POLITECNICO DI MILANO

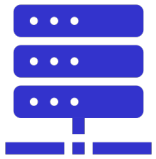
Computing Infrastructures





Software Infrastructures: VIRTUALIZATION (i.e., from Datacenter to Cloud)

The topics of the course: what are we going to see today?



HW Infrastructures:

System-level: Computing Infrastructures and Data Center Architectures, Rack/Structure;

Node-level: Server (computation, HW accelerators), Storage (Type, technology), Networking (architecture and technology);

Building-level: Cooling systems, power supply, failure recovery

SW Infrastructures:

Virtualization: Process/System VM, Virtualization Mechanisms (Hypervisor, Para/Full virtualization)

Computing Architectures: Cloud Computing (types, characteristics), Edge/Fog Computing, X-as-a service

Methods:

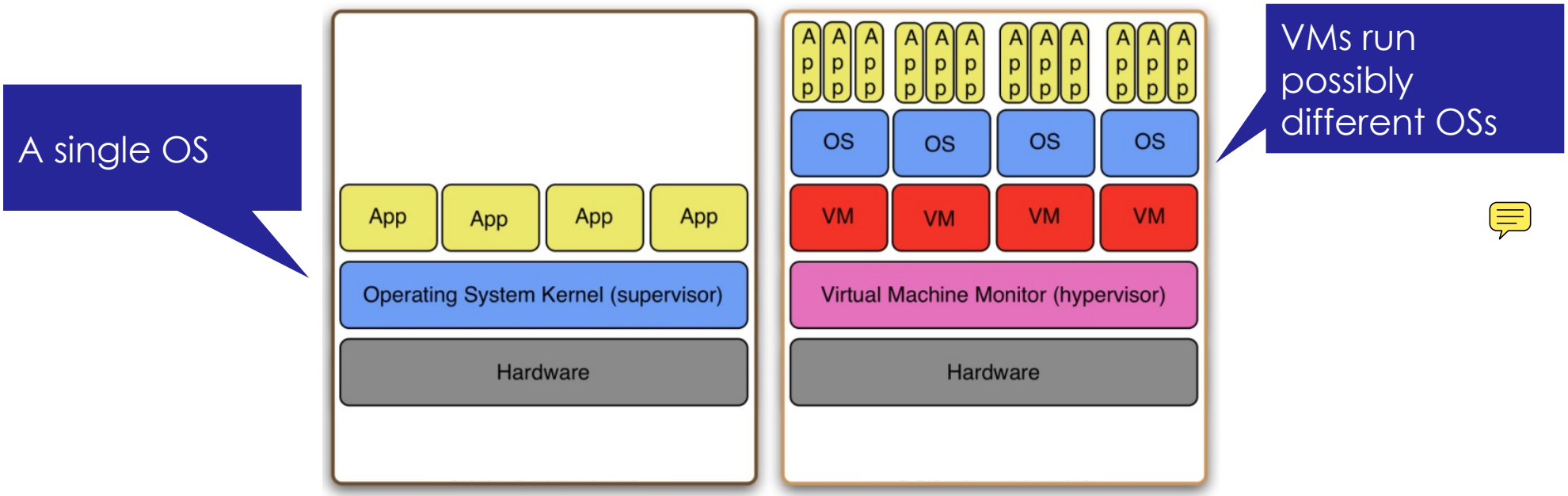
Reliability and availability of datacenters (definition, fundamental laws, RBDs)

Disk performance (Type, Performance, RAID)

Scalability and performance of datacenters (definitions, fundamental laws, queuing network theory)

How is Cloud implemented? Virtualization!!!

- Hardware resources (CPU, RAM, ecc...) are partitioned and shared among multiple **virtual machines** (VMs)
- The virtual machine monitor (VMM) governs the access to the physical resources among running VMs
- Performance, isolation and security



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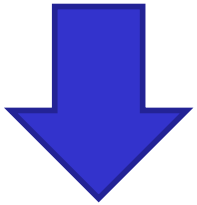
Computing Infrastructures





Virtual Machines

What's the difference between a physical machine and a virtual machine?

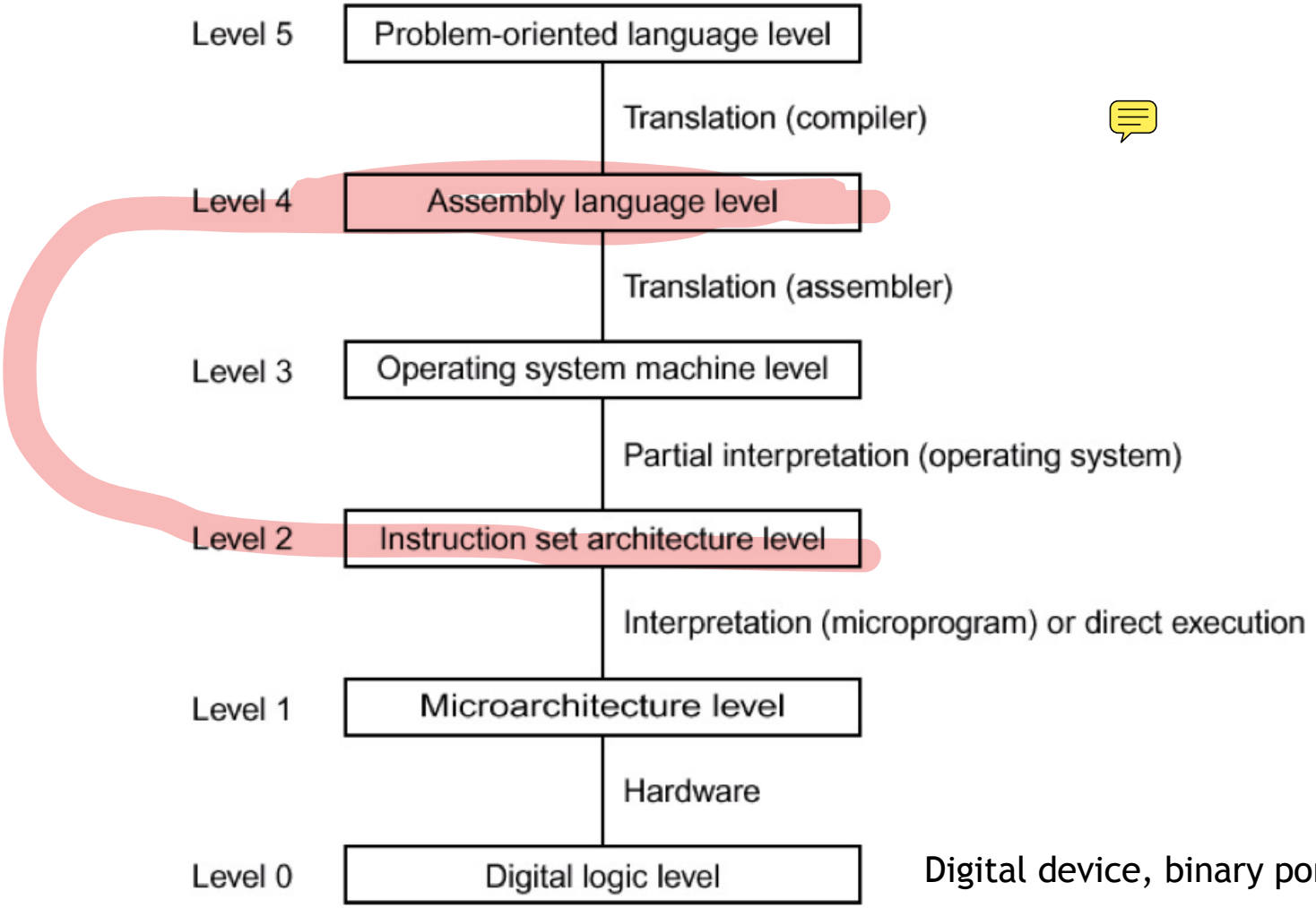


We have to go back to the **computer architecture**:

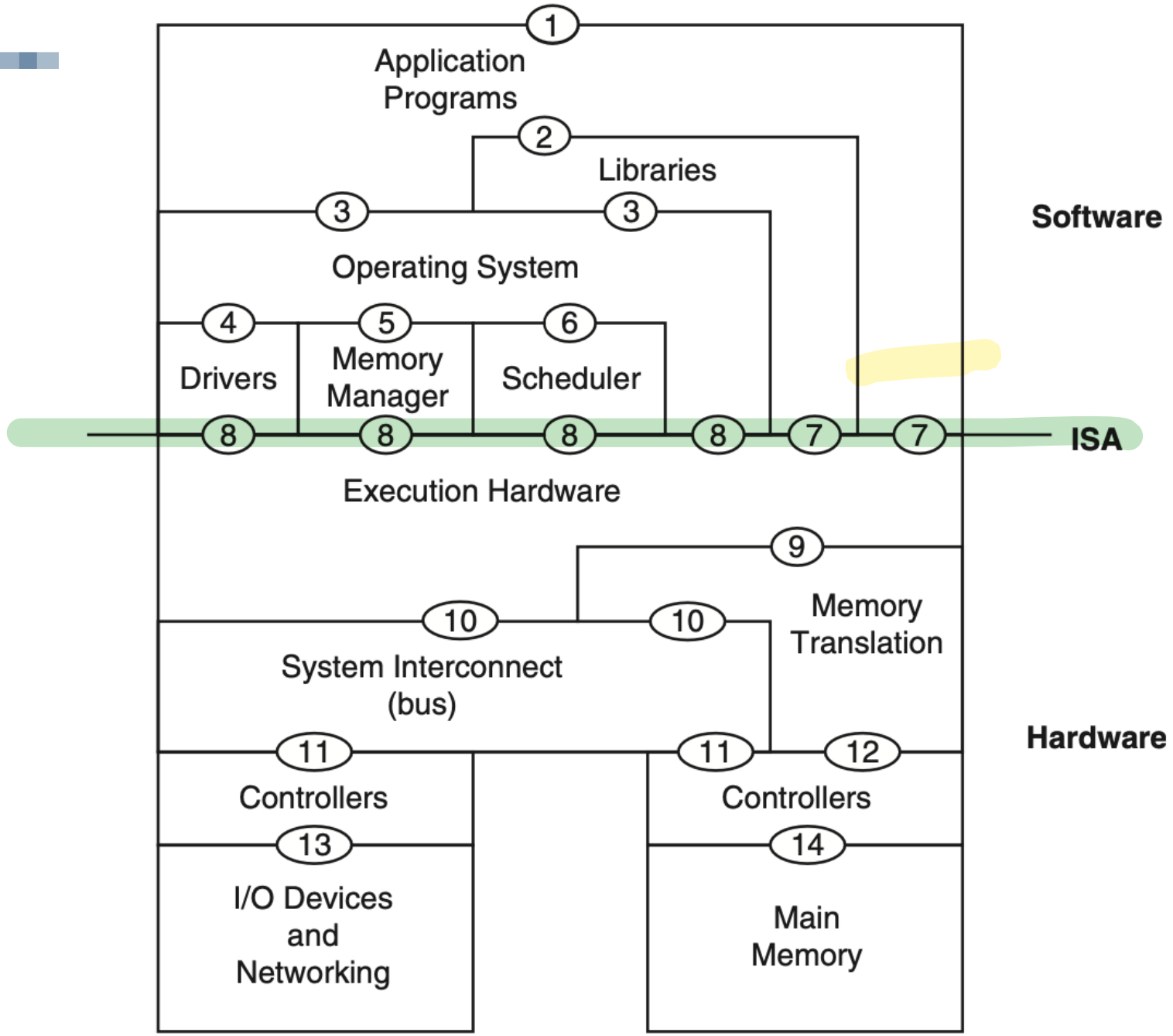
- Sets of instructions characterized by the levels at which are considered
- OS creates new instructions for programs to access devices/hw

Machine levels

In computer architecture, the set of instructions that a program can use might be structured at different levels.

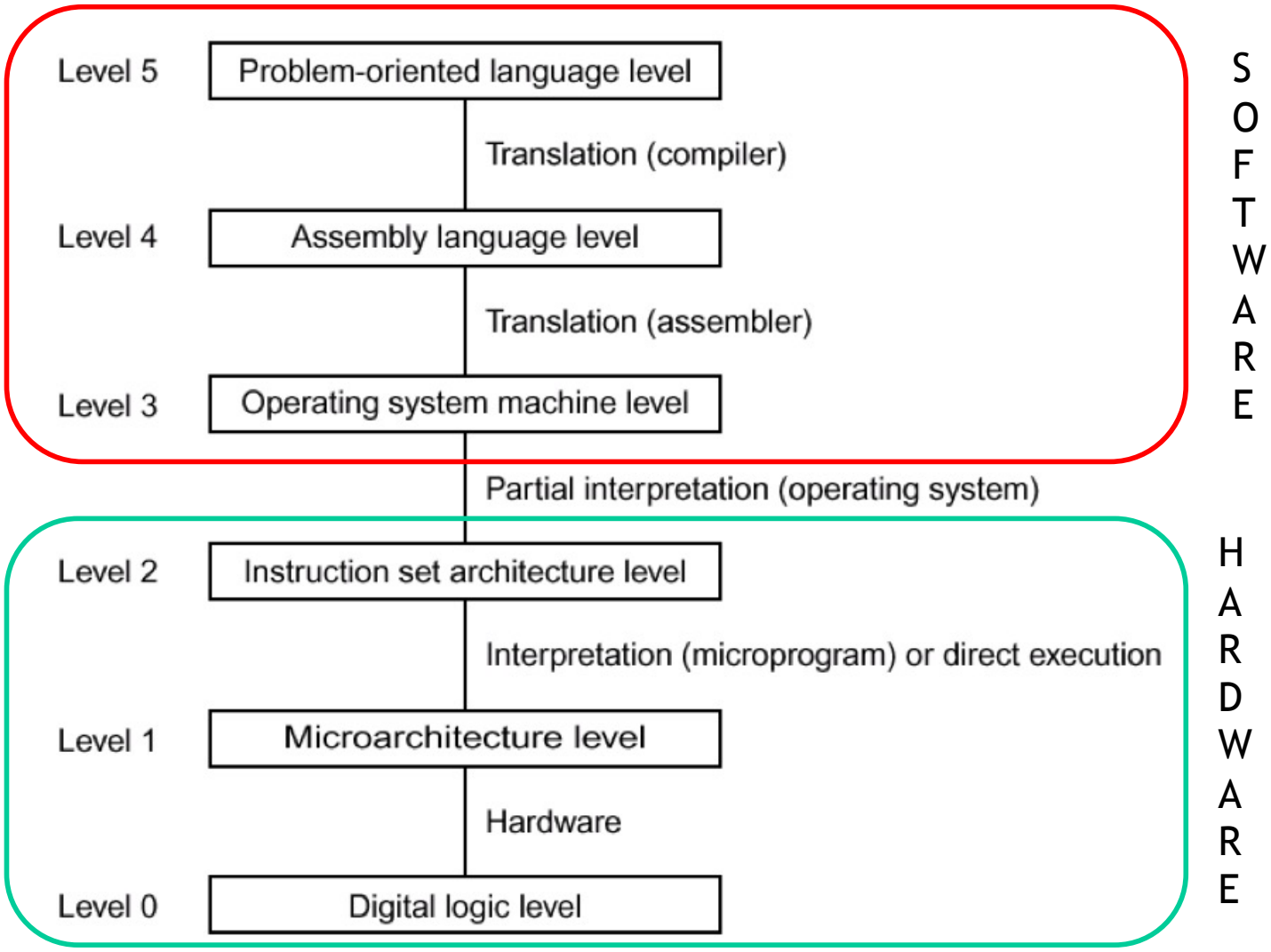


Digital device, binary ports,…


1
Application Programs
2
Libraries
3
3
Operating System
Software
4
5
6
Drivers
Memory Manager
Scheduler
8
8
8
8
7
7
ISA
Execution Hardware
9
10
10
Memory Translation
System Interconnect (bus)
Hardware
11
11
12
Controllers
Controllers
13
14
I/O Devices and Networking
Main Memory

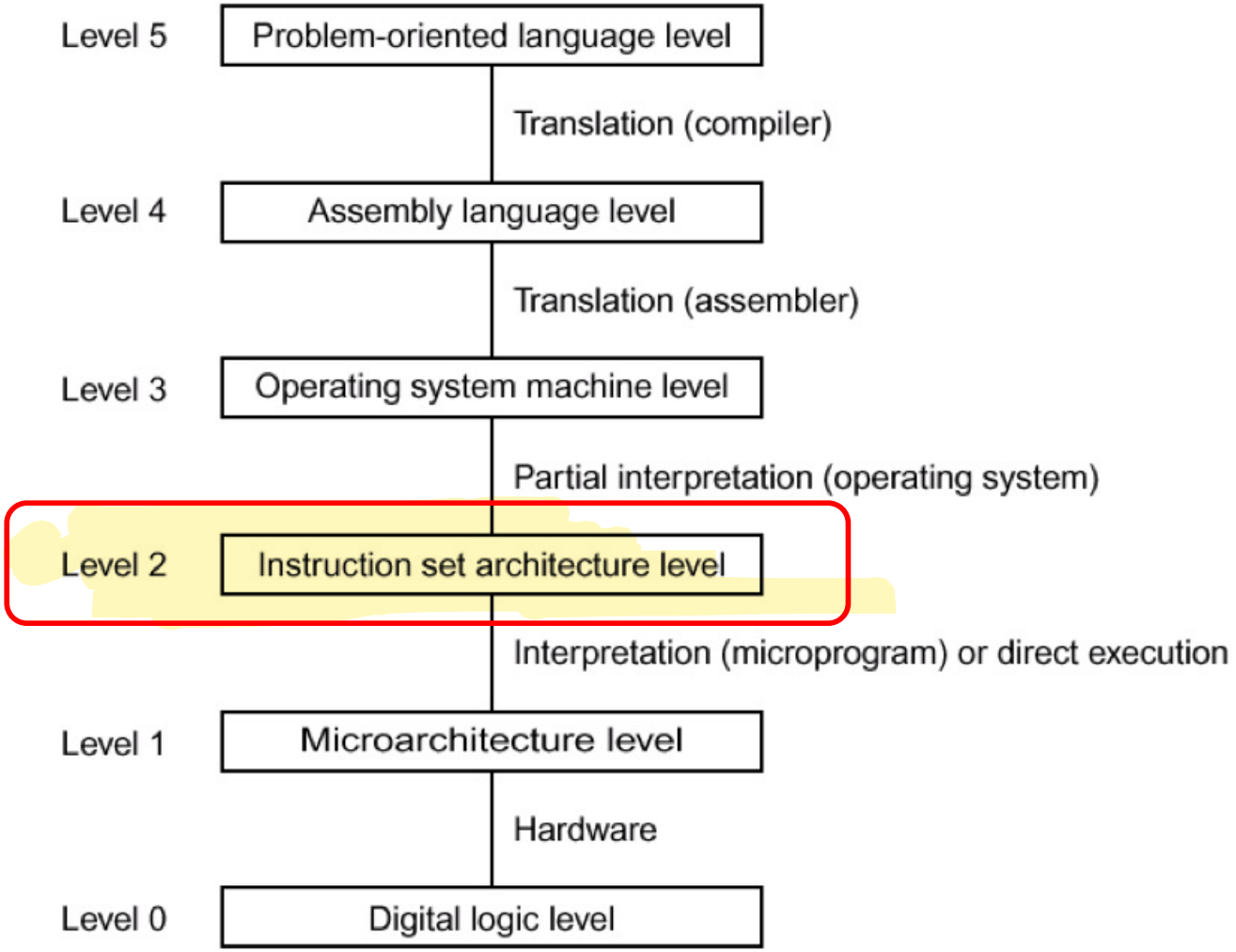
Machine levels

We usually program the software part, exploiting the hardware.



Instruction Set Architecture

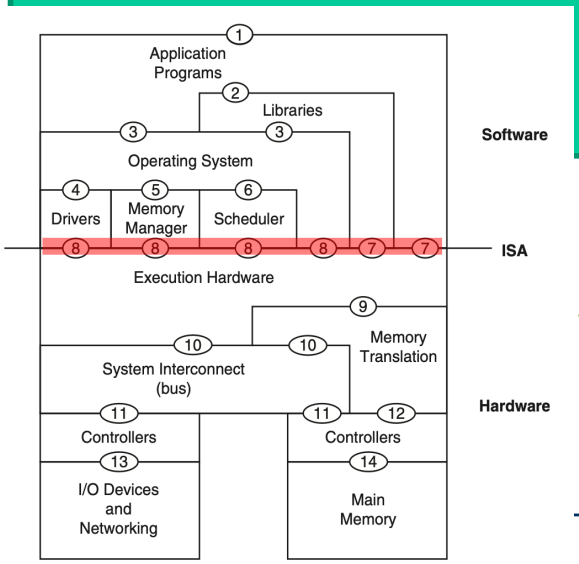
- The ISA corresponds to Level 2 in the layered execution model.
- ISA marks the division between hardware and software.



Instruction Set Architecture

- The ISA corresponds to Level 2 in the layered execution model.
- ISA marks the division between hardware and software

- **User ISA**: aspects of the ISA that are visible to an application program (sum, multiplication,…, logical operations, branches, etc...). When application interacts with the HW, User ISA is used.

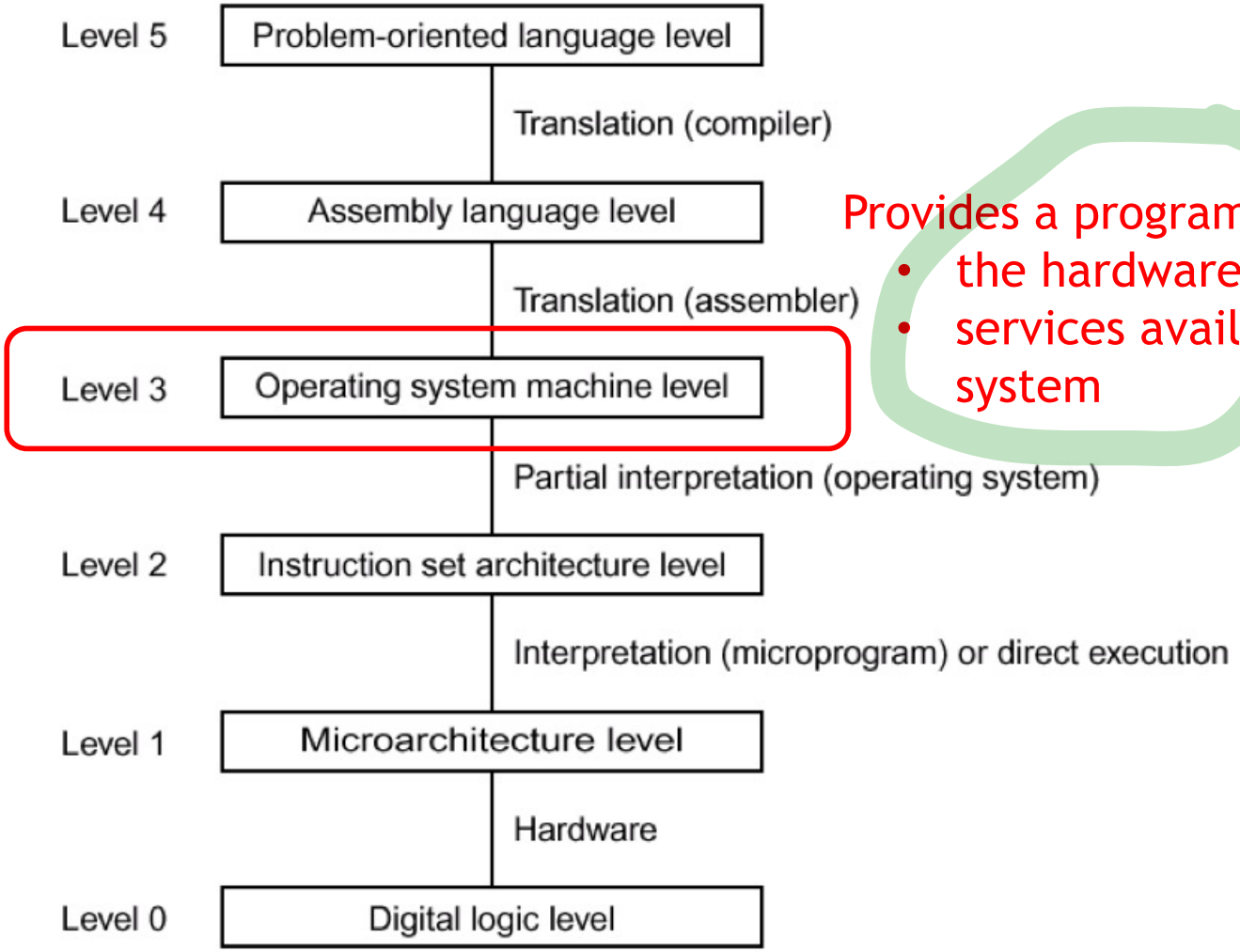


(7)+(8)

- **System ISA**: aspects visible to supervisor software (i.e., the OS) which is responsible for managing hardware resources (e.g., hide the complexity of CPUs, define how app access memory, communicate with the HW). When the OS interacts with the HW (Drivers, MM, Sched.), System ISA is used.

Application Binary Interface

The ABI corresponds to Level 3 in the layered execution model.



Provides a program (via the OS):

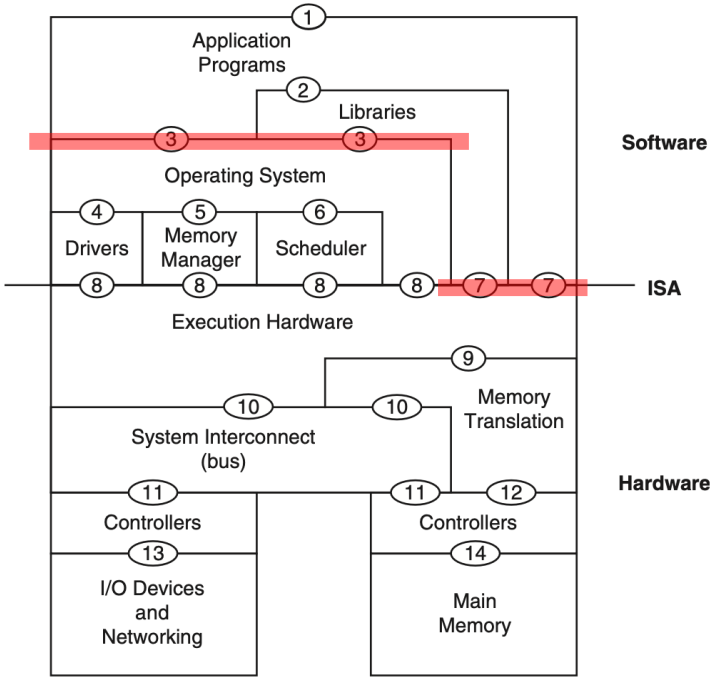
- the hardware resources
- services available in a system

Application Binary Interface

The ABI corresponds to Level 3 in the layered execution model.

- **User ISA**: aspects of the ISA that are visible to an application program (sum, multiplication,…, logical operations, branches, etc...).

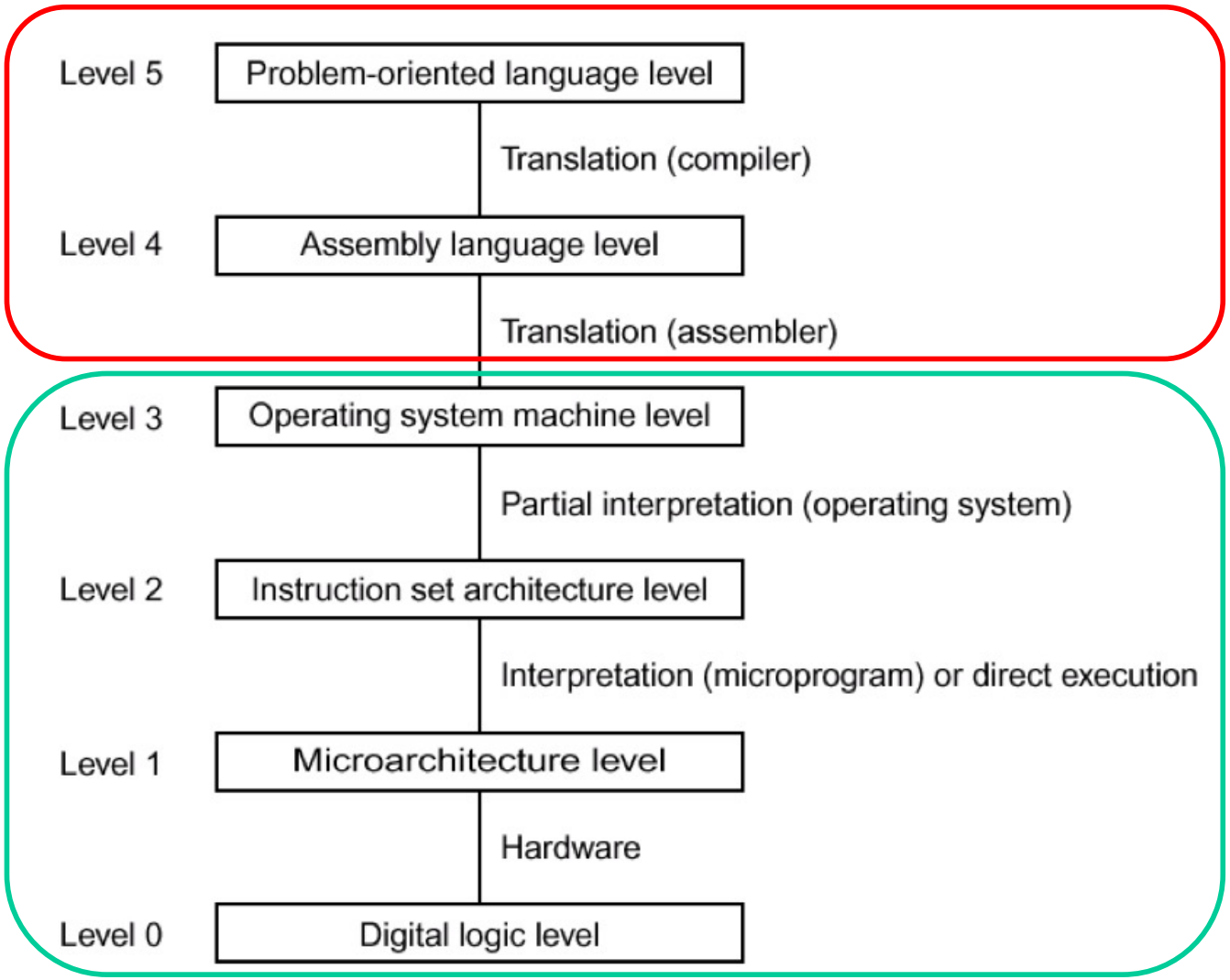
- **System Calls**: calls that allow programs to interact with shared hardware resources indirectly by OS

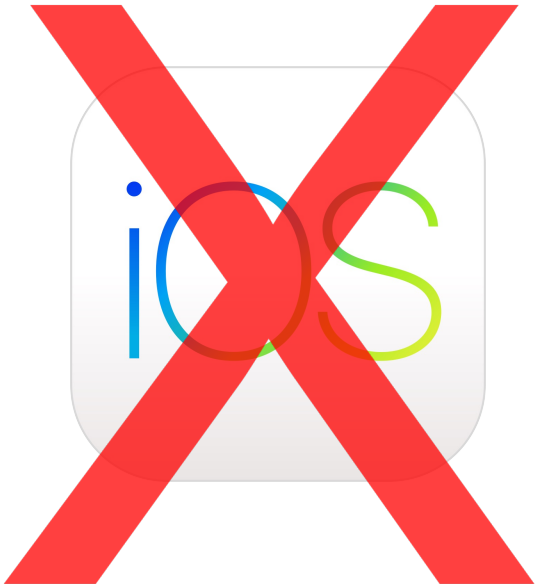


(7)+(3)

Machine Levels

One machine level can only run instructions that were meant for it





Machine Virtualization

A **Virtual Machine** (**VM**) is a logical abstraction able to provide a virtualized *execution environment*. More specifically, a VM:

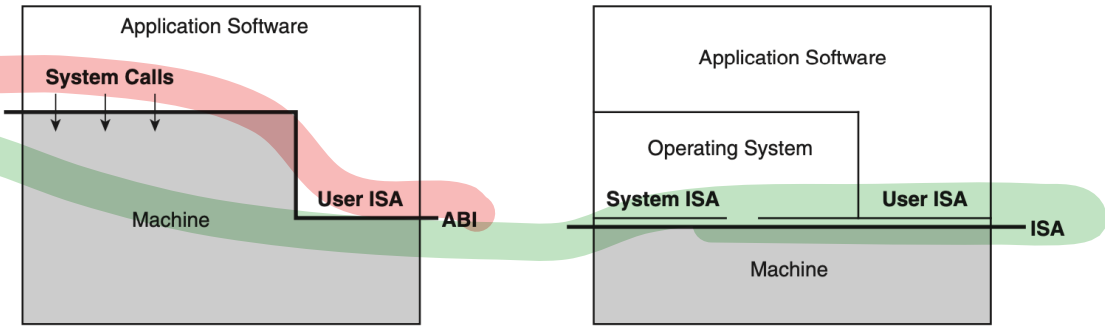
- (provides) Identical Software behavior
- (consists in a) Combination of physical machine and virtualizing software
- (may appear as) Different resources than physical machine
- (may result in) Different level of performances

Its tasks are:

- To map virtual resources or states to corresponding physical ones
- To use physical machine instructions/calls to execute the virtual ones.

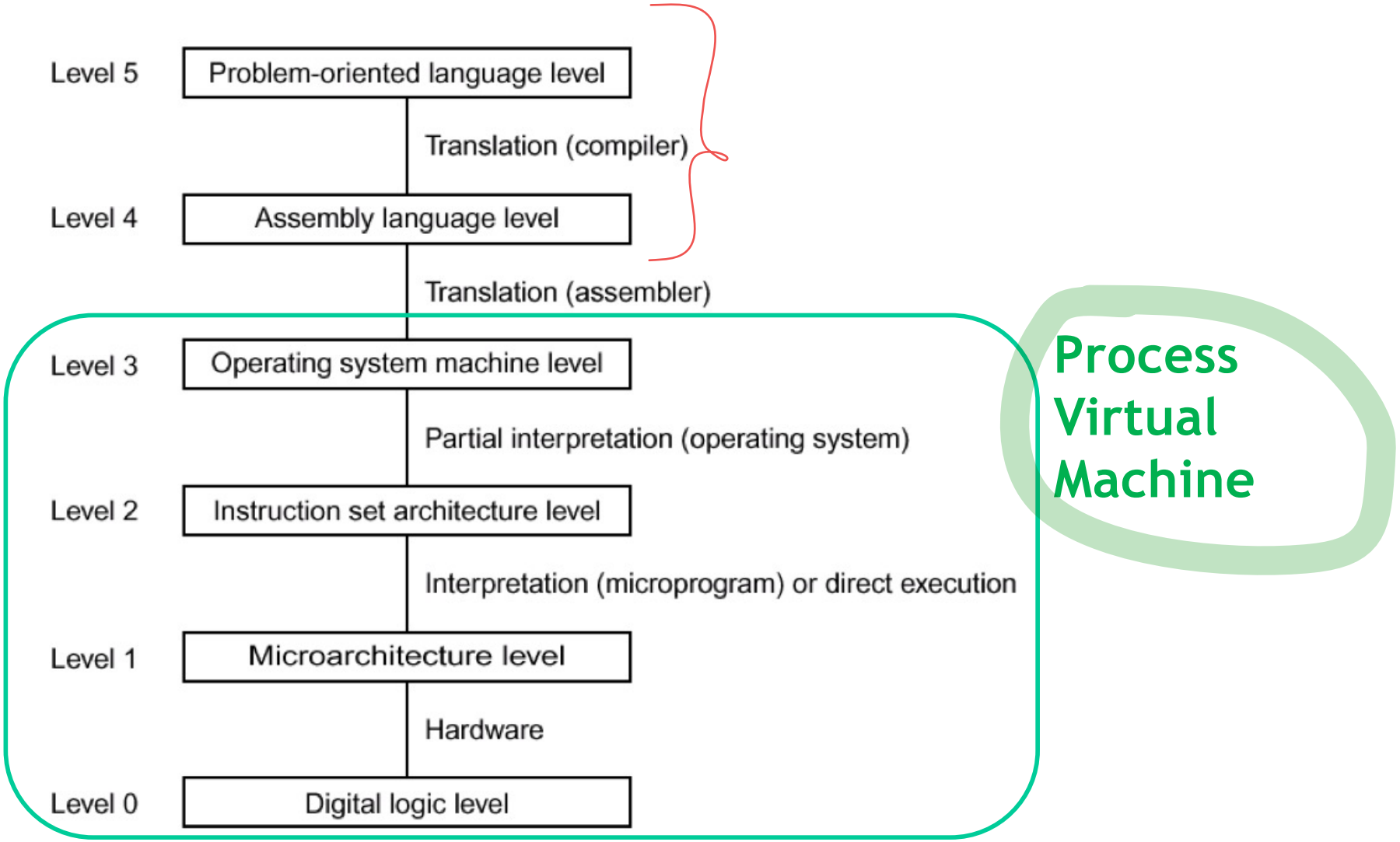
Two types of Virtual Machines:

- Process VMs
- System VMs



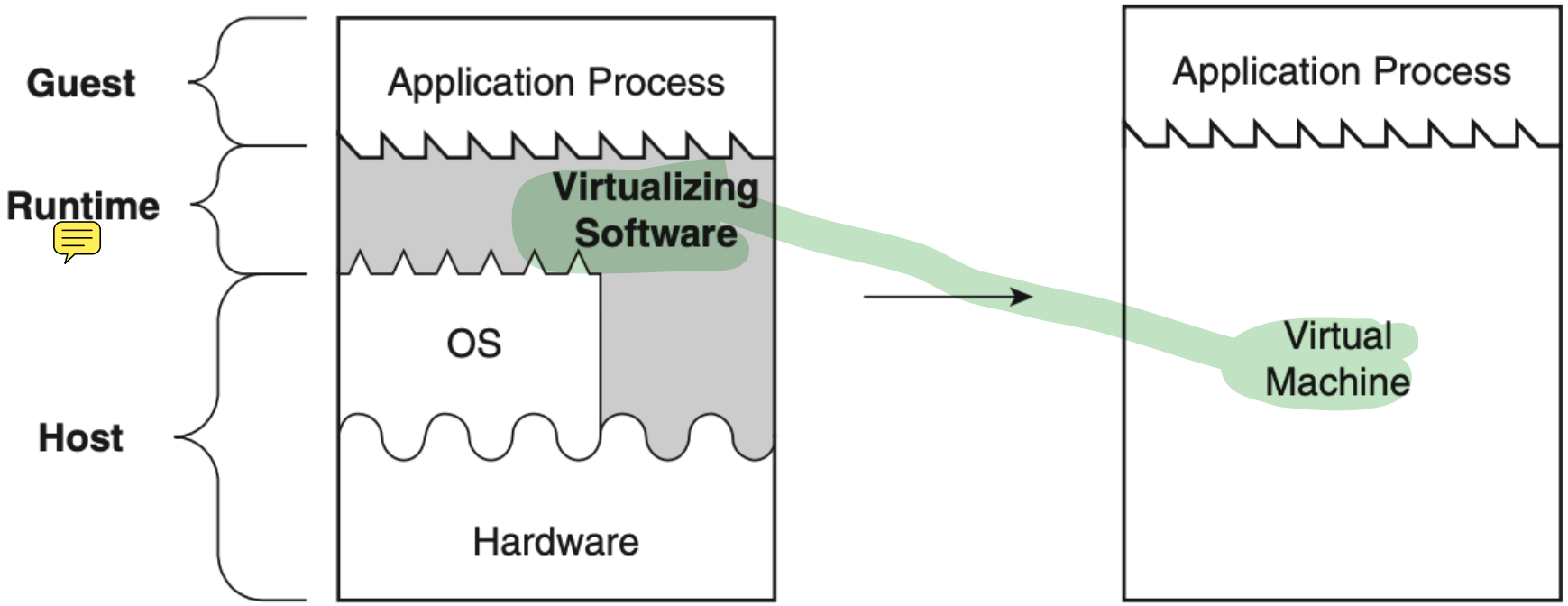
Process VMs

The runtime software supports the levels 0-3 of the architecture



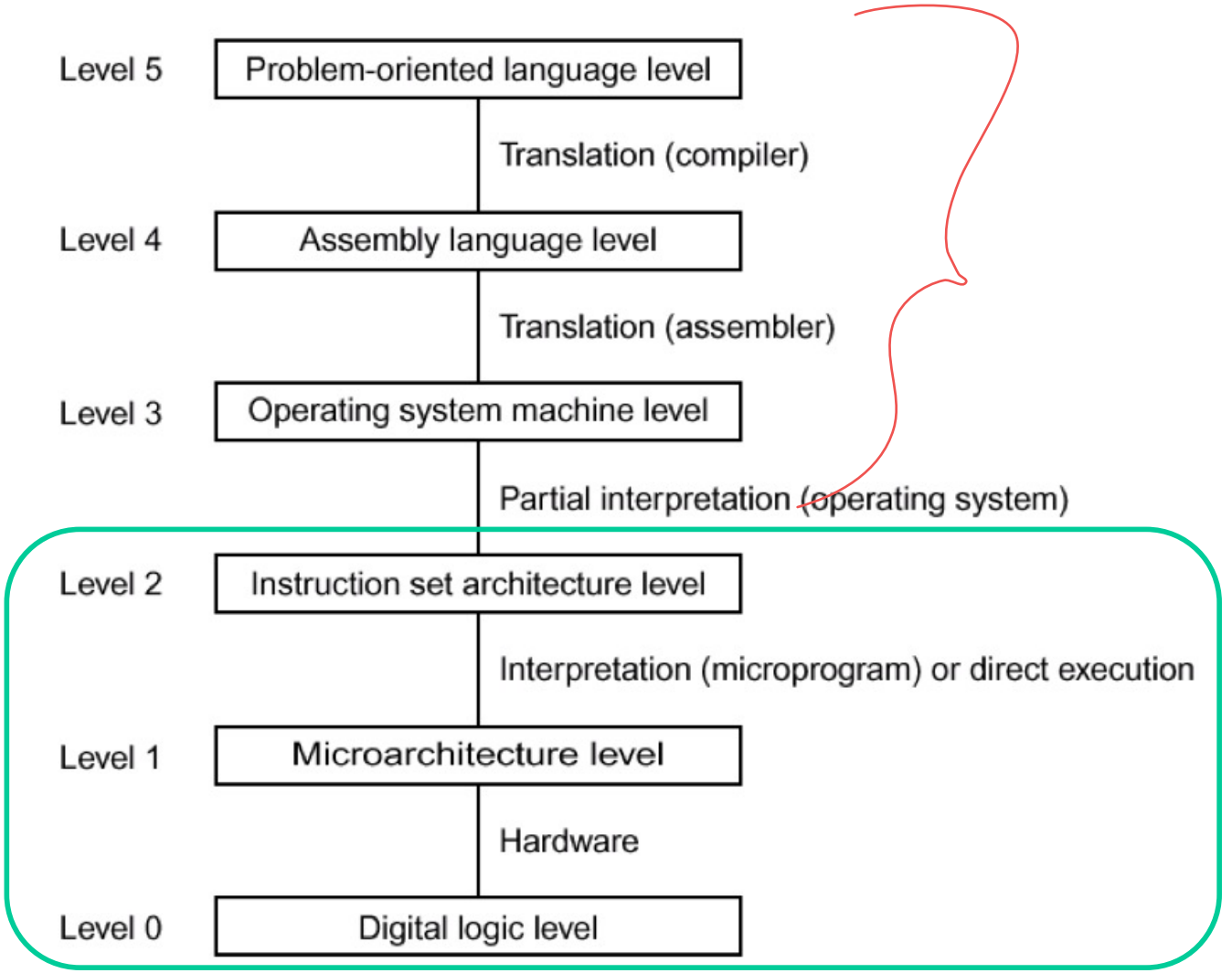
Process VMs

- Able to support an individual process
- The virtualizing software is placed at the **ABI interface**, on top of the OS/hardware combination.
- The virtualizing software emulates both user-level instructions and operating system calls.
- The virtualization software is usually called **Runtime Software.**



System VMs

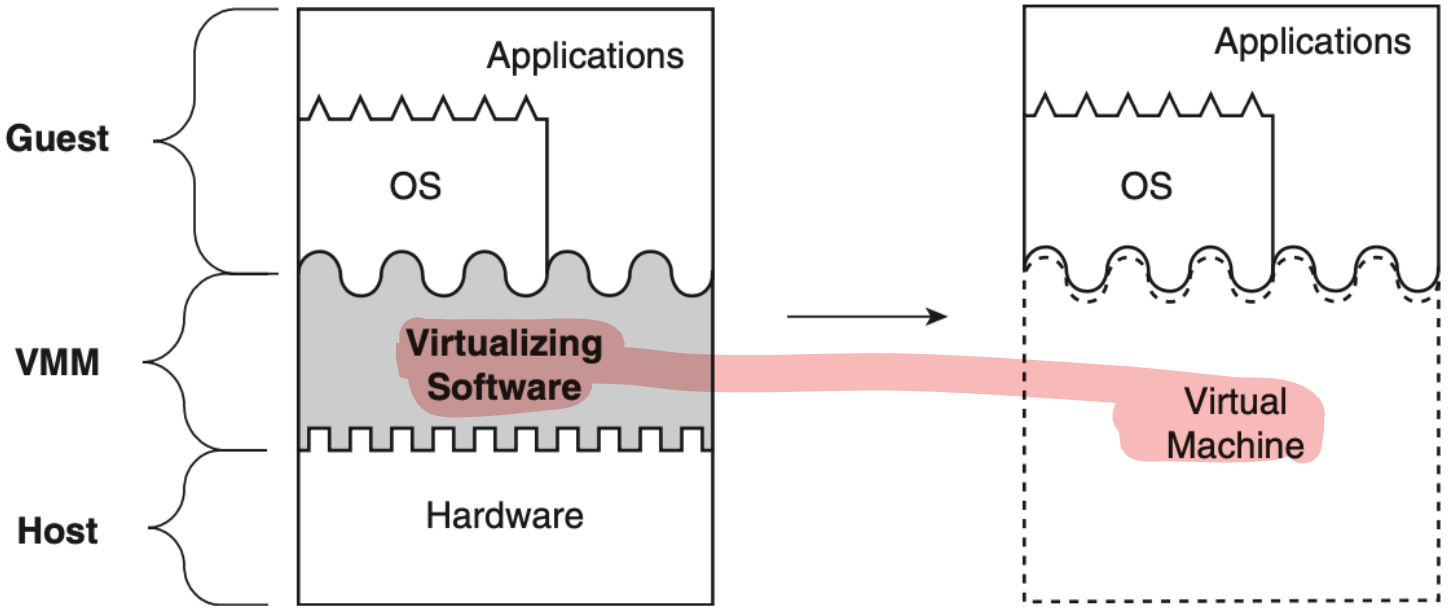
The VMM supports the levels 0-2 of the architecture



System Virtual Machine

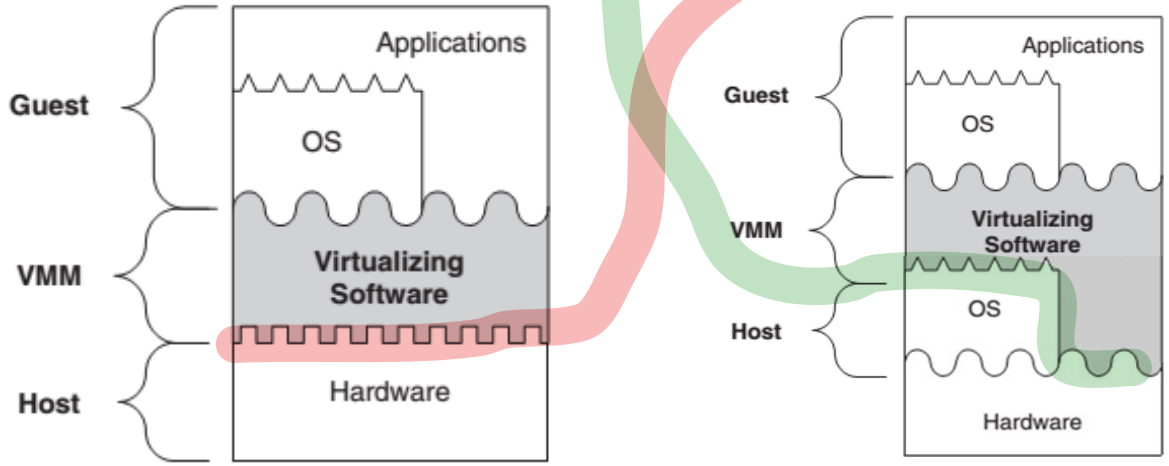
System VMs

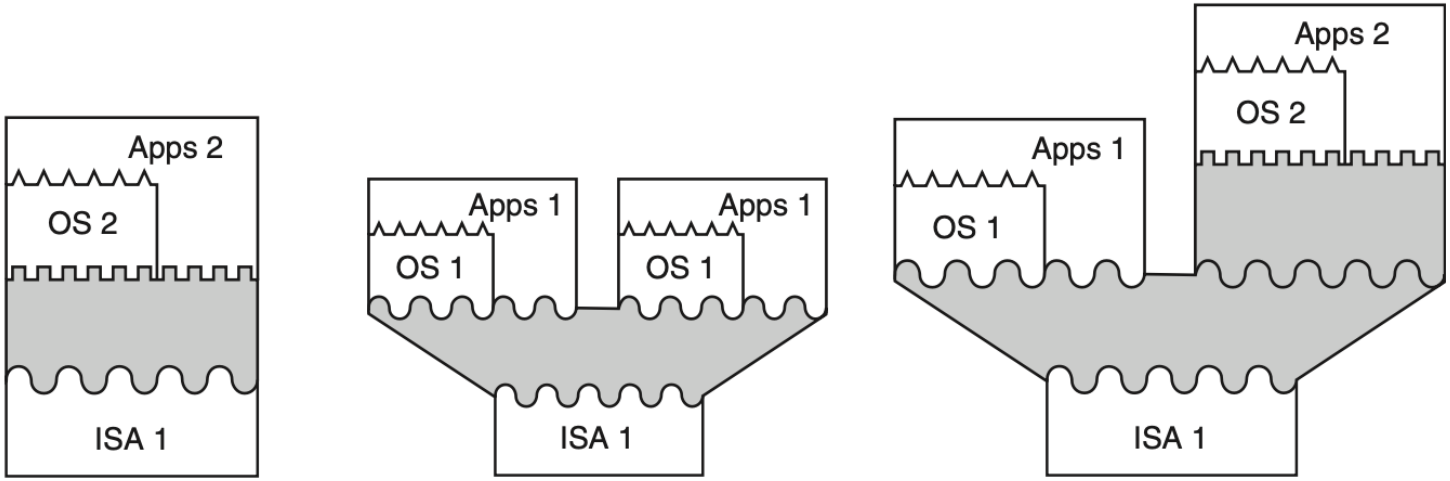
- **Provide a complete system environment** that can support an operating system (potentially with many user processes)
- It provides **operating system running in it access to underlying hardware resources** (networking, I/O, a GUI).
- Virtualizing software placed between hardware and software (**emulates the ISA interface seen by software**)
- The virtualization software is called **VMM (Virtual Machine Monitor)**



System VMs

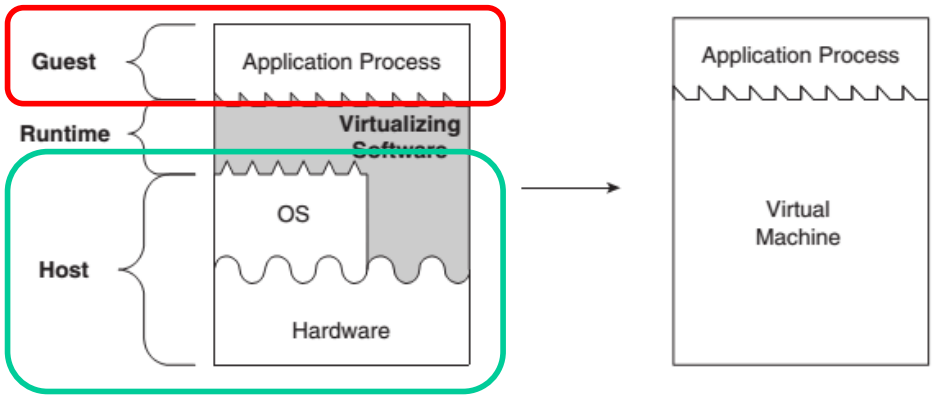
The VMM can provide its functionality either **working directly on the hardware**, or **running on another OS**.



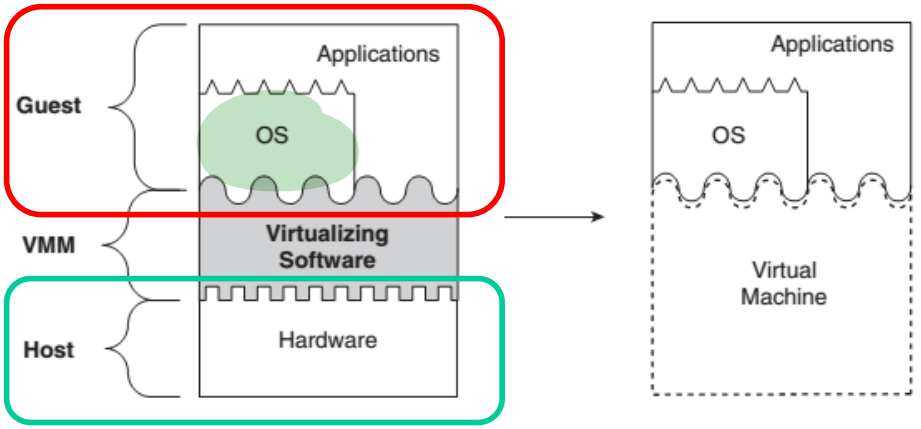


Terminology (the *host* and the *guest*)

Process Virtual Machine



System Virtual Machine



Host: the underlying platform supporting the environment/system

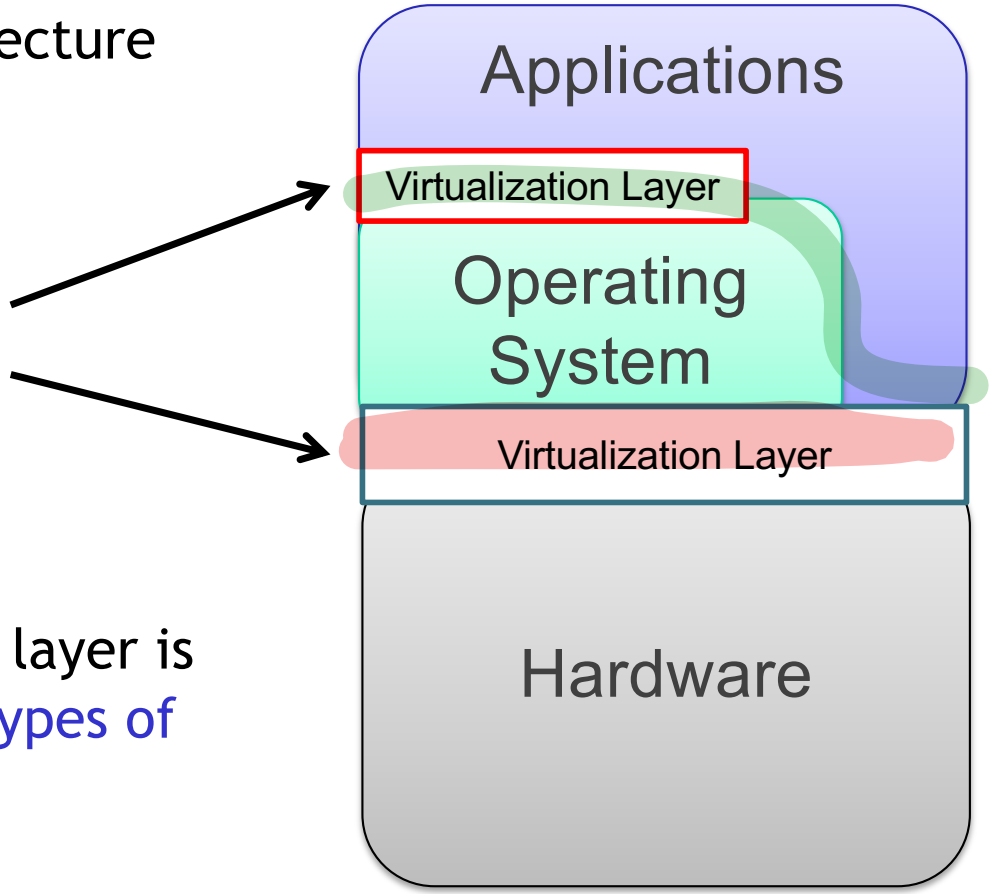
Guest: the software that runs in the VM environment as the guest.

How is Virtualization Implemented?

How is Virtualization implemented?

Given a typical layered architecture of a system…

… by adding layers between execution stack layers.

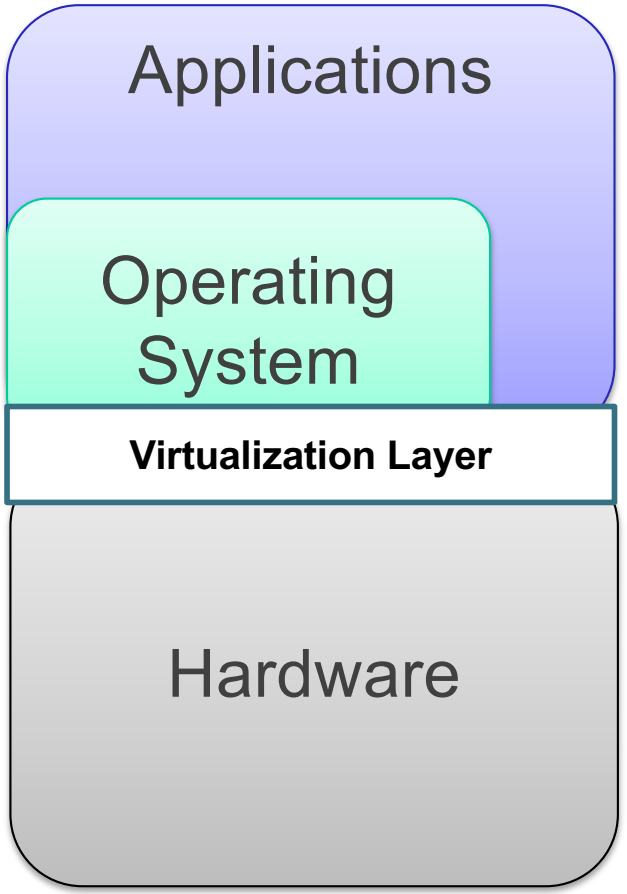


Depending on where the new layer is placed, we obtain different types of Virtualization.

How is Virtualization implemented?

Hardware-level virtualization:

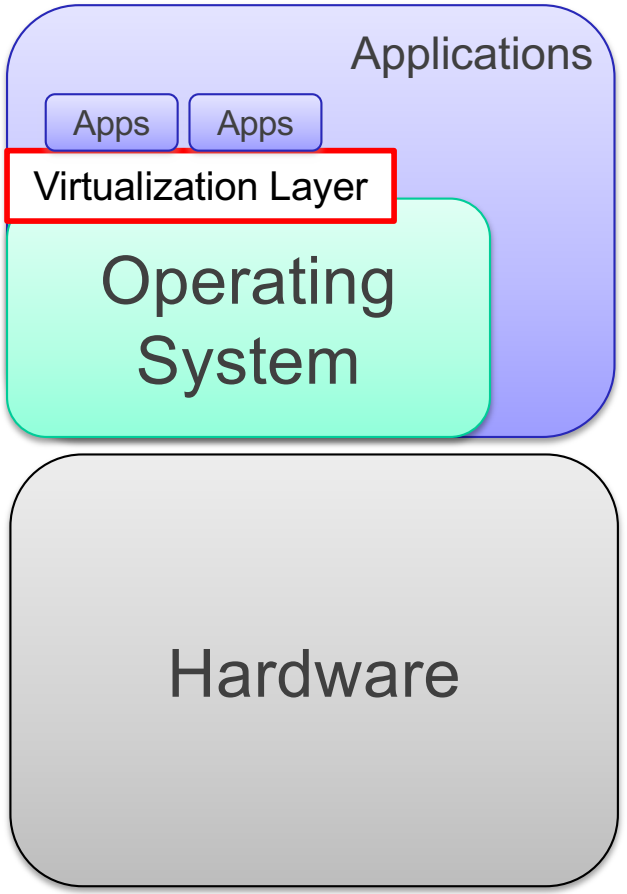
- Virtualization layer is placed between hardware and OS.
- The interface seen by OS and application might be different from the physical one



How is Virtualization implemented?

Application-level virtualization:

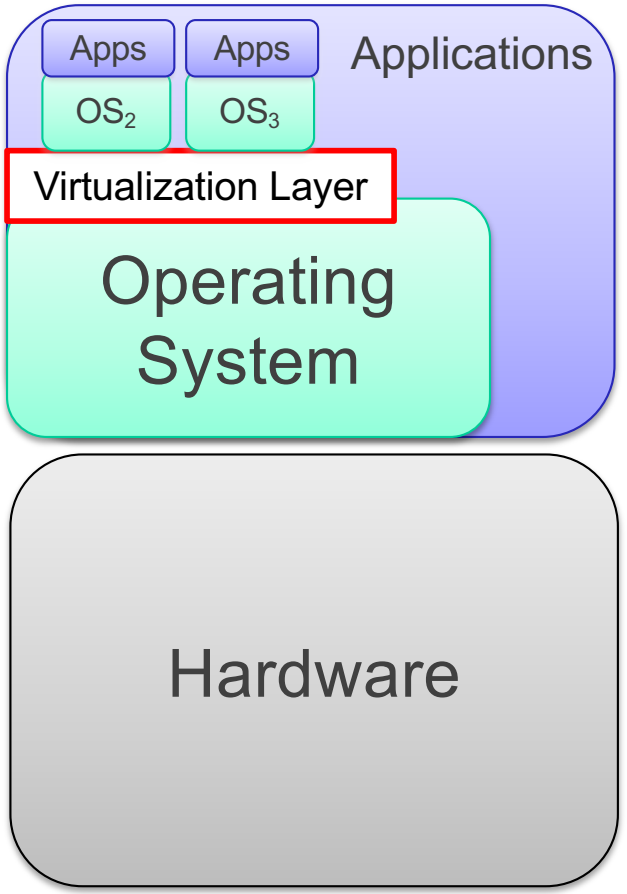
- A virtualization layer is placed between the OS and some applications
  - E.g.: JVM (Java Virtual Machine)
- Provides the same interface to the applications.
- Applications run in their environment, independently from OS



How is Virtualization implemented?

System-level virtualization:

- The virtualization layer provides the interface of a physical machine to a secondary OS and a set of application running in it, allowing them to run on top of an existing OS.
- Placed between the system's OS and other OS
  - E.g.: VMware Wks/Player, VirtualBox
- Enable several OSs to run on a single HW



Virtualization technologies: properties

Partitioning

- Execution of multiple OSs on a single physical machine
- Partitioning of resources between the different VMs

Isolation

- Fault tolerance e security (as at the hardware level)
- Advanced resource control to guarantee performance (managed by the *hypervisor*)

Encapsulation

- The entire state of a VM can be saved in a file (e.g., freeze and restart the execution)
- Because a VM is a file, can be copied/moved as a file

HW-independence

- Provisioning/migration of a given VM on a given physical server.

Virtual Machine Managers (System VMs – Same ISA)

Virtual Machine Manager

An application that:

- manages the virtual machines
- mediates access to the hardware resources on the physical host system
- intercepts and handles any privileged or protected instructions issued by the virtual machines

- This type of virtualization typically runs virtual machines whose operating system, libraries, and utilities have been compiled for the same type of processor and instruction set as the physical machine on which the virtual systems are running.

- Crucial to support Cloud Computing

VMM and Hypervisor

Three terms are used to identify the same thing:

- Virtual Machine Manager
- Virtual Machine Monitor
- Hypervisor

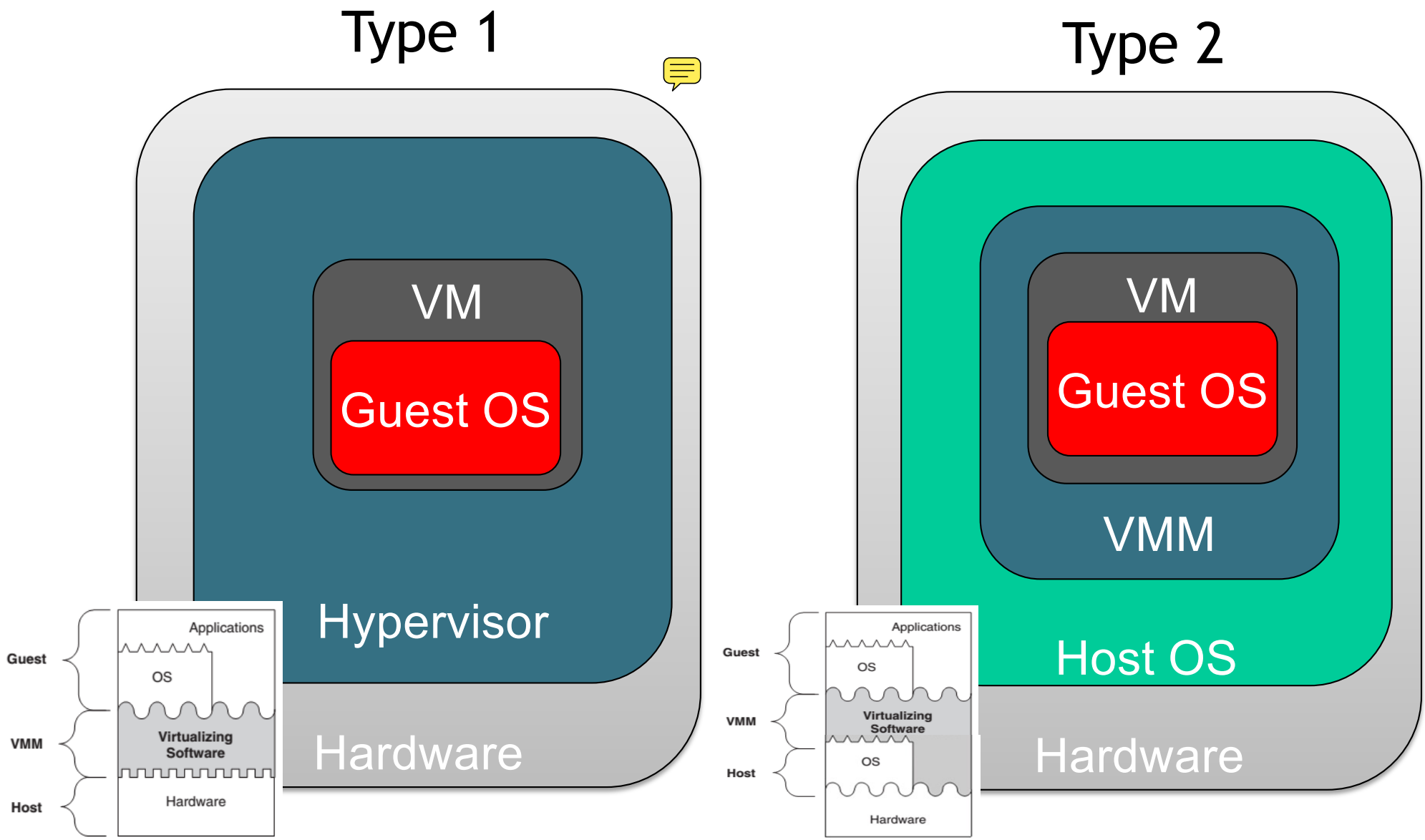
Some authors gives slightly different meanings to the three:

- *Virtual Machine Monitor*:
  - The virtualization software

- *Hypervisor*:
  - A virtualization software that runs directly on the hardware

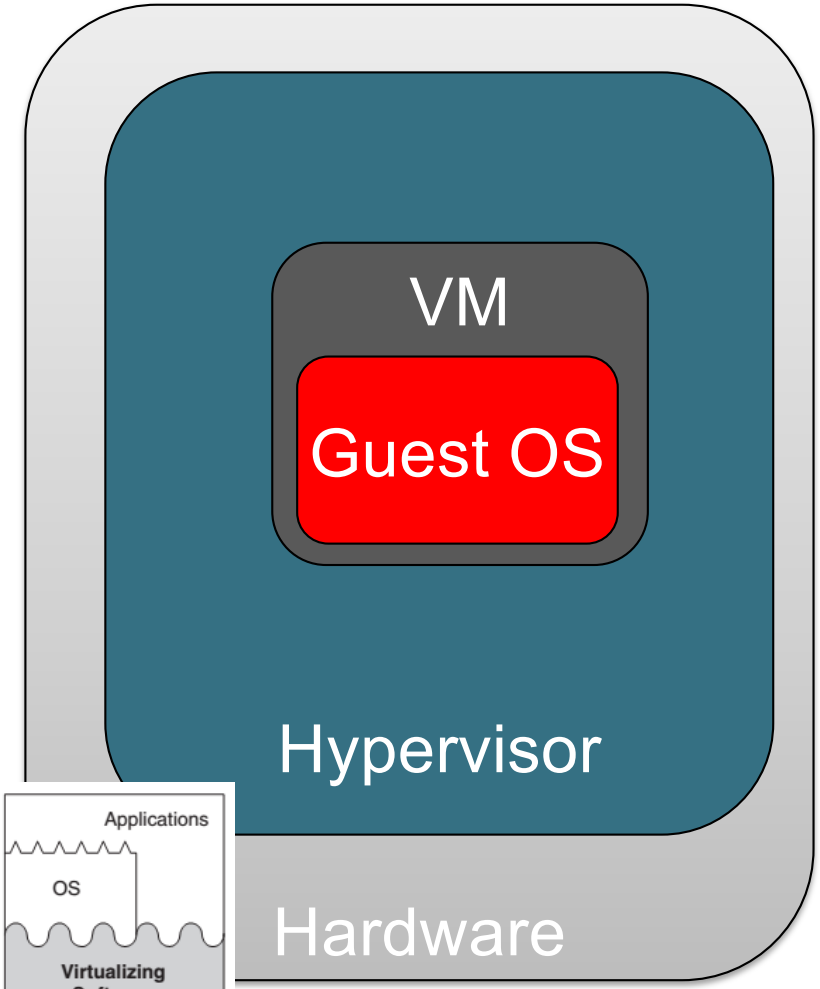
- *Virtual Machine Manager*:
  - A VMM or Hypervisor that is also used to create, configure and maintain virtualized resources.
  - It provides a user-friendly interface to the underlying virtualization software

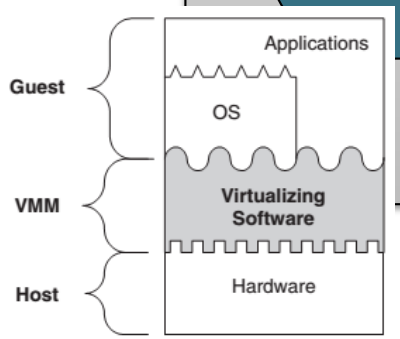
Hypervisor types



Hypervisor types

Type 1





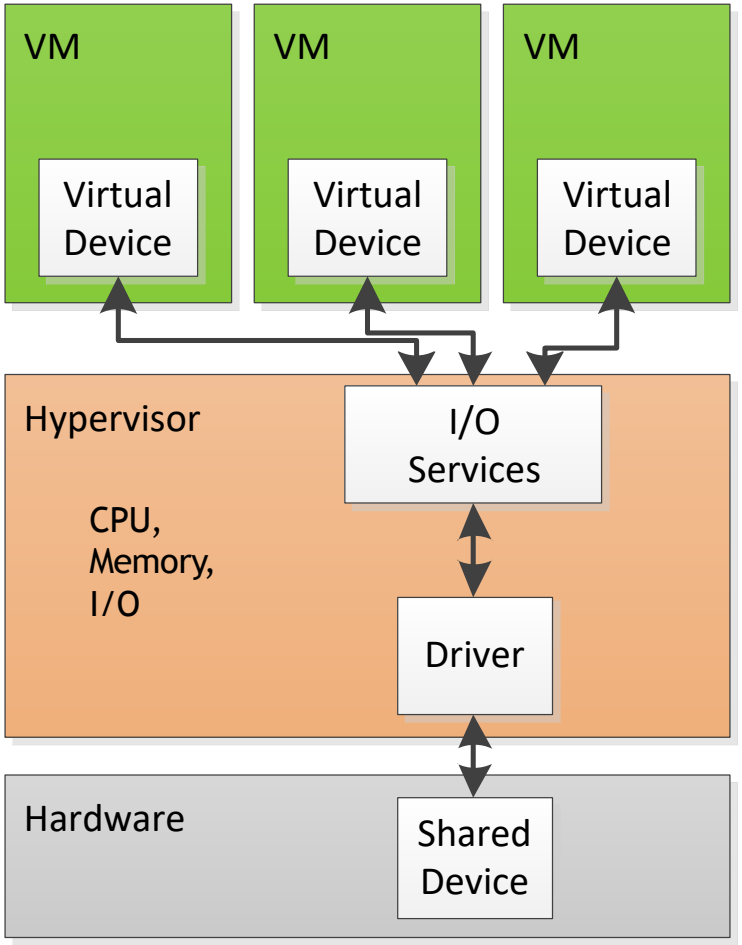
Bare-metal or type 1 hypervisors

- Takes direct control of the hardware
- The hypervisor is also called "NATIVE or BARE METAL" because it runs directly on the hardware

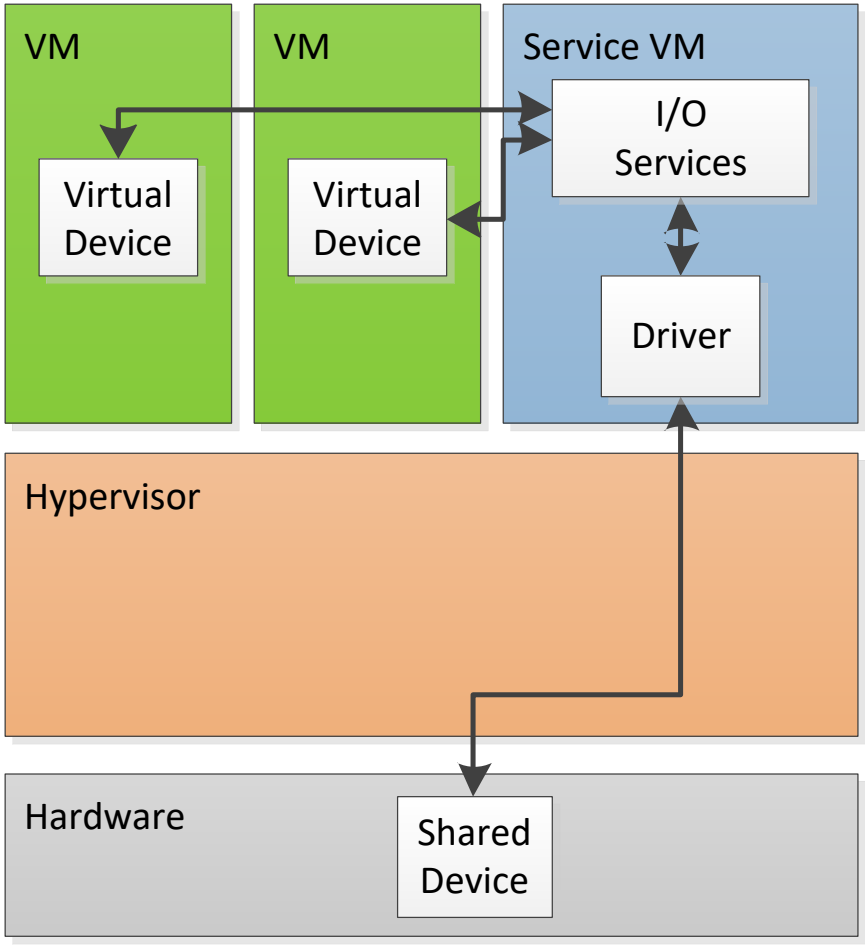
- E.g. KVM, Microsoft Hyper-V, and VMware vSphere
- 2 different types:
  - Monolithic
  - Microkernel

Type 1 hypervisor architecture

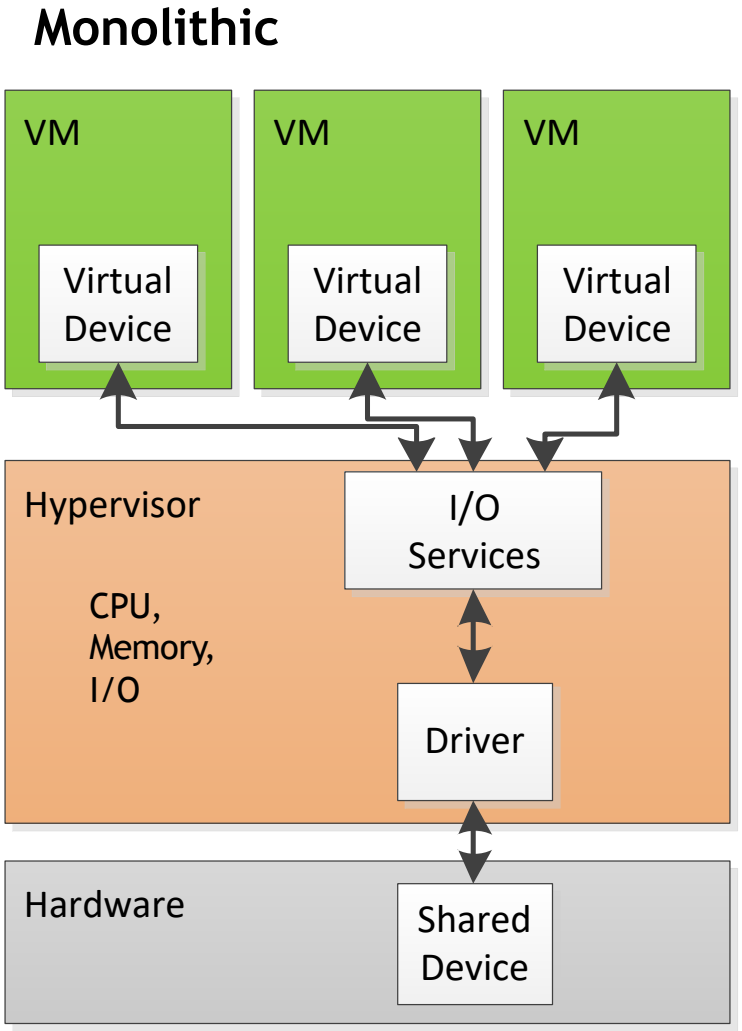
Monolithic



Microkernel



Type 1 hypervisor architecture: Monolithic

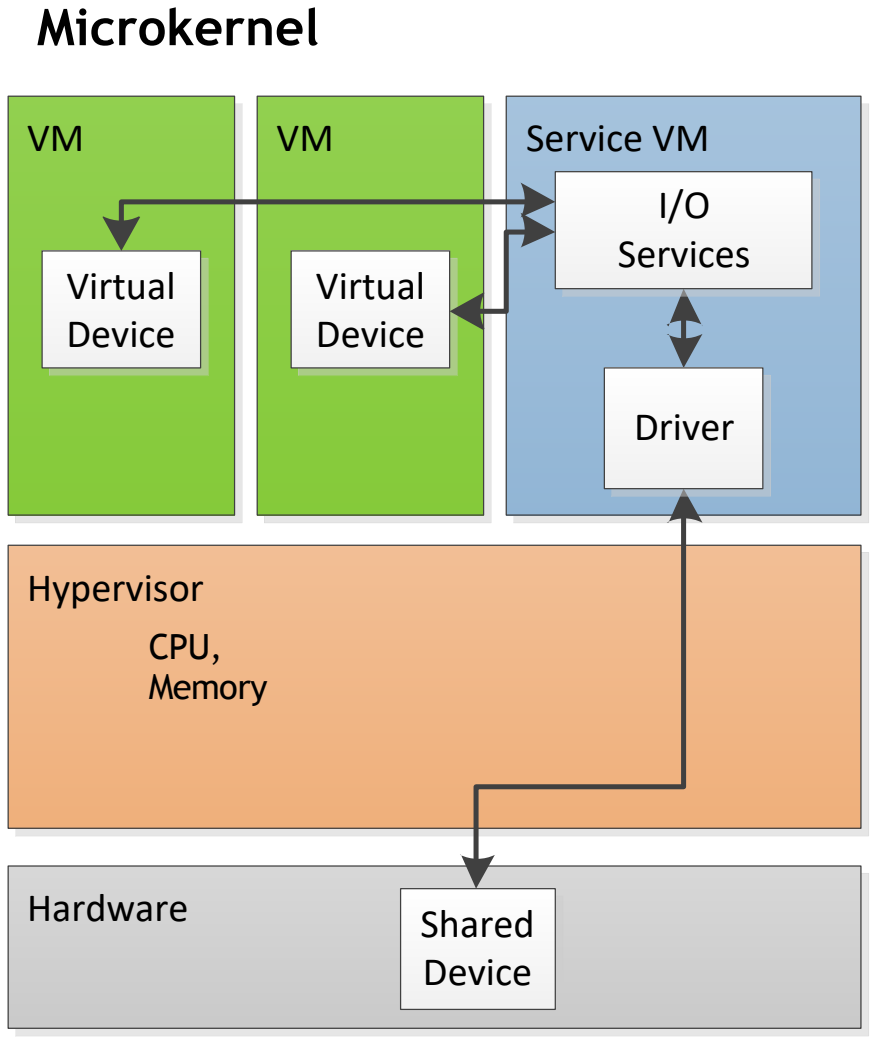


- Device drivers run within the hypervisor
  + Better performance
  + Better isolation
  - Can run only on hardware for which the hypervisor has drivers

Type 1 hypervisor architecture: Microkernel

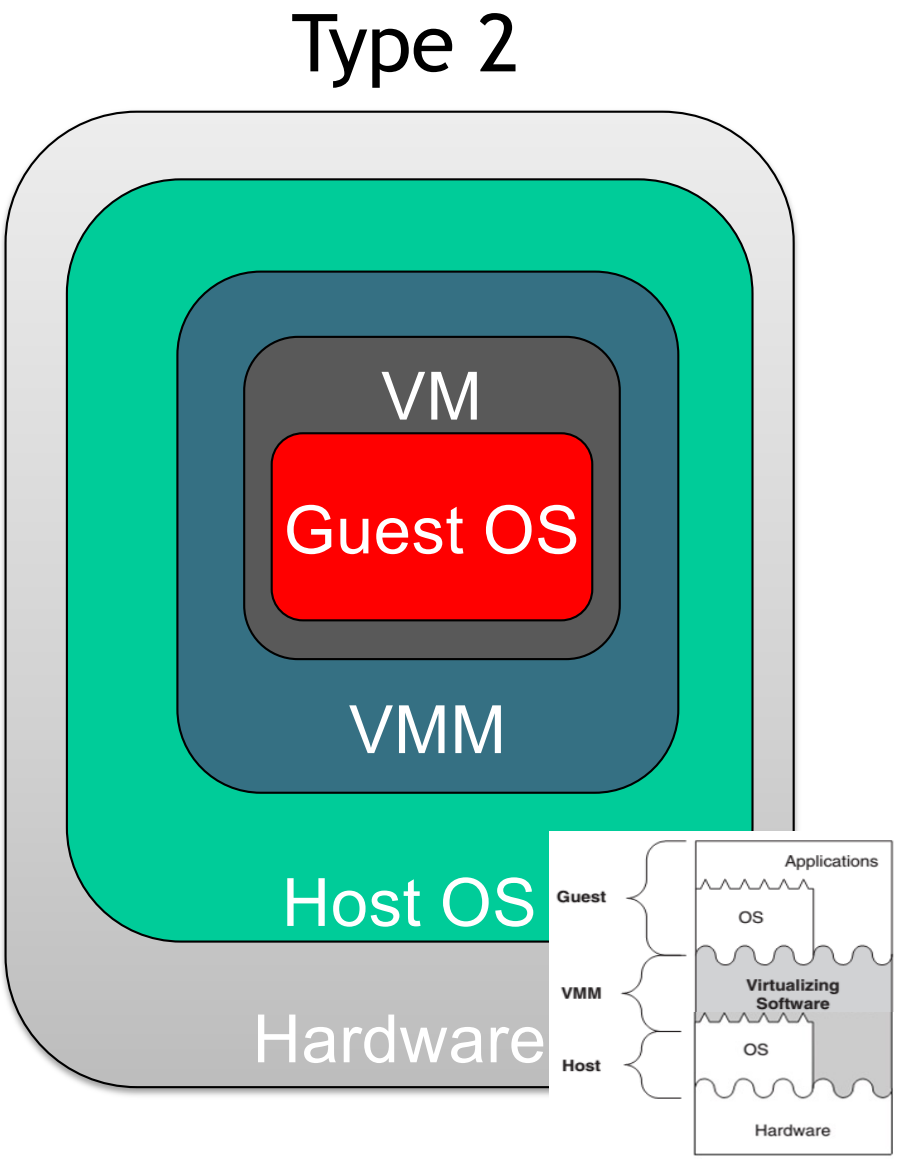
Device drivers run within a service VM

+ Smaller hypervisor
+ Leverages driver ecosystem of an existing OS
+ Can use 3rd party driver (even if not always easy, recompiling might be required)

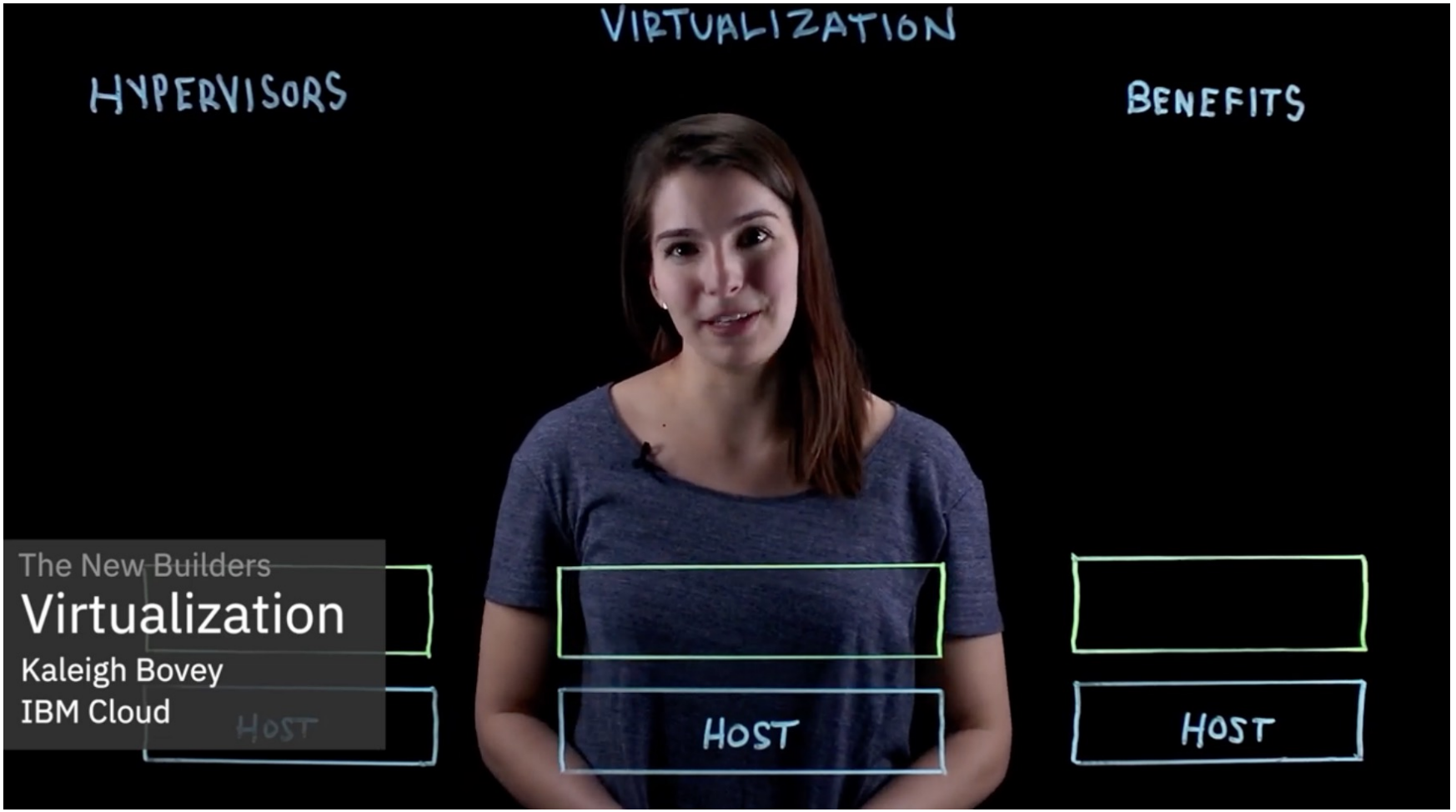


Hypervisor types

- Reside within a host operating system
  - This type of hypervisor is also called “HOSTED”
  - The *VMM* runs in the *Host OS*, the *Guest OS* is the one the runs in the VM while *applications* run in the *Guest O*
- Leverage the code of the host OS
  - The *Host OS* controls the hardware of the system
  - E.g. CPU scheduling, memory management
- + More flexible in terms of underlying hardware.
- + Simpler to manage and configure
- - The Host OS might consume a non-negligible set of physical resources
- E.g. VMware Workstation and Oracle VirtualBox



... Webeep Video



System-Level Virtualization Techniques

Different ways to implement (system level / same ISA) virtualization:

Paravirtualization

Full Virtualization

Full Virtualization

Provides a **complete simulation of the underlying hardware**.

- the full instruction set
- input/output operations
- Interrupts
- memory access

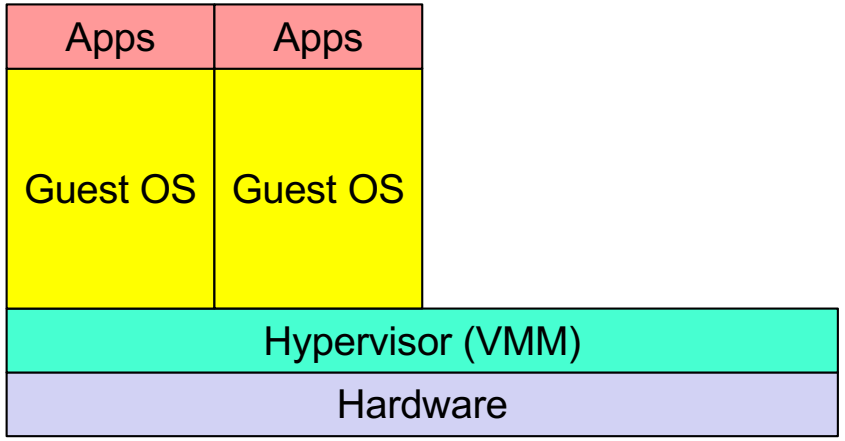
Some protected instructions are trapped and handled by Hypervisor

Pros:

- Running unmodified OS
- Complete Isolation

Cons:

- Performance
- Hypervisor mediation
  (to allow the guest(s) and host to request and acknowledge tasks which would otherwise be executed in the virtual domain)
- Not on every architecture
  (requires some hardware support)



Paravirtualization

Guest OS and VMM collaborates:

- VMM present to VMs an interface similar but not identical to that of the underlying hardware
- To reduce guest's executions of tasks too expensive for the virtualized environment (by means of ***"hooks" to allow the guest(s) and host to request and acknowledge tasks*** which would otherwise be executed in the virtual domain, where execution performance is worse).

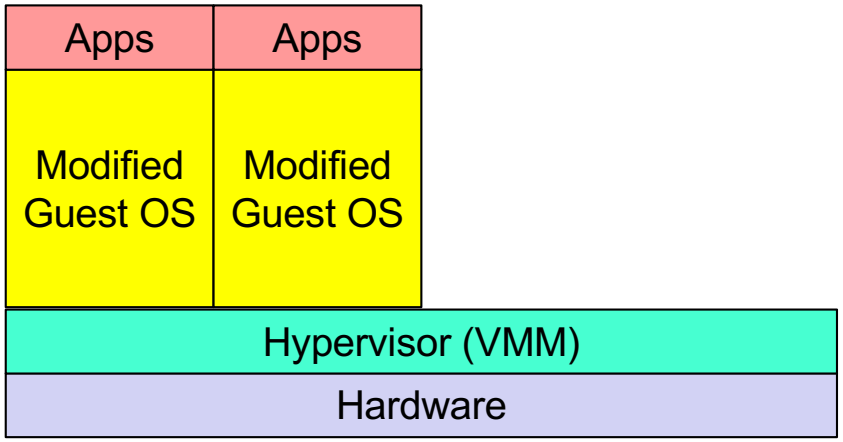
Pros:

- Simpler VMM
- High Performance

Cons:

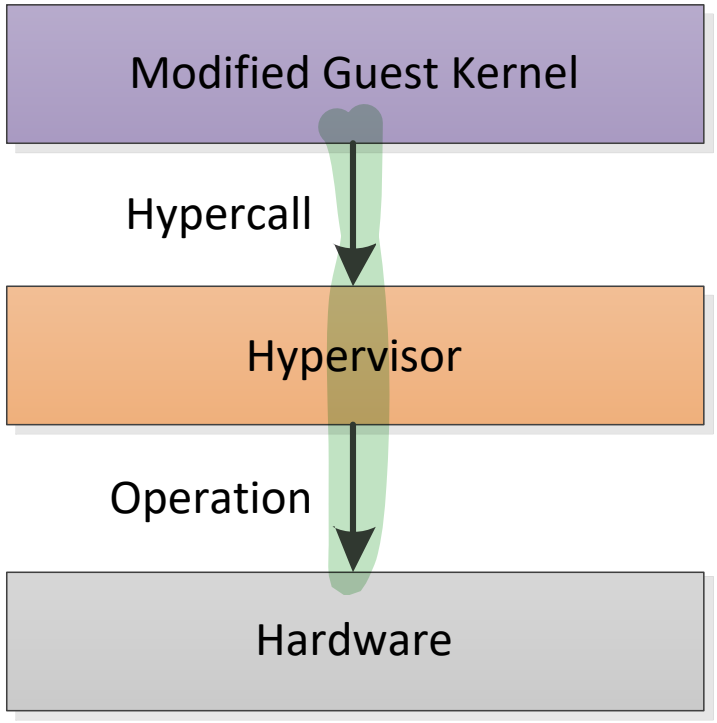
- Modified Guest OS

(Cannot be used with traditional OSs, e.g., available on some Linux Releases)

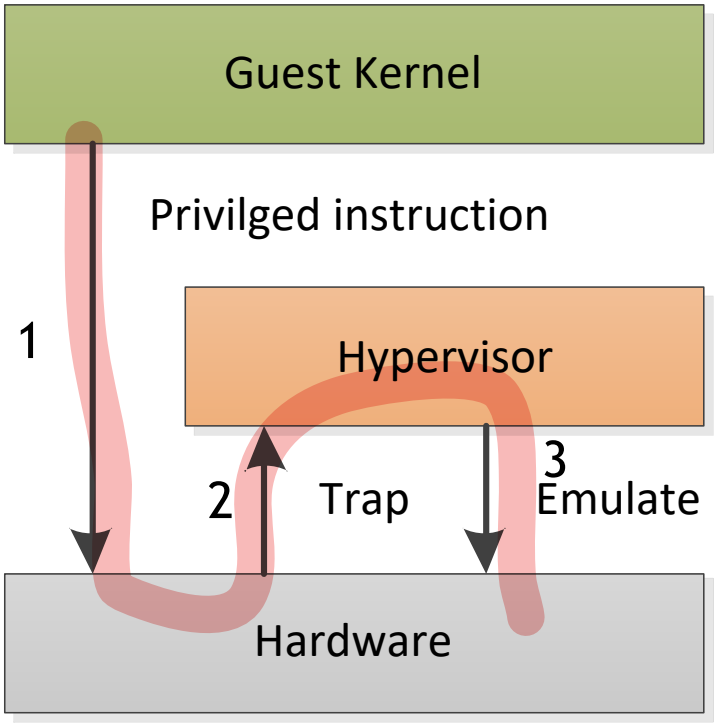


Para VS Full-virtualization

Para-virtualization



“Classical” Full-virtualization



Paravirtualize some devices even in Full Virtualization,
e.g., Guest additions in VMWare or Virtual Box (drivers are replaced)

Containers

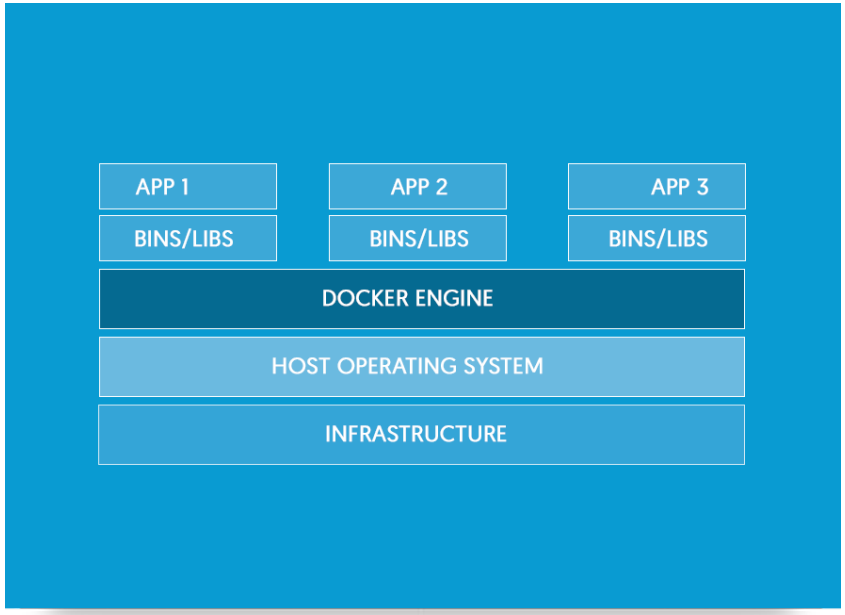
What is a container?

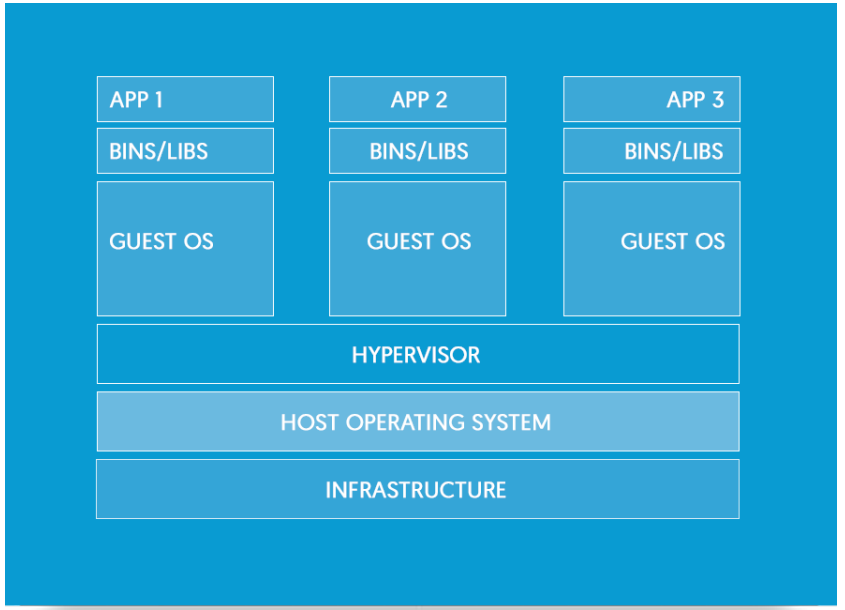
- **Containers** are **pre-configured packages**, with everything you need to execute the code (code, libraries, variables and configurations) in the target machine.
- The **main advantage of containers is that their behavior is predictable, repeatable and immutable:**
  - When I create a "master" container and duplicate it on another server, **I know exactly how it will be executed**
  - There are no unexpected errors when moving it to a new machine or between environments
- **Example: a container for a website**,
  - We are not required to export/import the development/test/production environments,
  - We create a container that contains the site and bring it to the destination environment

Containers and Virtual Machine

- VM provides hardware virtualization, while containers provide virtualization at the operating system level
- The main difference is that the containers share the host system kernel with other containers.

Containers
applications are packaged with all of their dependencies into a standardized unit for software development/deployment.





VMMs
applications depend on guest OS.

Characteristics of containers

Containers are:

- Flexible: even the most complex applications can be containerized;
- Light: the containers exploit and share the host kernel;
- Interchangeable: updates and updates can be distributed on the fly;
- Portable: you can create locally, deploy in the Cloud and run anywhere;
- Scalable: it is possible to automatically increase and distribute replicas of the container;
- Stackable: containers can be stacked vertically and on the fly.

Containers ease the deployment of applications and increase the scalability but they also impose **a modular application development where the modules are independent and uncoupled**.

What can you use Containers for?

- Helping make your local development and build workflow faster, more efficient, and more lightweight.
- Running stand-alone services and applications consistently across multiple environments.
- Using Container to create isolated instances to run tests.
- Building and testing complex applications and architectures on a local host prior to deployment into a production environment.
- Building a multi-user Platform-as-a-Service (PAAS) infrastructure.
- Providing lightweight stand-alone sandbox environments for developing, testing, and teaching technologies, such as the Unix shell or a programming language.
- Software as a Service applications.

Software for “Containers”

… Video on WEBEEP