Advanced Operating Systems

Topic 6. **Virtualization**

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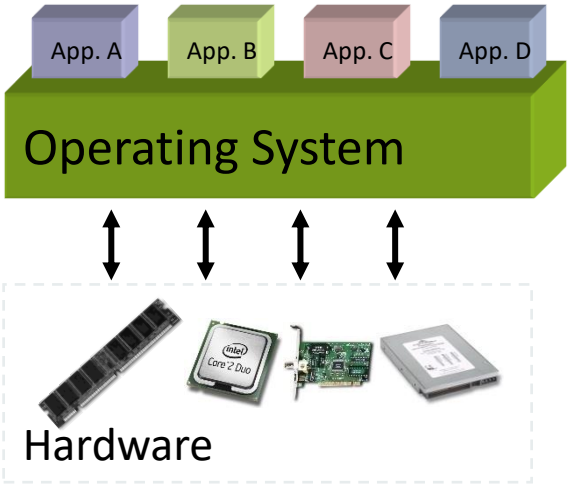
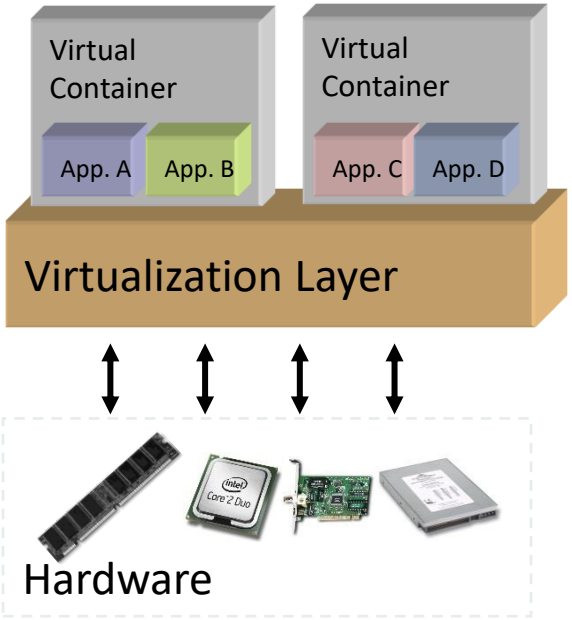
What is Virtualization?



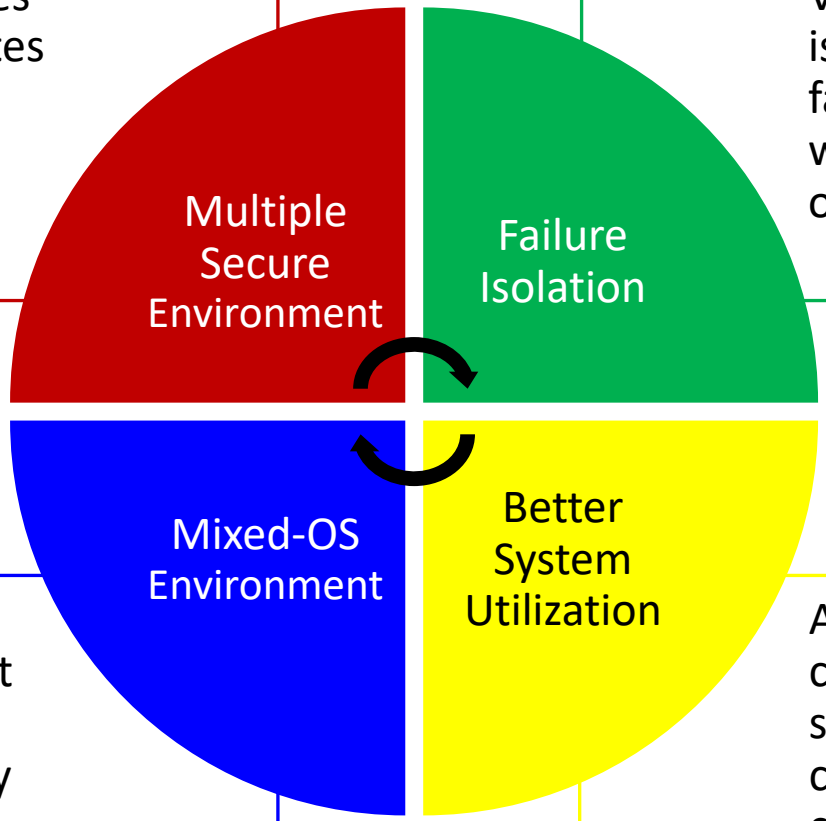
'Nonvirtualized' system
A single OS controls all hardware platform resources



Virtualized system
It makes it possible to run multiple virtual Containers on a single physical platform

Benefits of Virtualization

A system VM provides a sandbox that isolates one system environment from other environments



Virtualization helps isolate the effects of a failure to the VM where the failure occurred

A single hardware platform can support multiple operating systems concurrently

A virtualized system can be (dynamically or statically) re-configured for changing needs

Virtualization Properties

- Fault Isolation
- Software Isolation
- Performance Isolation (accomplished through scheduling and resource allocation)

Isolation

- All VM state can be captured into a file (i.e., you can operate on VM by operating on file– cp, rm)

Encapsulation

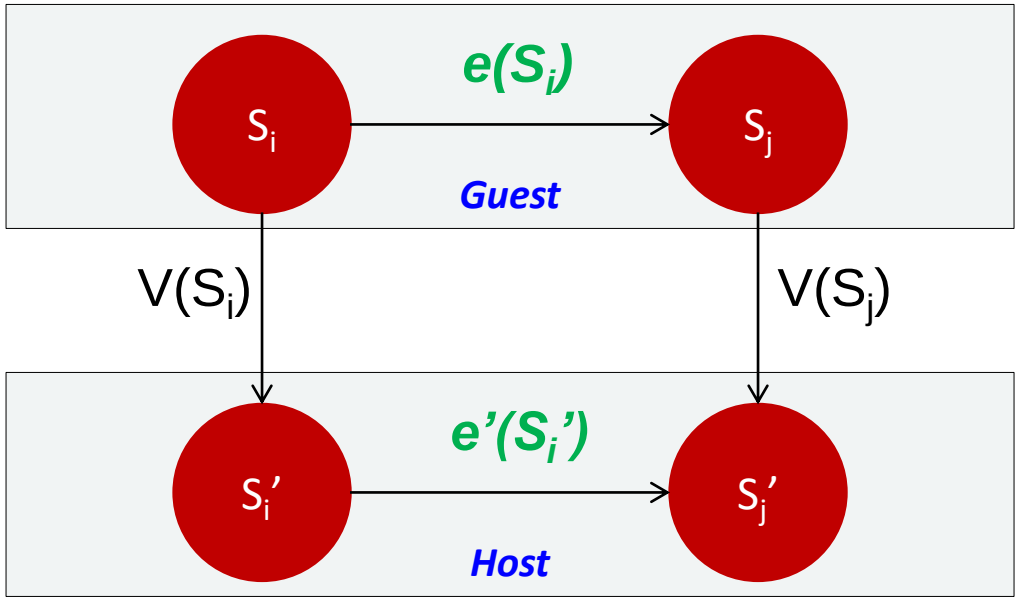
- All guest actions go through the virtualizing software which can inspect, modify, and deny operations

Interposition

What is Virtualization?

- Virtualization basically allows one computer to do the job of multiple computers, by **sharing the resources of a single hardware across multiple environments**

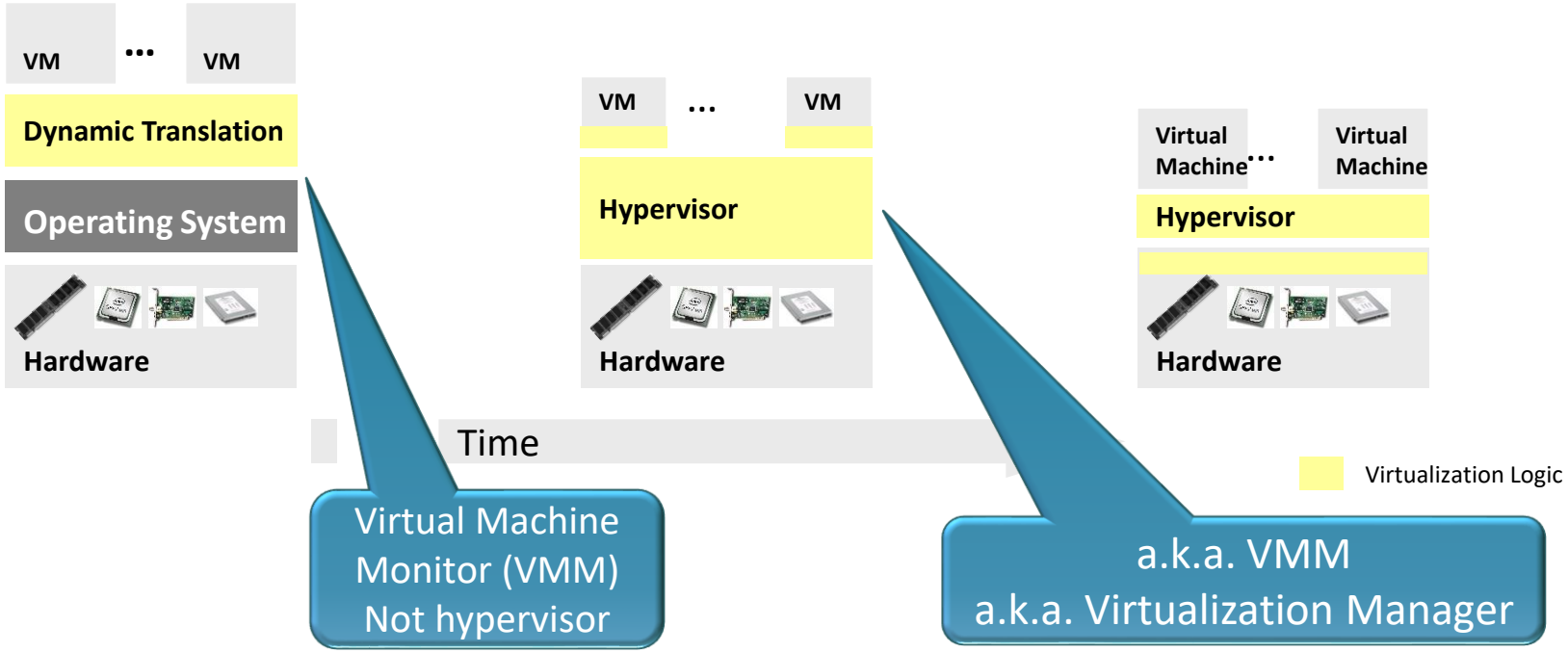
- Formally, virtualization involves the construction of an **isomorphism** that *maps* a virtual guest system to a real host system (Popek and Goldberg 1974)



Introduced by IBM in the 1960s

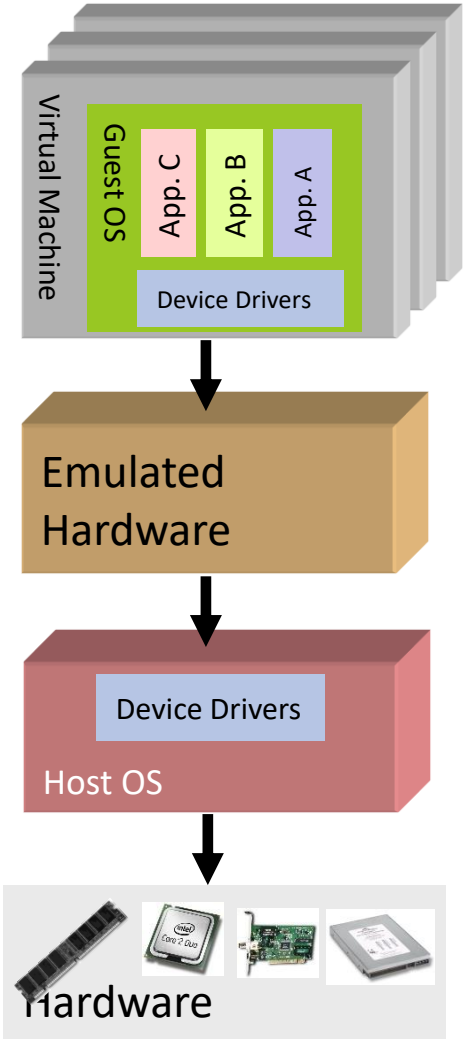
Server virtualization approaches

- 1st Generation: Full virtualization (Binary translation)
  - Software Based
- 2nd Generation: Paravirtualization
  - Cooperative virtualization
  - Modified guest
- 3rd Generation: Silicon-based (Hardware-assisted) virtualization
  - Unmodified guest



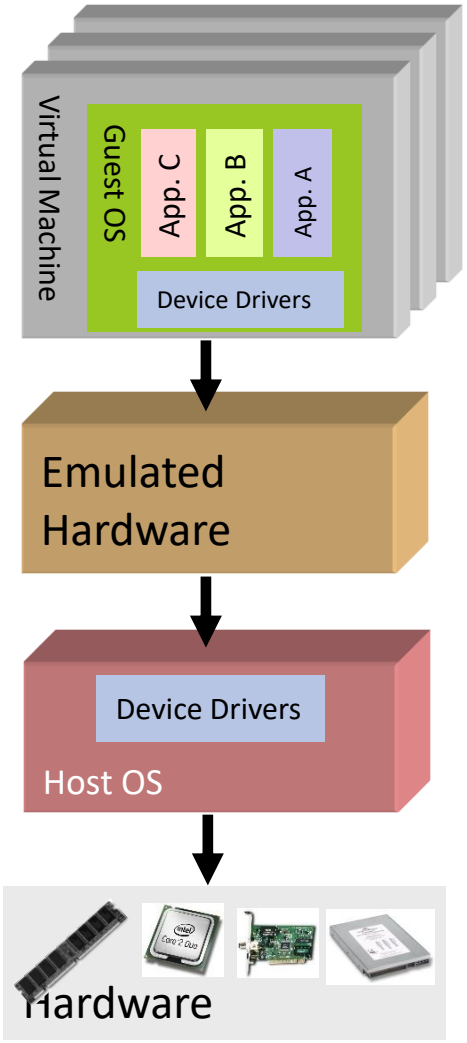
Full virtualization

- Runs **unmodified** guests
- Dynamic binary translation
- **Software emulates** CPU (full instruction set), input/output operations, interrupts, memory access, motherboard, device buses, etc.
  - Guests cannot access hardware
- **Examples:** QEMU, VMWare, Xen HVM, KVM, Microsoft VM, Parallels, virtualbox



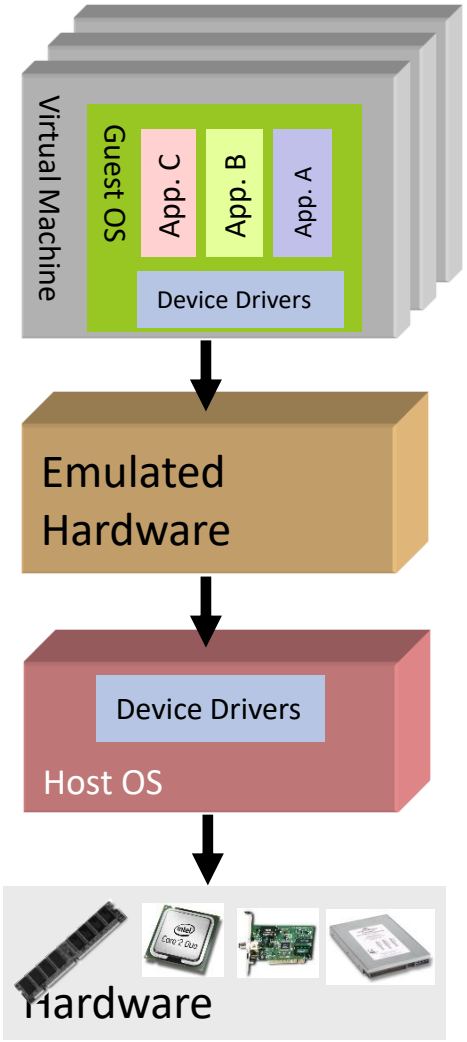
Full virtualization - Advantages

- The emulation layer
  - **Isolates** VMs from the host OS and from each other.
  - **Controls** individual **VM access to** system **resources**, preventing an unstable VM from impacting system performance.
- Total VM portability
  - VMs have the ability to transparently **move between hosts** with **dissimilar hardware**
  - It is possible to **run** an **OS** that was developed for **another architecture** on your own architecture



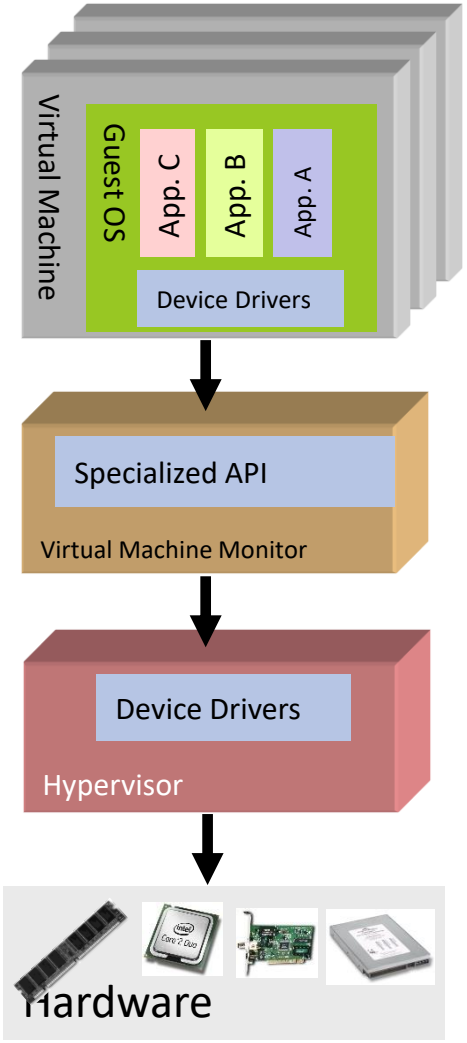
Full virtualization - Disadvantages

- Hardware emulation comes with a performance price. It's the worst performance.
  - ~ usually **less than 2%** for emulated devices such as RAM
  - **from 8% to 20%** for input/output – intensive devices such as network cards and hard disks.



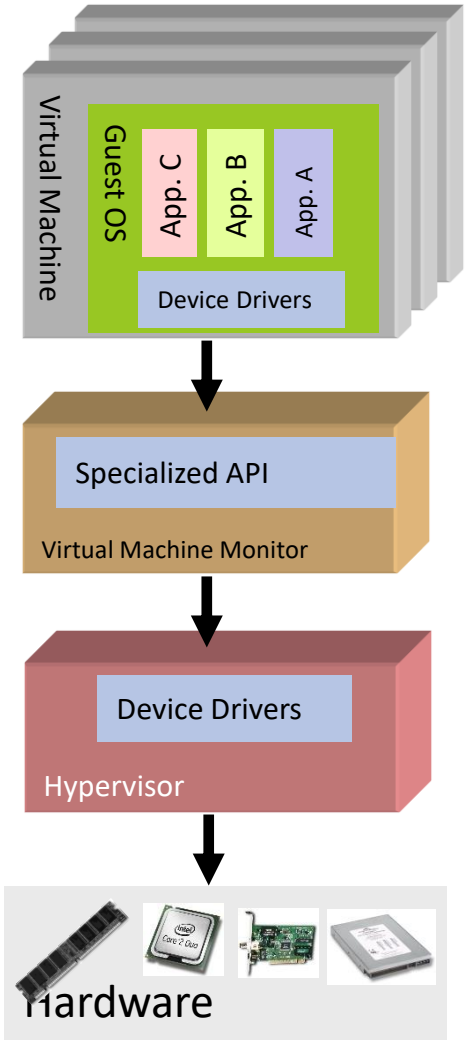
Paravirtualization

- The **Guest OS is modified** and thus
  - The guest is fully aware of how to process **privileged instructions** (access to I/O devices, interrupt handling, etc.)
  - The **guest** operating system **uses** a specialized **API to talk to the VMM** and, in this way, executes the privileged instructions
  - With appropriate device drivers in its kernel, the **guest OS** is now capable of directly **communicating** with the **system hardware**.



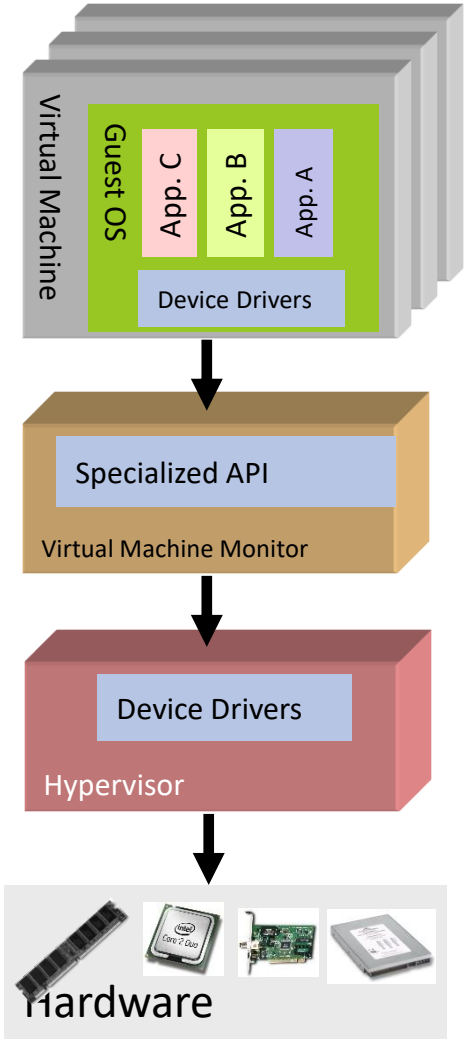
Paravirtualization

- VM ***guest OSs*** are paravirtualized using two different approaches:
  - Recompiling the OS kernel
  - Installing paravirtualized drivers (**partial paravirtualization**)



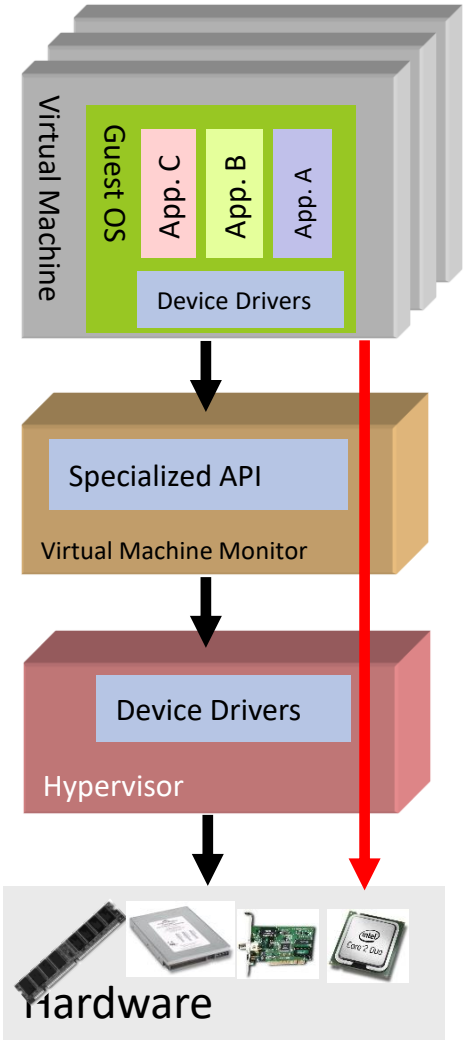
Paravirtualization

- Advantages
  - Better performance than full virtualization.
- Disadvantages
  - Modify the guest OS to cooperate with the VMM
  - In some OSs it is not possible to use complete paravirtualization
  - Guest OS and hypervisor tightly coupled
  - Guest kernel must be recompiled when hypervisor is updated



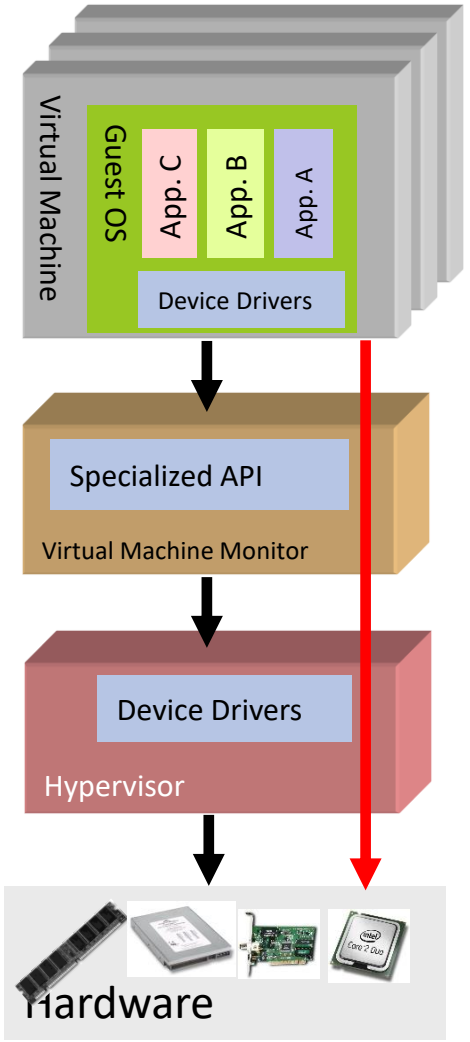
Hardware-assisted virtualization

- **Guest OSs** can process **privileged instructions** without the need for any translation on the part of the VMM
- The VMM uses **processor extensions** (such as Intel®-VT or AMD-V) to intercept and emulate privileged operations in the guest
- Dedicated address space that is assignable to each VM
  - **Chips** containing **Extended Page Tables**



Hardware-assisted virtualization

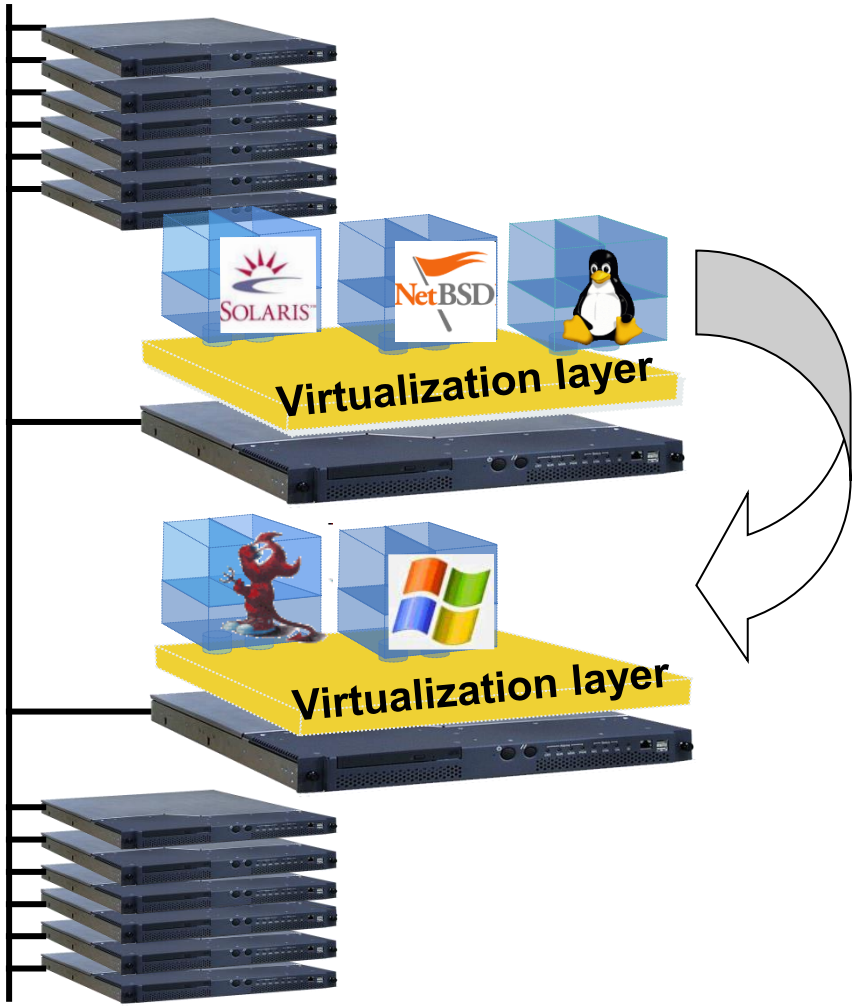
- **Advantages**
  - "Better" CPU performance than full and para-virtualization
  - Improved virtual machine isolation
  - It allows running "unmodified" OSs
- **Disadvantages**
  - Specialized and Expensive Hardware
  - An unmodified OS does not know it is running in a virtualized environment and so, it can't take advantage of any of the virtualization features
    - It can be resolved using partial paravirtualization.



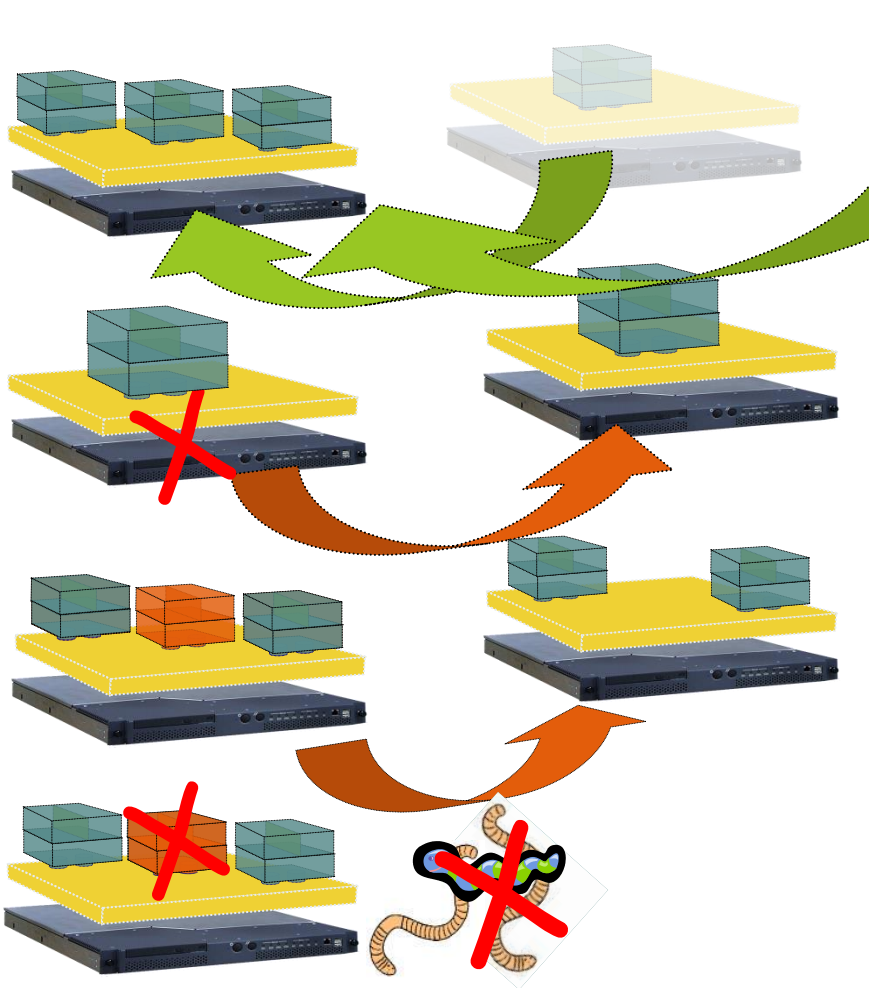

vmware®


all in one

Virtual Machine Migration



Virtual Machine Migration



- Server consolidation
- Reduce downtimes
- Load balancing – SLAs
- Security

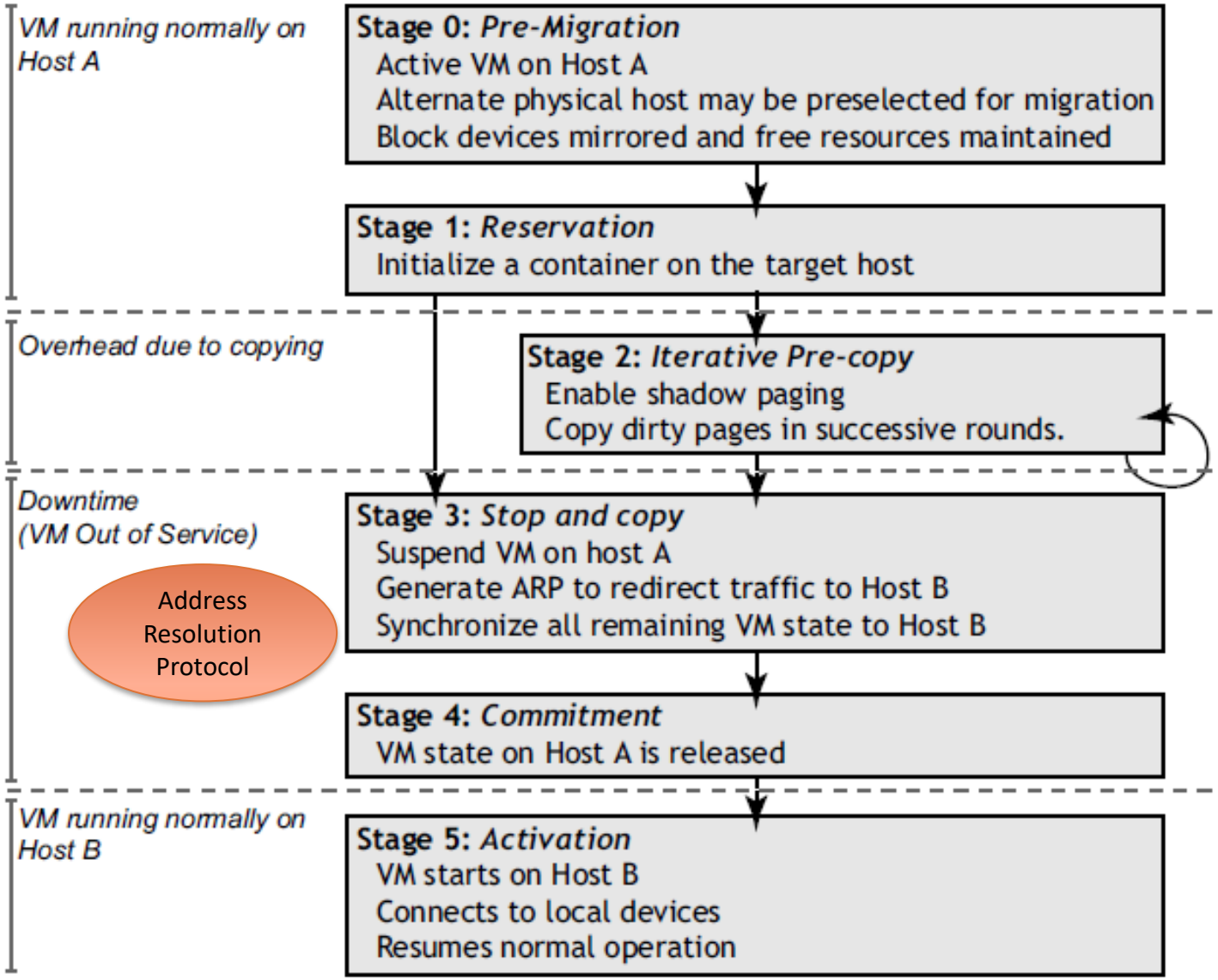
Virtual Machine Migration

- When to migrate?
- Where to move to?
- How much of each resource to allocate?
- How much information needed to make decisions?

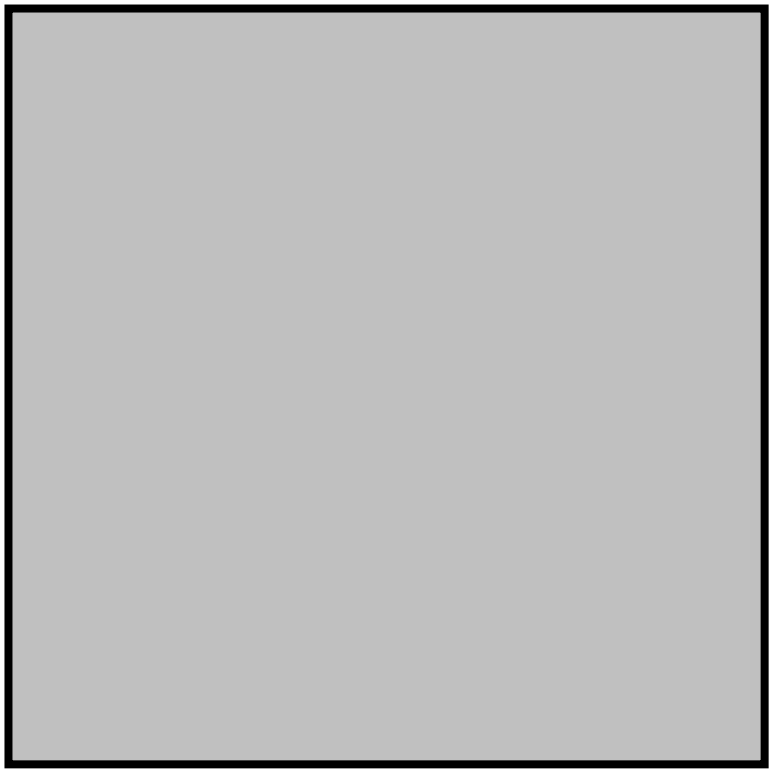
Live Virtual Machine Migration

- Metrics
  - **Downtime**
    - How long the VM is suspended
  - **Total migration time**
    - how long a live migration lasts
  - **Amount of migrated data**
    - How many data is transferred

Live Virtual Machine Migration

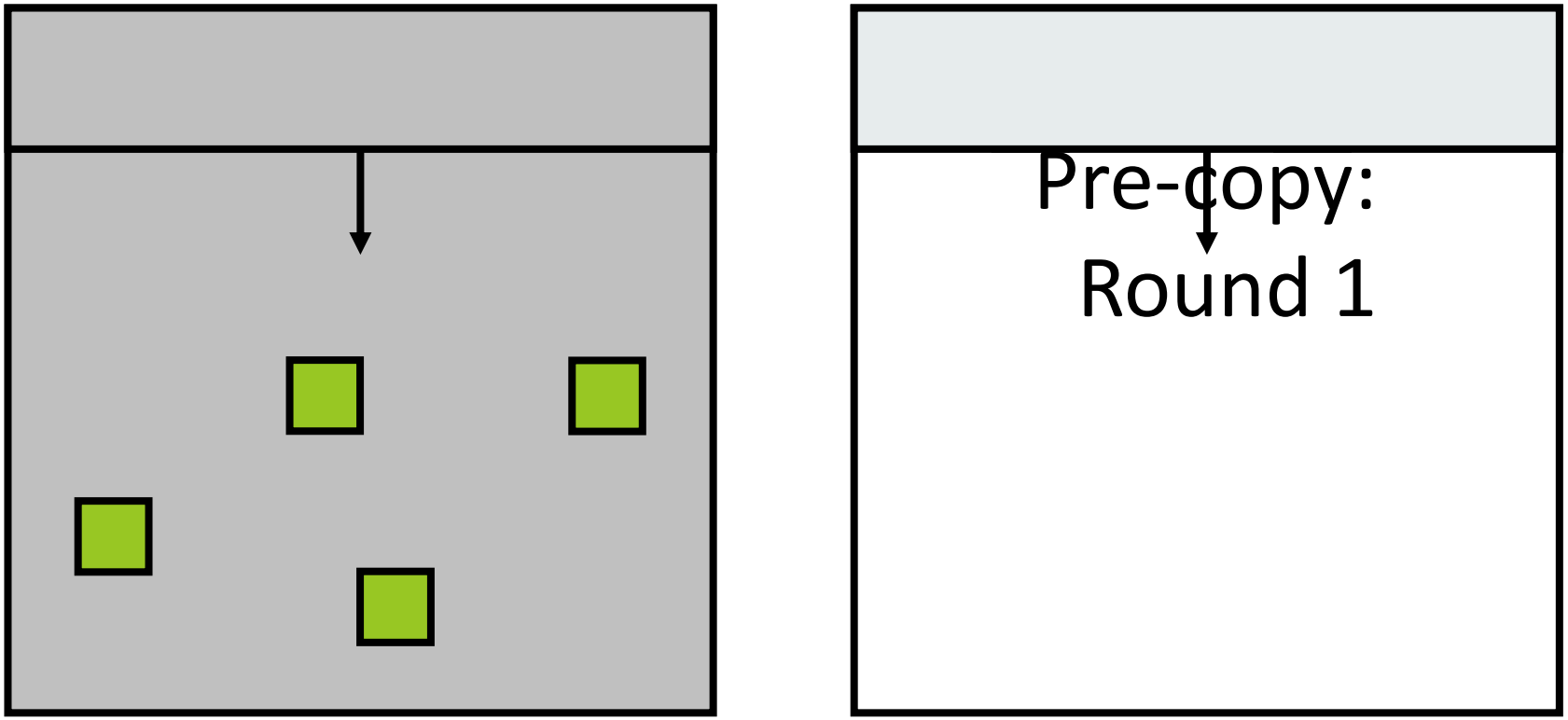


Live Virtual Machine Migration

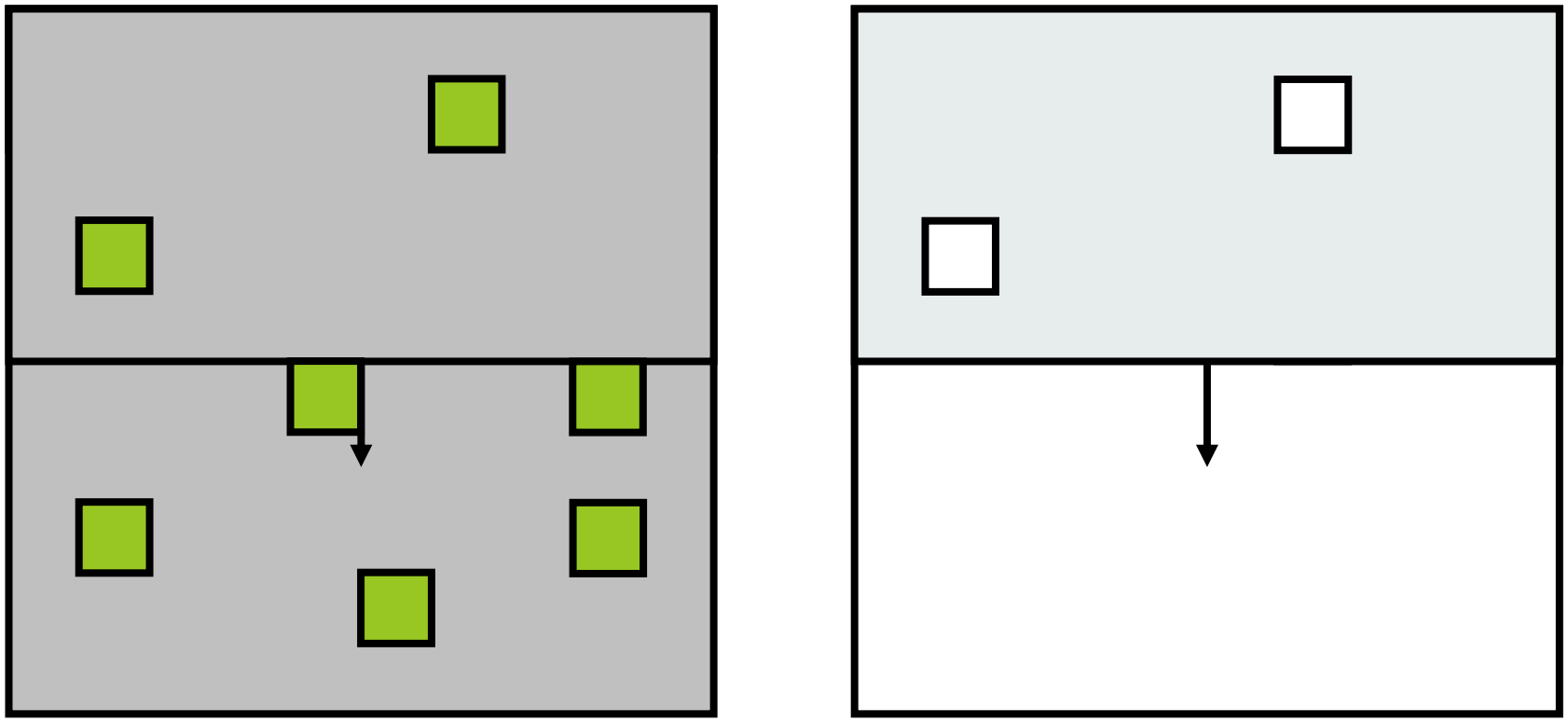


Pre-copy:
Round 1

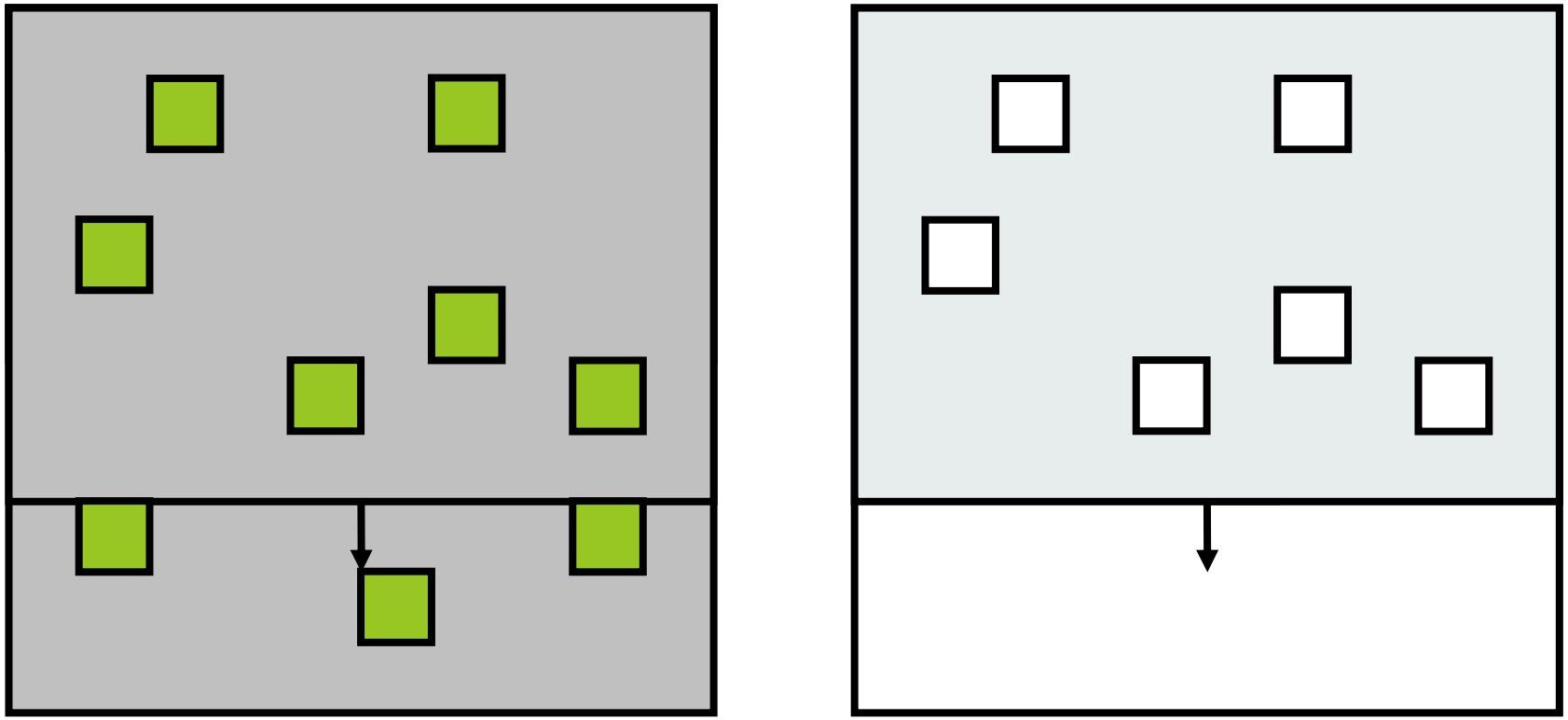
Live Virtual Machine Migration



Live Virtual Machine Migration



Live Virtual Machine Migration



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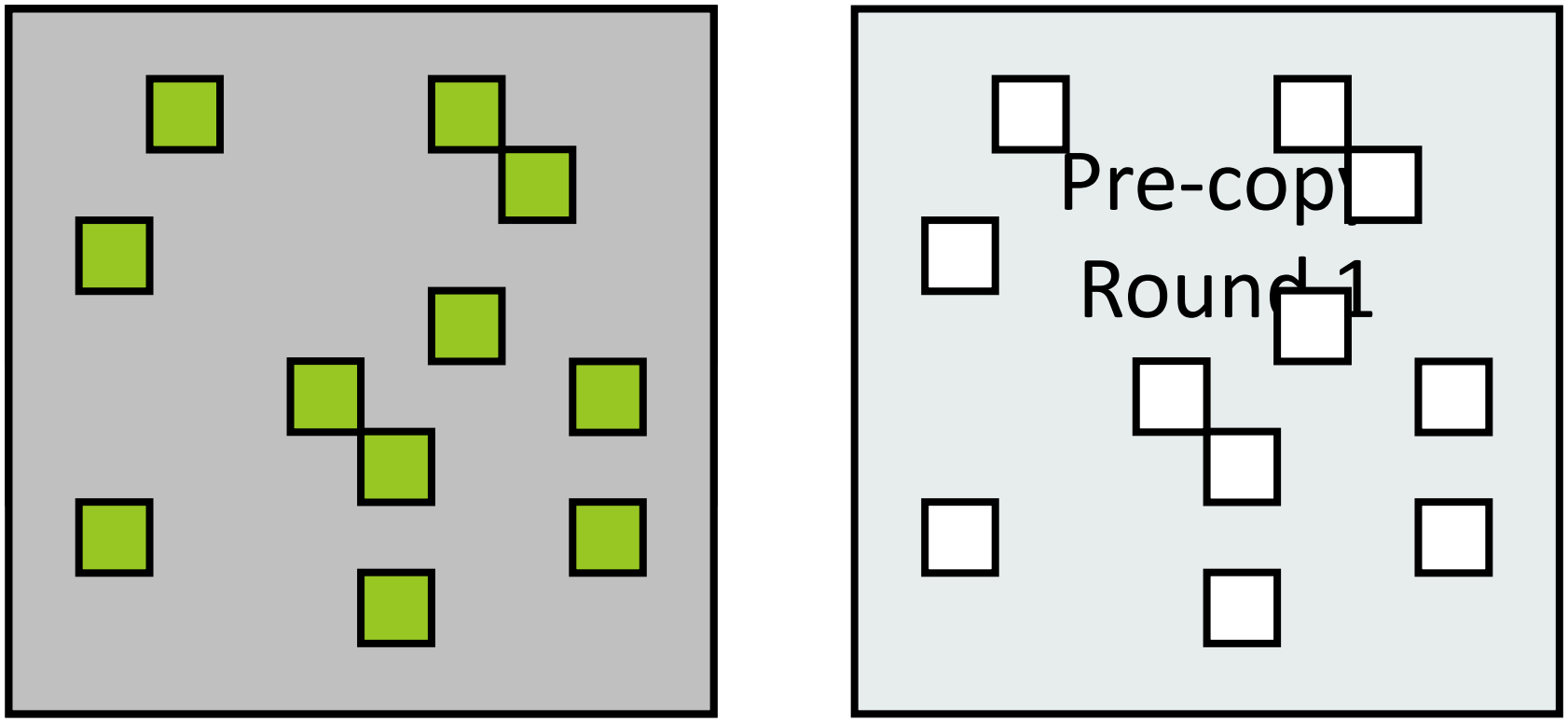

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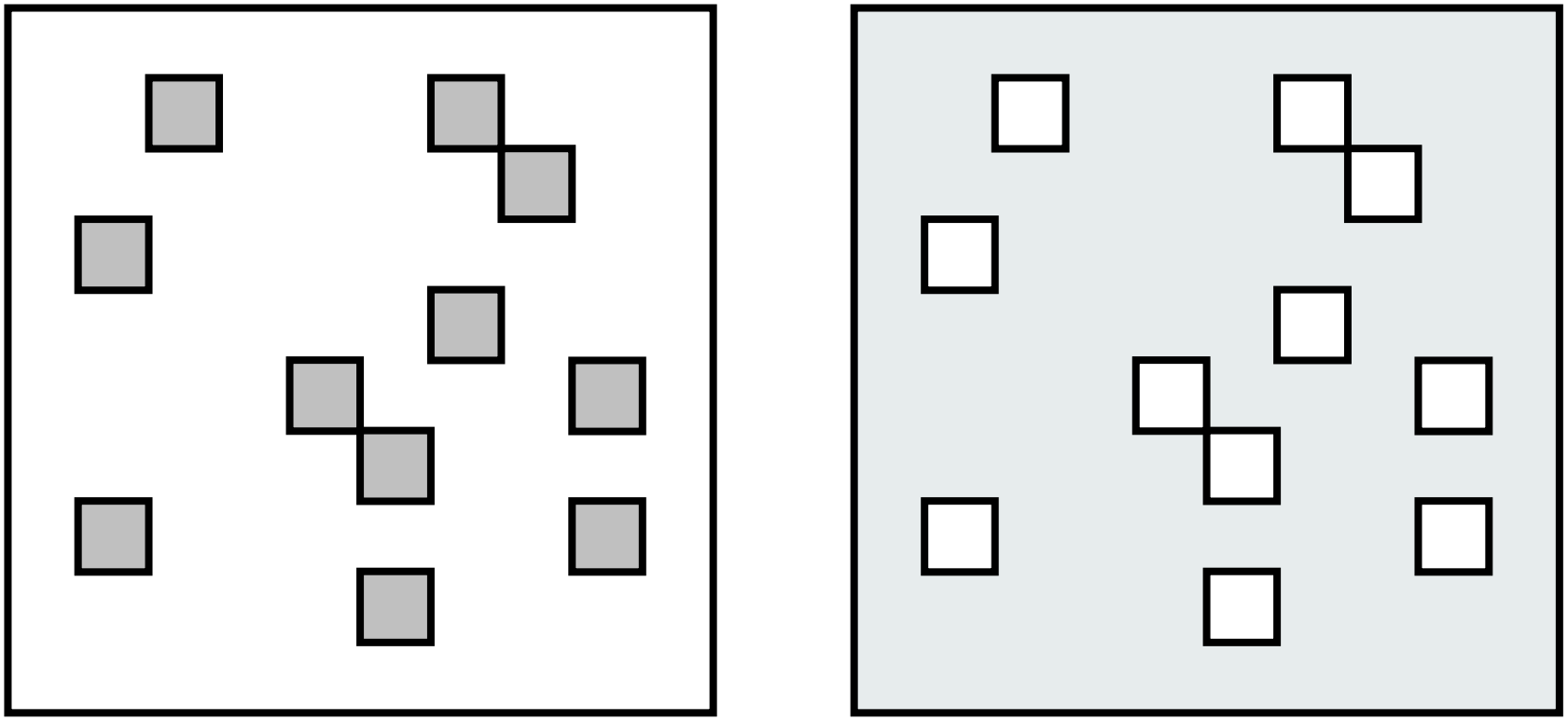

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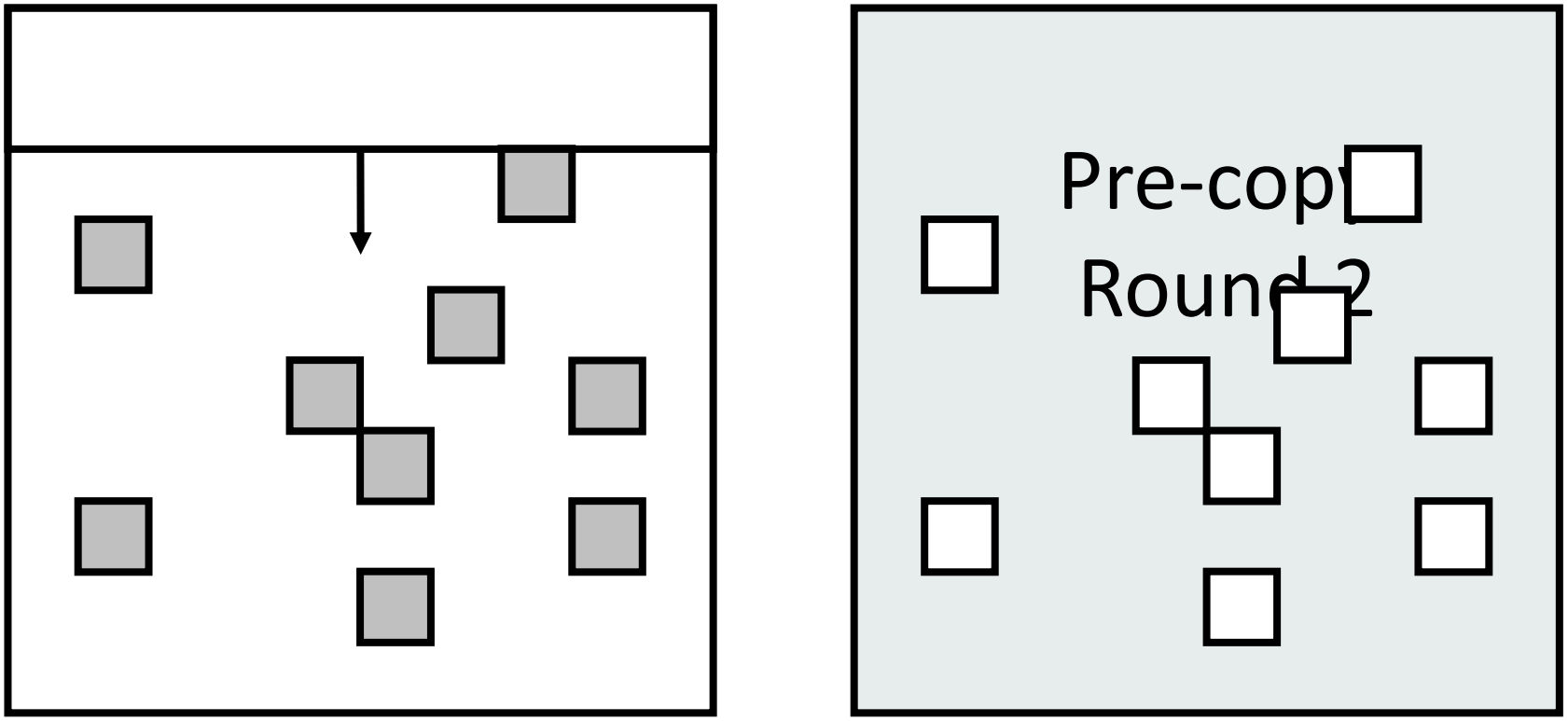

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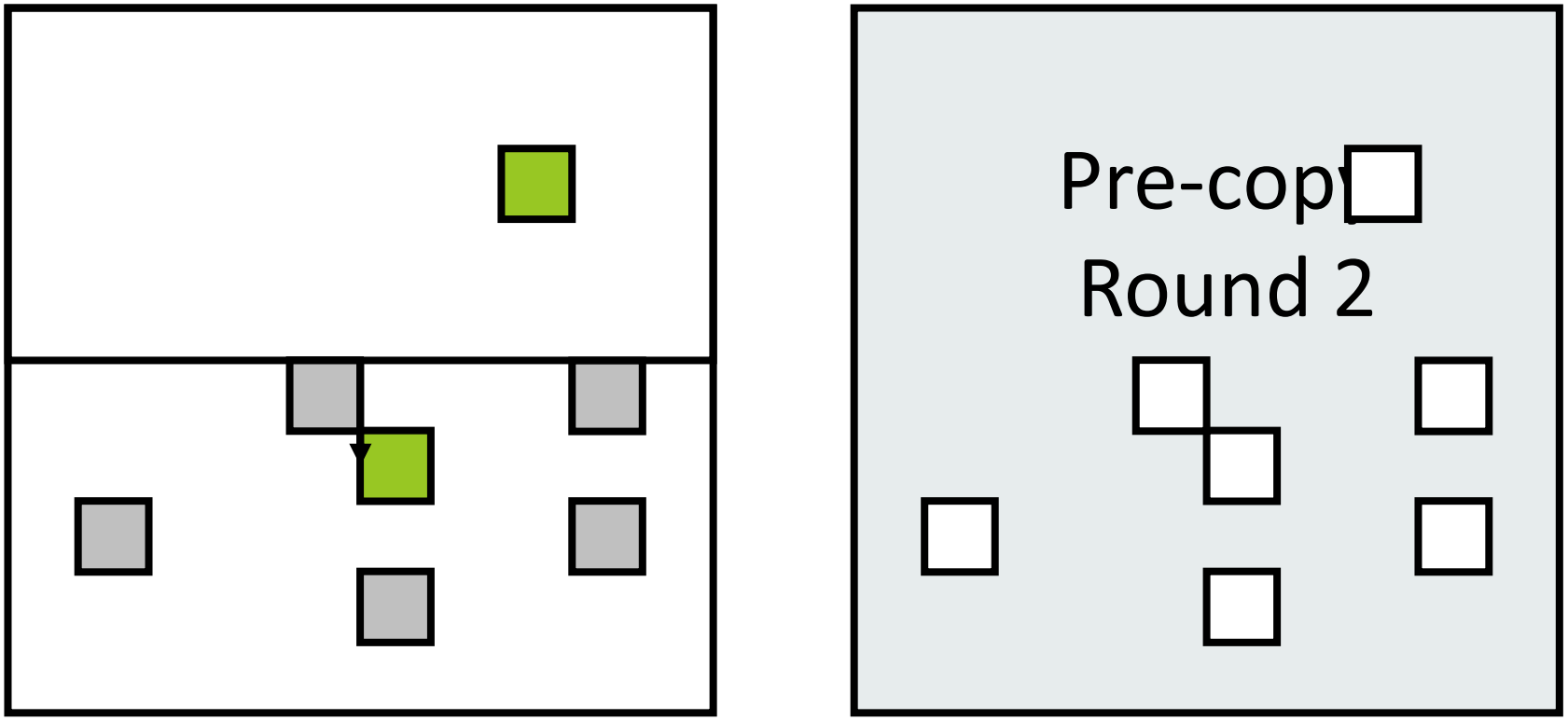

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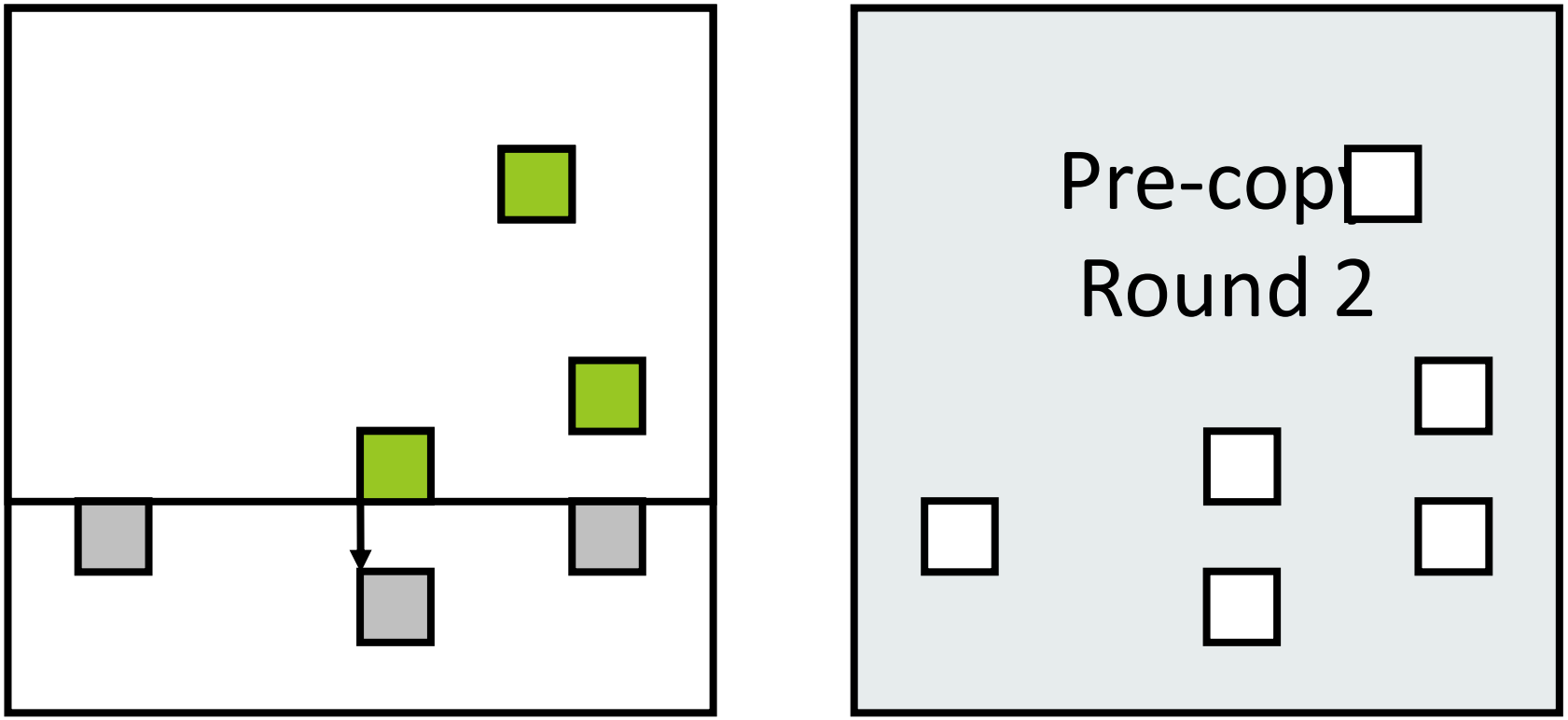

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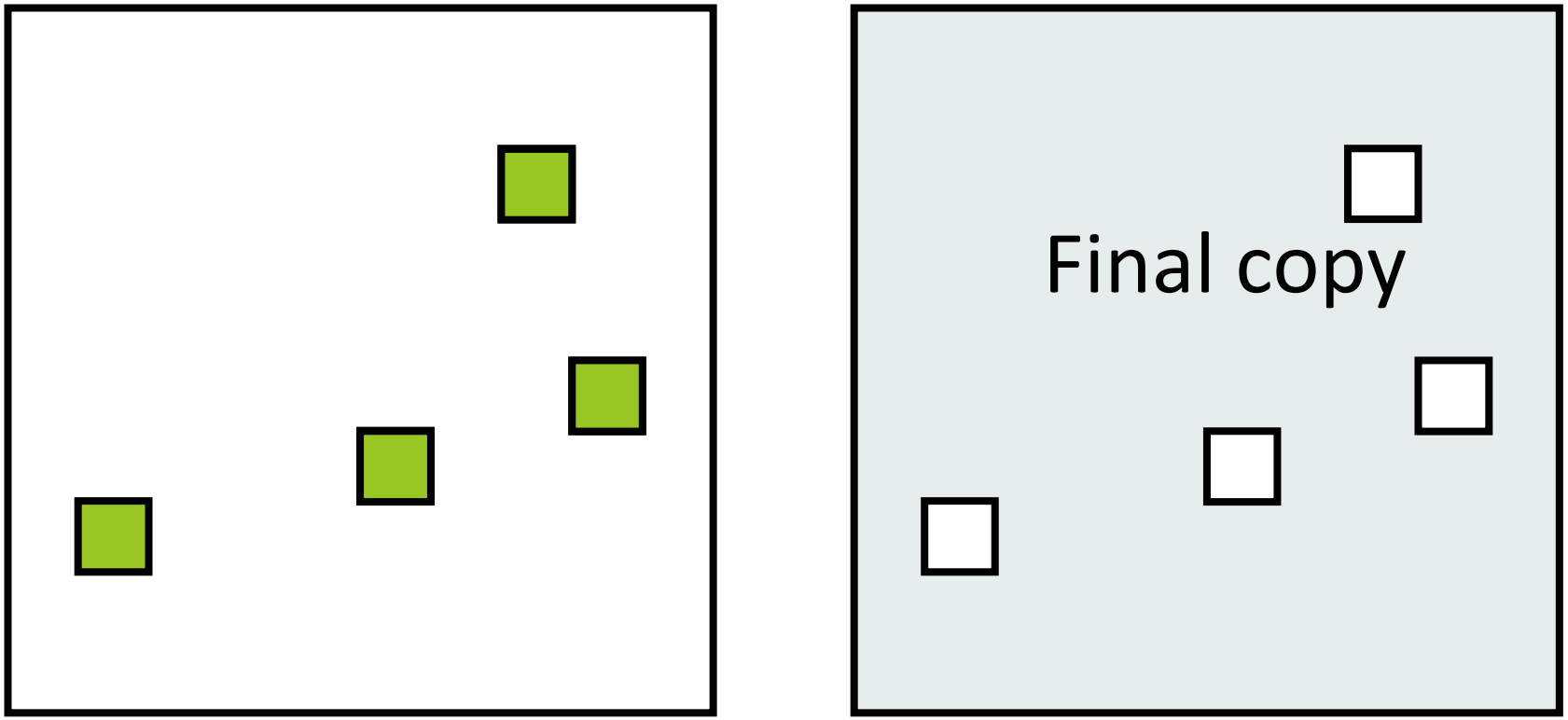

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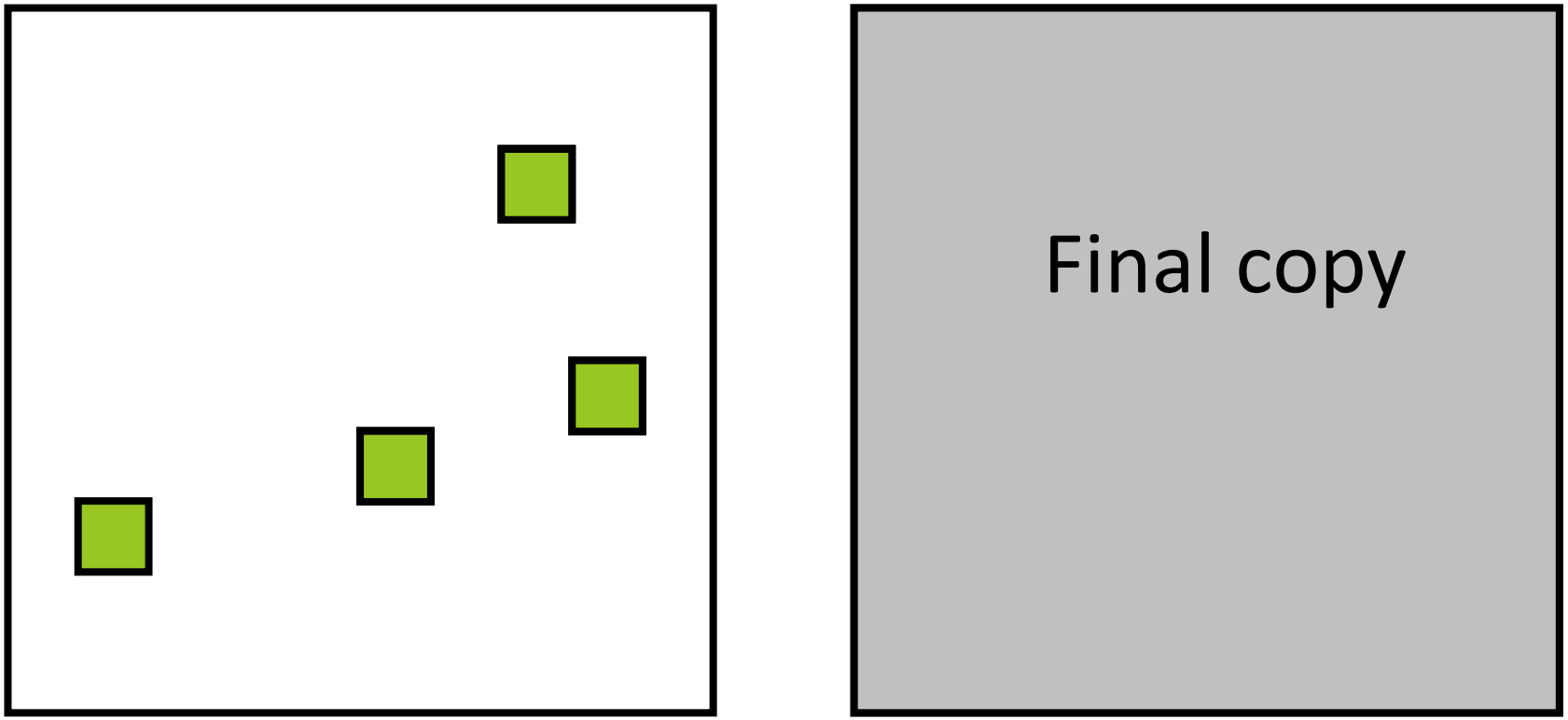


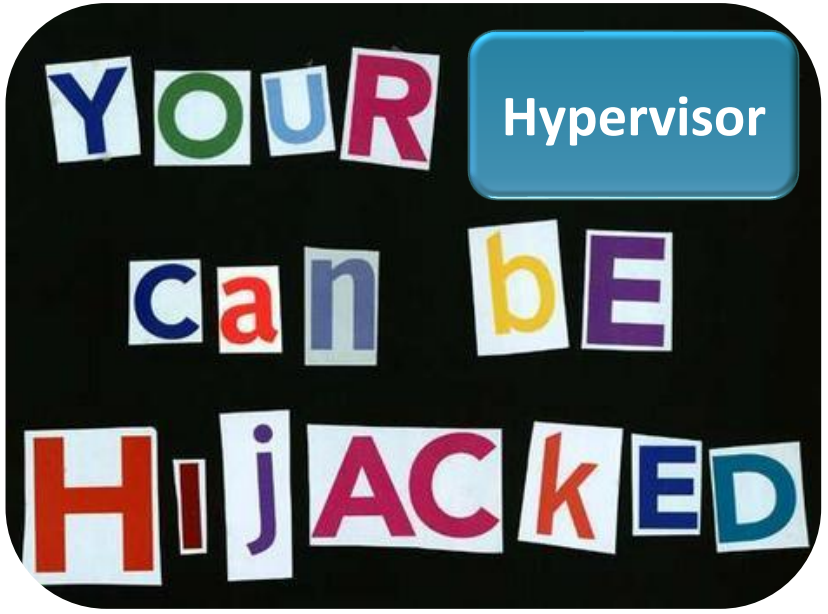
VMware: (Anti-)Affinity rules

- VM-to-VM
- VM-to-Physical server

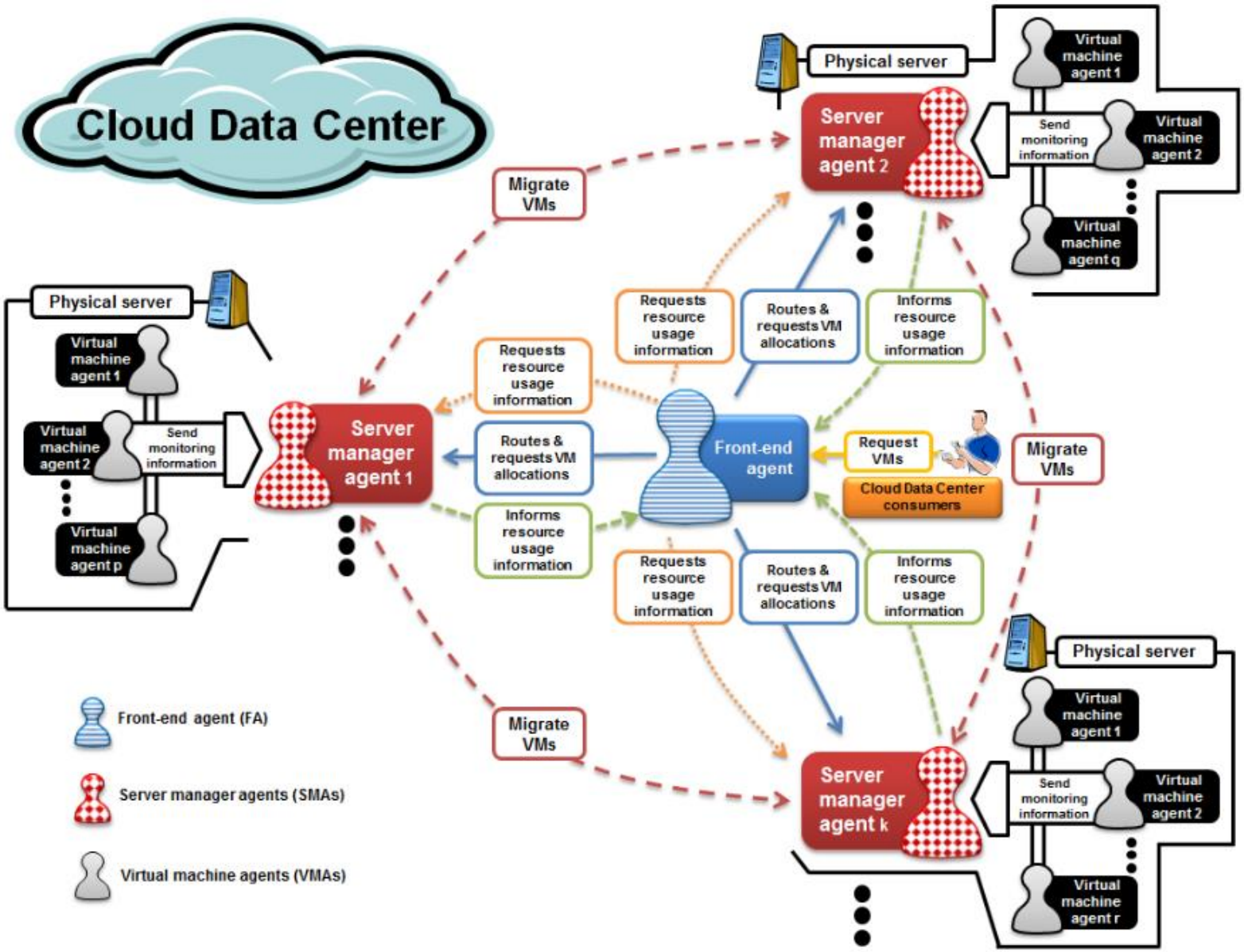
Affinity Solution

Some security issues

Multitenancy

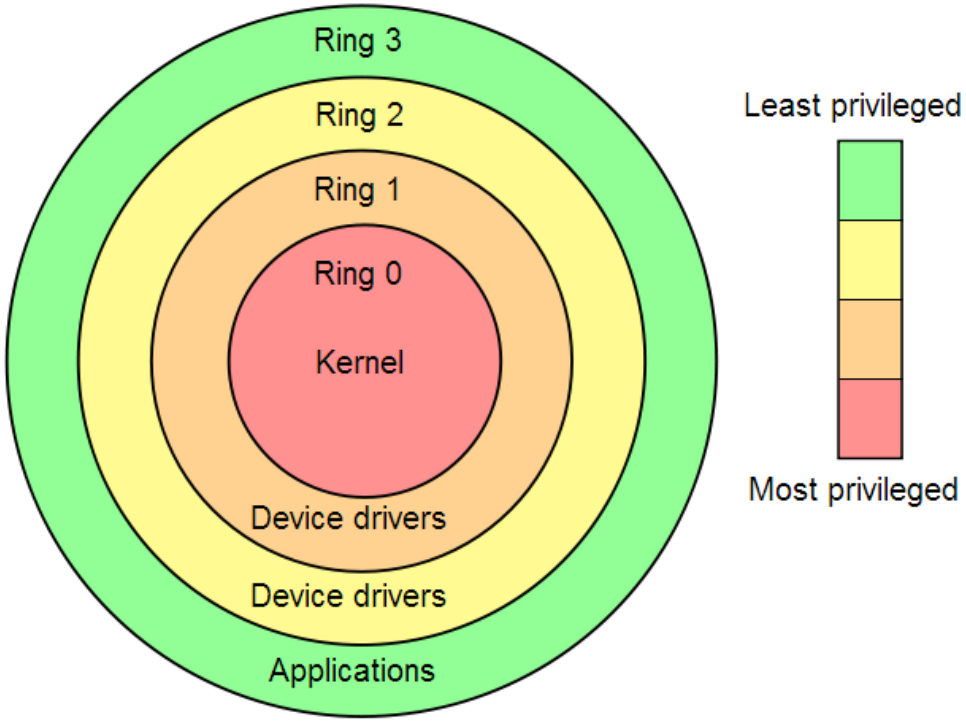


Agent-based load balancing using live migration of VMs



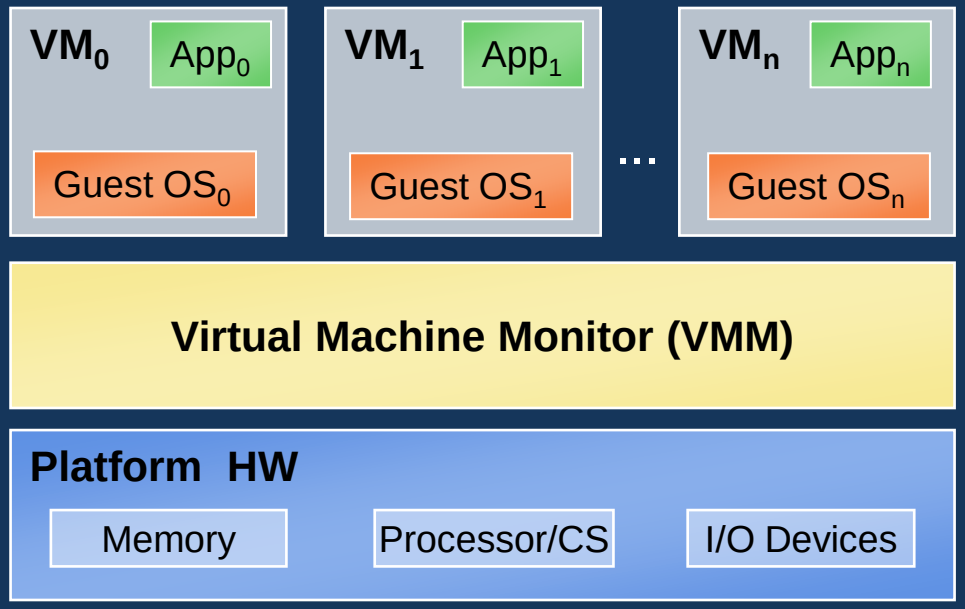
Hardware-assisted virtualization

- The hypervisor/VMM runs at Ring -1
  - super-privileged mode



Understanding Intel® Virtualization Technology (VT)

Virtual Machine Monitors (VMMs)

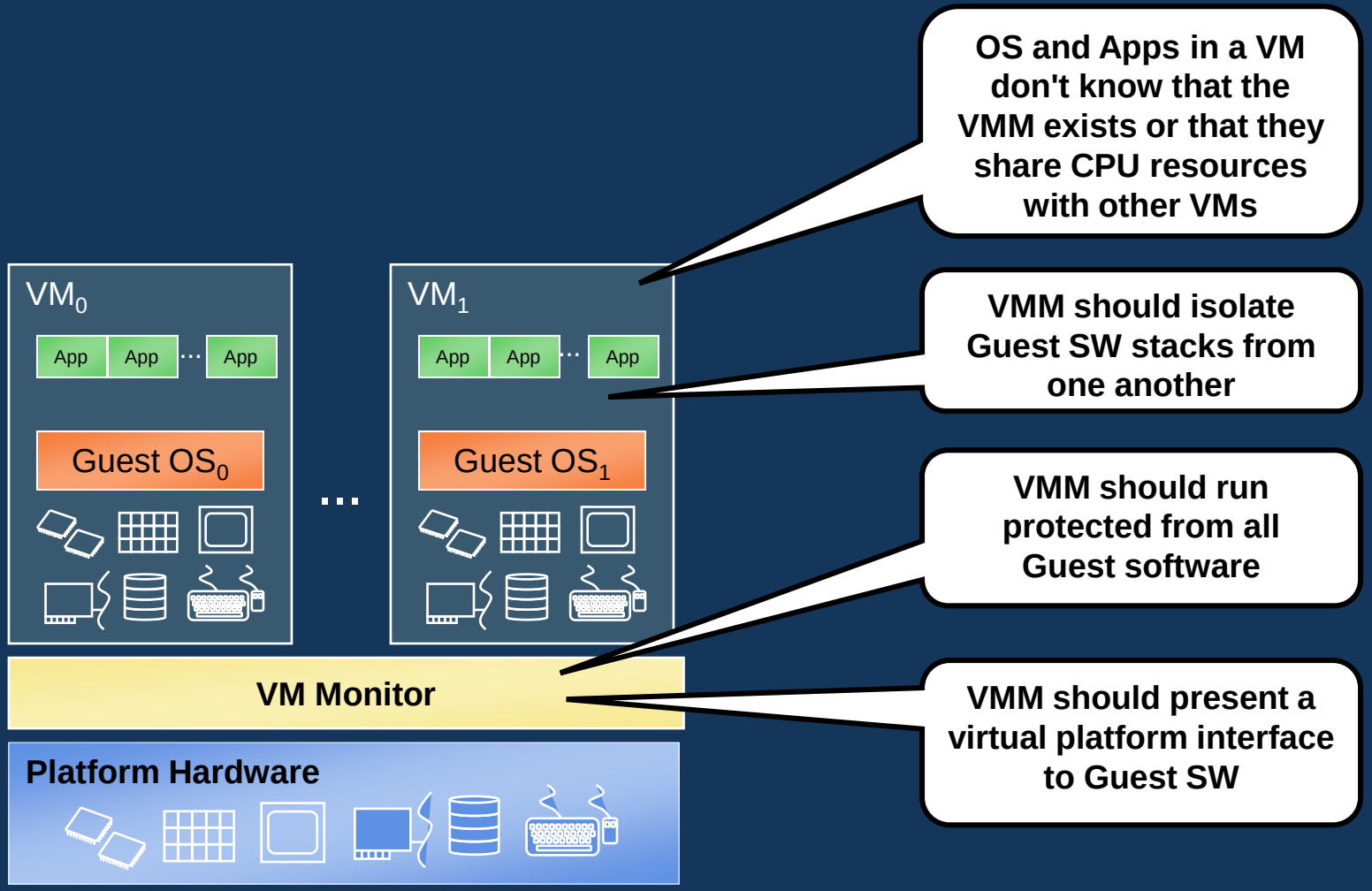


- VMM is a layer of system software
  - Allows Apps to run without modifications

What is Intel® Virtualization Technology ?

- VT is a set of hardware enhancements to Intel server and client platforms
- VT is designed to simplify virtualization software
- VT-x and VT-i are the first in the VT series of Intel processor and chipset innovations

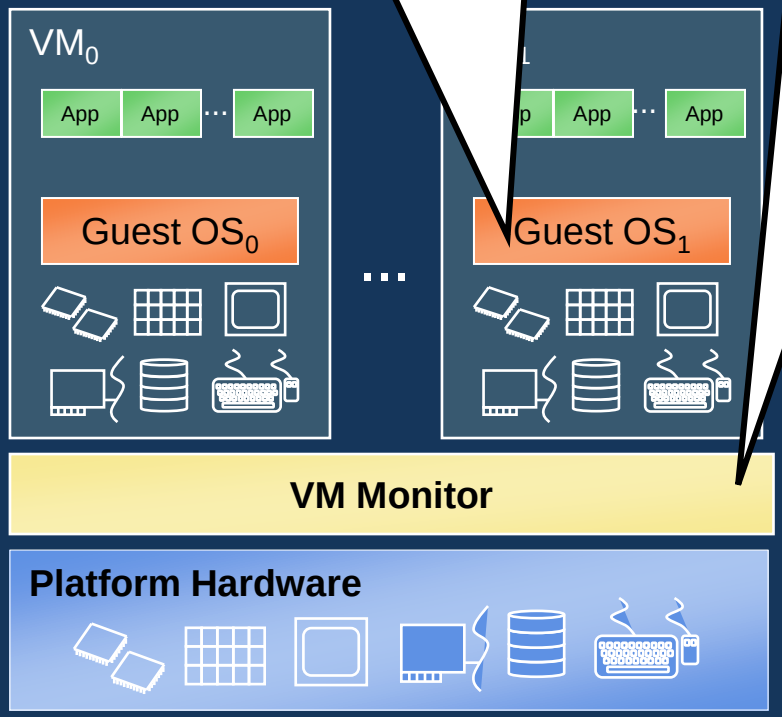
Challenges of Running a VMM



SW Solution: Guest Ring Deprivileging

Run Guest OS above Ring-0 and have privileged instructions generate faults...

Run VMM in Ring-0 as a collection of fault handlers



Top IA (Intel Architecture) Virtualization Holes :

- Ring Aliasing
- Excessive Faulting
- CPU state context switching
- Addr Space Compression

…

Virtualization of current IA CPUs requires complex software workarounds

Challenges

Ring Aliasing

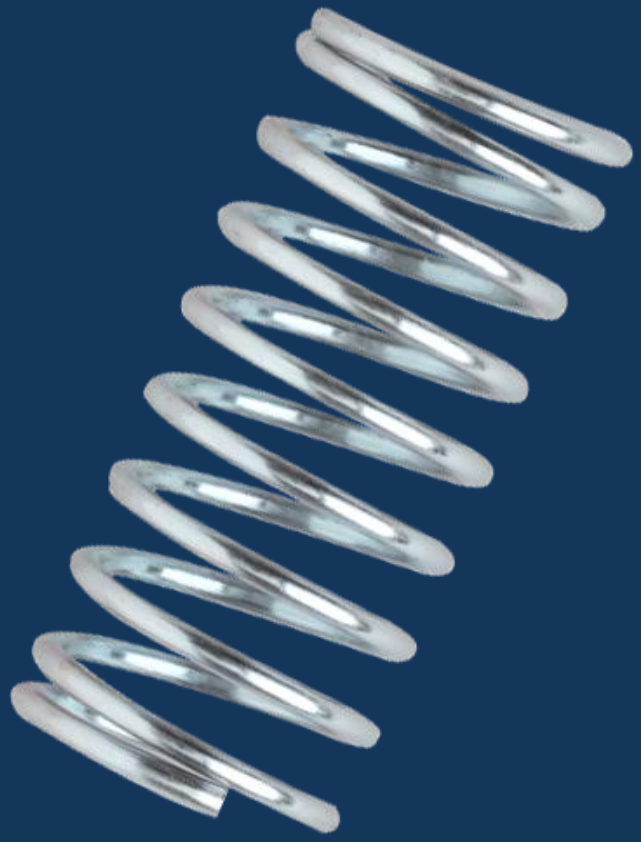
- The problem that arise when software is run at a privilege level other than the privilege level for which it was written
- An existing OS may be written to run with ring 0
- VMM must run with ring 0

Challenges

Address-Space Compression

- VMM must use some of the guest's virtual-address space to manage transition between guest OS and VMM

- VMM's address spaces must be protected
  - Guest could detect that it is running in a VM



Challenges

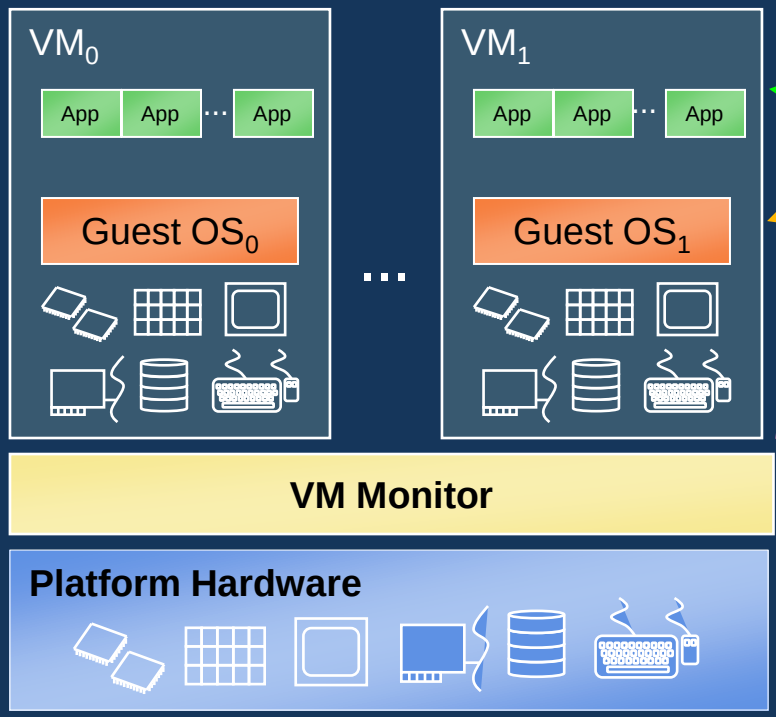
Faulting Access to Privileged State

- In most cases, accessing privilege states result in faults
- Performance is compromised by excessive faults

Ring Compression

- Guest OS must run at ring 3
- Guest OS runs at the same privilege level as applications

Intel® Virtualization Technology



Guest SW runs deprivileged in a new operating mode:

- Apps run deprivileged in ring 3
- OS runs deprivileged in ring 0
- VMM runs in new mode with full privilege

VMM preempts execution of Guest SW via new HW-based transition mechanism

By design, VT eliminates virtualization holes and the need for complex software workarounds

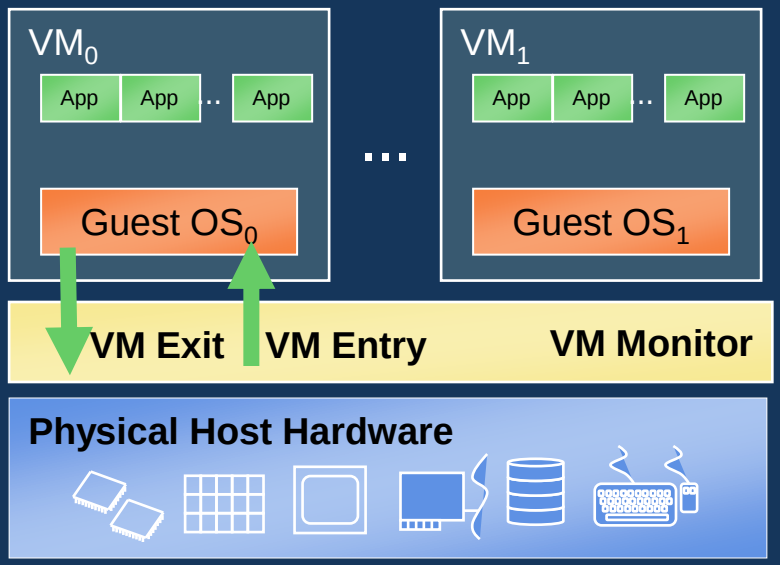
Operating Modes

- VMX root operation:
  - Fully privileged, intended for VM monitor
- VMX non-root operation:
  - Not fully privileged, intended for guest software
  - Reduces Guest SW privilege w/o relying on rings
  - Solution to Ring Aliasing and Ring Compression

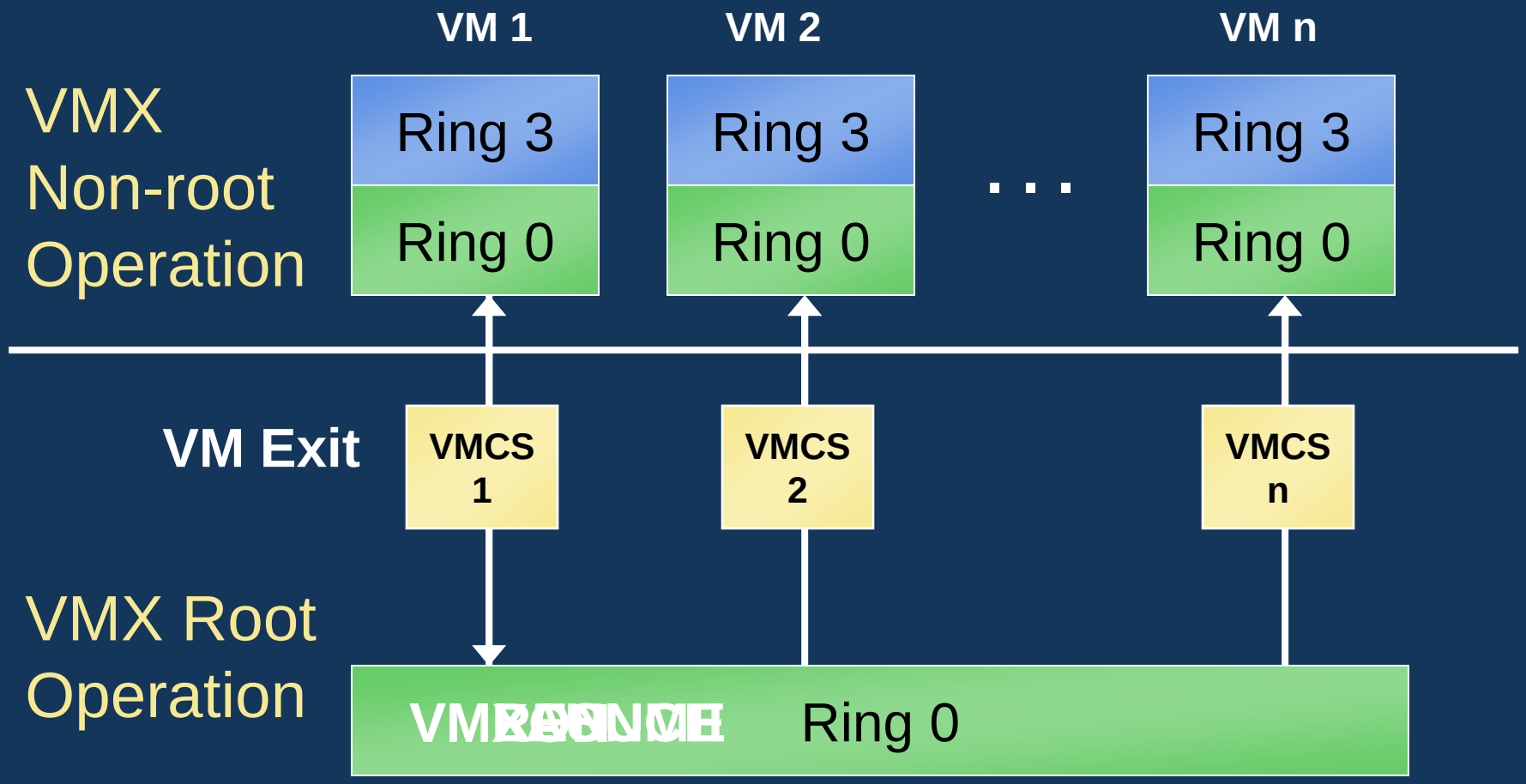
VM Entry and VM Exit

Virtual Machine Control Structure

- VM Entry
  - Transition from VMM to Guest
  - Enters VMX non-root operation
  - Loads Guest state and Exit criteria from VMCS
  - VMLAUNCH instruction used on initial entry
    VMRESUME instruction used on subsequent entries
- VM Exit
  - VMEXIT instruction used on transition from Guest to VMM
  - Enters VMX root operation
  - Saves Guest state in VMCS
  - Loads VMM state from VMCS



VT-x Operations



Virtual Machine Control Structure (VMCS)

- VMCSs are Control Structures in Memory
  - Only one VMCS active per virtual processor at any given time
- VMCS Payload (body data):
  - VM execution, VM exit, and VM entry controls
  - Guest and host state
  - VM-exit information fields
- VMCS Format not defined and may vary

Some Causes of VMEXIT

- Paging state exits allow page-table control
  - Selectively exit on page faults
- Selective exception and I/O exiting reduce unnecessary exits
- Controls provided for asynchronous events
- Detection of guest inactivity to support VM scheduling
  - HLT, MWAIT, PAUSE