INTERNALS OF LINUX CONTAINERS

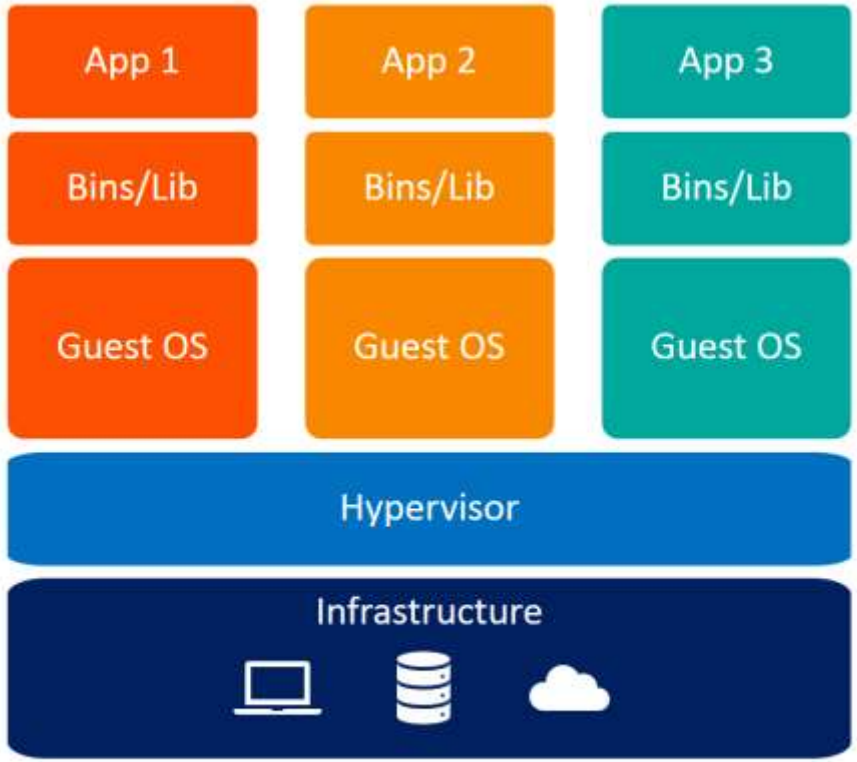
NOISY NEIGHBOUR PROBLEM?

ISOLATION

- As far as a process is concerned, it has the whole system to itself.
- A process should only know about the resources it has access to.
- A process should only worry about itself and not other processes.

VIRTUAL MACHINES

- Run on a hypervisor.
- A hypervisor emulates the physical hardware.
- A VM running on a hypervisor appears as if it has its own CPU, memory and resources.



Virtual Machines

QUIZ: WHAT ARE TYPE 1 &TYPE 2 HYPERVISORS?

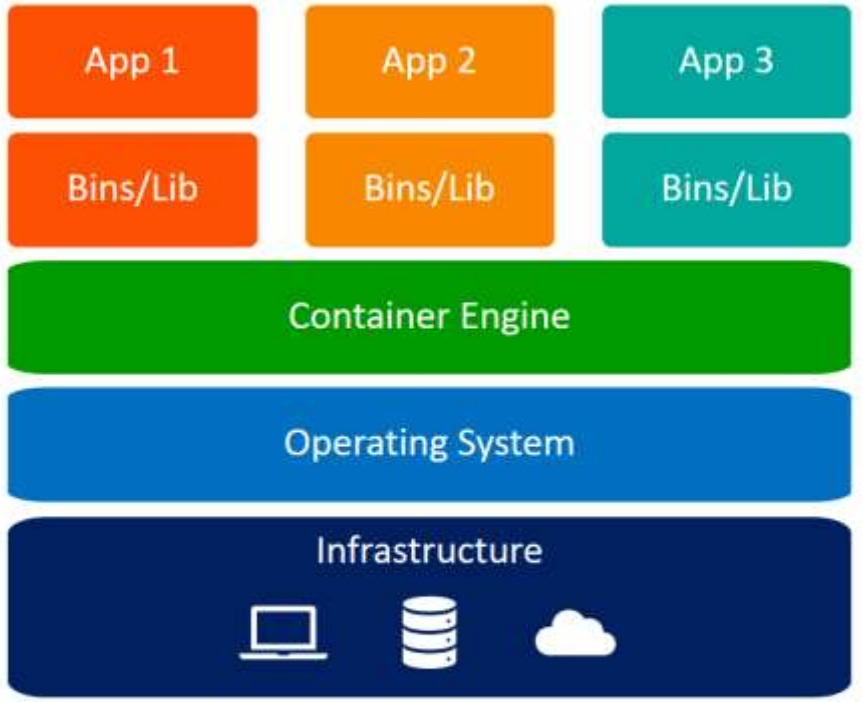
VIRTUAL MACHINES: DISADVANTAGES

- Too much time to load, because it goes through the same boot process as the OS running.

- Hence, Heavy.

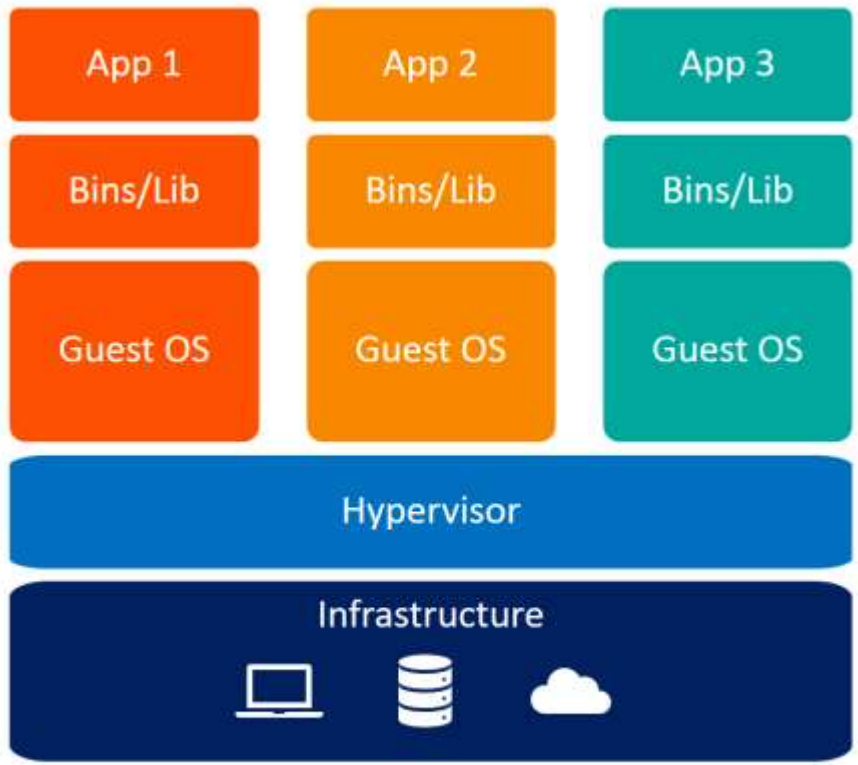
CONTAINERS

- Are not Virtual machines, since there is no hypervisor involved.
- Isolation is provided by a container engine.
- Container Engine uses some specific features of the Linux operating system implement isolation.
- The rest of this session is about these features that enable isolation:
  - OverlayFS
  - Chroot
  - Namespaces

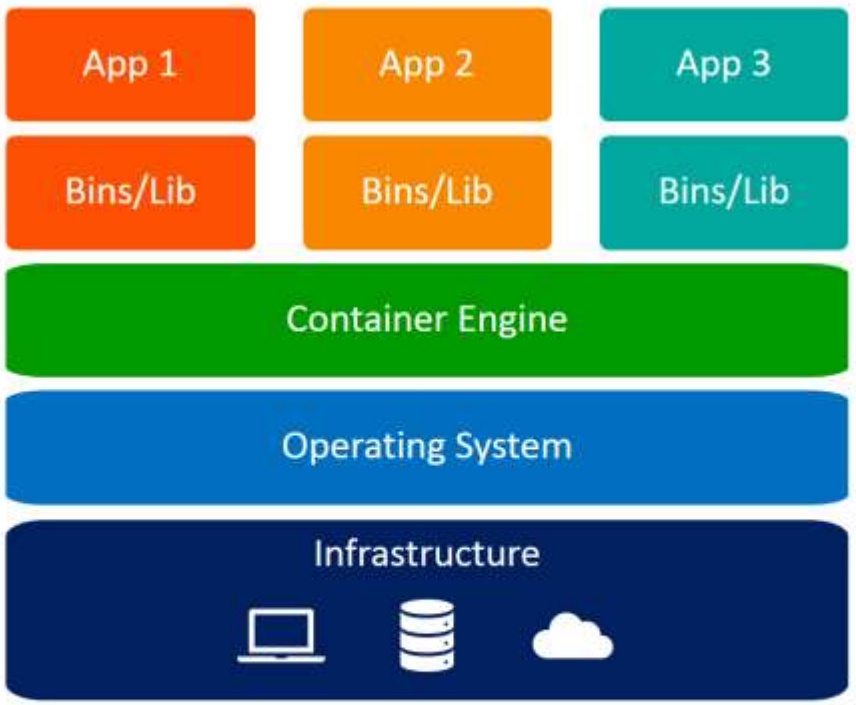


Containers

DIFFERENCE BETWEEN CONTAINERS AND VMs



Virtual Machines



Containers

CONTAINERS

- Quick intro
  - A logical way to package applications
  - Provides isolated execution environments
  - Composable
  - Portable

```
# Example Dockerfile
FROM ubuntu
MAINTAINER asbilgi@microsoft.com

RUN apt-get update
RUN apt-get install –y python
CMD [/bin/bash]
```

CONTAINERS

- Use features of the Linux operating system to implement isolation.
- The rest of this session is about those Linux Operating System Features.
- If you know these Linux Operating System features, you can write your own container runtime, like docker, containerd, rkt, podman, etc.
- Even if you do not plan to write your own container runtime, it is good to know how containers work.

CONTAINER FILE SYSTEM

CONTAINER FILE SYSTEM

- Let us see what a docker image’s directory structure looks like.
- Let’s see a demo

DOCKER FILE SYSTEM

```
#!/bin/bash

sudo docker run --name test ubuntu

sudo docker export test > container.tar

mkdir ~/containerfs

tar -xf container.tar -C ~/containerfs

ls ~/containerfs
```

WHAT JUST HAPPENED HERE?

- I ran the ubuntu container image.
- Then I exited it.
- I exported the contents of the container file system to a tar file.
- I extracted the contents of the tar file to a directory.
- I examined the contents of the extracted tar file
- **The file system of a container image is very much like that of a standard Linux filesystem.**

BUILDROOT

BUILDROOT

- So how can you build a filesystem directory structure by yourself?

- https://www.buildroot.org

- The BuildRoot tool compiles source code and generates a linux filesystem as a tarball.

- You can then import this tarball as a docker image

```
cat container.tar | sudo docker import - newimage:latest
```

OverlayFS

OverlayFS

- We now know how the docker file system is very similar to the root filesystem of a linux system.
- In fact, many images have common file contents.
- Now, how do we minimize disk space usage, and reuse images that we have already pulled?
- Is there a better way than pulling an entire OS image for every single container that we run?

- Enter OverlayFS

OverlayFS

- OverlayFS allows you to merge multiple directories and present them as a single filesystem.

- This is great for sharing common files across multiple programs, without having to duplicate them.

- Let us see a demo

OverlayFS

```
#!/bin/bash

pushd ~

mkdir test

pushd test

mkdir upper lower work merged

echo "This is in lower" > lower/lower_1.txt

echo "This is in upper" > upper/upper_1.txt

echo "This is in lower" > lower/both_1.txt

echo "This is in upper" > upper/both_1.txt

sudo mount -t overlay overlay -o \
lowerdir=/home/vagrant/test/lower,upperdir=/home/vagrant/test/upper,workdir=/home/vagrant/test/work \
/home/vagrant/test/merged

ls /home/vagrant/test/merged
```

WHAT JUST HAPPENED HERE?

- I created 4 directories: upper, lower, work, and merged.
- I created some files in the upper and lower directories.
- I created an overlay filesystem using the upper and lower directories and mounted them onto the merge directory.
- I examined the contents of the merged directory.
- We can observe that the contents of upper and lower have been presented as a single, merged, filesystem.

HOW DOCKER USES OVERLAYFS

Tree: 0b1fb9529c ▾ python / 3.8 / alpine3.10 / Dockerfile

gliptak Remove idle_test directory

3 contributors

135 lines (124 sloc) | 3.95 KB

```
1  #
2  # NOTE: THIS DOCKERFILE IS GENERATED VIA "update.sh"
3  #
4  # PLEASE DO NOT EDIT IT DIRECTLY.
5  #
6
7  FROM alpine:3.10
8
9  # ensure local python is preferred over distribution python
10 ENV PATH /usr/local/bin:$PATH
11
12 # http://bugs.python.org/issue19846
13 # > At the moment, setting "LANG=C" on a Linux system *fundam
14 ENV LANG C.UTF-8
15
16 # install ca-certificates so that HTTPS works consistently
```

Tree: 410e490d5b ▾ docker-alpine / x86_64 / Dockerfile

ncopa Update Alpine v3.10 - 3.10.3

1 contributor

4 lines (3 sloc) | 74 Bytes

```
1  FROM scratch
2  ADD alpine-minirootfs-3.10.3-x86_64.tar.gz /
3  CMD ["/bin/sh"]
```

CHROOT

CHROOT

- Provides filesystem level isolation.
- A process can view its files alone and not the system’s.

CHROOT

```
#!/bin/bash

echo ”I am inside a container” > /home/vagrant/containerfs/inside-container.txt

chroot /home/vagrant/containerfs /bin/bash

cat /inside-container.txt
```

WHAT JUST HAPPENED HERE?

- I created a file inside the container file system.
- Using the chroot command, I invoked the shell binary "*/bin/bash*".
- This started a process which ran the bash shell.
- The chroot command restricted this bash processes view of the filesystem to the containerfs directory.
- I could now see the file that I created, in the root directory.

NAMESPACES

- So how do we *contain the processes?*
- We use a Linux kernel feature called **namespaces**.
- Namespaces isolate processes:
- A process can only see other processes belonging to the same namespace.

TYPES OF NAMESPACES

- Process
- User ID
- UTS
- Mount
- CGroup
- Network
- IPC

PREREQUISITES:
LEARN JUST ENOUGH GOLANG

JUST ENOUGH GOLANG

```go
package main

import (
    "fmt"
    "log"
    "os"
    "os/exec"
    "syscall"
)

func main() {
    fmt.Println("Entering go program")

    cmd := exec.Command("/bin/bash")
    cmd.Stdout = os.Stdout
    cmd.Stderr = os.Stderr
    cmd.Stdin = os.Stdin
    cmd.SysProcAttr = &syscall.SysProcAttr{}

    if err := cmd.Run(); err != nil {
        log.Fatal(err)
    }

    fmt.Println("Exiting go program")
}
```

WHAT JUST HAPPENED HERE?

- I ran a go program that invoked a new process.
- This new process is a bash shell.
- When I exit the bash shell, the go program will also terminate.
- Currently, this bash shell is unrestricted; it has access to the rest of the system.
- This is our container runtime; albeit a rather shitty one. It doesn't *contain* anything!
- ... at least, not yet ☺

JUST ENOUGH GOLANG

```
cmd.SysProcAttr = &syscall.SysProcAttr{}

cmd.Run()
```

- Our goal is to isolate the bash process, and all the child processes that it spawns.

- So that it is not disturbed by, and it cannot disturb, the rest of the system.
- So let us isolate the process, resource by resource.

PROCESS NAMESPACES

PROCESS NAMESPACES

- We want the processes running inside the container to think that it is the only process running there.
- This is where we have process namespaces
- Let’s see a demo

PROCESS NAMESPACES

```
package main

import (
"fmt"
"log"
"os"
"os/exec"
"syscall"
)

func main() {
    fmt.Println("Entering go program")

    cmd := exec.Command("/bin/bash")
    cmd.Stdout = os.Stdout
    cmd.Stderr = os.Stderr
    cmd.Stdin = os.Stdin

    cmd.SysProcAttr = &syscall.SysProcAttr{}
    cmd.SysProcAttr.Cloneflags = syscall.CLONE_NEWPID

    if err := cmd.Run(); err != nil {
        log.Fatal(err)
    }

    fmt.Println("Exiting go program")
}
```

WHAT JUST HAPPENED HERE?

- My go program created a new process that ran the bash shell.
- It used the flag CLONE_NEWPID to create the new process.
- This creates a new process namespace, which gives the process a PID of 1.
- We can even nest processes this way!

USER NAMESPACE

USER NAMESPACE

- Allows a process to have arbitrary user and group ids within the namespace.
- i.e. UID 42, GID 42.

- Let’s see a demo.

USER NAMESPACE

```
cmd.SysProcAttr = &syscall.SysProcAttr{
    Cloneflags: syscall.CLONE_NEWPID | syscall.CLONE_NEWUSER,
    UidMappings: []syscall.SysProcIDMap{
        {
            ContainerID: 42,
            HostID: os.Getuid(),
            Size: 1,
        },
    },
    GidMappings: []syscall.SysProcIDMap{
        {
            ContainerID: 42,
            HostID: os.Getgid(),
            Size: 1,
        },
    },
}
```

WHAT JUST HAPPENED HERE?

- My go program created a new process that ran the bash shell.
- It used the flag **CLONE_NEWUSER** to create the new process.
- It also mapped the external user to ID 42 inside the user namespace.
- This means that the user running the process has the ID 0 (root) inside the namespace.

UTS NAMESPACE

UTS NAMESPACE

- The UTS namespace isolates two specific identifiers of the system: nodename and domainname.

- Let’s see a demo

UTS NAMESPACE

```
cmd.SysProcAttr = &syscall.SysProcAttr{}
cmd.SysProcAttr.Cloneflags = syscall.CLONE_NEWPID | syscall.CLONE_NEWUSER | syscall.CLONE_NEWUTS
```

WHAT JUST HAPPENED HERE?

- My go program created a new process that ran the bash shell.
- It used the flag CLONE_NEWUTS to create the new process.
- Using the bash shell, I ran the command “hostname inside-container”.
- Then I checked the hostname using “uname --nodename” command.
- I confirmed that the hostname is now “inside-container”.
- I opened another shell, outside the namespace and confirmed that the hostname has not changed.

MOUNT NAMESPACE

MOUNT NAMESPACE

- Mount namespaces allow you to create mount points specific to processes.
- We have already seen the mount namespace in action. (Quiz: Where?)
- Mount points created within the mount namespaces are visible only to the processes in that namespace.
- A cool use case is to create a temp file system that is visible only to a process and no one else.
- Let’s see a demo.

MOUNT NAMESPACE

```
cmd.SysProcAttr = &syscall.SysProcAttr{}
cmd.SysProcAttr.Cloneflags = syscall.CLONE_NEWPID | syscall.CLONE_NEWUSER | syscall.CLONE_NEWUTS |
syscall.CLONE_NEWNS
```

WHAT JUST HAPPENED HERE?

- I launched a shell with its own mount namespace.
- Created a temp directory using “mkdir /tmp/testmount”.
- “mount -n -o size=1m -t tmpfs tmpfs /tmp/testmount” to mount a temp file system.
- Created some files in the temp file system.
- Inspected the contents of the /tmp/testmount temp directory, verify that the mount was not visible outside the namespace.

NETWORK NAMESPACES

NETWORK NAMESPACES

- The network namespace isolates the process’s view of the network
- Let’s see a demo

NETWORK NAMESPACE

```
cmd.SysProcAttr = &syscall.SysProcAttr{}
cmd.SysProcAttr.Cloneflags = syscall.CLONE_NEWPID | syscall.CLONE_NEWUSER |
syscall.CLONE_NEWUTS | syscall.CLONE_NEWNS | syscall.CLONE_NEWNET
```

WHAT JUST HAPPENED HERE?

- I ran “ip link” command to display all the devices in the link layer.
- It showed all the link layer devices.
- My go program created a new process that ran the bash shell.
- It used the flag CLONE_NEWNET to create the new process.
- Using the bash shell, I ran “ip link” again.
- This time, it showed only the loopback device. The other network interfaces were not available inside the network namespace.

NETWORK NAMESPACE

- Container networking is vast.
- The network setup we saw inside the namespace is not usable.

NETWORK NAMESPACE

- To make it work, we need to
  - set up additional “virtual” network interfaces
  - create Ethernet bridges (connect two separate networks as if they were a single network)
  - Have a routing process in the global network namespace to receive traffic from the physical interface
  - Route it through the appropriate virtual interfaces to to the correct child network namespaces.

NETWORK NAMESPACE

- There are a lot of libraries and packages that do this for you in the container world

https://kubernetes.io/docs/concepts/cluster-administration/networking/

CGROUP NAMESPACES

CGROUP NAMESPACES

- How do you restrict the resource usage of processes running inside a container
- Lets see a demo

CGROUP NAMESPACES

```
#!/bin/bash
mkdir /sys/fs/cgroup/memory/demo
echo "100000000" > /sys/fs/cgroup/memory/demo/memory.limit_in_bytes
echo "0" > /sys/fs/cgroup/memory/demo/memory.swappiness
echo $$ > /sys/fs/cgroup/memory/demo/tasks
python /vagrant/code/hungry.py
```

WHAT JUST HAPPENED HERE?

- The kernel exposes cgroups through the /sys/fs/cgroup directory.
- Creating a directory here creates a cgroup
- You can see how the contents of the memory/demo directory are automatically populated
- I then set the max memory limit to 100 MB and the processes belonging to the cgroup to the current process
- I then spawned off a memory hungry program.
- You can see that the program got killed once the memory limit was exceeded.

Future proposed Namespaces

- Syslog namespace
- Time namespace

QUESTIONS?

Source code

https://github.com/ashwnacharya/containers_from_scratch_talk

THANK YOU!