Goals for Today

- Learning Objective:
  - Understanding how operating systems support containers and modern cloud computing paradigms
- Announcements, etc:
  - MP4 due **May 6th**
    - Get started ASAP!
  - HW1 available! Due **May 8th**
    - Just an "appetizer" for the final exam
    - Multiple attempts allowed, but first attempt is graded

Reminder: Please put away devices at the start of class

CS 423
Operating System Design:
OS Support for Containers

Professor Adam Bates
Spring 2018

Advanced Configuration and Power Interface (ACPI)

Part of UEFI since 2013:

- Exposes different power saving states in a platform-independent manner
- The standard was originally developed by Intel, Microsoft, and Toshiba (in 1996), then later joined by HP, and Phoenix.
- The latest version is "Revision 6.3" published in January 2019!

ACPI Global States

- **G0**: working
- **G1**: Sleeping and hibernation (several degrees available)
- **G2**:, Soft Off: almost the same as G3 Mechanical Off, except that the power supply still supplies power, at a minimum, to the power button to allow wakeup. A full reboot is required.
- **G3**, Mechanical Off: The computer's power has been totally removed via a mechanical switch (as on the rear of a power supply unit).

ACPI Global States

Processor-specific

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ACPI "Sleep" States

C-States:

Core-specific

- **C0**: is the operating state.
- **C1** (often known as Halt): is a state where the processor is not executing instructions, but can return to an executing state instantaneously. All ACPI-conformant processors must support this power state.
- **C2** (often known as Stop-Clock): is a state where the processor maintains all software-visible state, but may take longer to wake up. This processor state is optional.
- **C3** (often known as Sleep) is a state where the processor does not need to keep its cache, but maintains other state. This processor state is optional.

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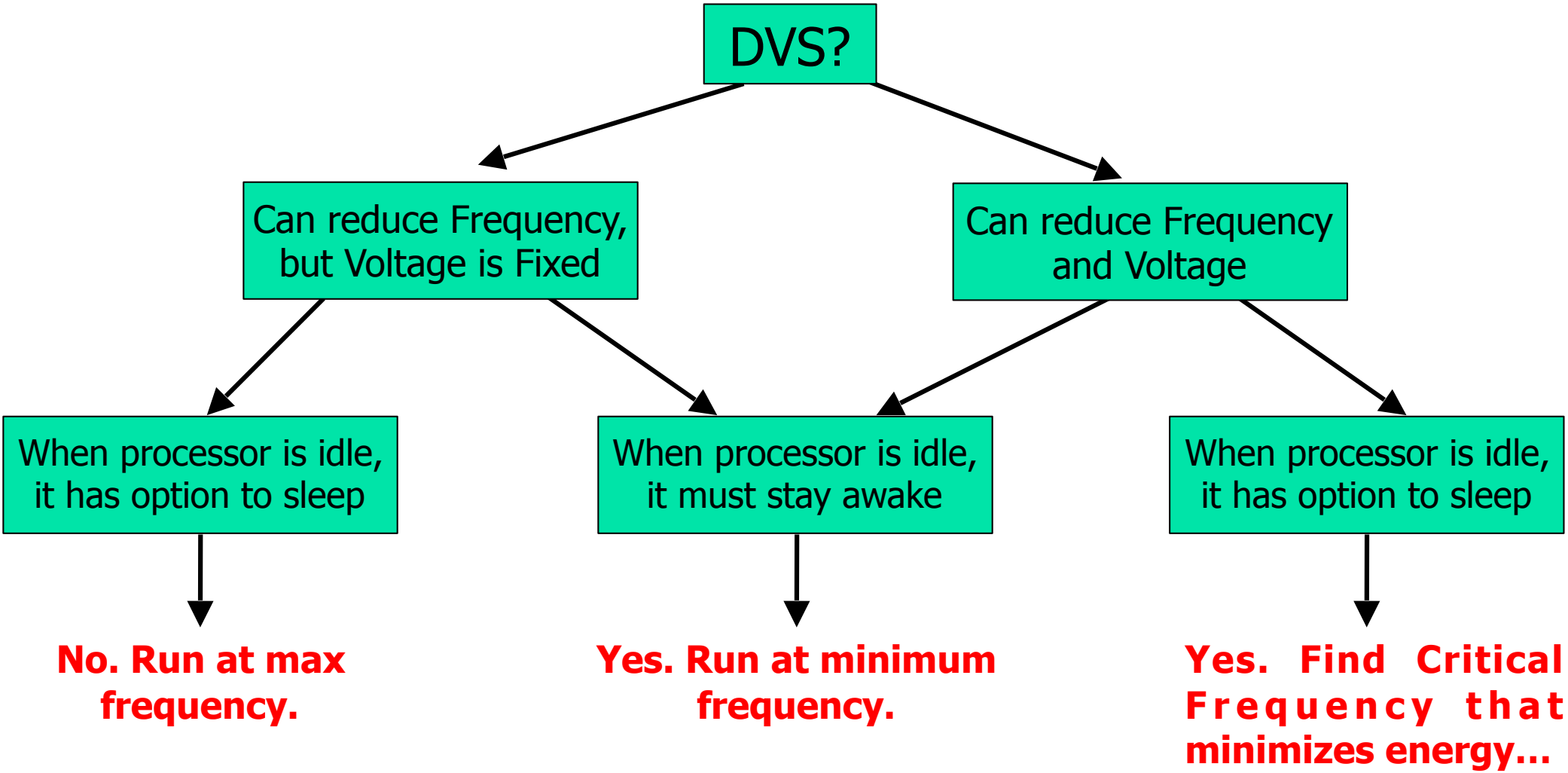
Last Class…

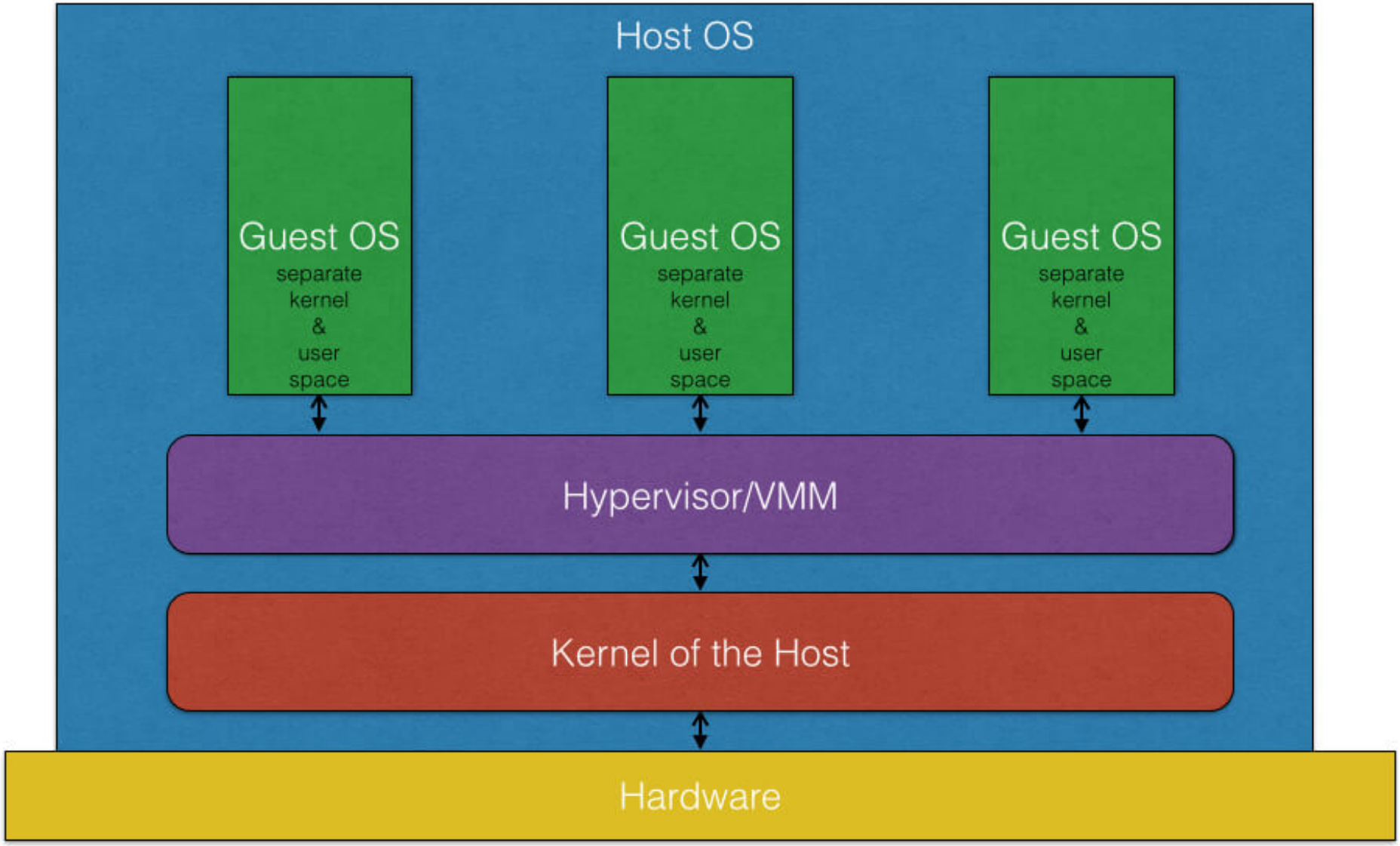
When should we perform dynamic voltage scaling?



Cloud Computing (Gen 1)

- Dominated by Infrastructure-as-a-Service clouds (and storage services)
- Big winner was Amazon EC2
- Hypervisors that virtualized the hardware-software interface
- Customers were responsible for provisioning the software stack from the kernel up

Hypervisors

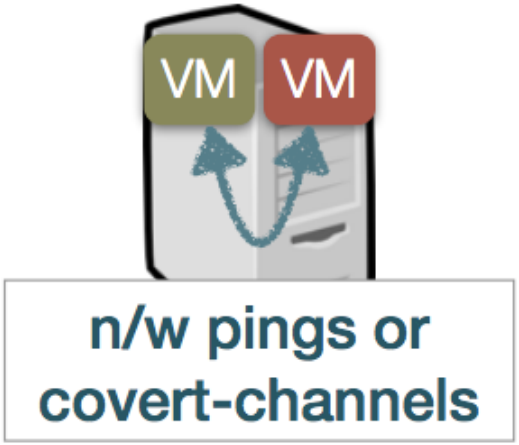


Hypervisors

- Strong isolation between different customer's virtual machines
- VMM is 'small' compared to the kernel… less LoC means less bugs means (~)more security.

Hypervisors

- 'Practical' attacks on IaaS clouds relied on side channels to detect co-location between attacker and victim VM
- E.g., we could correlate the performance of a shared resource
  - network RTT's, cache performance
- After co-resident, make inferences about victim's activities



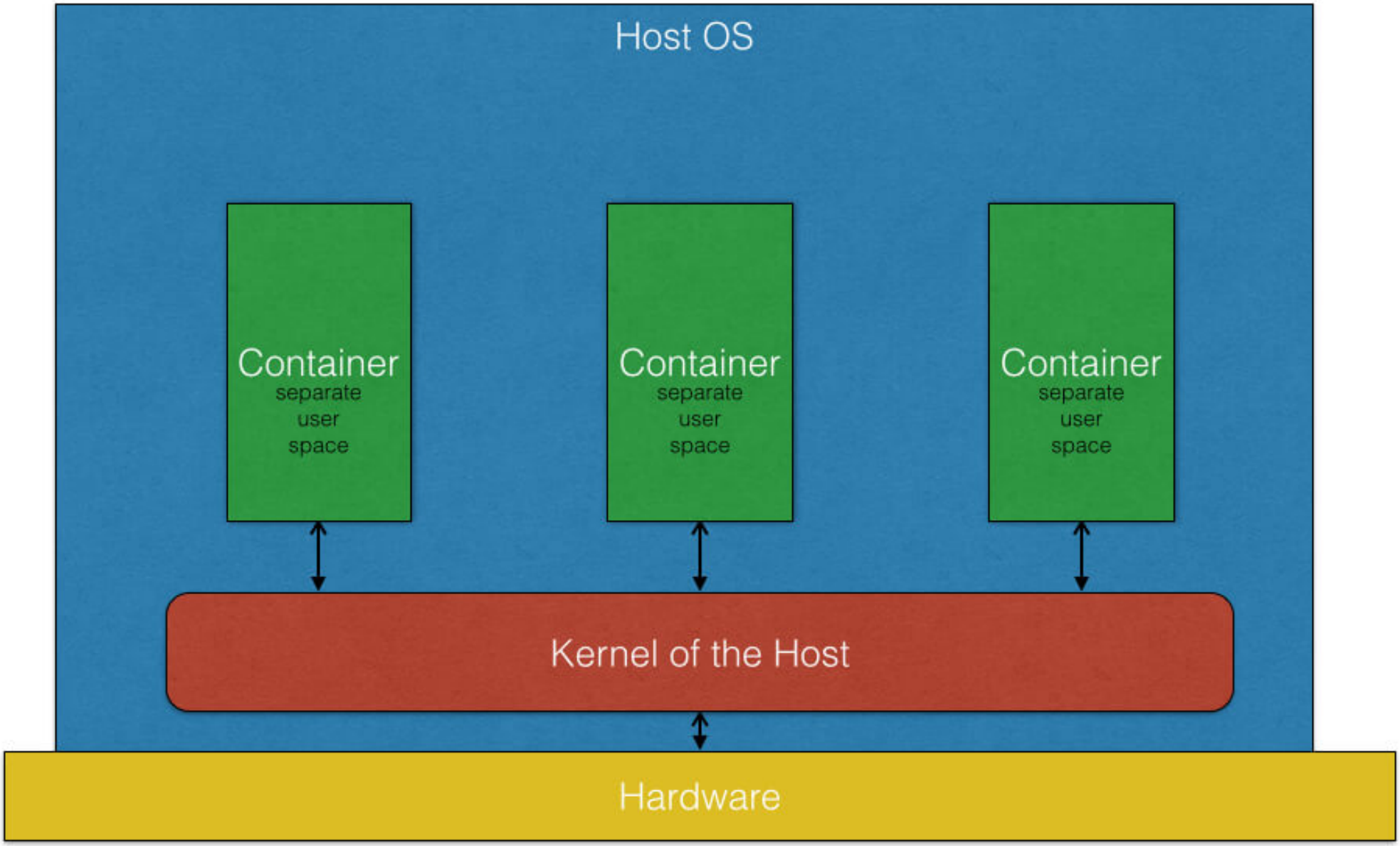
Hypervisors

- Strong isolation between different customer's virtual machines
- VMM is 'small' compared to the kernel… less LoC means less bugs means (~)more security.
- High degree of flexibility… but did most customers really need it?

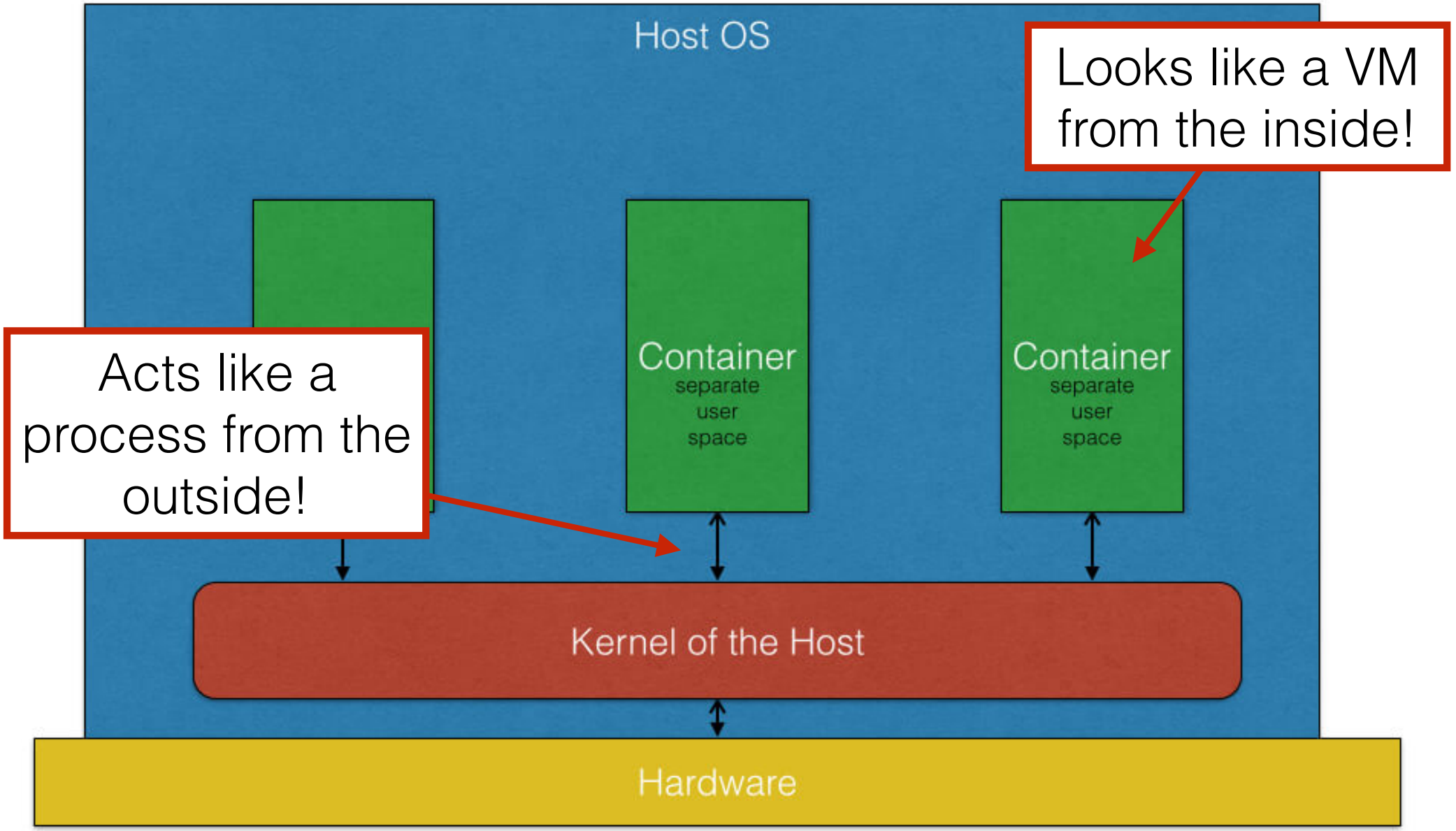
Enter Containers

- Rather than virtualize both user space and kernel space… why not just 'virtualize' user space?
- Meets the needs of most customers, who don't require significant customization of the OS.
- Sometimes called 'operating system virtualization,' which is highly misleading given our existing taxonomy of virtualization techniques
- Running natively on host, containers enjoy bare metal performance without reliance on advanced virtualization support from hardware.

Enter Containers



Enter Containers



OS Support for Containers

- Linux Containers (LXC):
  - chroot
  - Kernel Namespaces
    - PID, Network, User, IPC, uts, mount
  - cgroups for HW isolation
  - Security profiles and policies
    - Apparmor, SELinux, Seccomp

containers = chroot on steroids

- `chroot` changes the apparent root directory for a given process and all of its children
- An old idea! POSIX call dating back to 1979
- Not intended to defend against privileged attackers… they still have root access and can do all sorts of things to break out (like `chroot`'ing again)
- Hiding the true root FS isolates a lot; in *nix, file abstraction used extensively.
- Does not completely hide processes, network, etc., though!

Namespaces

- The key feature enabling containerization!
- Partition practically all OS functionalities so that different process domains see different things
- Mount (mnt): Controls mount points
- Process ID (pid): Exposes a new set of process IDs distinct from other namespaces (i.e., the hosts)
- Network (net): Dedicated network stack per container; each interface present in exactly 1 namespace at a time.
- ….

Namespaces

- The key feature enabling containerization!
- Partition practically all OS functionalities so that different process domains see different things
- Interprocess Comm. (IPC): Isolate processes from various methods of POSIX IPC.
    - e.g., no shared memory between containers!
- UTS: Allows the host to present different host/domain names to different containers.
- There's also a User ID (user) and cgroup namespace

User Namespace

- Like others, can provide a unique UID space to the container.
- More nuanced though — we can map UID 0 inside the container to UID 1000 outside; allows processes inside of container to think they're root.
- Enables containers to perform administration actions, e.g., adding more users, while remaining confined to their namespace.

cgroups

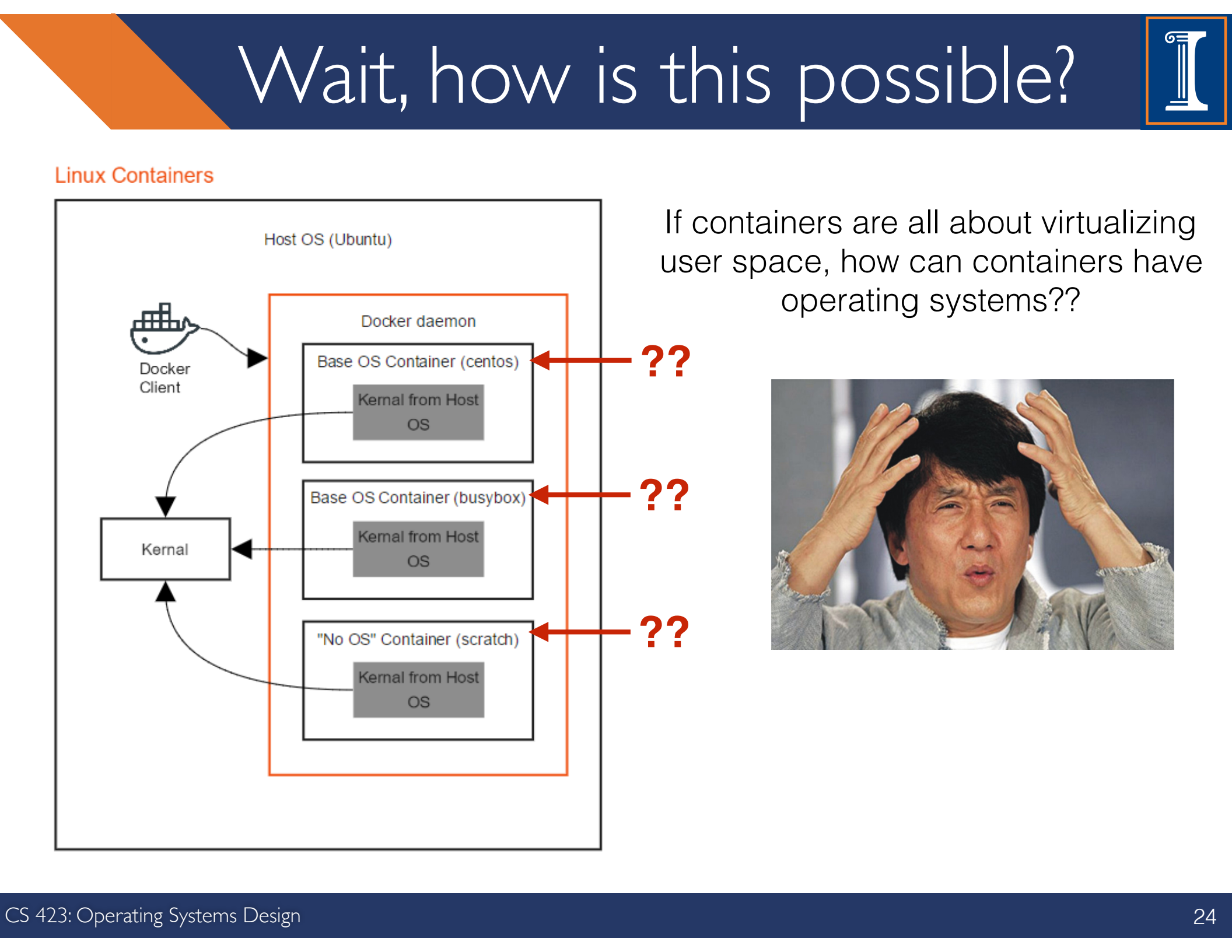
- Limit, track, and isolate utilization of hardware resources including CPU, memory, and disk.
- Important for ensuring QoS between customers! Protects against bad neighbors
- Operate at the namespace granularity, not per-process
- Features:
  - Resource limitation
  - Prioritization
  - Accounting (for billing customers!)
  - Control, e.g., freezing groups
- The cgroup namespace prevents containers from viewing or modifying their own group assignment

Container Security?

"Containers do not contain." - Dan Walsh (SELinux contributor)

- In a nutshell, it's *real hard* to prove that every feature of the operating system is namespaced.
  - /sys? /proc? /dev? LKMs? kernel keyrings?
- Root access to any of these enables pwning the host
- Solution? Just don't forget about MAC; at this point SELinux pretty good support for namespace labeling.
- SELinux and Namespaces actually synergize nicely; *much* easier to express a correct isolation policy over a coarse-grained namespace than, say, individual processes

Wait, how is this possible?



Linux Containers

If containers are all about virtualizing user space, how can containers have operating systems??

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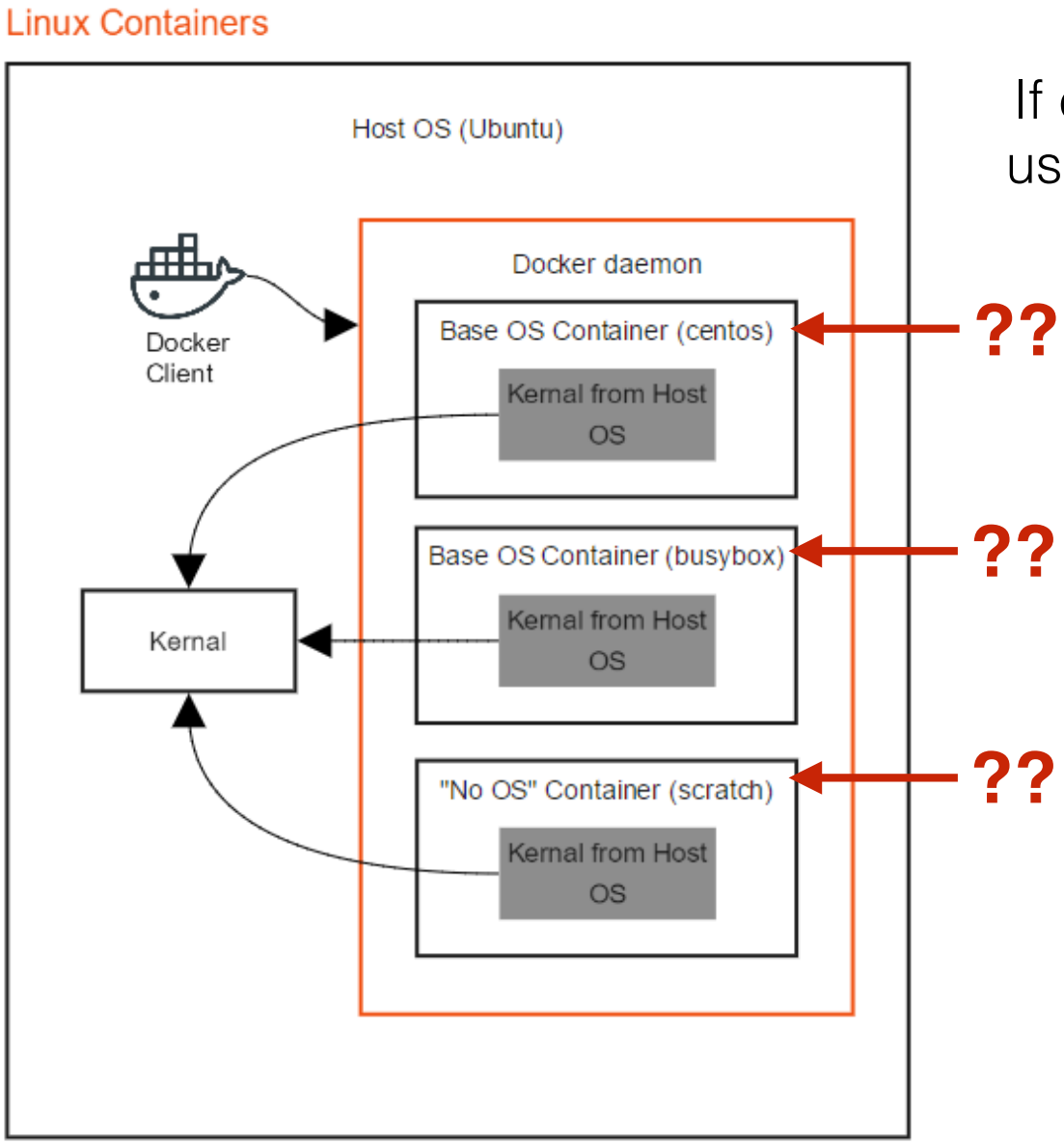
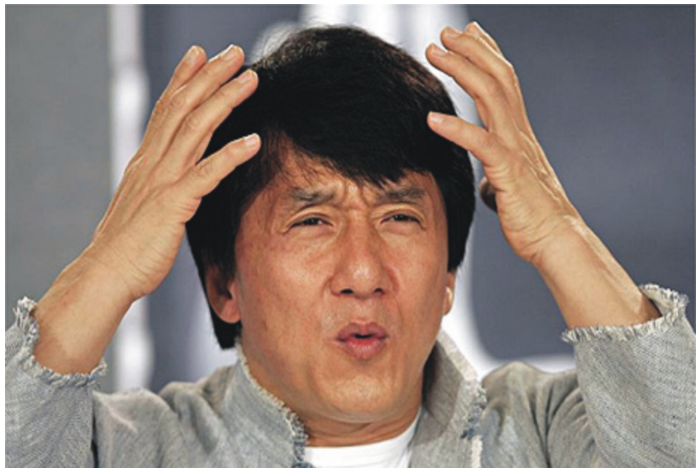


If containers are all about virtualizing user space, how can containers have operating systems??



Answer: These aren't kernels; they're the system utilities of the distro that have been tricked by process namespaces!

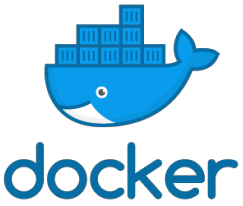
Namespaces in the Linux kernel

- Start by looking in `include/linux/*/*_namespace.h`

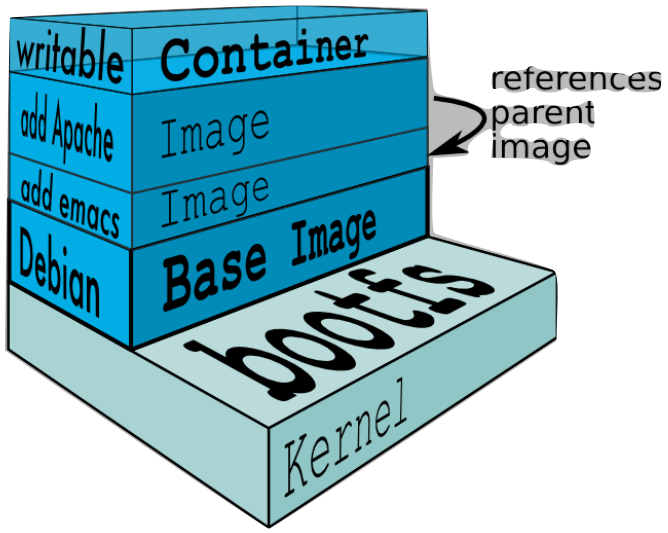
```
struct user_namespace {
        struct uid_gid_map      uid_map;
        struct uid_gid_map      gid_map;
        struct uid_gid_map      projid_map;
        atomic_t                count;
        struct user_namespace   *parent;
        int                     level;
        kuid_t                  owner;
        kgid_t                  group;
        struct ns_common        ns;
        unsigned long           flags;

        /* Register of per-UID persistent keyrings for this namespace */
#ifdef CONFIG_PERSISTENT_KEYRINGS
        struct key              *persistent_keyring_register;
        struct rw_semaphore     persistent_keyring_register_sem;
#endif
};
```

How Docker fits in



- Not an OS thing. ;)
- Utilities that allow you to leverage (e.g.) LXC to build a portable, self-sufficient application using containers.
- Assures that all libraries and dependencies are packaged inside of a container image



Above the clouds…

- Container (~PaaS clouds) are strictly easier to manage than traditional IaaS VMs.
- The era of Container hype has somewhat come and gone… containers still expose more flexibility than most users need!!
- Th hype now is about Function-as-a-Service cloud; individual programs/functions executed by invocation, great for event-driven stuff.
- Enabled by containers
- Instruction-as-a-Service next? ;)

Takeaways

- Container support has existing in Linux for many years
- Foundations of containerization has been around for decades!
- Automating LXC for portability (i.e., Docker) has revolutionized cloud computing
- Lasting legacy of containers may be enabling the Function-as-a-Service revolution… cloud customers can now pay by the method invocation without any idle costs.