OS-level virtualization (Containers)

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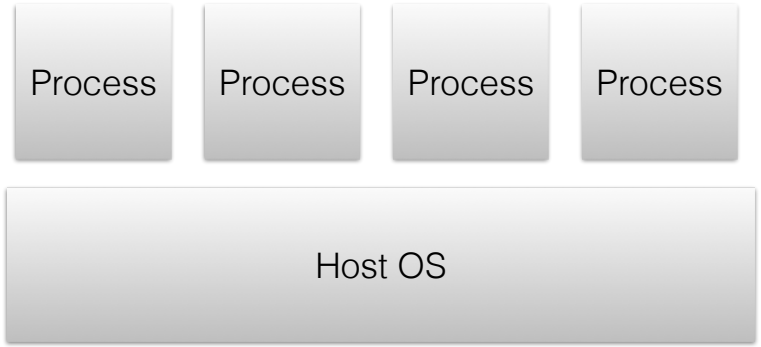
Containers

- A lightweight virtualization technology that packages software and its dependencies into an isolated environment
- Used to deploy and run applications more conveniently and efficiently than traditional virtual machines.
- There are many different container platforms available, such as Docker, Kubernetes, and OpenShift.

Isolation Models

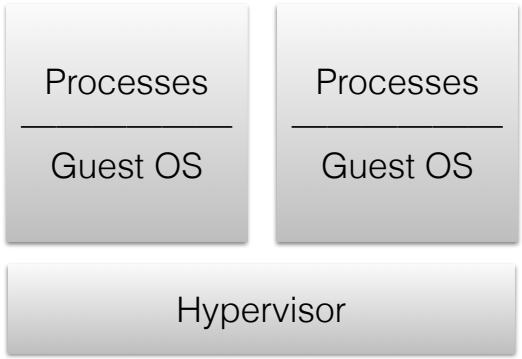
- Isolation means
  - Limiting what/who a process/application can see.
  - Limiting who can see a process/application
- Traditionally there were two extremes of isolation models
  - Traditional Process
  - System Virtual Machines

Traditional Processes



- Each process gets its own
  - Virtual memory
  - One or more virtual CPUs (threads)
  - Access to OS services via system calls
- All co-located processes can see/share a lot (in an OS-controlled manner)
  - File system, storage, network, and I/O devices
  - Other processes (for Inter-process communication)

System Virtual Machines

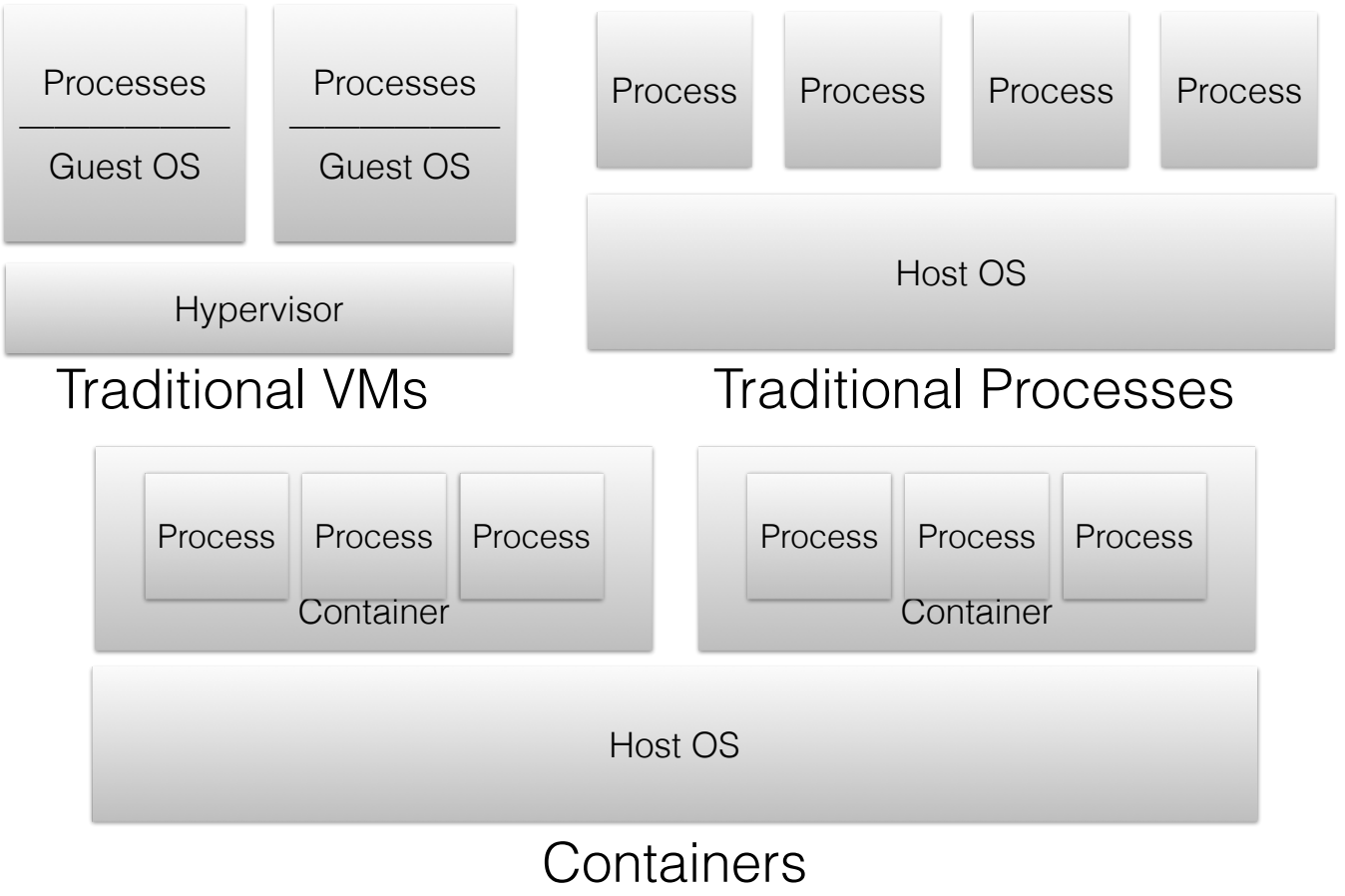


- Co-related processes grouped into VMs
- Each VM has its own
  - Guest OS
  - Guest physical memory (“virtualized” view of memory seen by guest OS)
  - One or more virtual CPUs
  - Virtual I/O devices: virtual disk, virtual network
- Ideally: Co-located VMs don’t see/share ANYTHING

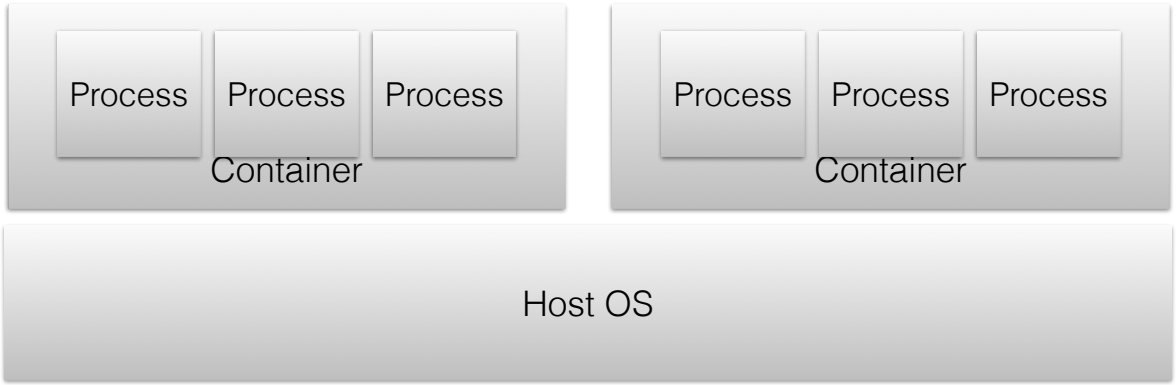
What level to isolate?

- Processes share too much
  - Great performance but not isolated enough
- System VMs are too heavy
  - Great Isolation but too heavy due to separate guest OS per VM
- **Alternative: Operating-system-level virtualization**
  - Multiple isolated user-spaces
  - Share one kernel.
  - Native performance

Process, VM, Container



Containers



- Containers
  - group traditional processes together and
  - restrict what resources they can see/access.
- In Linux, containers consist of
  - Namespaces
  - Control Groups (cgroups)

Chroot

- An early precursor to modern namespaces
- Change root directory for the calling process and its children to a given path
- `$ chroot NEWROOT`

  OR

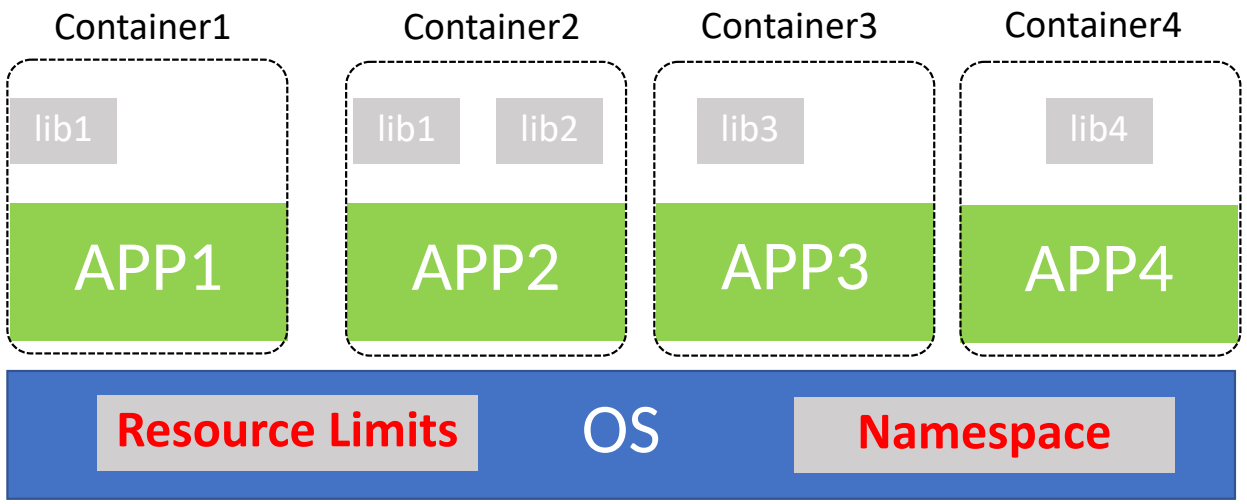
- `$ chroot(path)`
- “This call changes an ingredient in the pathname resolution process and does nothing else.” — man chroot
- Not secure. Lots of ways to escape chroot jail.

FreeBSD Jails

- Builds upon chroot to compartmentalize files and other resources
- Jails protects rest of the system from the jailed process
  - Not the other way around!
- Virtualized resources
  - file system,
  - the set of users, including own root account.
  - networking subsystem
- Again: Jail escapes were possible!

Linux Containers

Two main underpinning techniques:
(1)Namespace
(2)Control Groups - Resource limits



Linux Namespaces

- Linux namespaces are a feature of the Linux kernel that partitions kernel resources such as processes, networking, and file systems.
    - *“A **namespace** wraps a global system resource in an abstraction that makes it appear to the processes within the namespace that they have their own isolated instance of the global resource.” - from “* from $ man namespaces”
- This allows different processes to run in isolated environments, each with its own view of the system resources.
- Namespaces are used to implement lightweight virtualization technologies such as containers.

Types of Linux Namespaces

Namespace	Flag	Page	Isolates
Cgroup	CLONE_NEWCGROUP	cgroup_namespaces(7)	Cgroup root directory
IPC	CLONE_NEWIPC	ipc_namespaces(7)	System V IPC, POSIX message queues
Network	CLONE_NEWNET	network_namespaces(7)	Network devices, stacks, ports, etc.
Mount	CLONE_NEWNS	mount_namespaces(7)	Mount points
PID	CLONE_NEWPID	pid_namespaces(7)	Process IDs
Time	CLONE_NEWTIME	time_namespaces(7)	Boot and monotonic clocks
User	CLONE_NEWUSER	user_namespaces(7)	User and group IDs
UTS	CLONE_NEWUTS	uts_namespaces(7)	Hostname and NIS domain name

Namespaces example

- ls -al /proc/<pid>/ns

- By default, all “native” processes are placed under the same default namespaces

Namespace Implementation Details

- Three system calls are used for namespaces:
  - clone()
    - creates a new process attached to a new namespace
  - unshare()
    - Attaches an existing process to a new namespace
  - setns()
    - attaches a process an existing namespace.

PID Namespace

- Isolates the set of processes that can see each other.
- PID namespaces isolate the process ID number space, meaning that processes in different PID namespaces can have the same PID.
- PID namespaces allow containers to provide functionality such as
    - suspending/resuming the set of processes in the container
    - migrating the container to a new host while the processes inside the container maintain the same PIDs.
- PIDs in a new PID namespace start at 1, somewhat like a standalone system
- Calls to fork(2), vfork(2), or clone(2) will produce processes with PIDs that are unique within the namespace.
- Example: $ unshare --fork -p /bin/bash
    - This create a new PID namespace for a new process /bin/bash

IPC Namespace

- Isolates which processes are allowed to communicate with each other
- IPC namespaces isolate three types of IPC objects
  - message queues, semaphores, and shared memory
- The common characteristic of these IPC mechanisms is that IPC objects are identified by mechanisms other than filesystem pathnames.
- Each IPC namespace has its own set of IPC identifiers.
- Objects created in an IPC namespace are visible to all other processes that are members of that namespace, but are not visible to processes in other IPC namespaces.

Mount Namespace

- Isolates which part of filesystem is seen by a process group
- Provide isolation of the list of mount points seen by the processes in each namespace.
- The processes in each of the mount namespace instances will see distinct single-directory hierarchies.
- A new mount namespace is created using either clone(2) or unshare(2) with the CLONE_NEWNS flag.
    - If the namespace is created using clone(2), the mount list of the child's namespace is a copy of the mount list in the parent process's mount namespace.
    - If the namespace is created using unshare(2), the mount list of the new namespace is a copy of the mount list in the caller's previous mount namespace.

Network Namespace

- Network namespaces provide isolation of the system resources associated with networking.
  - IP address
  - network devices
  - IPv4 and IPv6 protocol stacks
  - IP routing tables
  - firewall rules
  - associated configuration files.

User Namespace

- User namespaces isolate security-related identifiers and attributes
  - User IDs and Group IDs, the root directory, keys, and capabilities.
- A process's user and group IDs can be different inside and outside a user namespace.
- Process can have a normal unprivileged user ID outside a user namespace while at the same time having a user ID of 0 inside the namespace.
  - In other words, the process has full privileges for operations inside the user namespace, but is unprivileged for operations outside the namespace.

UTS Namespace

- UTS namespaces provide isolation of two system identifiers
  - the hostname and the NIS domain name.
- These identifiers are set using sethostname(2) and setdomainname(2), and can be retrieved using uname(2), gethostname(2), and getdomainname(2).
- When a process creates a new UTS namespace using clone(2) or unshare(2) with the CLONE_NEWUTS flag, the hostname and domain name of the new UTS namespace are copied from the corresponding values in the caller's UTS namespace.

Time Namespace

- Time namespaces virtualize the values of system clocks
- The processes in a time namespace share per-namespace values for system clocks.
- This affects various APIs that measure against these clocks, including: clock_gettime(2), clock_nanosleep(2), nanosleep(2), timer_settime(2), timerfd_settime(2), and /proc/uptime.

Cgroups (Control Groups)

- Linux kernel feature which allow processes to be organized into hierarchical groups whose usage of various types of resources can then be limited and monitored.
- Allows administrator to set soft/hard limits on cgroup-wide usage of
  - memory, network bandwidth, CPU etc.
- “Cgroup namespaces” virtualize the view of a process's cgroups as seen via /proc/pid/cgroup and /proc/pid/mountinfo.
- The kernel's cgroup interface is provided through a pseudo-filesystem called cgroupfs.

Single System Image

- Extend the notion of namespaces to multiple physical machines
- Multiple machines look like one (or more) namespace(s)
  - PID namespace
  - IPC Namespace
  - Filesystem namespace
- Process migration
  - Allows moving processes from one machine to another without changing its namespace.
- Examples: MOSIX, OpenSSI, Kerrighed