Virtual Machines Containers (A brief overview)

ICS332

Operating Systems

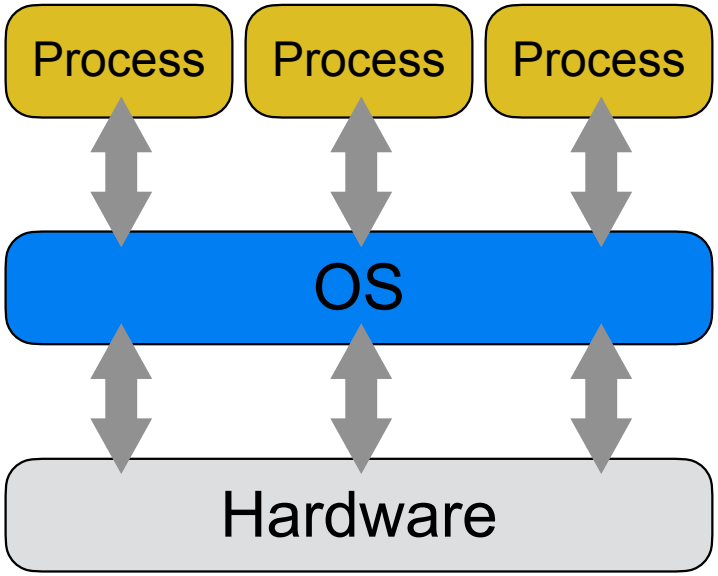
Henri Casanova (henric@hawaii.edu)

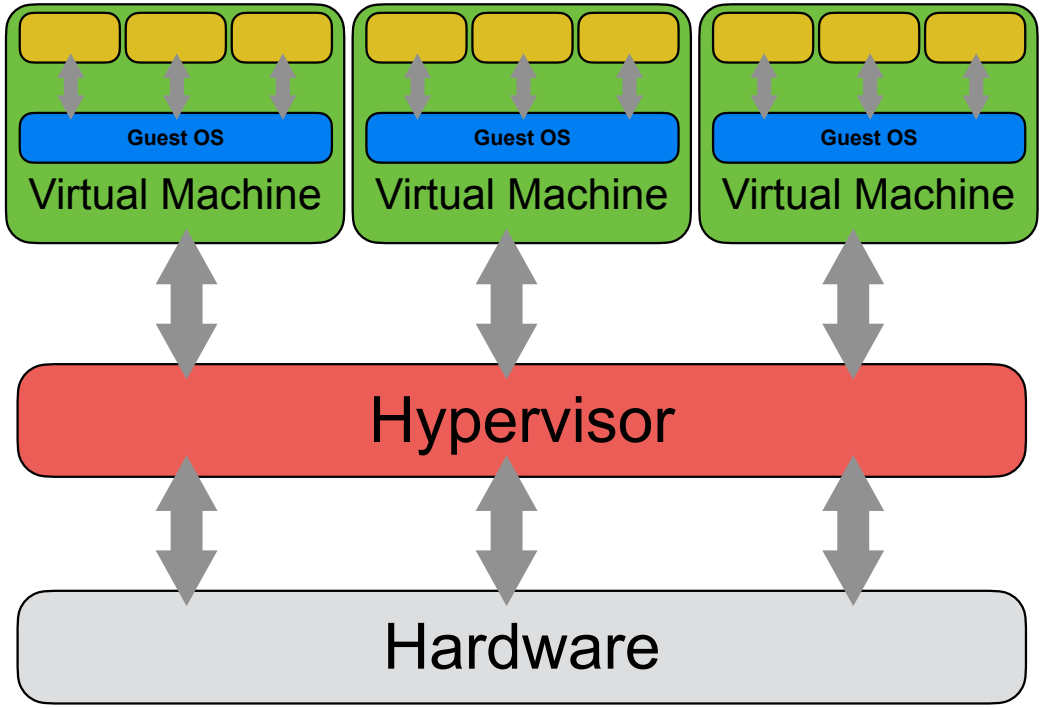
Objective

- Make sure you have a basic understanding of **Virtual Machines** (VMs)
- Make sure you have a basic understanding of **containers**
- They both have the same “run anywhere” goal: replicate the functionality and behavior of one system (the guest) on another system (the host)
  - A “system” is hardware and/or software
- And yet, there are different
  - Both useful in their own way
  - Often used together

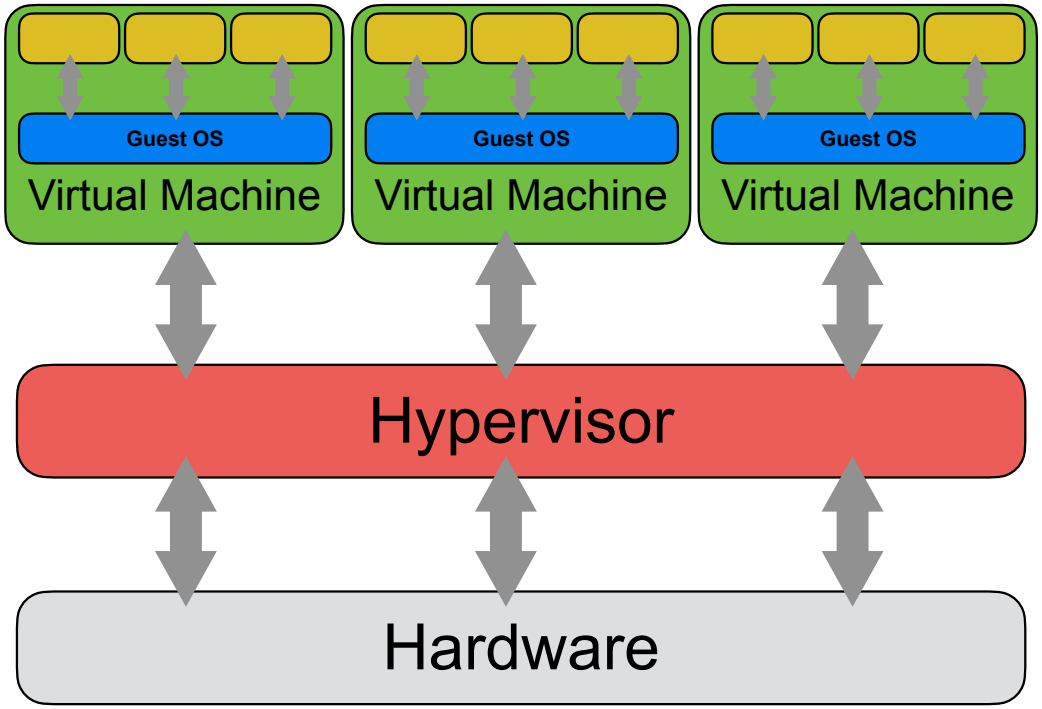
Virtual Machines (VMs)

- The software used to run guest VMs on a host is called a hypervisor or virtual machine monitor
  - It abstracts and allocates resources to VMs
- The hypervisor is to VMs what the OS is to processes:





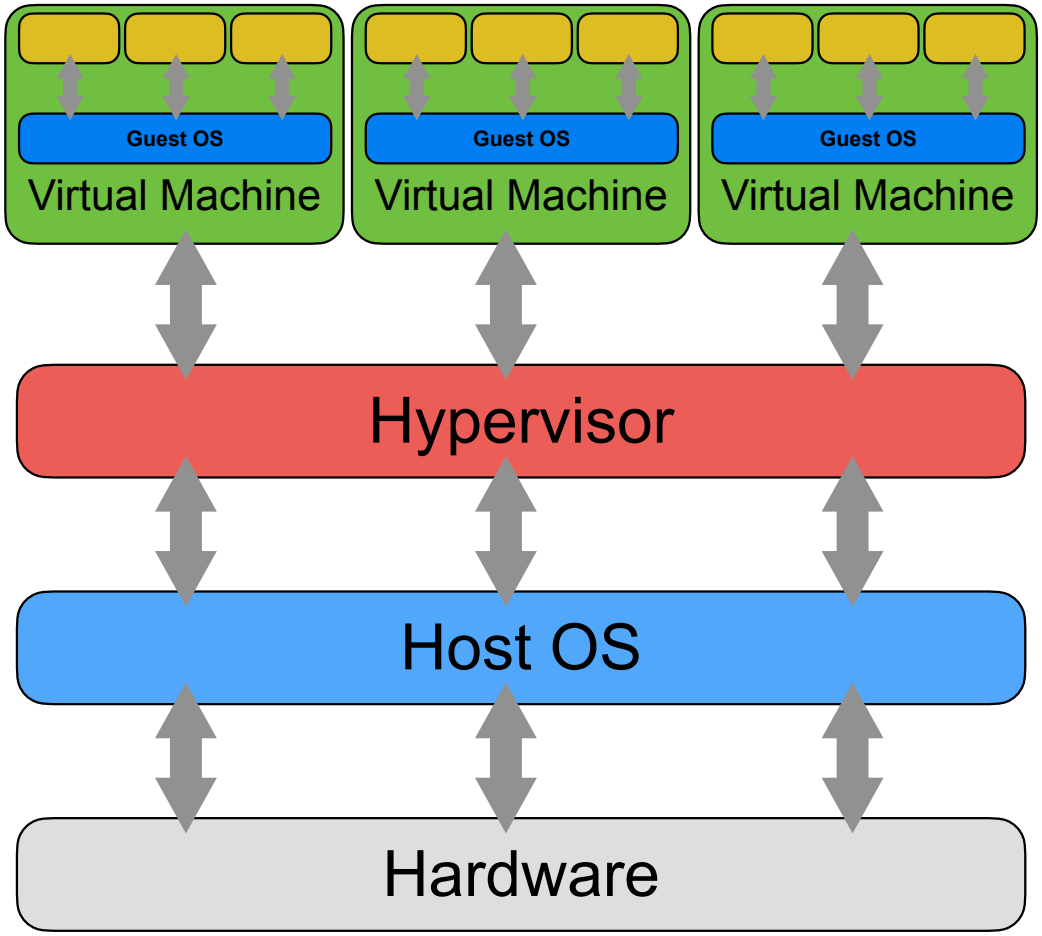
Hypervisor Type 1: Bare-Metal



This diagram showed the hypervisor running directly on the hardware

- Very efficient
- Used in enterprises, not on personal computers
- Examples: Hyper-V Server, Xen, VMWare ESXi

Hypervisor Type 2: Hosted



This diagram shows the hypervisor running on the host OS

- Less efficient, but easy to setup and convenient
- Used on personal computers
- Examples: VirtualBox, VMWare Workstation, Hyper-V Workstation, Parallels

Why Two Types?

- Bare-Metal better than Hosted?
  - Faster, more efficient, more secure (no OS taking time, taking space, or having vulnerabilities on the host)
- Bare-Metal worse than Hosted?
  - The host can ONLY run VMs, more complicated to set up and administrate
- It all depends on your use case:
  - On your laptop: for sure hosted
  - In data-center servers: for sure bare-metal

Virtualization / Emulation

- Everything is “easily virtualized” when the guest is for the same computer architecture as the host
  - e.g., an x86 VM running on an x86 host
- If this is not the case, then the hypervisor must use emulation to “mimic the hardware”
  - e.g., using QEMU on my Mac, which emulates a full system and does automatic binary translation of machine instructions of the guest architecture to the machine instructions of the host architecture!
  - Completely transparent to the user, but much slower
  - You may have used emulators before (for game consoles?)
    - These are really simulators in software of the guest machine (they don’t do binary instruction translation)

Reasons to use VMs (1)

- **Isolation / Sandboxing**
  - Running untrusted code, having untrusted users
    - `rm -rf /` on the guest does not do anything harmful on the host
- **Resource allocation**
  - The hypervisor can partition hardware resources (CPU, RAM, etc.) among the VMs and limit each VMs resource allocation
    - With hardware support from the CPU (Intel VT-x, AMD-V, etc.)
  - This makes it possible to have better hardware resource utilization, e.g., in cloud platforms
  - A cloud can run 1,000 useful VMs on 200 physical hosts
    - Because not all VMs need the full power of a host
  - This avoids overprovisioning the cloud with 1,000 physical hosts, which would leave most of them unused

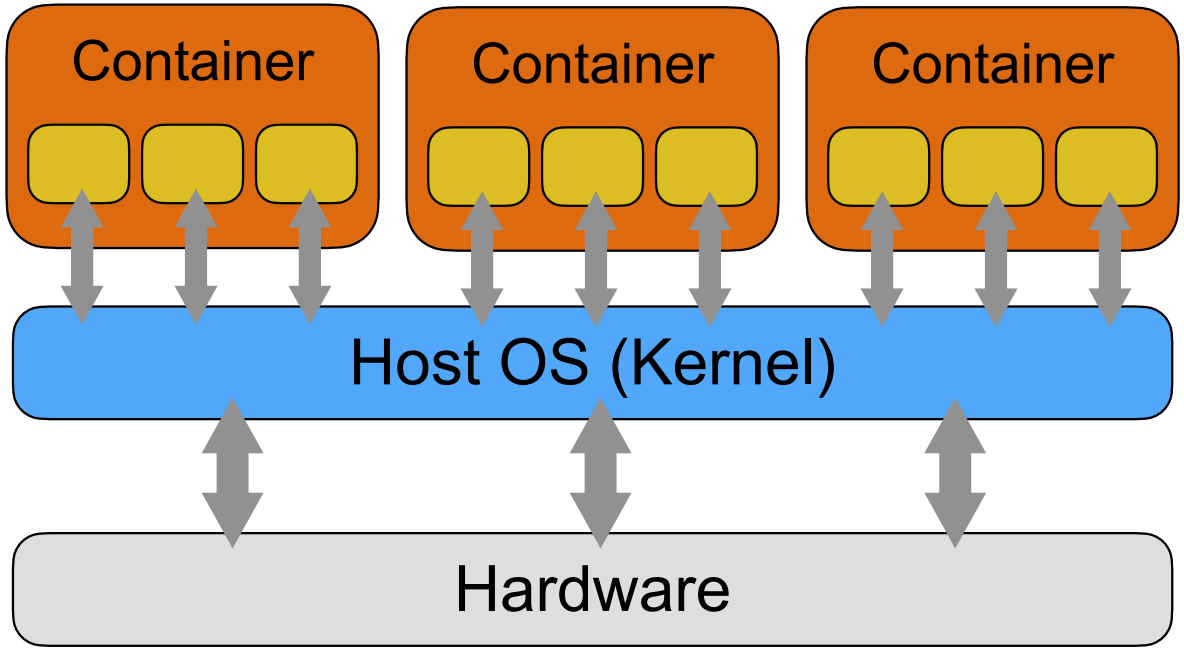
Reasons to use VMs (2)

- **Convenient to use**
  - Easy to suspend/save/restore/shutdown a VM without losing access to the host
- **Convenient to distribute software**
  - Easy to send somebody a VM image for them to run a specific system with all kinds of useful software pre-installed
    - Avoids the: “Oh, you want to use my software? First, you need to install a hundred dependencies…”
- **Cross-platform testing/development**
  - Makes it very easy to test and develop code on all kinds of system configurations
  - You can run multiple VMs with an emulated network to mimic a distributed system on a single host
  - Great for kernel experimentation and development

Containers

- Containers are useful for some of the same reasons, and at a very high level have the same goal: mimic a system on another system
  - Or the same system but with a bunch of useful software already installed!
- They are often said to be “lighter than VMs”
  - Faster to start / stop, less memory
  - Often pretty ephemeral / disposable
- The key difference: the container defines the OS to use but **not** the Kernel to use!
  - **Instead, it uses the Kernel of the host’s OS**
  - Therefore, *there is no such thing as booting a container*

Containers



Processes inside containers all use the same Kernel

If the container is not compatible with the host (different OS, different architecture), then it transparently use emulation or a VM underneath!

Docker

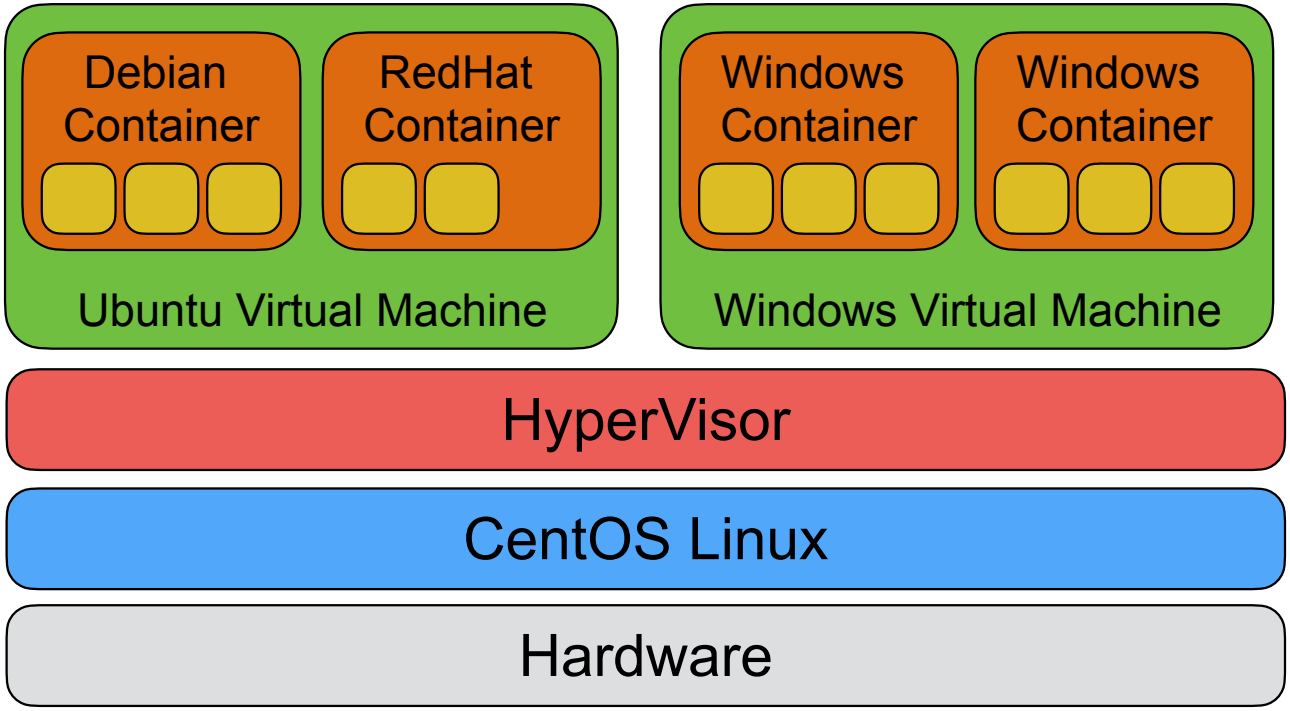
- In this course many of you have used Docker
  - The first highly popular container system
- A Docker image is described in a so-called Dockerfile
  - Defines the CPU's architecture family
  - Defines the OS
    - Can be for Linux or Windows
  - Will run anywhere
    - But perhaps using emulation and/or a VM, which slows things down considerably (like for instance on my M1)
  - Can inherit from another Dockerfile
  - Specifies software installation, among other things
- Then Docker containers can be created for the image
- Let's look at some of my Dockerfiles…

Containers vs. VMs

- Containers better than VMs?
  - Much faster to start (seconds vs. minutes) because no kernel boot
  - Not are resource demanding (kernel code and library code is shared), so we can run many more containers at the same time than VMs on a given host
  - Easier to distribute (small images)
- Containers worse than VMs?
  - Less isolation because all running with the same Kernel
  - You may need a VM if the container's kernel requirement is not the same as the host's kernel (e.g., Linux container on a Windows host)
- The above motivates the use of them in combination

Containers on VMs

- Often the two are used in combination:

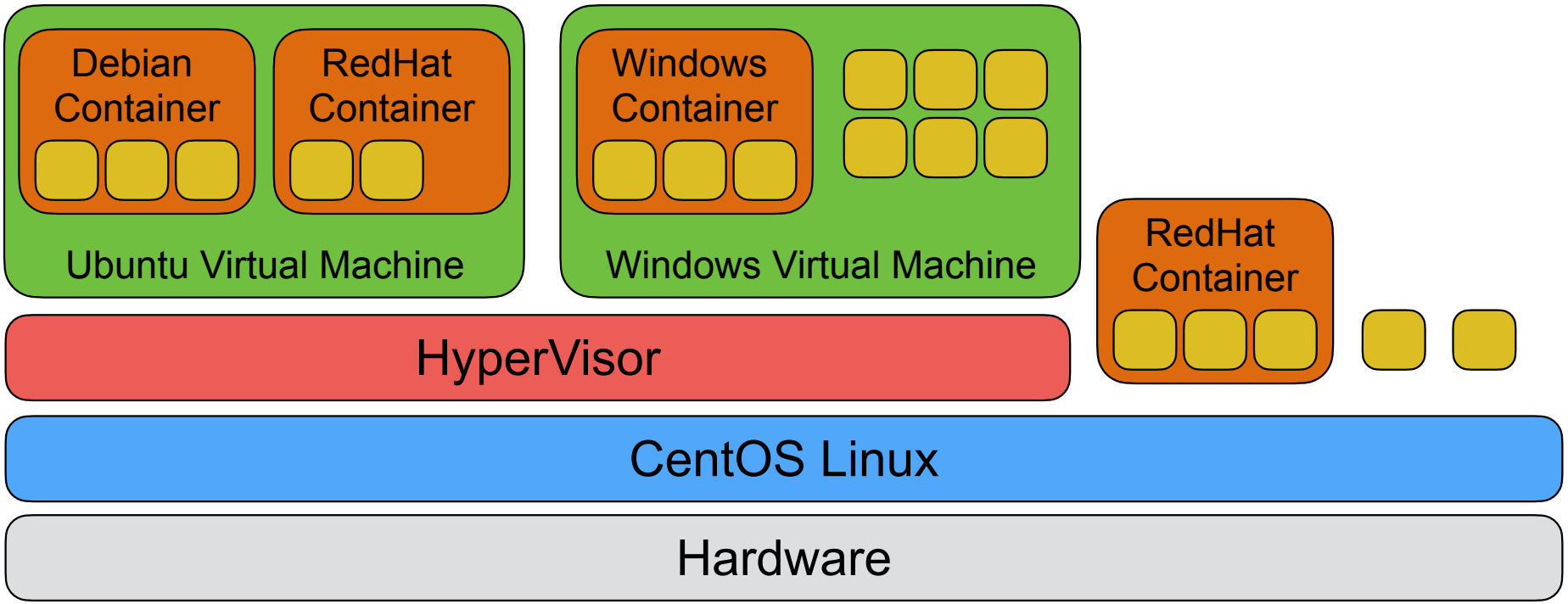


Virtual machines are used for 100% isolation and precise resource allocation

Containers run within each VM and come with all kinds of useful software

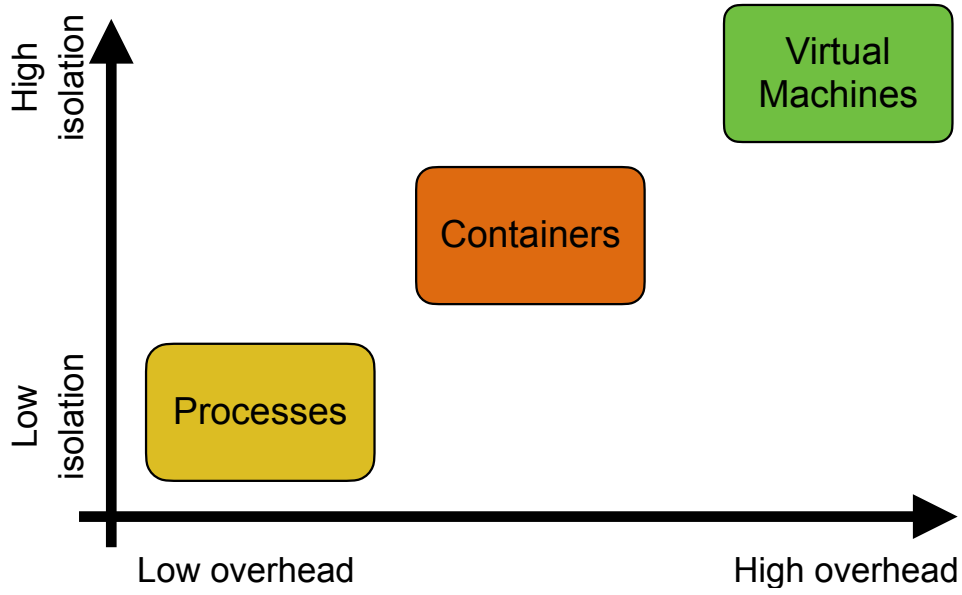
Containers on VMs

- You can mix and match in many, many ways with bare-metal, container, VM, or container-on-VM executions of your processes



Main Takeaways

- A VM is a full system with a kernel that must be booted
- A container uses the host's kernel and does not need to be booted
  - But if the host's kernel isn't compatible, then a VM has too be used behind the scene anyway
- On the same system one can mix/match at will



Conclusion

- In almost all conceivable jobs you will have after graduation you will use VMs and containers
  - If only for continuous integration purposes
- Some of you are probably doing it now anyway
- Personally, containers have changed the way in which I do everything… not sure about other professors
  - I probably create a new Docker image each week for something
- My claim to fame: Solomon Hykes, who created Docker, was my intern for one semester in his Senior year