CS 858: Software Security

Offensive and Defensive Approaches

Defenses: compartmentalization / sandboxing

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Outline

What is sandboxing?

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Sandboxing is a security mechanism for isolating vulnerable / untrusted code from its hosting platform, usually in an effort to confine the potential damage.

What damage?

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- Corrupt in-application data
- Corrupt memory
- Corrupt local filesystem
- Corrupt other processes
- Gain root privilege
- Spread into other network-connected computers
- .....

The ladder of separation

- Physical separation
  - *e.g.*, Airgap, RF-shield rooms
- Hardware isolation
  - *e.g.*, AWS dedicated instances
- Whole-system virtualization
  - *e.g.*, Full (VMware ESXi) / Para (Xen)
- Whole-system emulation
  - *e.g.*, QEMU (+ KVM) emulation, Android emulator
- Partial system resources emulation
  - *e.g.*, Docker, Landlock, Jail
- In-process application sandboxes
  - *e.g.*, Chrome Sandbox, capabilities, `seccomp`
- In-thread application sandboxes
  - *e.g.*, hardware-assisted solutions like CHERI

Airgap demonstration

Figure: Airgapped computers in the DARPA CGC event

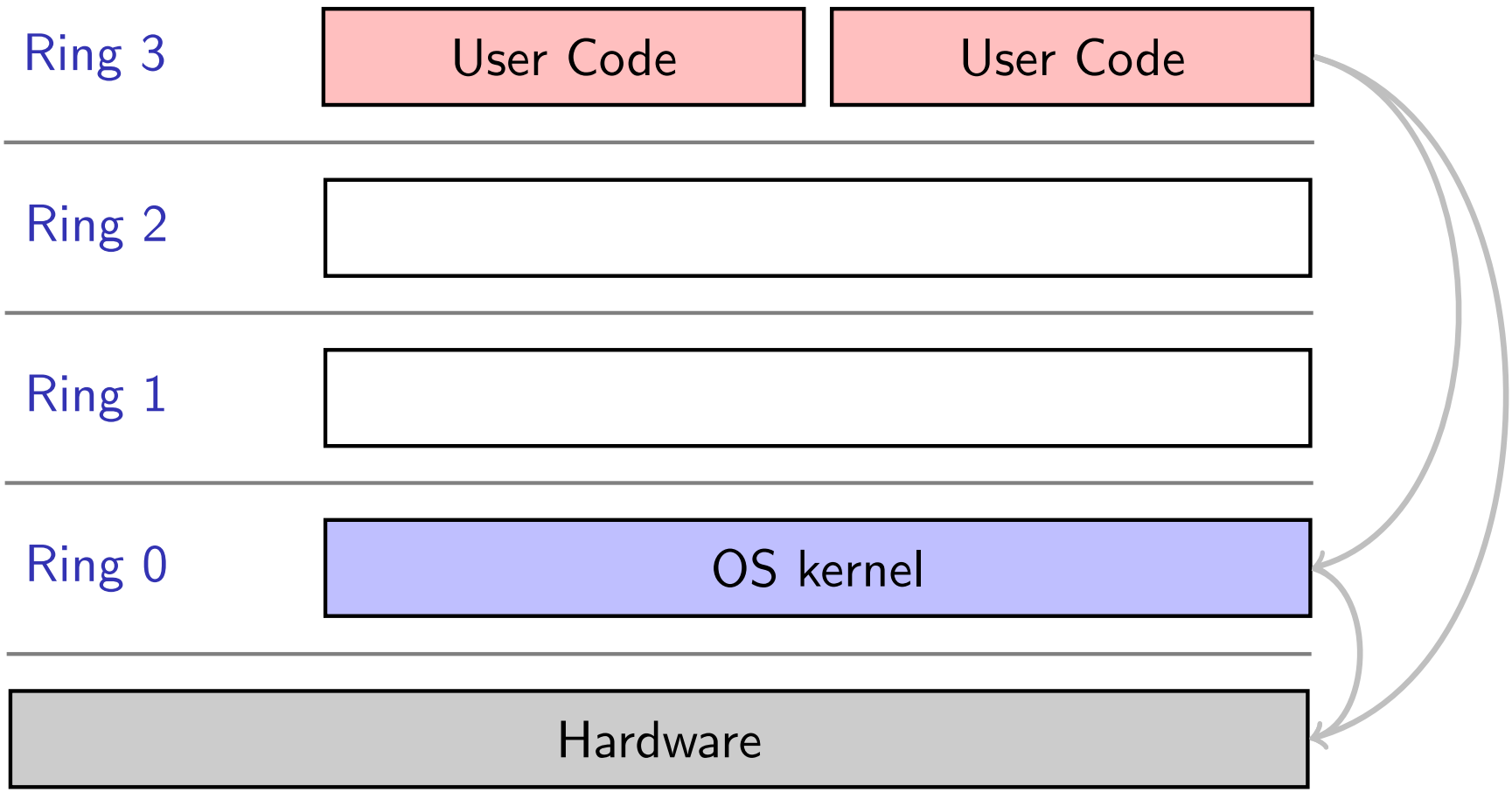
AWS dedicated instances

Based on AWS documentation

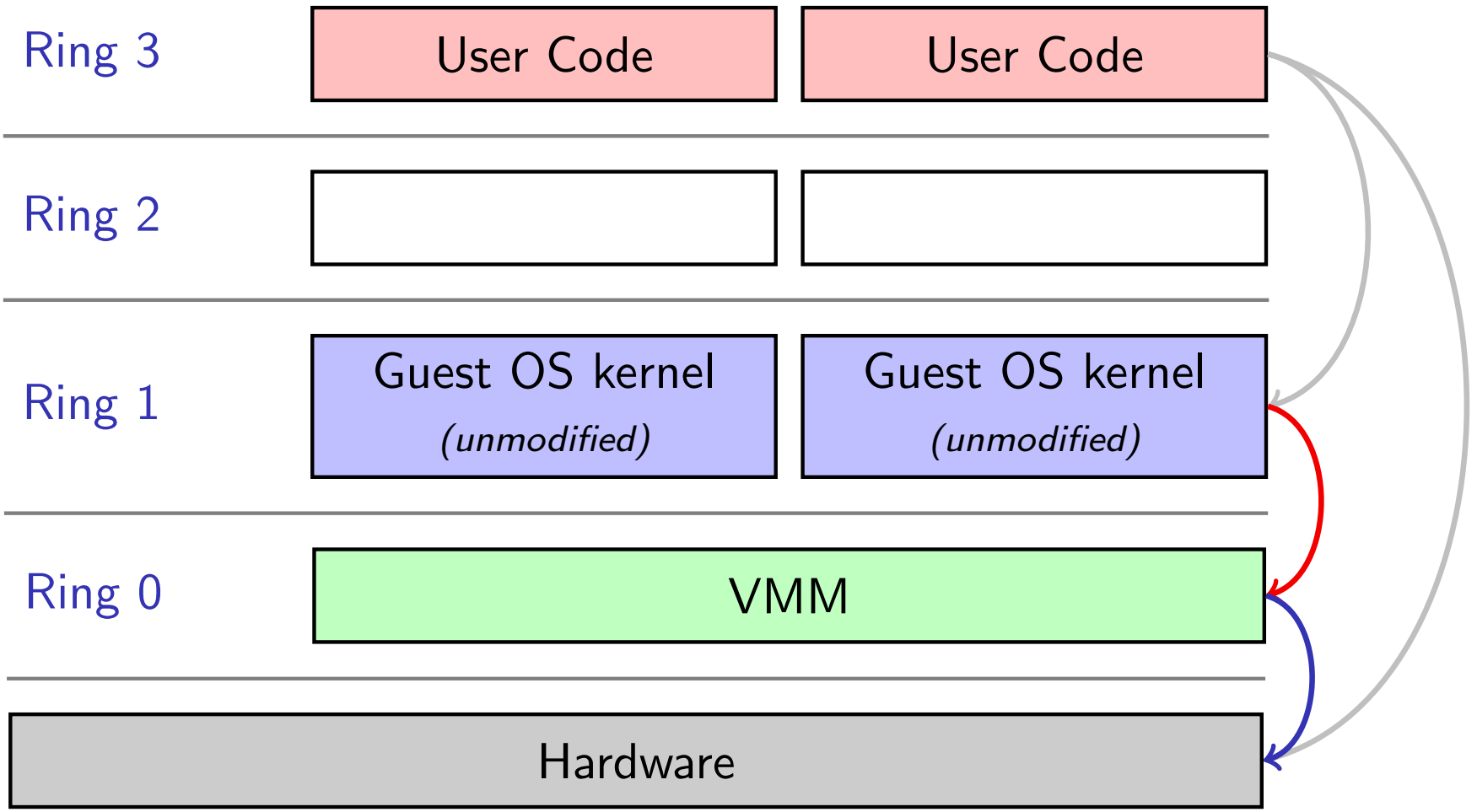
> *Dedicated Instances are Amazon EC2 instances that run in a virtual private cloud (VPC) on hardware that's dedicated to a single customer. Dedicated Instances that belong to different AWS accounts are physically isolated at a hardware level, even if those accounts are linked to a single payer account.*

Outline

x86 privilege levels

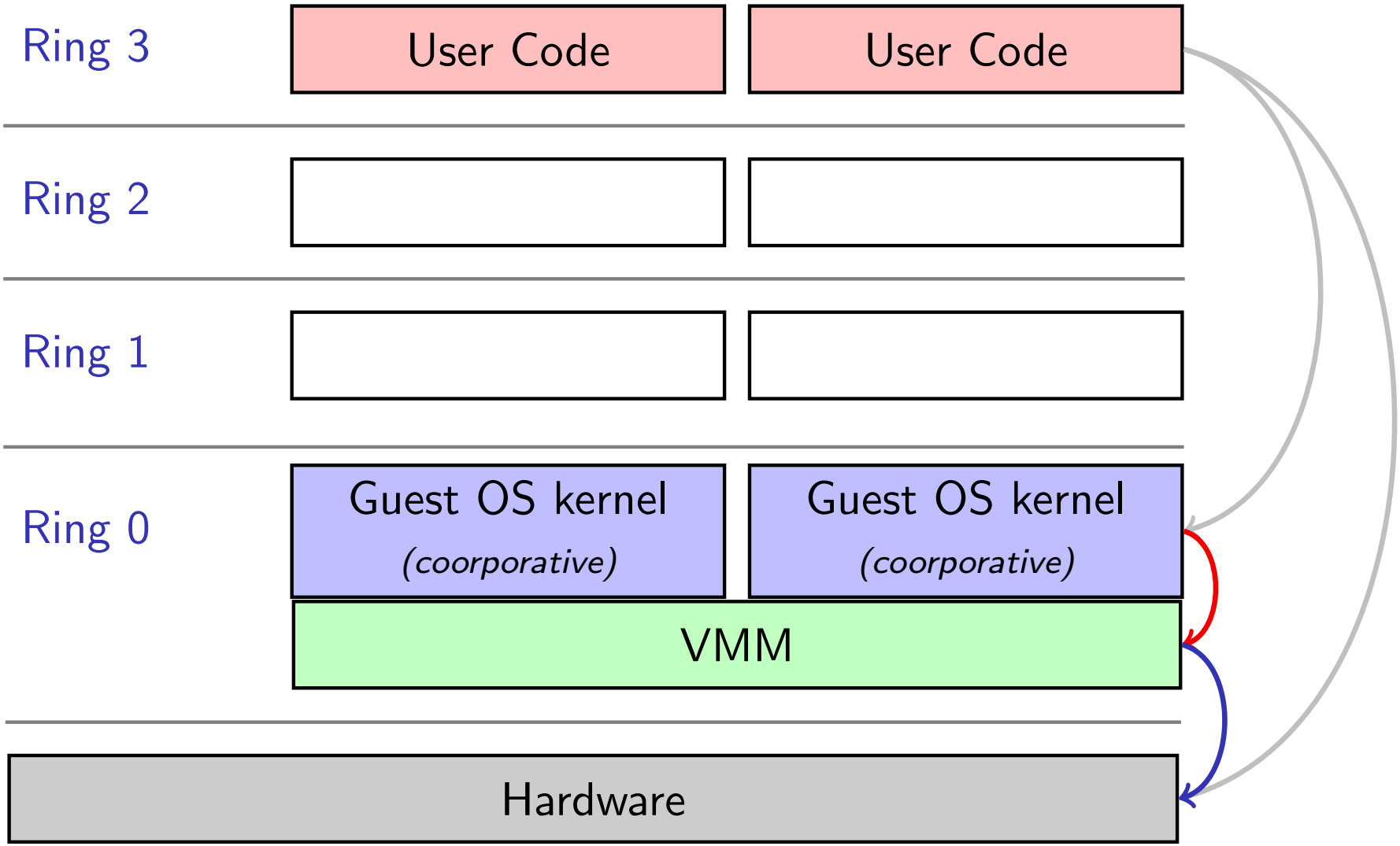


Full virtualization (bare-metal)



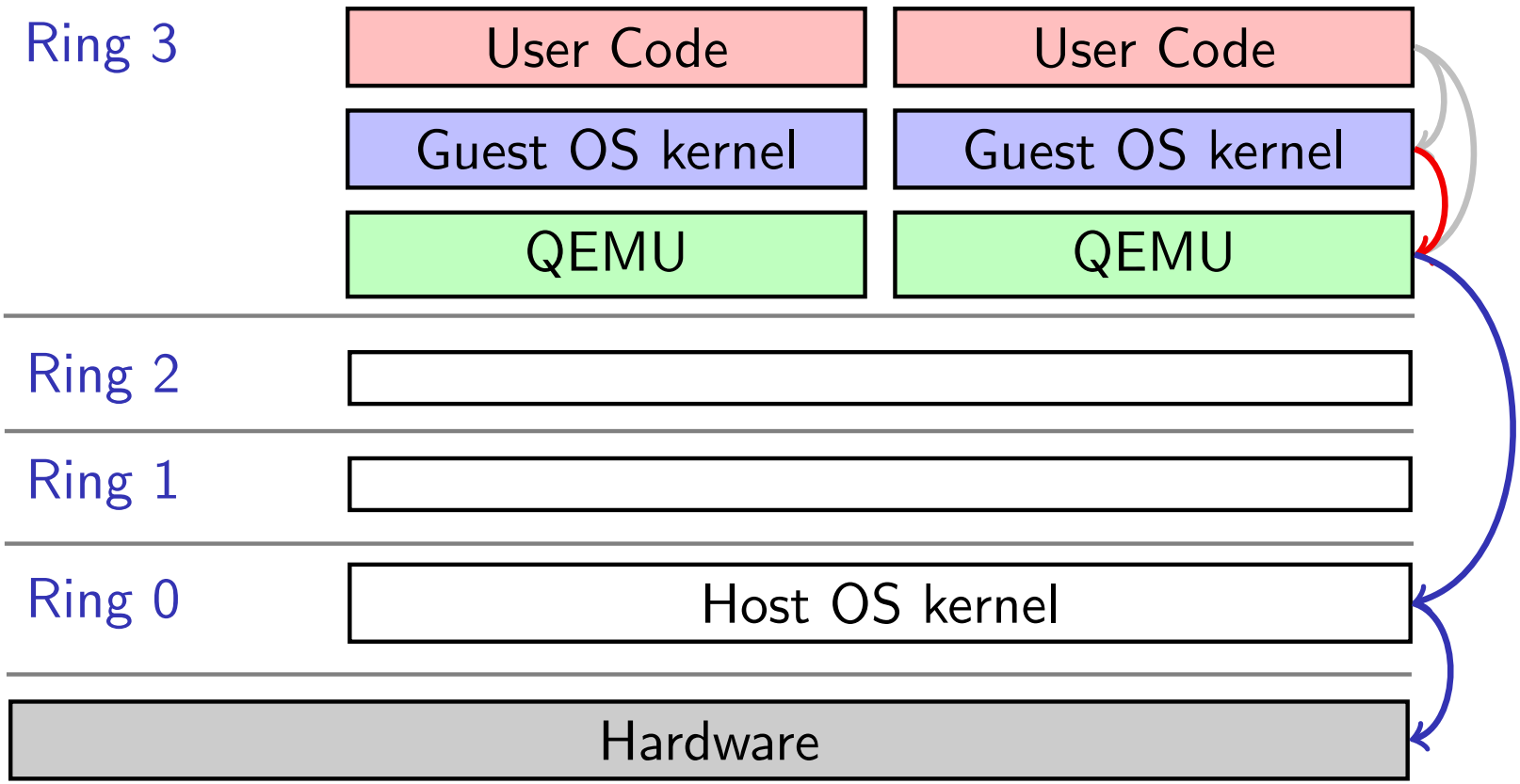
Trap accesses to hardware resources into the Virtual Machine Manager (VMM), possibly via binary translation.

Paravirtualization



Instrument the guest kernel with hypercalls to interact with VMM.

Whole-system emulation



Whole-system emulation attempts to run the entire stack in user-space, including the emulation of hardware devices.

Outline

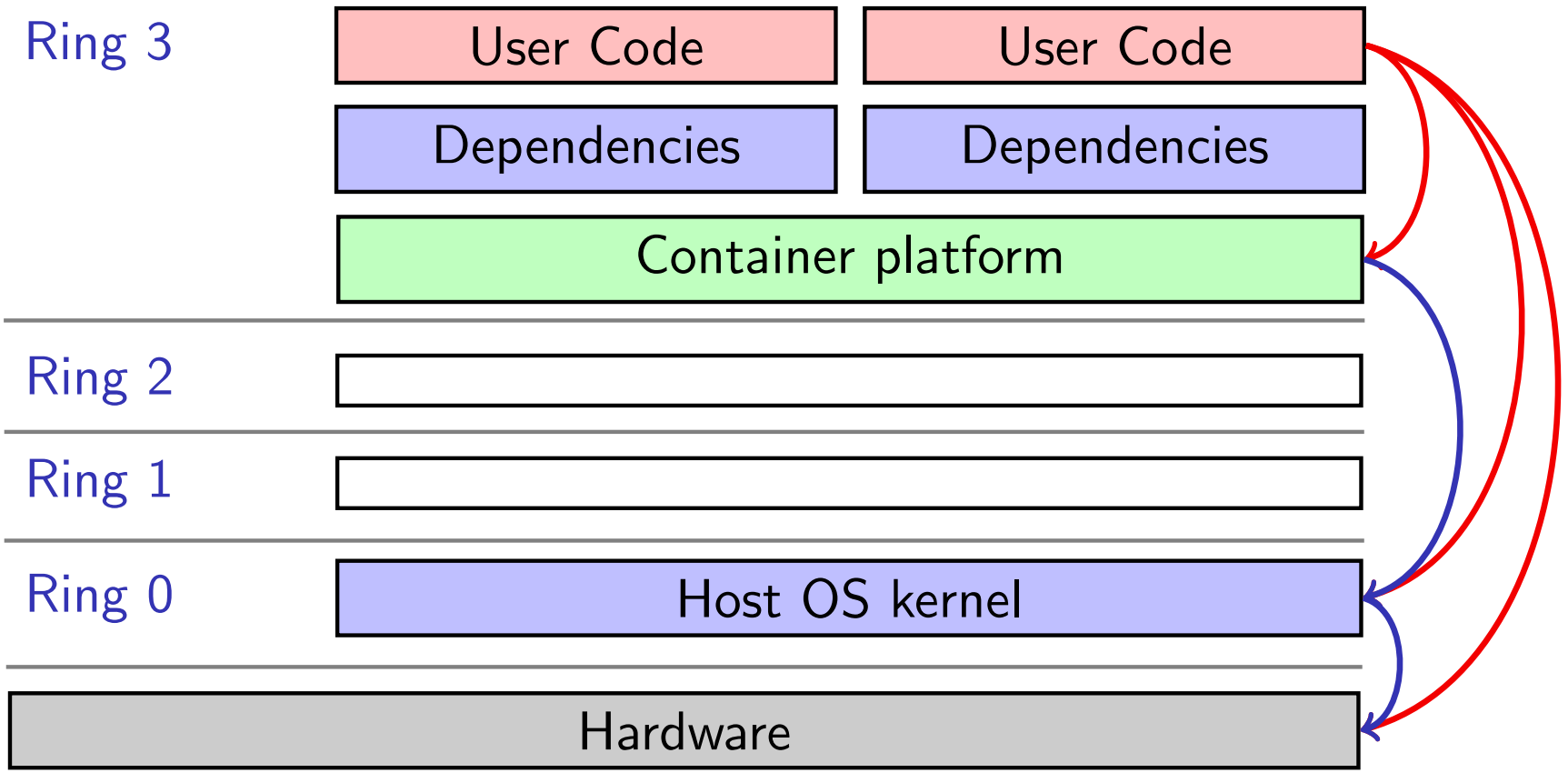
What is a container?

Figure: A cargo ship. Credits / Trademark: Tech Vision

What does a container sees itself?

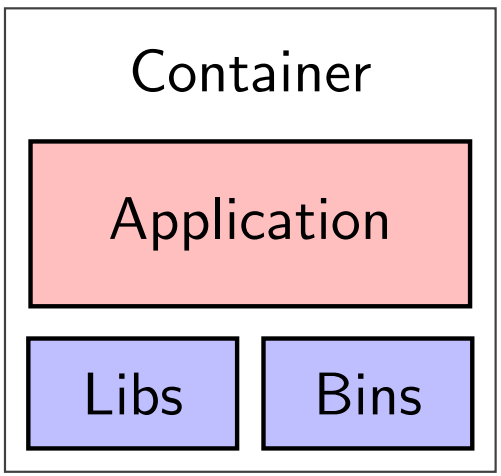
Figure: A single-container ship. Credits / Trademark: MarineTraffic

Containerized application



A containerized application has a delusion that it is the only application running on the platform (other than the dependencies).

From the view of a containerized application



Q: What does a containerized application need to run?

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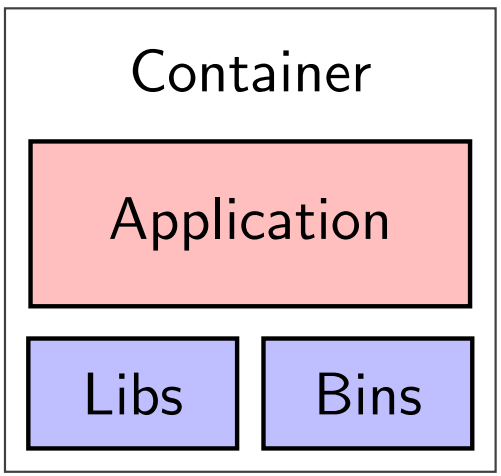

Q: What does a containerized application need to run?

- memory
- filesystem
- networking
- threading / scheduling
- process management
- inter-process communications

Docker on Linux — control groups (cgroups)

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- memory
- CPU
- block I/O
- network
- *device drivers ...*
- some exotic use cases, such as
  - huge pages (an efficient way of memory allocation)
  - RDMA (for faster memory accesses)
  - .....

Docker on Linux — control groups (cgroups)

cgroups also allows to group processes for batch operations such as:

- freezer (conceptually similar to a mass-SIGSTOP/SIGCONT)
- perf_event (gather performance statistics on these processes)
- cpuset (limit or pin processes to specific CPUs)
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When a process is created, it is placed in its parent's cgroups

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These namespaces are typically available in modern Linux kernels:

- pid: only "see" processes in the same PID namespace
- net: networking interfaces
- mnt: root fs, private mounts (`/tmp`), masking `/proc`, `/sys`, etc
- uts: hostname
- ipc: ns-specific IPC semaphores, message queues, shared memory
- user: allows UID/GID mapping (*e.g.*, UID 0→99 to 1000→1099)
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Each process belongs to one namespace of each type. A new process can re-use none / all / some of the namespaces of its parent

Docker on Linux — namespaces (ns)

```
$ sudo unshare --uts
```

- create new uts namespace while inheriting everything else.

```
$ hostname
> system76-pc
$ hostname cs858
$ hostname
> cs858
```

In another shell, check that the hostname remains:

```
$ hostname
> system76-pc
```

Docker on Linux — copy-on-write filesystem (`OverlayFS`)

While Docker generally considers it a mechanism for fast container launch, the overlay filesystem concept itself is a very powerful sandboxing mechanism.

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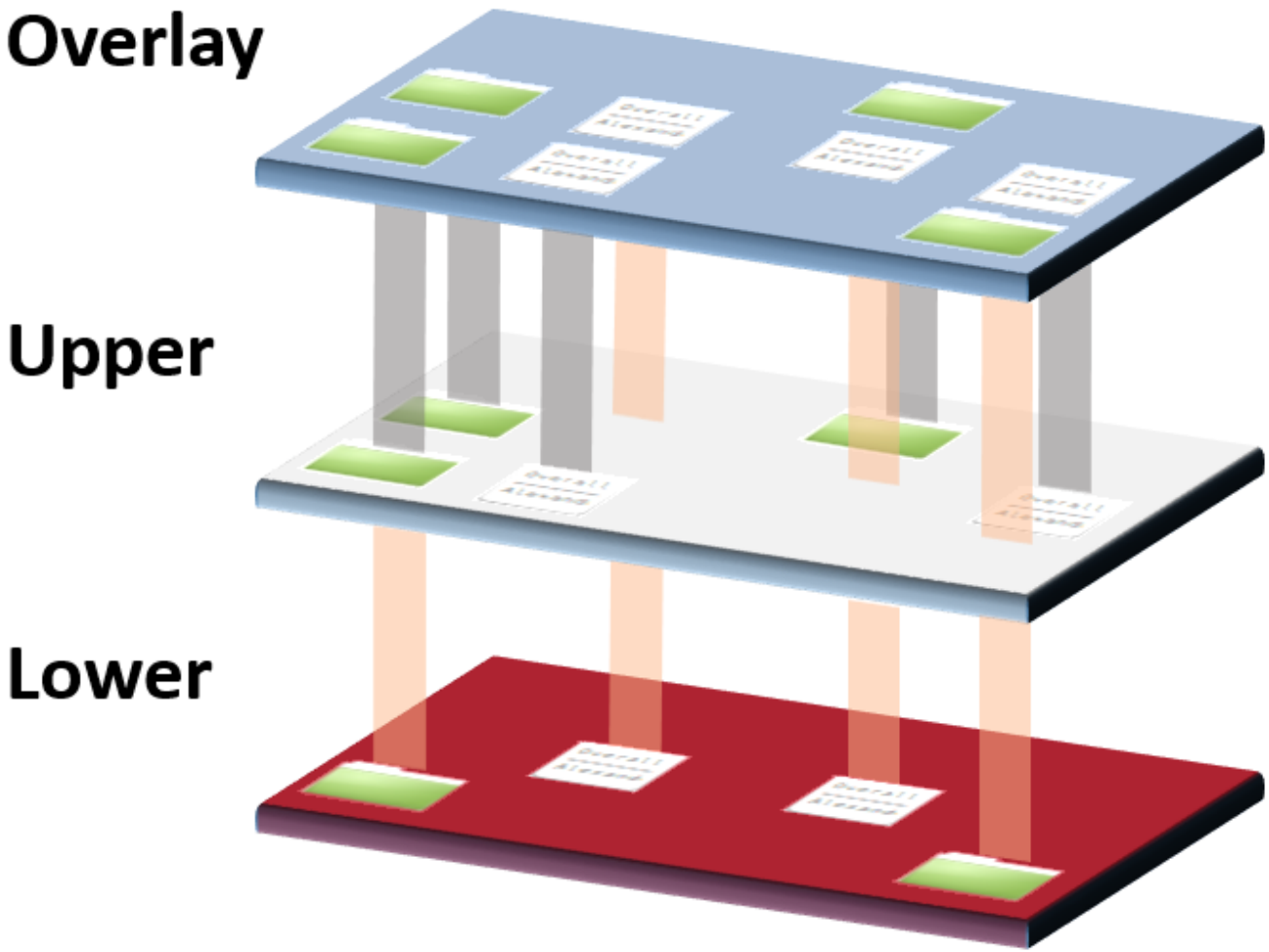

Figure: An illustration of the `OverlayFS`. Credits / Trademark: Datalight

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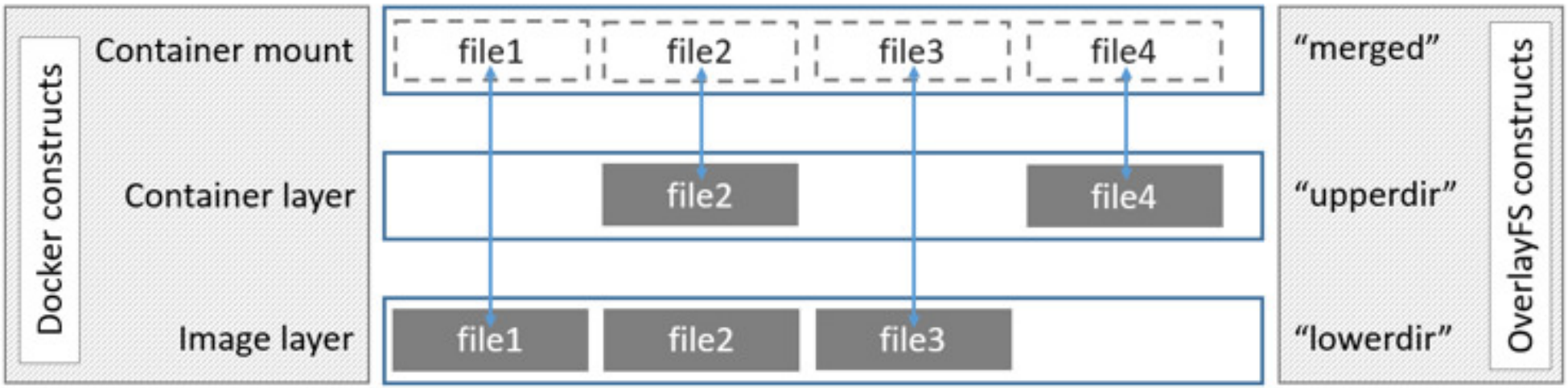

Figure: An illustration of the `OverlayFS`. Credits / Trademark: Docker

Outline

Why would a program sandbox itself?

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The most common reason is to deal with untrusted code, *e.g.*,

- Javascript received from website
- Macros carried in documents (*e.g.*, Excel or PDF)
- Language runtime running untrusted application code

Case study: Linux capabilities

In traditional UNIX, many operations are possible when you have UID = 0 (root):

- changing file ownership, accessing all files, ...
- setting up network interfaces, mounting filesystems ...
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But why would a web server has accesses to kernel modules or the ability to mount / unmount filesystems?

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- `CAP_CHOWN`: arbitrarily change file ownership and permissions.
- `CAP_DAC_OVERRIDE`: arbitrarily bypass file ownership and permissions.
- `CAP_NET_ADMIN`: configure network interfaces, iptables rules, etc.
- `CAP_NET_BIND_SERVICE`: bind a port below 1024.
- `CAP_SYS_MODULE`: load or unload kernel modules.
- ...

See `man capabilities` for the full list and more details.

Case study: Seccomp

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Enter `seccomp`, that prevent execution of certain system calls by an application, through a customizable filter.

Why system calls?

The Linux kernel exposes a large number of system calls (≈400), while most program only need a small subset to function. — The practicality argument.

In addition, the most common way of making an impact on the host platform is via system calls. — The effectiveness argument.

Seccomp: strict mode

Only permit the following system calls: `read()`, `write()`, `_exit()`, `sigreturn()`. Any other system calls leads to `SIGKILL`.

- NOTE: `open()` not included.

Designed to sandbox untrusted code that is compute-intensive.

Seccomp: BPF filter

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Steps to use BPF filter:

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Once install, every system call triggers execution of filter.

Seccomp: from BPF to eBPF

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In essence, eBPF allows arbitrarily complex checks to be performed quickly and safely.

⟨ End ⟩