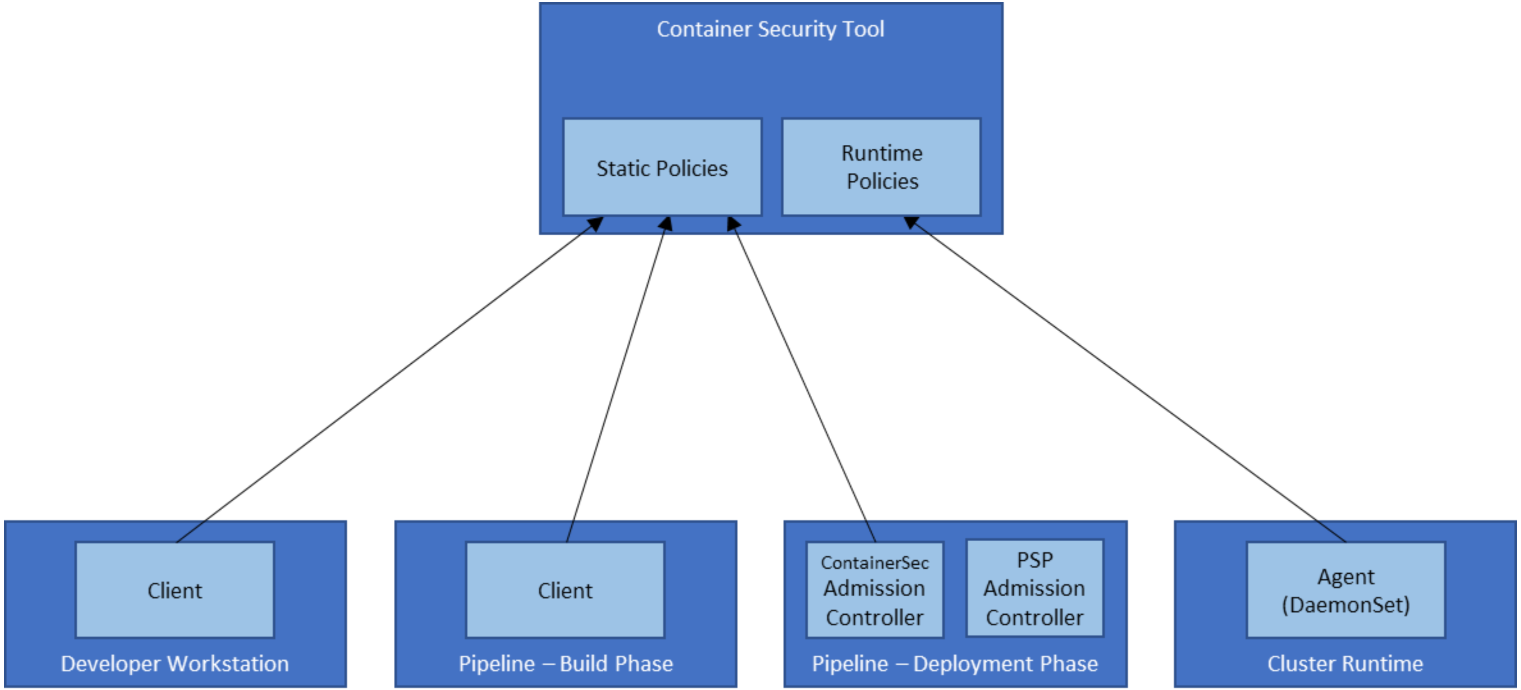
Note: *This is a very basic pipeline and there are many more security tasks that can/should be performed (automated penetration tests, image signing, abuse case, identity & access, compliance etc etc).*

However implementing even just these initial security tasks can really aid developers with secure by design.

Registry

- Access Control: consider human and programmatic
- Secure connections: TLS
- Separation between environments: control image use
- Stale images

ContainerSec Tool Interactions



Container Vulnerability & Configuration Flaw Checking

Some useful checks against the image filesystem that can be performed:

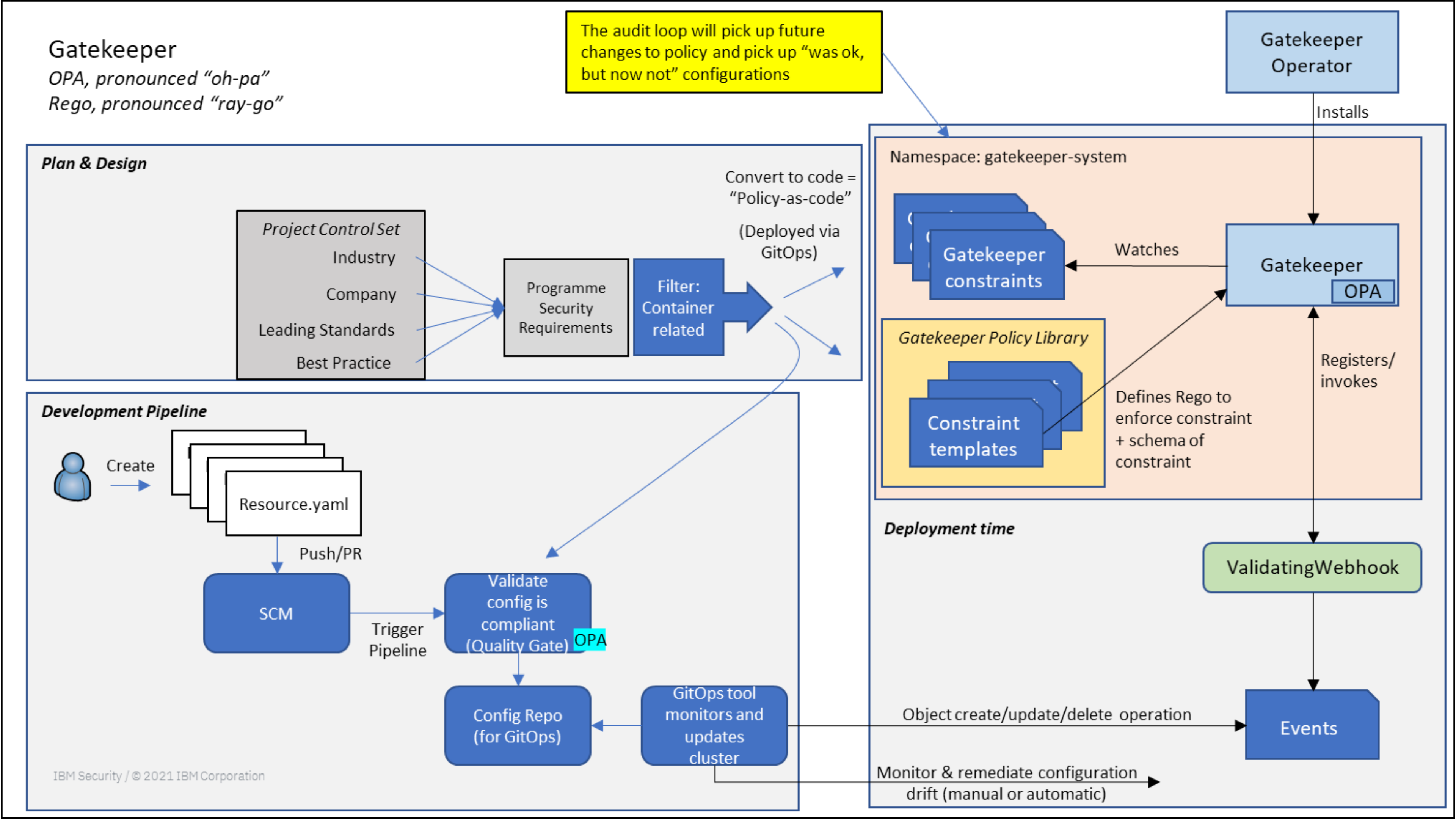
- Checking the age of the vulnerability feeds
- Checking if unknown (i.e., non-official) NPM or Ruby feeds are used.
- OS and non-OS packages with vulnerabilities
    - Consider those with fixes vs those without

Useful Dockerfile checks:

- The Dockerfile sets effective user as 'root’
- Dockerfile exposing port tcp/22 (SSH)
- Secrets, such as 'AWS_SECRET_KEY', 'password' being included in the image
- The Dockerfile includes secrets set as environment variables
- The Dockerfile contains an instruction to 'ADD’ (vs ‘COPY’)

Cluster Configuration Control

- Remember it’s not just the container images that are changing
- What about cluster configuration?


Gatekeeper
OPA, pronounced "oh-pa"
Rego, pronounced "ray-go"
The audit loop will pick up future changes to policy and pick up "was ok, but now not" configurations
Gatekeeper Operator
Installs
Plan & Design
Project Control Set
Industry
Company
Leading Standards
Best Practice
Programme Security Requirements
Filter: Container related
Convert to code = "Policy-as-code"
(Deployed via GitOps)
Namespace: gatekeeper-system
Gatekeeper constraints
Watches
Gatekeeper
OPA
Gatekeeper Policy Library
Constraint templates
Defines Rego to enforce constraint + schema of constraint
Registers/ invokes
Development Pipeline
Create
Resource.yaml
Push/PR
SCM
Trigger Pipeline
Validate config is compliant (Quality Gate)
OPA
Config Repo (for GitOps)
GitOps tool monitors and updates cluster
Deployment time
ValidatingWebhook
Object create/update/delete operation
Events
Monitor & remediate configuration drift (manual or automatic)

Deploy

Securing Container Deployments: Best Practices

- Use admission control, linked to container security tool policies
- Use securityContexts and associated admission control to:
  - Reduce/remove privilege and running as root
  - If root and privilege must be given; restrict (drop) capabilities to those truly needed
  - Utilise MAC (SELinux, AppArmor etc)
  - Utilise Seccomp where possible (Restricting system calls)
  - Restrict access to underlying host
- Also consider:
  - Image signature checking
  - Image registry source checking

Summary

- Plan security into the application container lifecycle
- Ensure the 5 key risk areas are secured
- “Security Opportunities”:
  - Code & build = chance to shift-left
  - Deployment = last chance to stop something
  - Runtime = View of what has been deployed and ongoing security status

Part 3

Best practices for addressing runtime security concerns for containerised applications and Kubernetes environments.

Securing Container Runtime: Best Practices

- Segregation of privileged vs non-privileged containers by segregating worker nodes
- Only run containers with the same purpose, sensitivity, & threat posture on a single host OS kernel
- Specify resource requests and limits and project/namespace quotas
- Control network communication via microsegmentation

Monitor Cluster and Workloads

- Monitor the cluster:
  - Network flows
  - Configuration compliance
  - Audit logs
- Monitor workloads:
  - Processes within containers
  - Interactions with the API
  - Vulnerabilities requiring attention

Summary

We must consider best practices during:

- **Development:** base image – trusted, minimal?, component versions/ages, included packages, tags, configuration of the container image
- **Build:** malware, vulnerability, configuration checking
- **Release & Deployment:** vulnerability and malware, repository, privilege
- **Runtime:** malicious process monitoring, visibility of deployments vs vulnerabilities

And finally…

Remember:

- Educate your team
- Consider your Host OS
- Deploy Kubernetes in a secure manner
- Separate and control image registries
- Configure the image securely
- Configure the workload object (deployment, statefulset etc) securely
- Check for vulnerabilities and weak configuration in pipeline
- Implement robust admission control for workloads
    - Get everything running with minimal privilege and permissions
- Monitor the runtime

Useful Links

- Namespaces and cgroups:
  - https://www.nginx.com/blog/what-are-namespaces-cgroups-how-do-they-work/
  - https://medium.com/@BeNitinAgarwal/understanding-the-docker-internals-7ccb052ce9fe
- Container Image layers: https://betterprogramming.pub/how-to-improve-docker-image-size-with-layers-3ad62be0da9b
- Container Runtimes: https://www.tutorialworks.com/difference-docker-containerd-runc-crio-oci/
- NIST SP 800-190: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-190.pdf
- Kubernetes CIS Benchmark v1.6.1: https://workbench.cisecurity.org/benchmarks/6083
- PSP replacement:
  - https://github.com/kubernetes/enhancements/tree/master/keps/sig-auth/2579-psp-replacement
  - https://kubernetes.io/docs/concepts/security/pod-security-standards/
- Encrypt secrets at rest: https://kubernetes.io/docs/tasks/administer-cluster/encrypt-data/
- OPA Gatekeeper: https://open-policy-agent.github.io/gatekeeper/website/docs/

Any questions?

Thank you

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