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Lecture IV
Server virtualization

Operating system concepts – Infrastructure concepts for applications

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2025-2026

(based on material from T. Deneut)

(Server) virtualization

Almost every single application is running within a virtual environment.

Why?
A normal server often has 24 or more processor cores and 128GB or more RAM.
Is there a single application that even knows how to address such amounts?

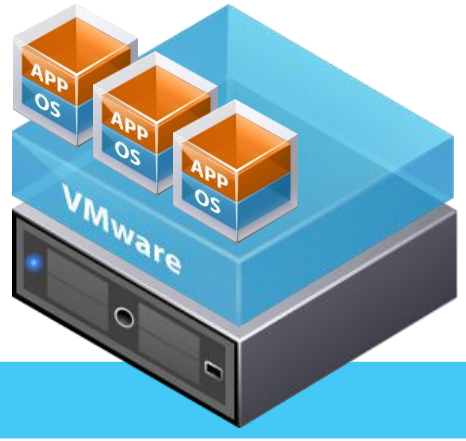
Virtualization

Physical machine

- Difficult to move or copy
  - Bound to specific hardware
- Often has a short lifecycle
- Requires personal contact to upgrade hardware

Virtual machine

- Easy to move and copy:
  - Encapsulated into files
  - Independent of physical hardware
- Easy to manage:
  - Isolated from other virtual machines
  - Insulated from hardware changes
- Provides the ability to support legacy applications
- Allows servers to be consolidated



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Virtualization

Different Kinds of virtualization

1. **Hypervisor-based** or ***bare metal*** virtualization (or ***Type 1***)
   - Software based or hardware assisted (e.g. Intel VT-d, AMD-V)

2. **Hosted** virtualization (or ***Type 2***)
   - Using a software inside an OS

3. Container-based virtualization
   - E.g. docker

4. LXC containers

5. …Desktop, application, data, device … virtualization
   - E.g. what a sandbox does (and most browsers)

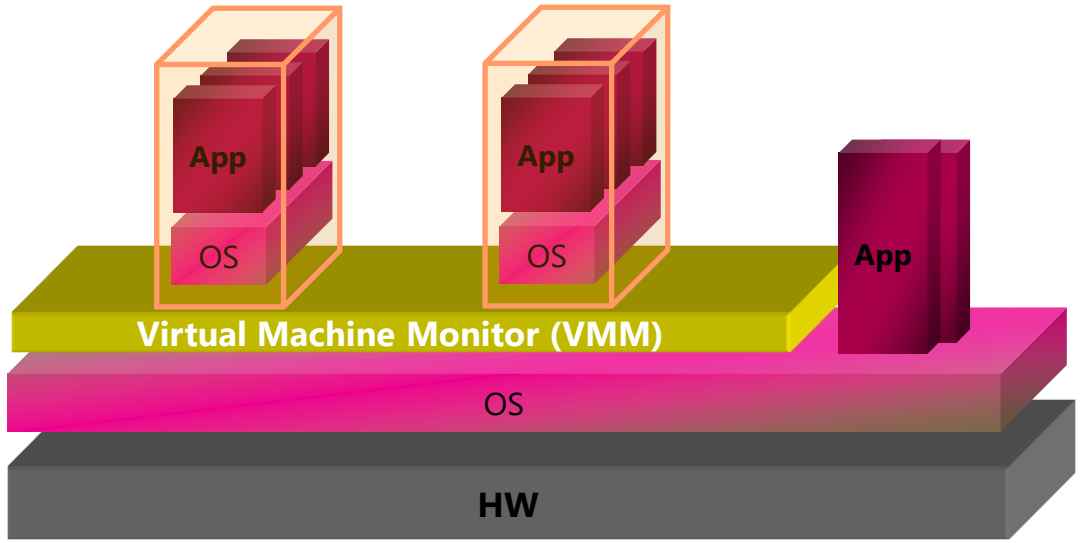
Type 2 vs Type 1 virtualization

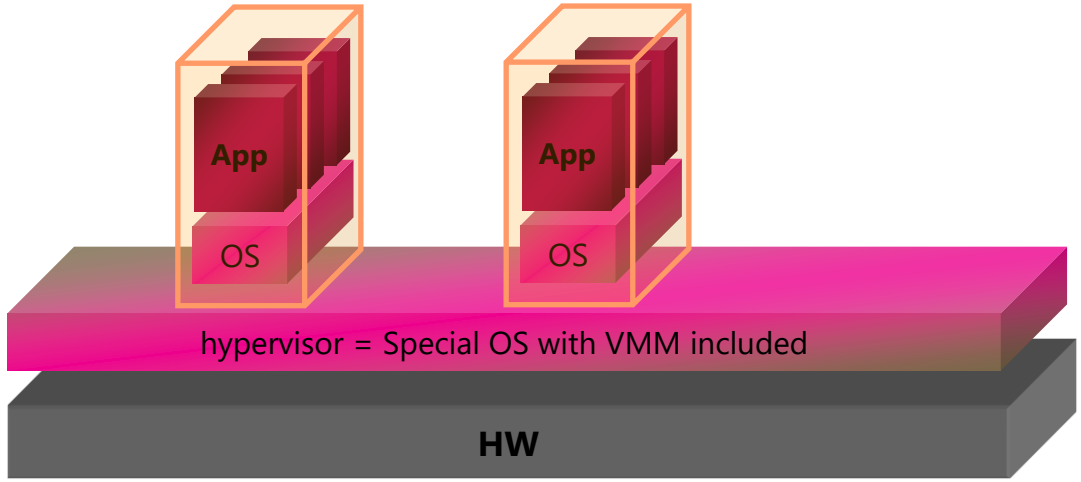
Hosted virtualization

- VMware Fusion and Workstation
- Oracle VM Virtualbox
- Parallels
- Microsoft Virtual Server and VirtualPC (discontinued)

Bare-metal virtualization

- VMware ESXi
- Microsoft Hyper-V
- Citrix XenServer
- RedHat (& others) Kernel Virtual Machines (KVM)





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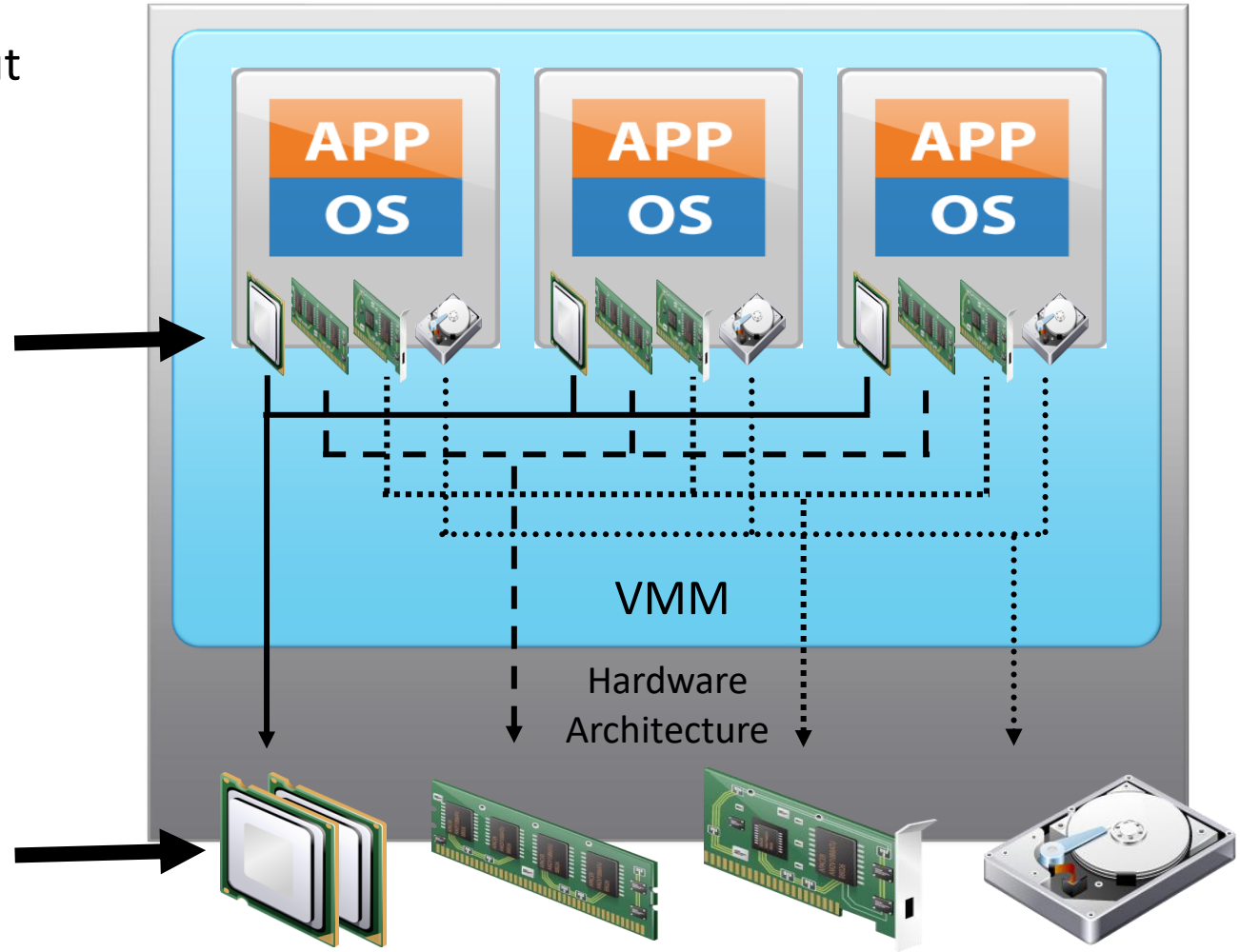
First: General virtualization

- Virtualization is NOT emulation but more about **isolation**
- The concept of a Virtual Machine is actually:
  a VM is a bunch of files



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Source: vSphere Install documentation

What is a VM?

a VM is a bunch of files:

VM firmware config

Virtual Hard Drive (like VHD)

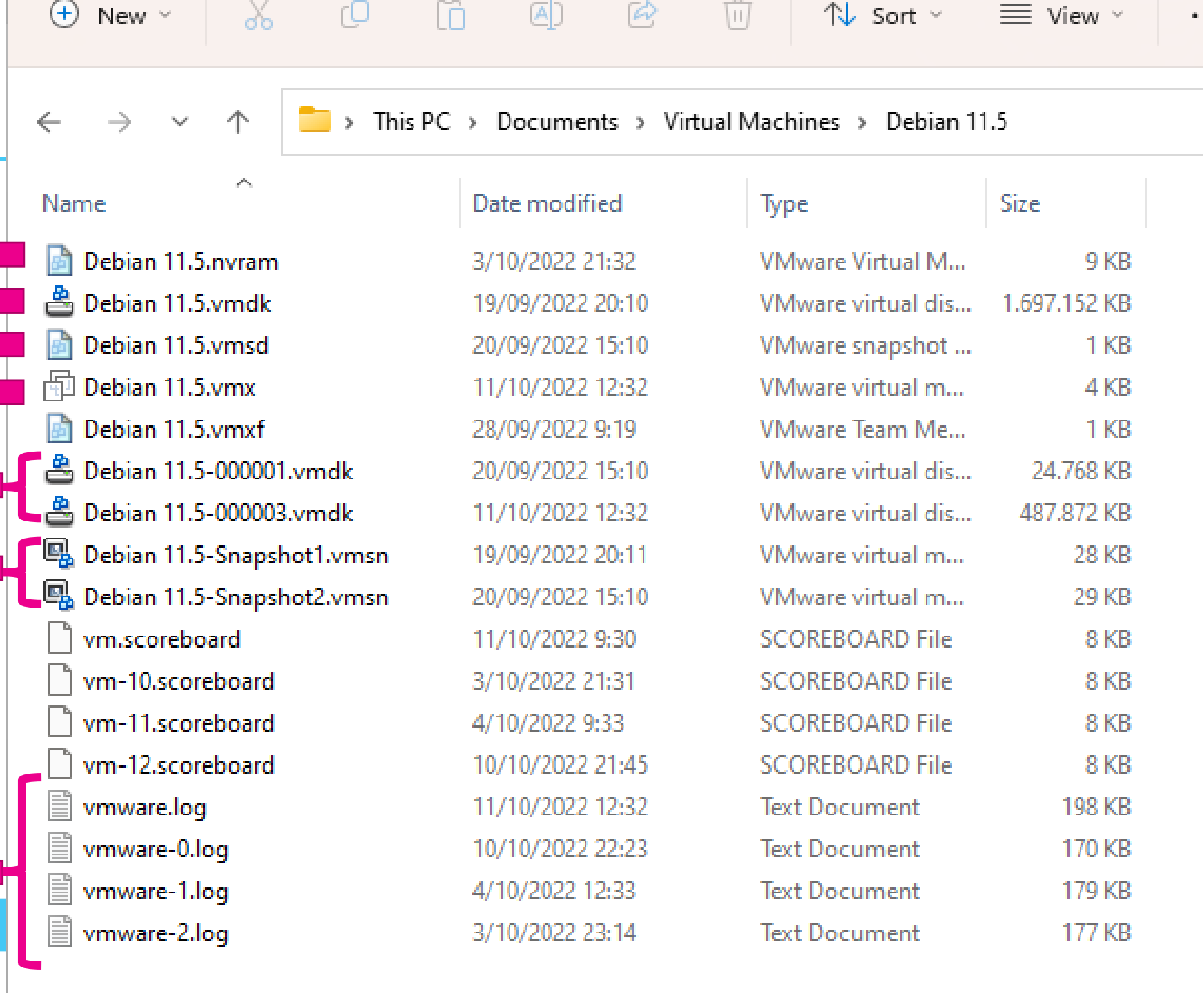
snapshot overview (vmsn+vmdk)

VM config file (very important)

“Child” VMDKs (of the snapshots)

VM snapshot config

Detailed log files
(created upon every VM boot)



This means interesting functionality

- A VM (being a bunch of files) can be moved very easily
  - Move to another machine and your VM runs on completely different hardware in minutes
- Not only moved but also copied (called a Clone), just copying the files of the VM
- No more “driver” issues; they do not require drivers for Nvidia, Intel, AMD, etc.
  - VMs allow for Operating Systems with small disk footprints
- We can create “snapshots”, **freezing** the state of a VM in a certain point in time.
  - Be aware that not only the VMDK is frozen but also the VM configuration.
  - Can be very powerful to have multiple states for one VM
  - Especially in combination with clones, called “linked clones”
- Entire network environments can be configured

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VMware server virtualization

VMware acquisition by Broadcom

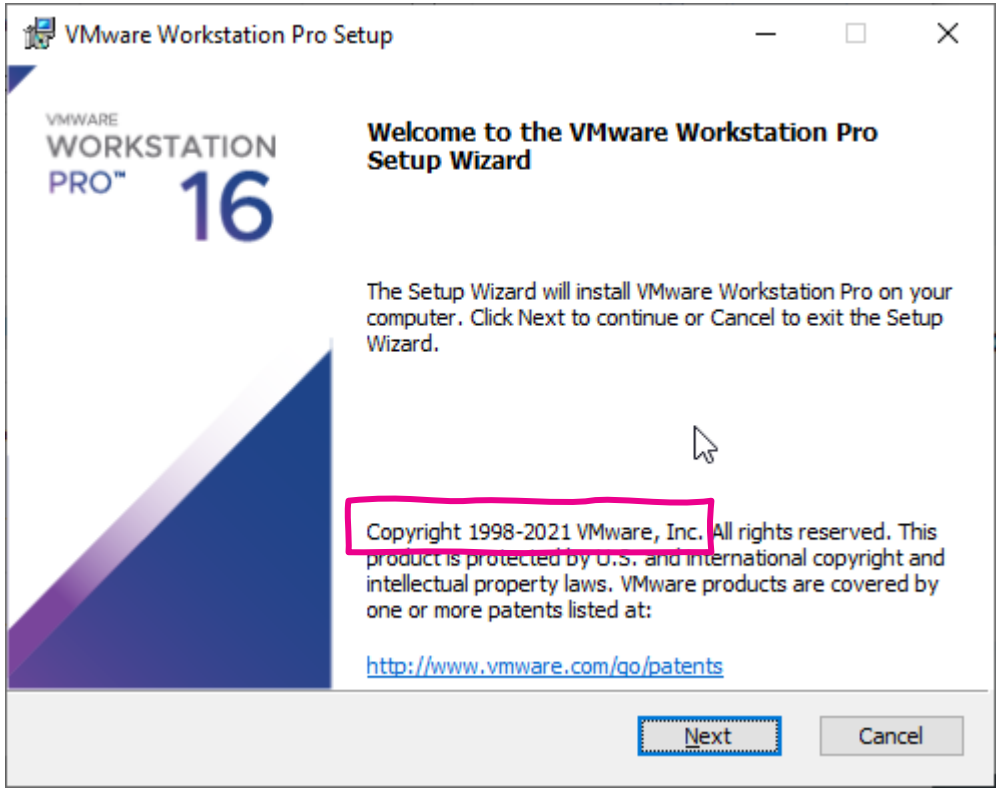
- **Deal Value**: $61 billion in cash and stock
- **Completion Date**: November 22,2023

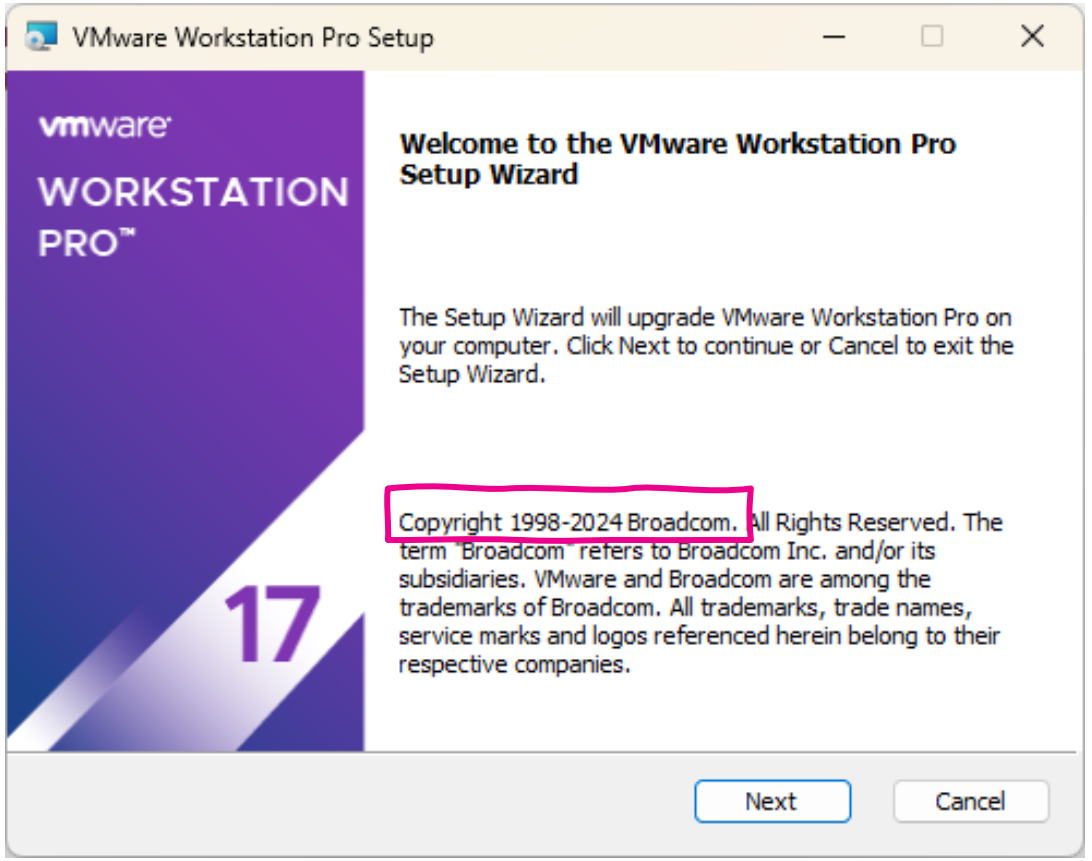
- **Criticism and Concerns**
  - Significant increase in licensing costs
  - Shift from perpetual licenses to subscriptions
  - Concerns over support quality and disrupted partnerships

https://investors.broadcom.com/news-releases/news-release-details/broadcom-acquire-vmware-approximately-61-billion-cash-and-stock

VMware acquisition by Broadcom

Since May 2024: VMware Workstation/Fusion Pro are free of charge for personal usage.





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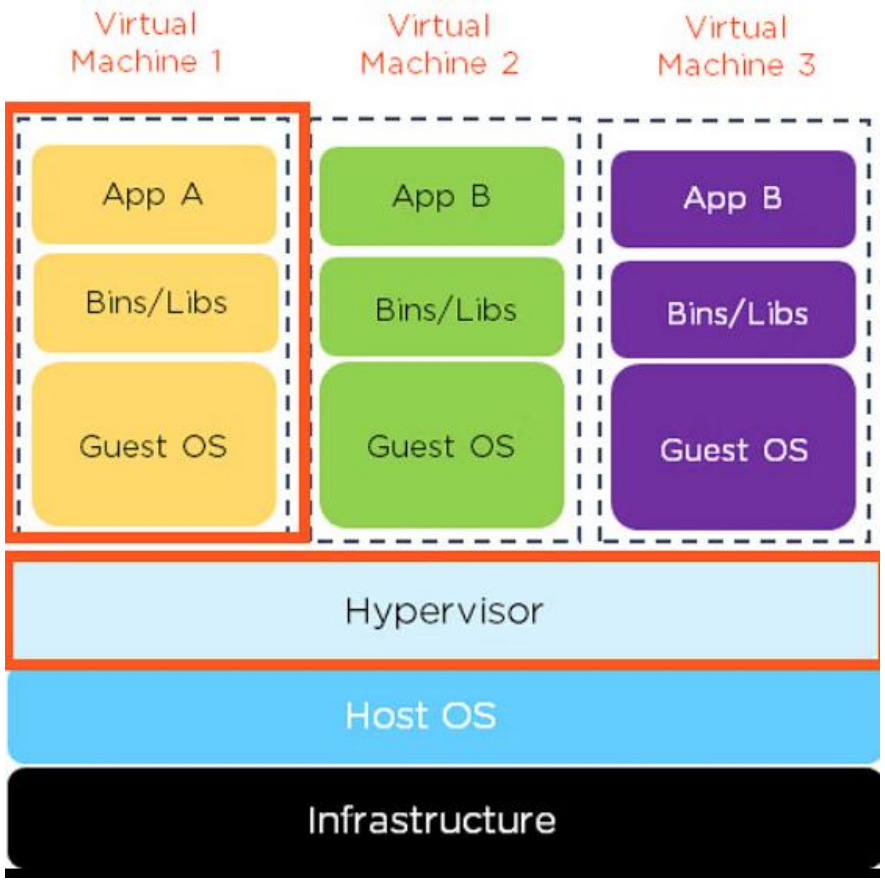
VMware workstation virtualization

VMware Workstation : hosted virtualization

- Your primary OS provides the virtualization



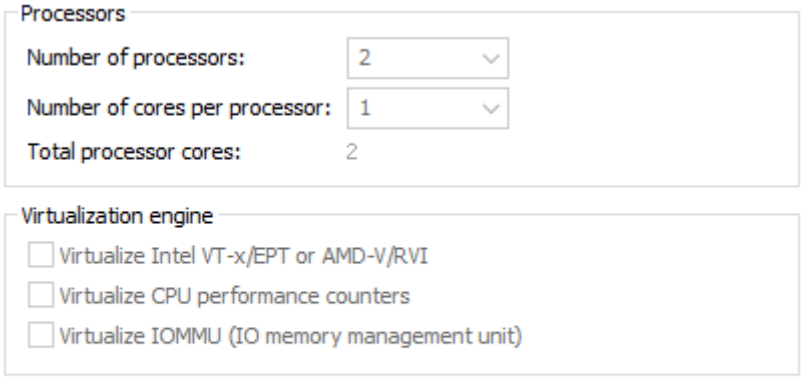
source: https://microage.com/wp-content/uploads/2016/02/ESXi_architecture.pdf

Workstation architecure

- **Type-2 Hosted Hypervisor**
  - •VMware Workstation operates as a hosted hypervisor, meaning it runs atop an existing host OS (Windows or Linux). It interfaces with the OS to manage guest VMs, rather than being installed directly on hardware.
- **Integration of a Virtual Machine Monitor (VMM)**
  - •It combines a hosted architecture with a VMM. This VMM includes a trap-and-emulate mechanism and a dynamic binary translator to virtualize x86 instructions effectively—even when hardware support for virtualization isn't available.
- **Full Virtualization via Binary Translation**
  - •VMware fully virtualizes guest OS environments by running non-sensitive instructions directly on hardware and using binary translation (or trapping) for sensitive ones. This allows the guest OS to remain unmodified while still maintaining high performance (typically achieving >80–95% of native speed).
- **Software-Emulated I/O Devices**
  - •The hypervisor emulates canonical I/O devices in software rather than exposing the full diversity of physical I/O hardware. This abstraction improves compatibility and portability across varied environments.

CPU

- Number of processors and number of core per processor
- Some features
  - Max or min Hhz per CPU
  - Shares per VCPU
    - "low" → 500 shares per vCPU
    - "normal" → 1000 shares per vCPU (default)
    - "high" → 2000 shares per vCPU
    - or a numeric value (custom)
  - Example :
    - VM1: 2 vCPUs, sched.cpu.shares = "high" (2000 × 2 = 4000 shares)
    - VM2: 2 vCPUs, sched.cpu.shares = "low" (500 × 2 = 1000 shares)
    - Total shares = 5000.
    - VM1 gets 4000 / 5000 = 80% of CPU time.
    - VM2 gets 1000 / 5000 = 20% of CPU time.




```
####################
# CPU Settings
####################
numvcpus = "2"
sched.cpu.min = "1000"        # Reservation in MHz
sched.cpu.max = "2000"        # Limit in MHz
sched.cpu.shares = "normal"    # Shares: low / normal / high / numeric
```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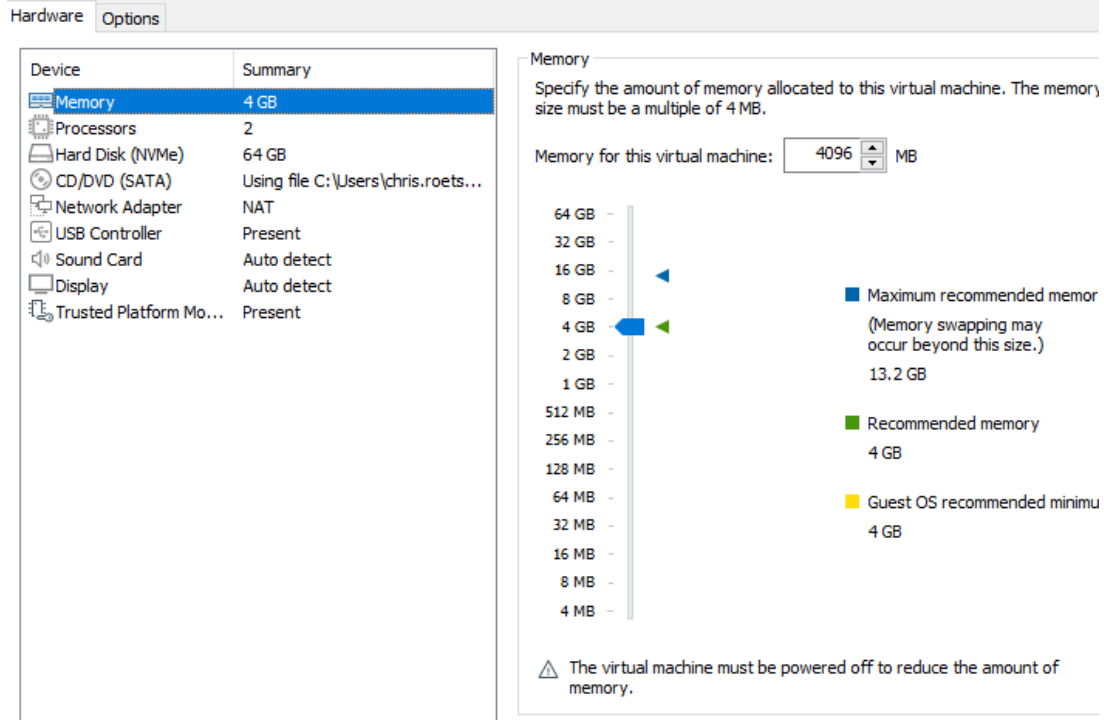
Memory

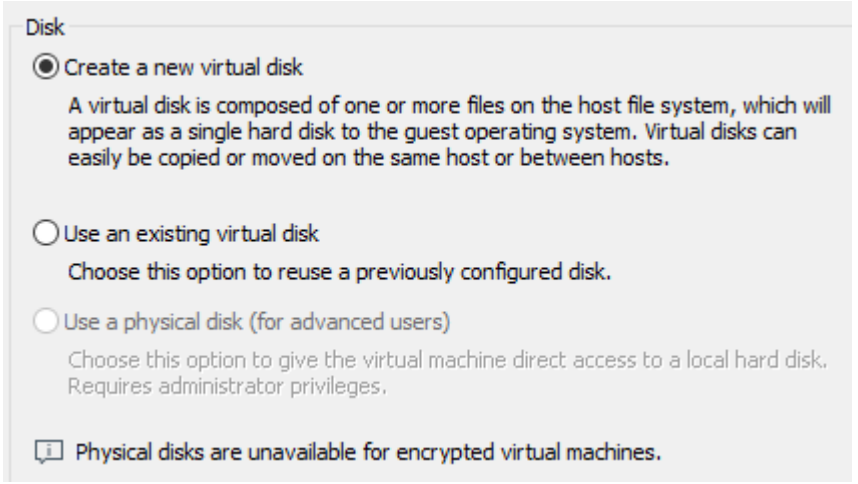
- dynamically allocating RAM to virtual machines (VMs) as they need it, with options to adjust settings like reserved memory, shares, limits, and reservations
- So the physical addresses are handed over to the address translation table of the guest OS
- Some features
  - **Memory Overcommitment**
  - **Memory Swapping**
  - **Memory Ballooning**
  - **Memory Reservation**
  - **Memory Limit**




```
####################
# Memory Settings
####################
memsize = "4096"
sched.mem.min = "2048"       # Reservation in MB
sched.mem.max = "4096"       # Limit in MB
mem.locked = "TRUE"          # Lock in host RAM
mem.force = "TRUE"
```

Disks

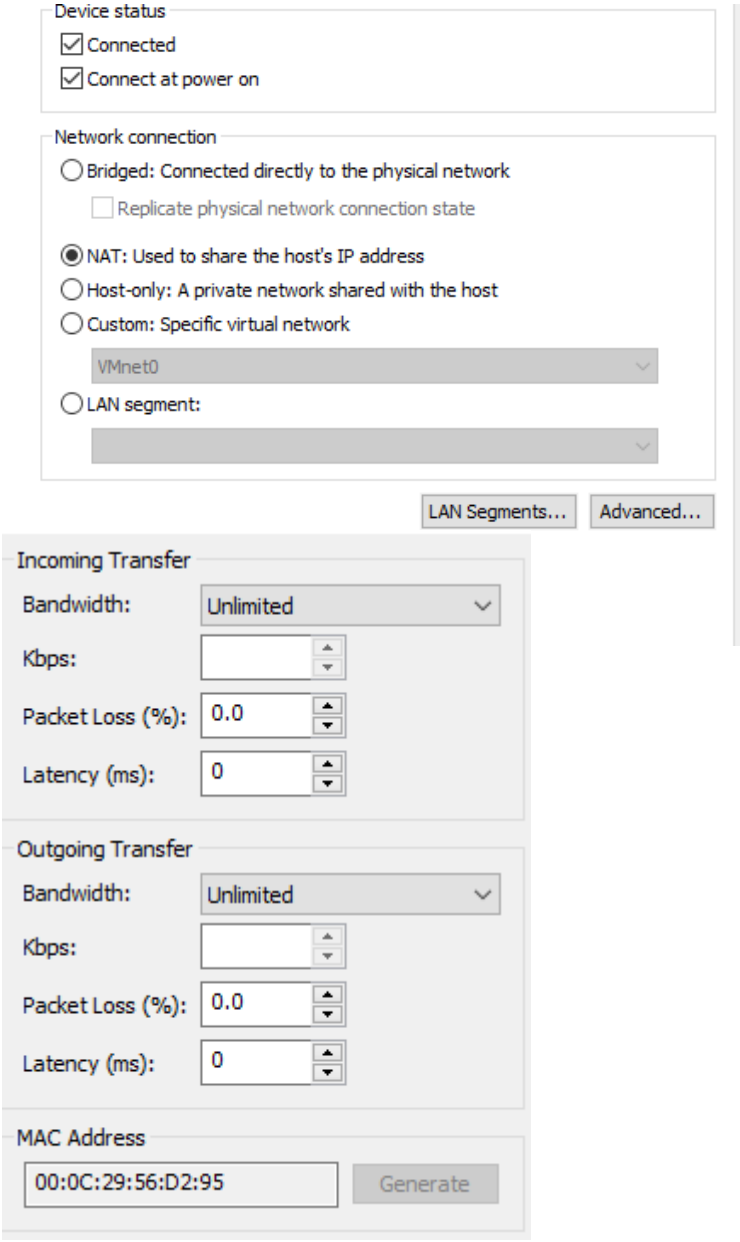
- Virtual disks
  - File on your host system (vmdk)
- Physical disks
  - Partition on your host system
- Features
  - Shares
  - through




```
####################
# Disk I/O Settings (per disk)
####################
scsi0:0.shares = "high"
scsi0:0.throughputCap = "20480"       # 20 MB/s limit
scsi0:0.throughputCap.enable = "TRUE"
```

Network

- Bridged :
- NAT : vmnet8
- Host only : vmnet0
- Custom
- Bandwidth
- Lan segment : compare with VLAN’s



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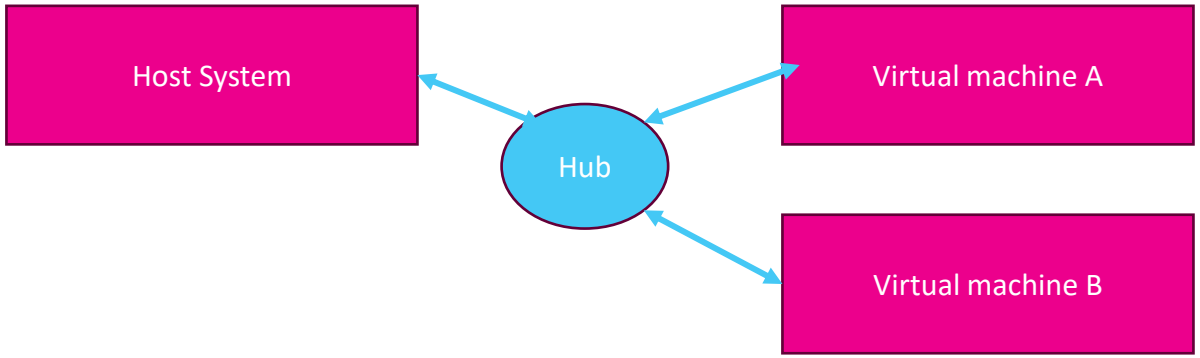
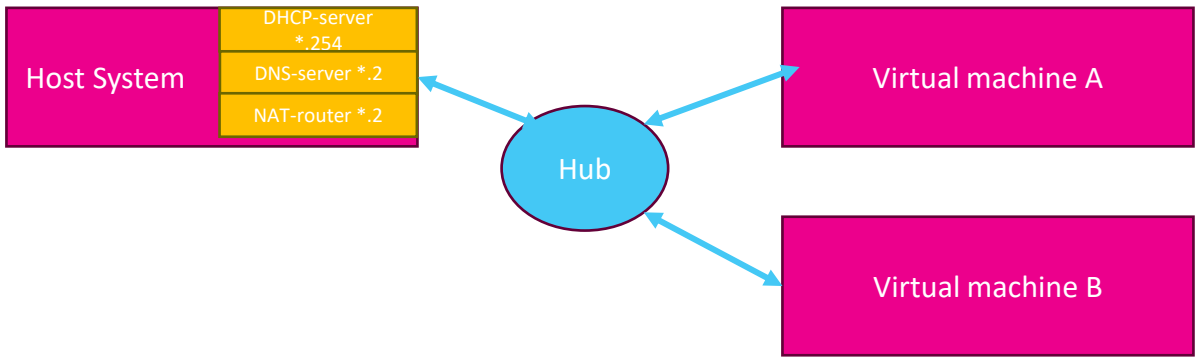
Virtual networking reexplained : Host only



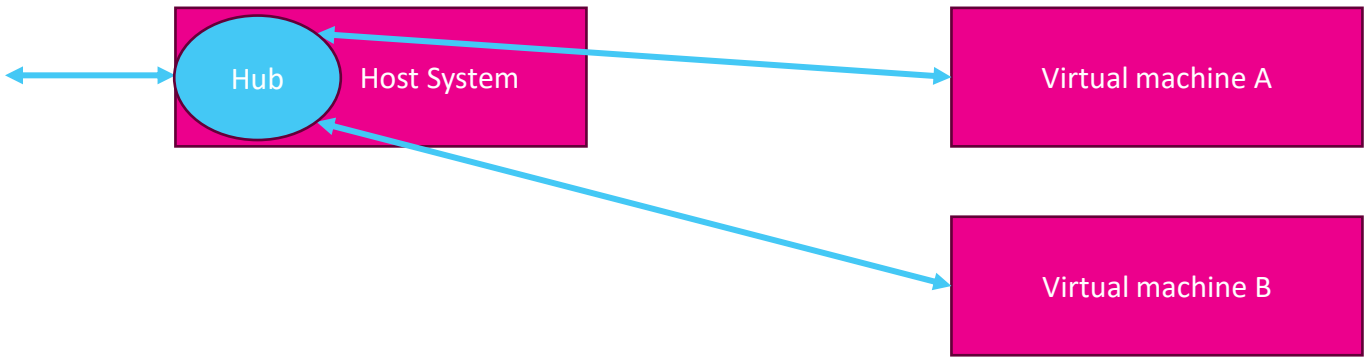
- IP address definitions is up to you

Virtual networking reexplained : Nat



- IP address are configured for you, using a network subnet defined in the virtual address editor

Virtual networking reexplained : Bridged



- IP addresses depend on external network of the host

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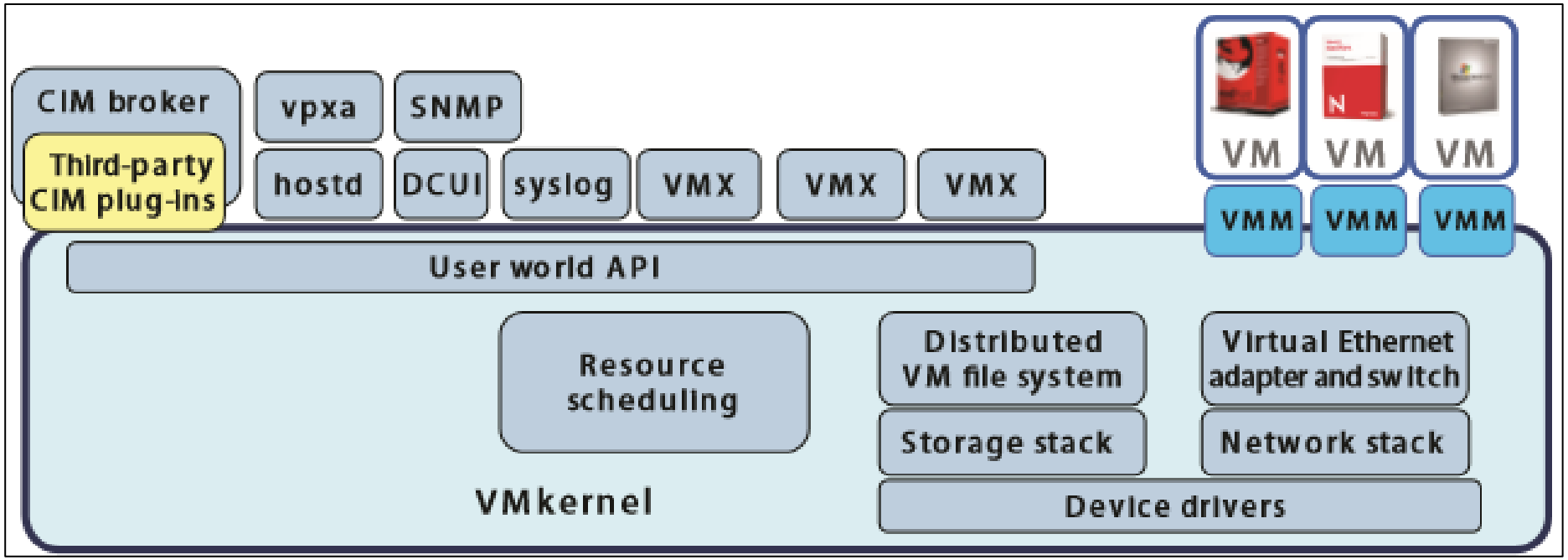
VMware server virtualization

Server Virtualization: ESXi

- As we know: a Hypervisor is a special kind of **operating system** that contains a virtualization layer
- VMware's hypervisor product is the **vSphere Hypervisor**, better known as **ESXi** (or 'VMvisor')
- The "magic" is in the kernel. VMware calls this the **VMkernel**.



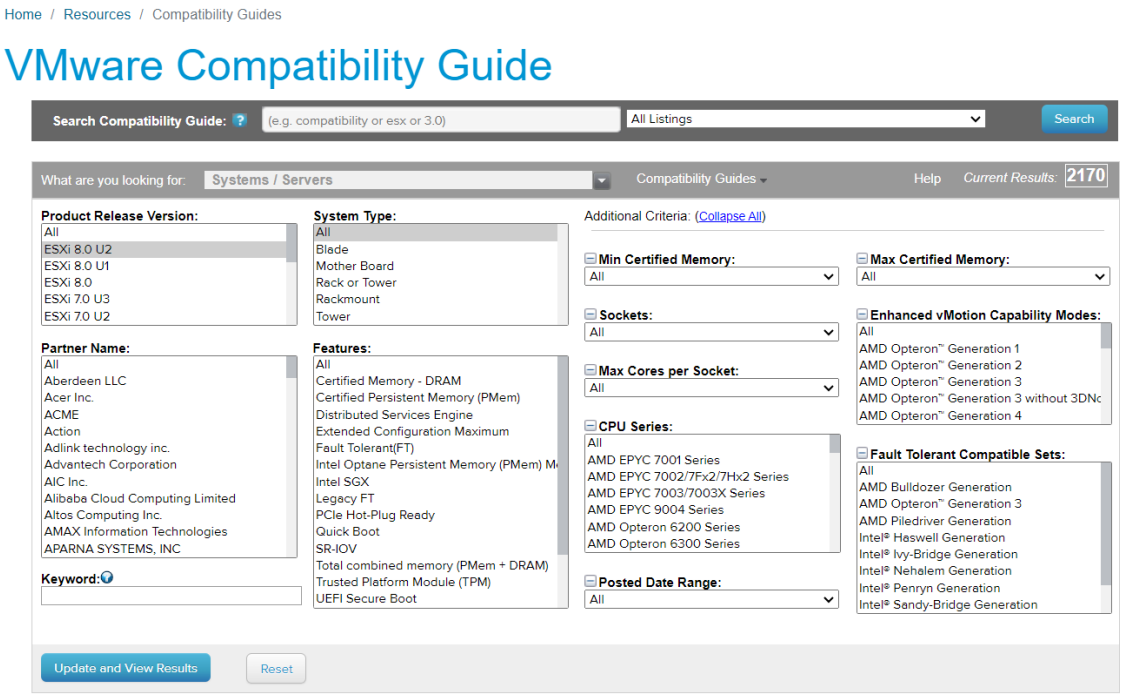
source: https://microage.com/wp-content/uploads/2016/02/ESXi_architecture.pdf

Hardware Compatibility List (HCL)

Compared to Windows and Linux only certain hardware is supported with ESXi.

There is an online list of supported hardware: the **ESXi Hardware Compatibility List (HCL)**:

- https://www.vmware.com/resources/compatibility/



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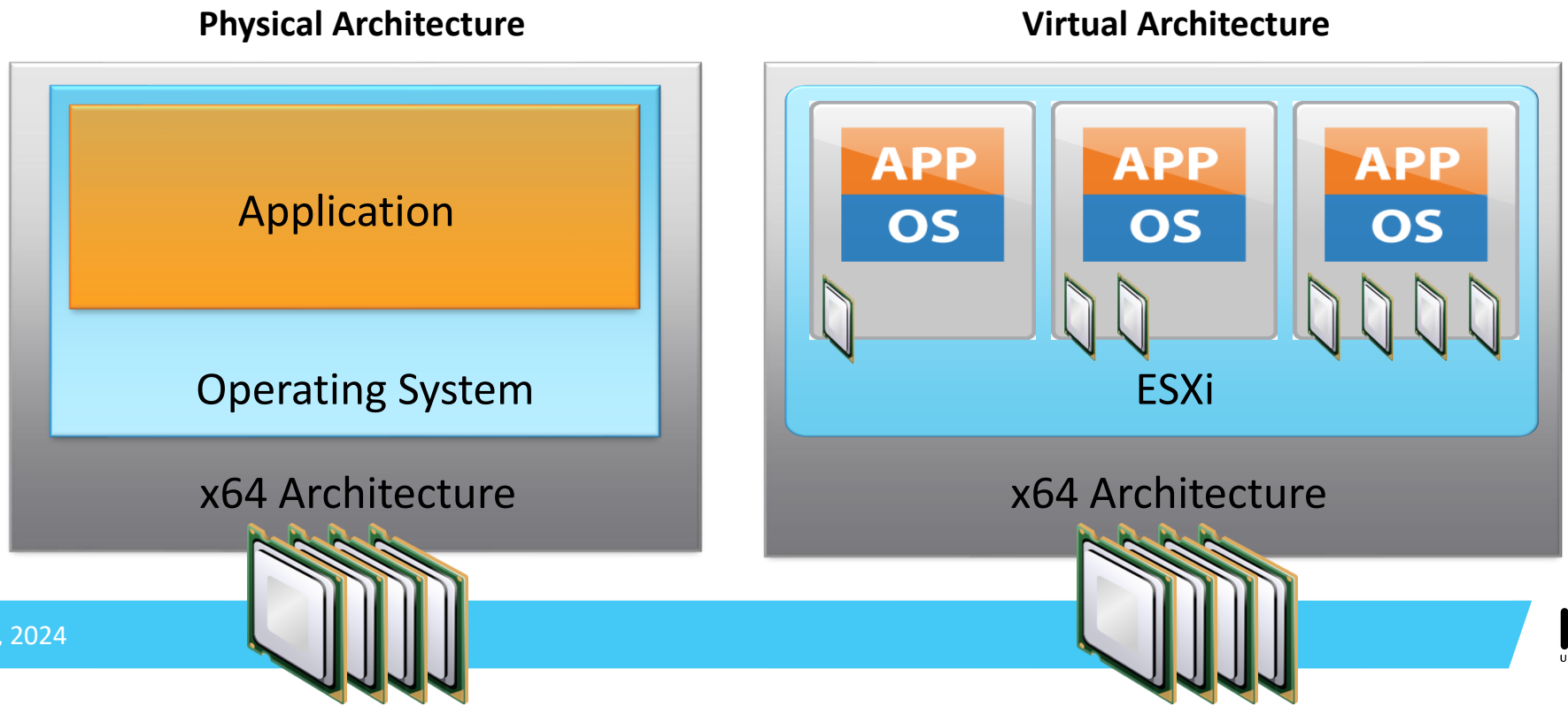
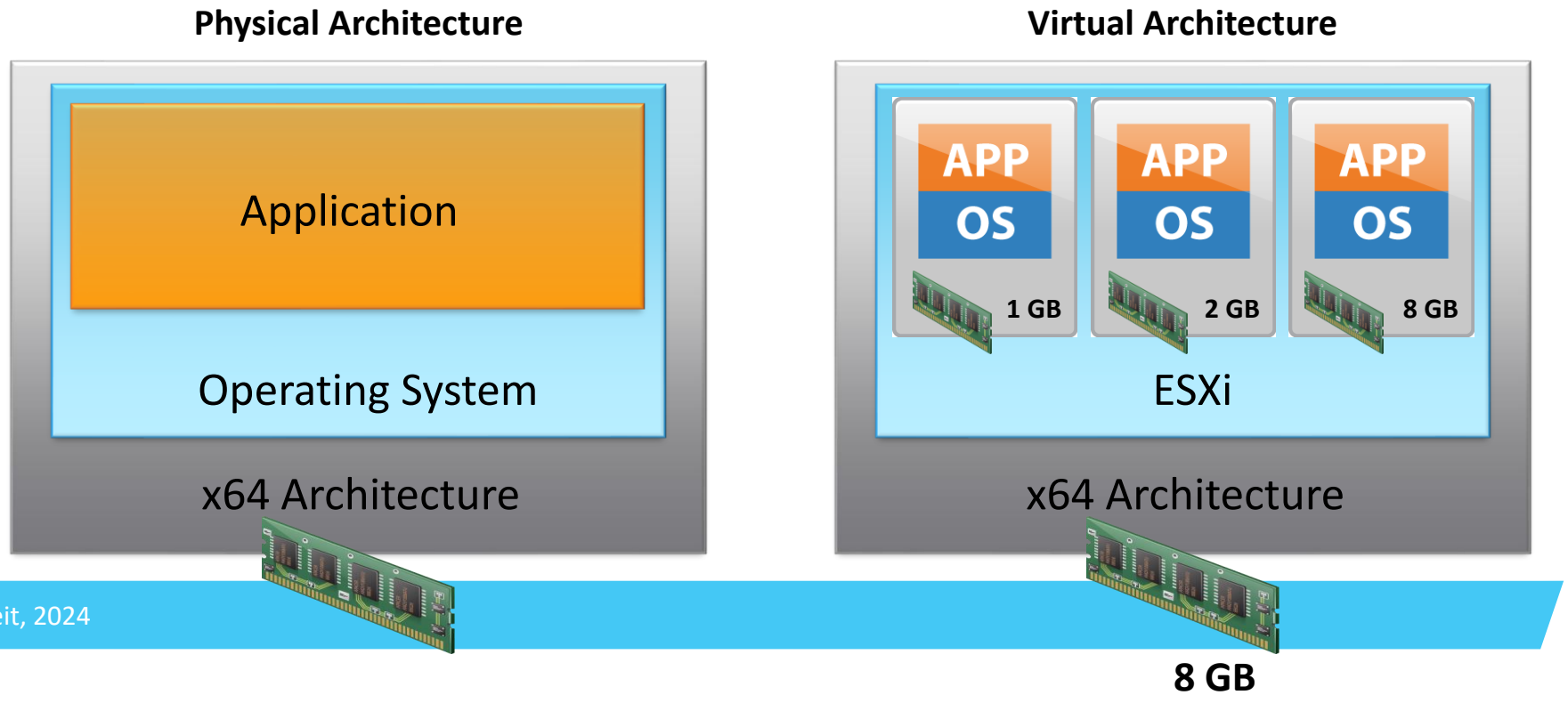
Some concepts: CPU

- It is perfectly possible to hand out more CPU's (or cores) in total for all VMs together than there are physically available in the device ("**overprovisioning**")
- Only when heavily used, contention will exist and there is performance impact



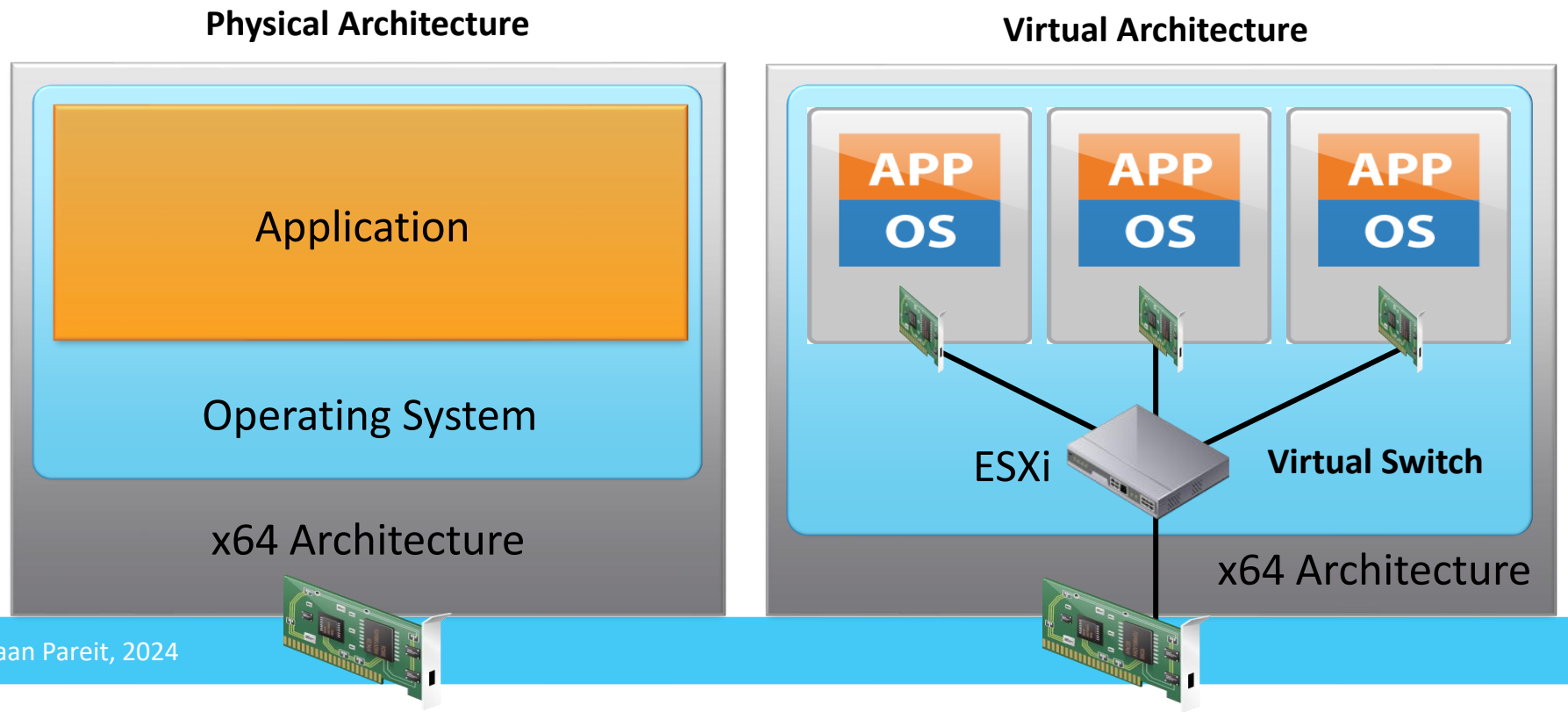
Some concepts: MEMORY

- It is also possible to hand out more memory than is physically present on the system
  - something which is only possible in VMware (thus not in e.g. Hyper-V)
  - ESXi uses several Memory Savings techniques
- vmem file is created when starting a VM: last resort for memory swapping, also for pausing a VM



Some concepts: NETWORKING

- ESXi uses the concept of virtual switches,
  - it **does not have built-in features** like ‘Host-Only’ or ‘NAT’ (unlike Workstation/Fusion)
- vSwitches have two sides: **‘virtual port groups’ (towards VM)** and **‘uplink’ (towards physical NIC)**.



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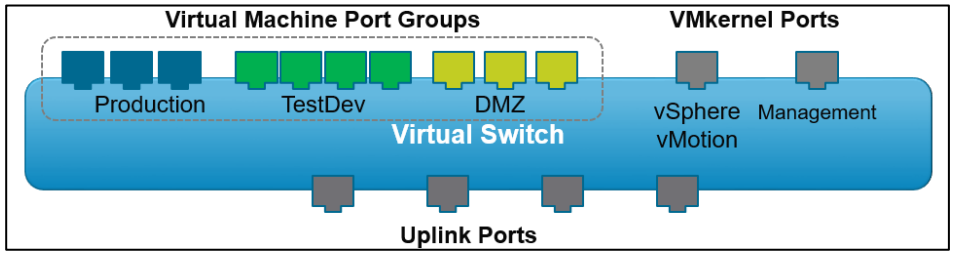
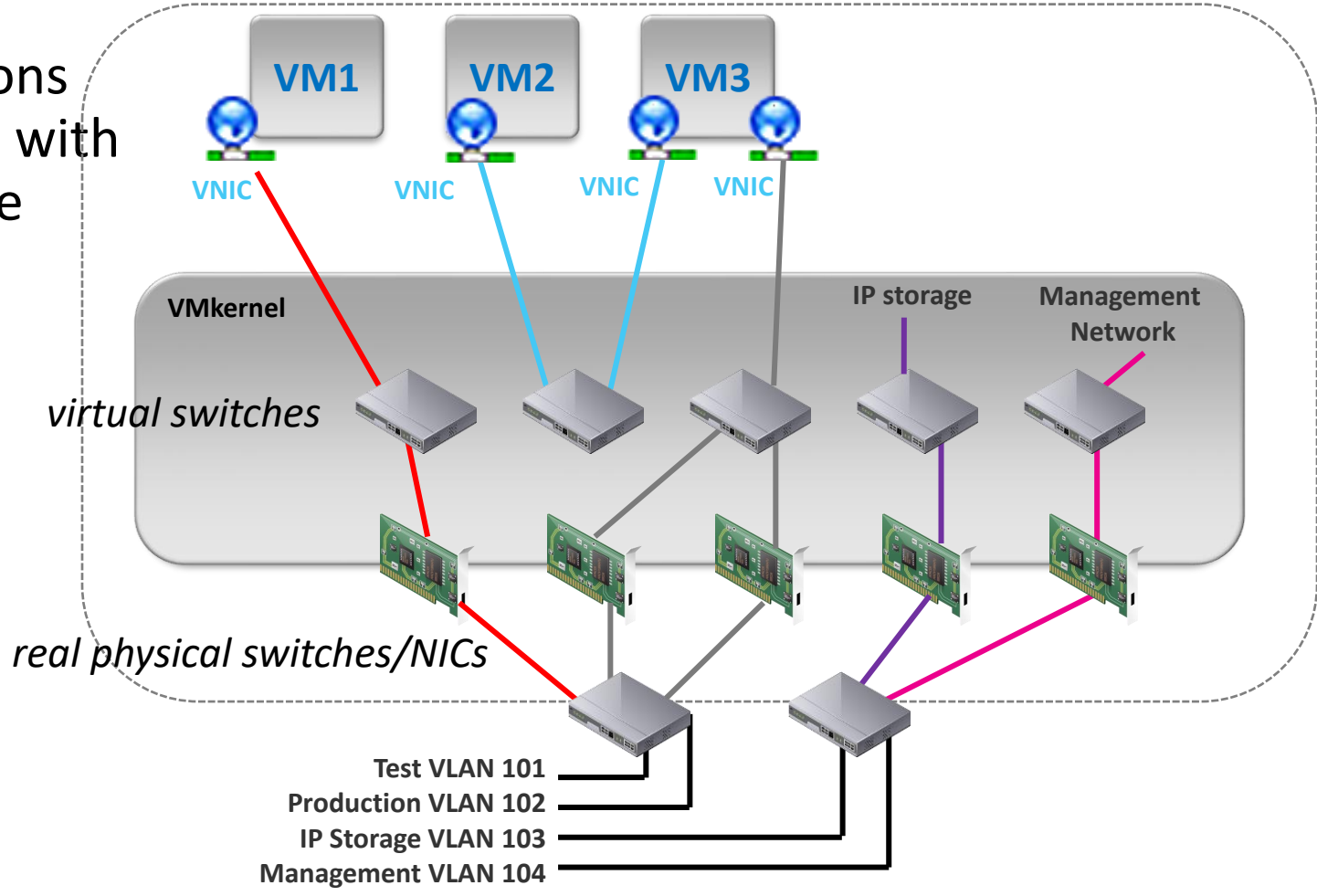
Components of Standard Switches

A standard switch provides connections for virtual machines to communicate with one another, whether they are on the same host or on different hosts.





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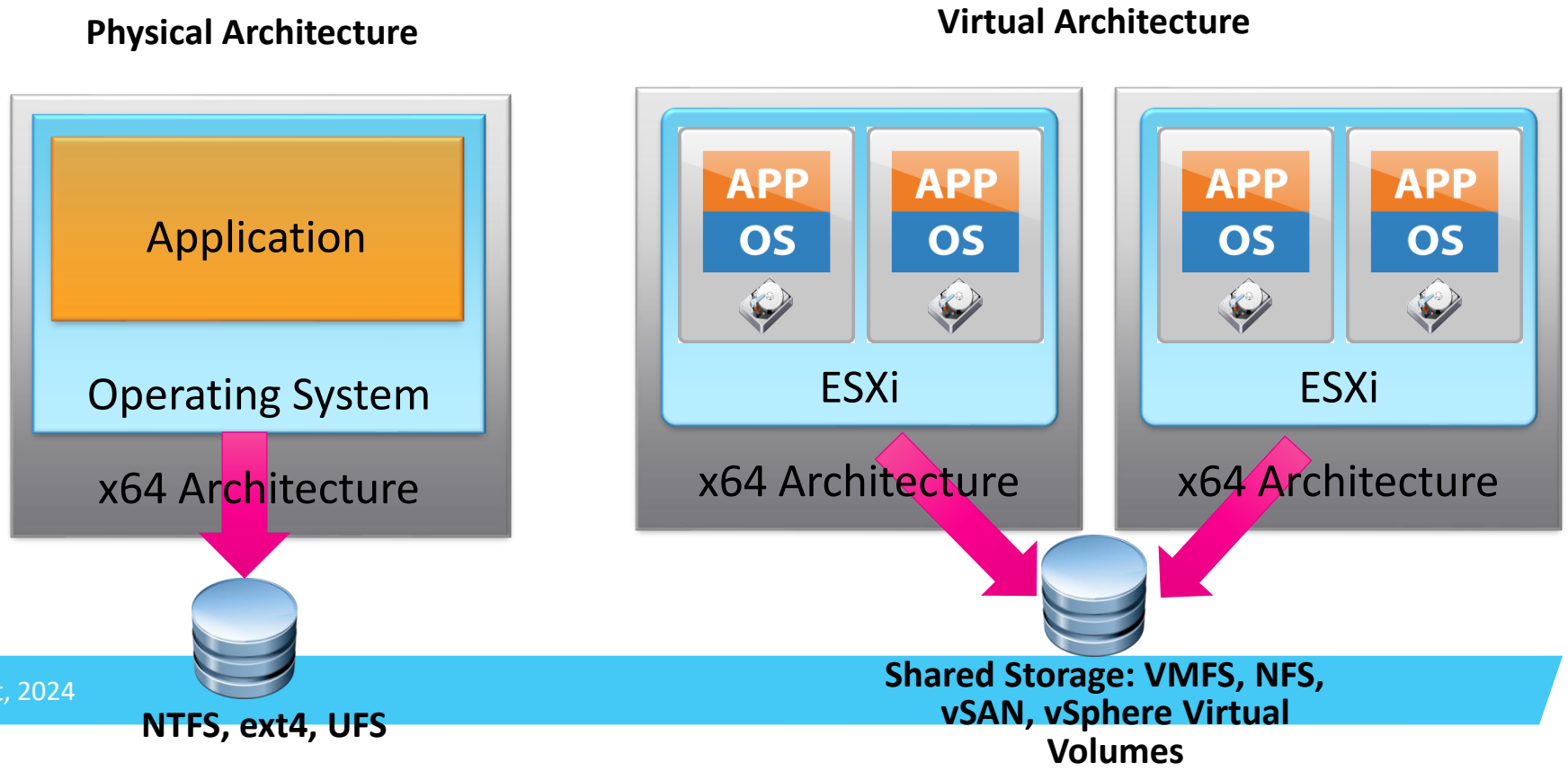
Some concepts: STORAGE

- VMware has created its own, special file system called **VMFS** or “Virtual Machine File System”
- It is optimized for Virtual Machine usage (large files),
- It supports simultaneous access (e.g. to the same SAN via iSCSI) by multiple ESXi servers (unique!)



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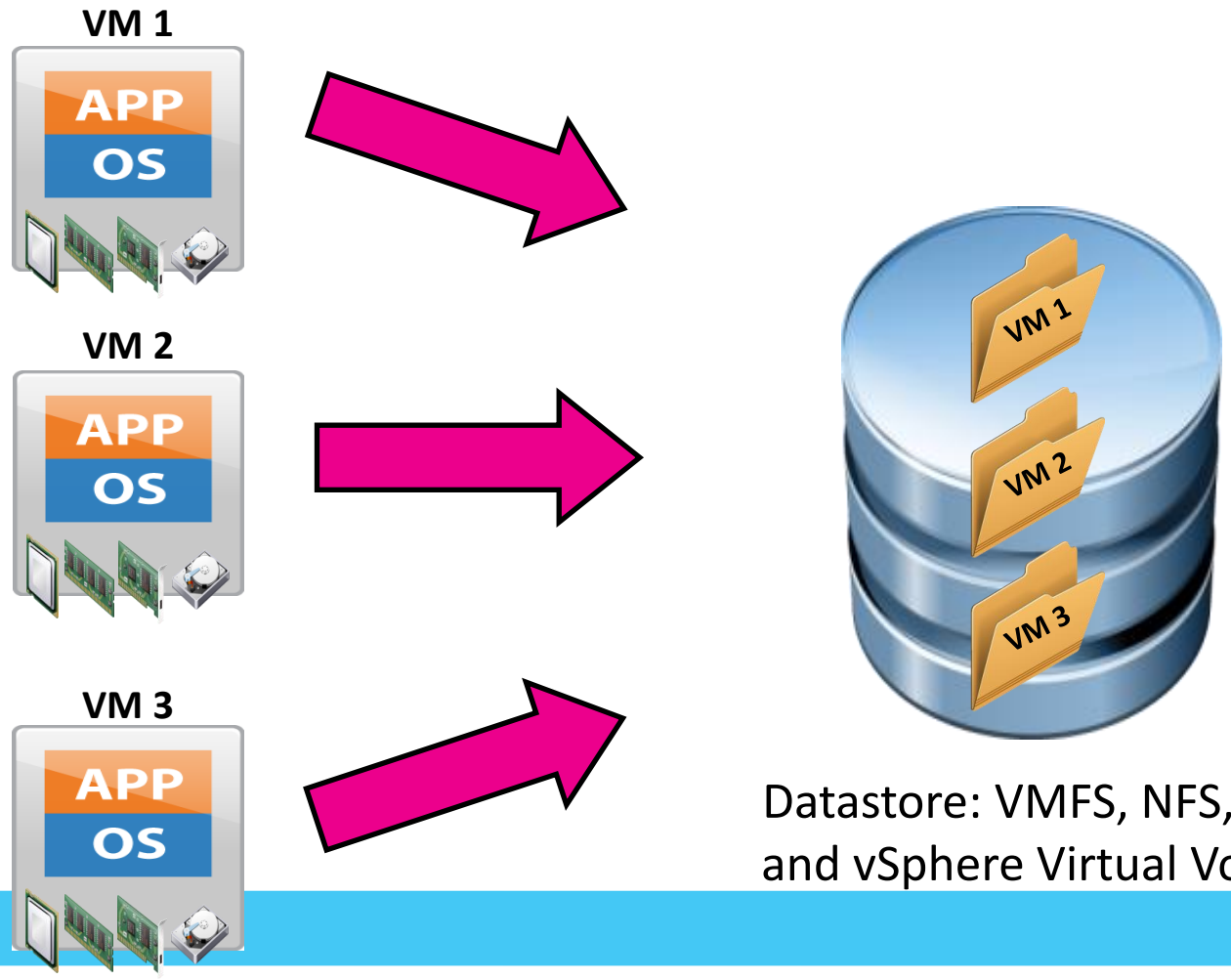
Encapsulation

Virtual machine files are stored in directories on a VMFS, NFS, VMware vSAN™ or VMware vSphere® Virtual Volumes™ datastore.



Datastore: VMFS, NFS, vSAN, and vSphere Virtual Volumes

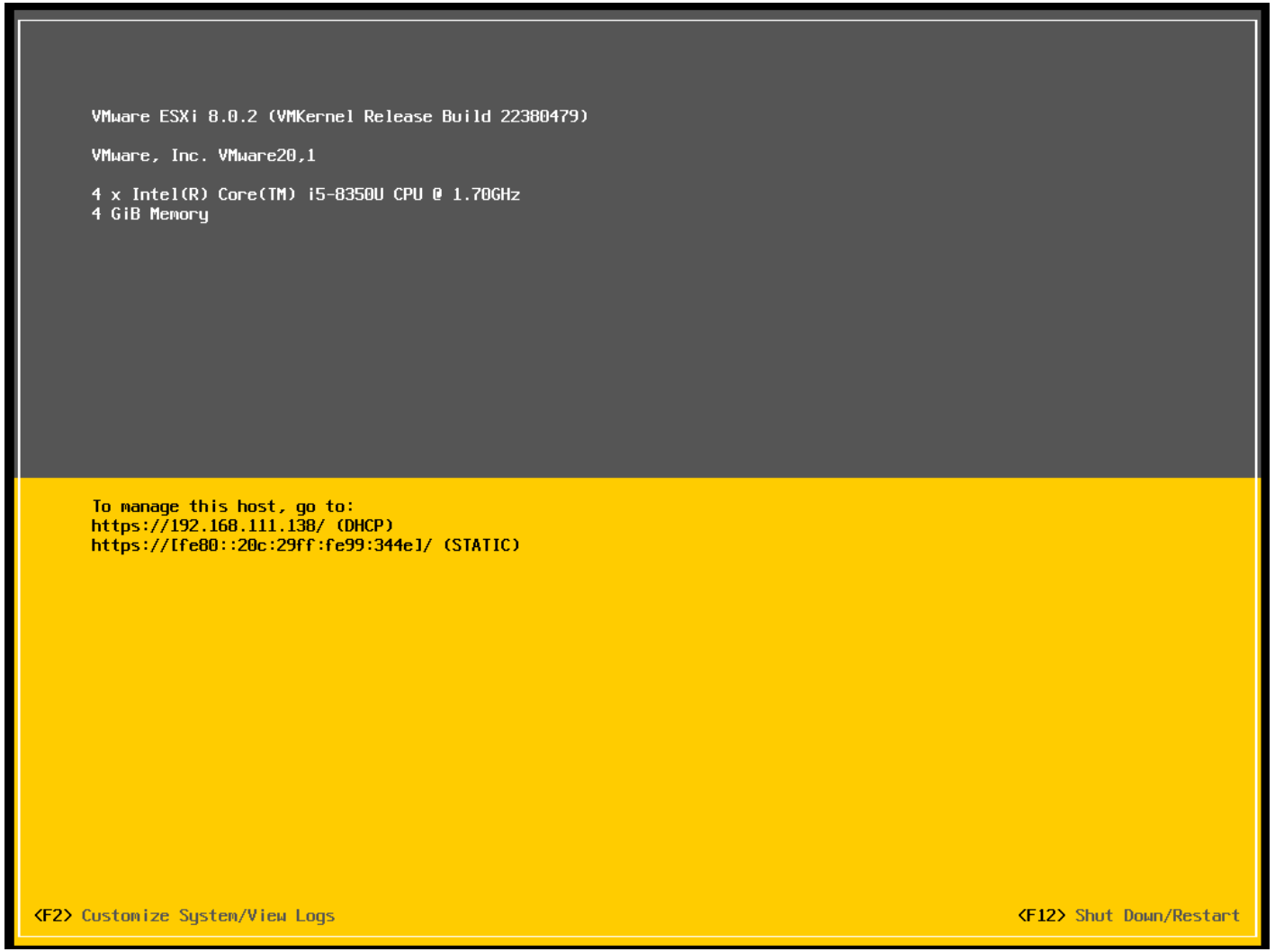
ESXi practicalities

- ESXi has a very simple installer:
  - Only a password and a hard drive selection is needed during installation
  - It also has a very **limited direct configuration**, it is **managed entirely via a Web interface**

- VMware used to recommend to install it to a USB thumb drive (or SD card, maybe in RAID1)
  - It loads into RAM and only uses the thumb drive to store ESXi image & configuration.
  - “ESXi configuration” is very limited: NIC settings, password, keyboard, service settings

- VMs are on a (VMFS) volume (not on thumb drives)
  - Resetting ESXi does not change the VMs …

ESXi Direct Console User Interface (DCUI)



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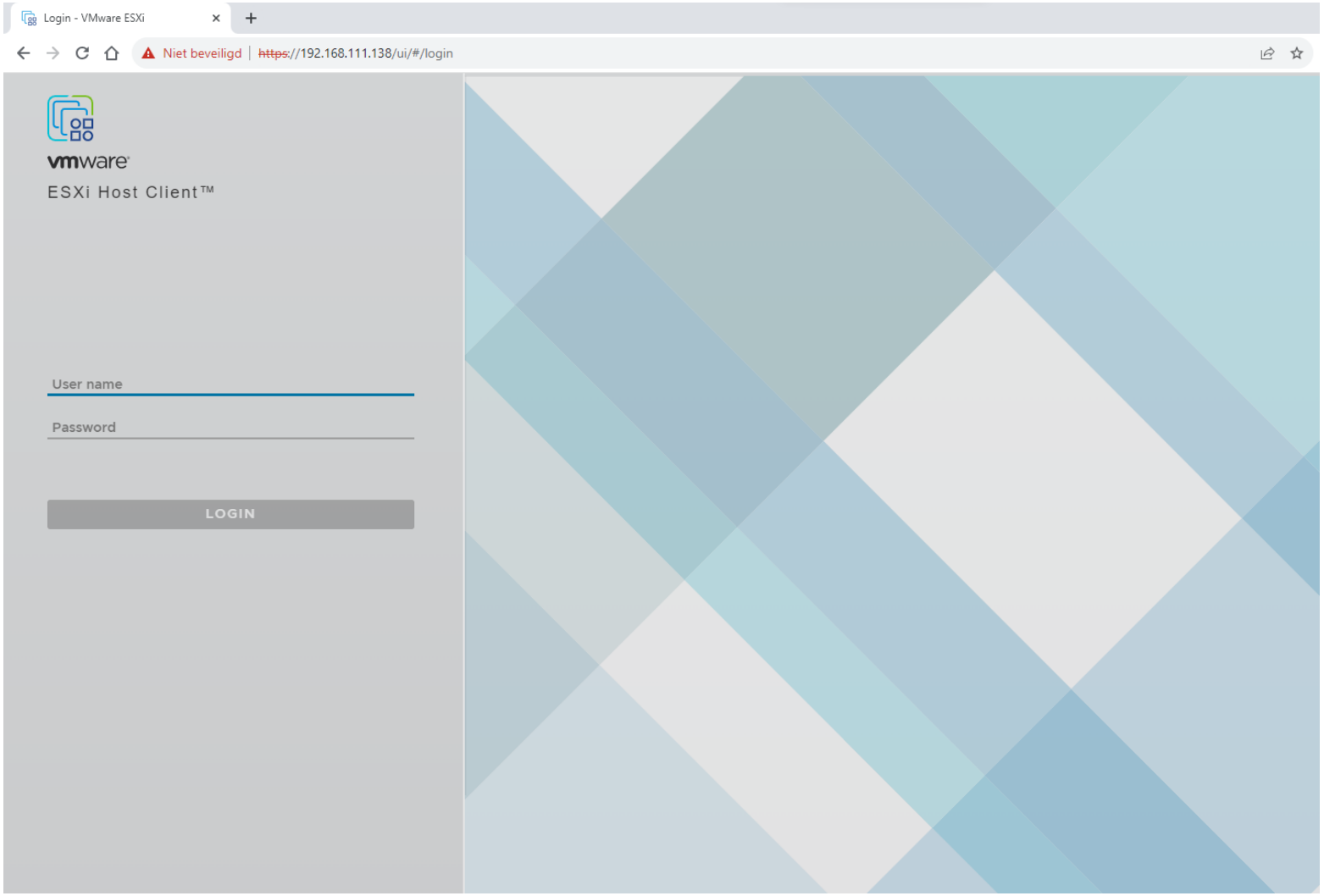
ESXi web interface



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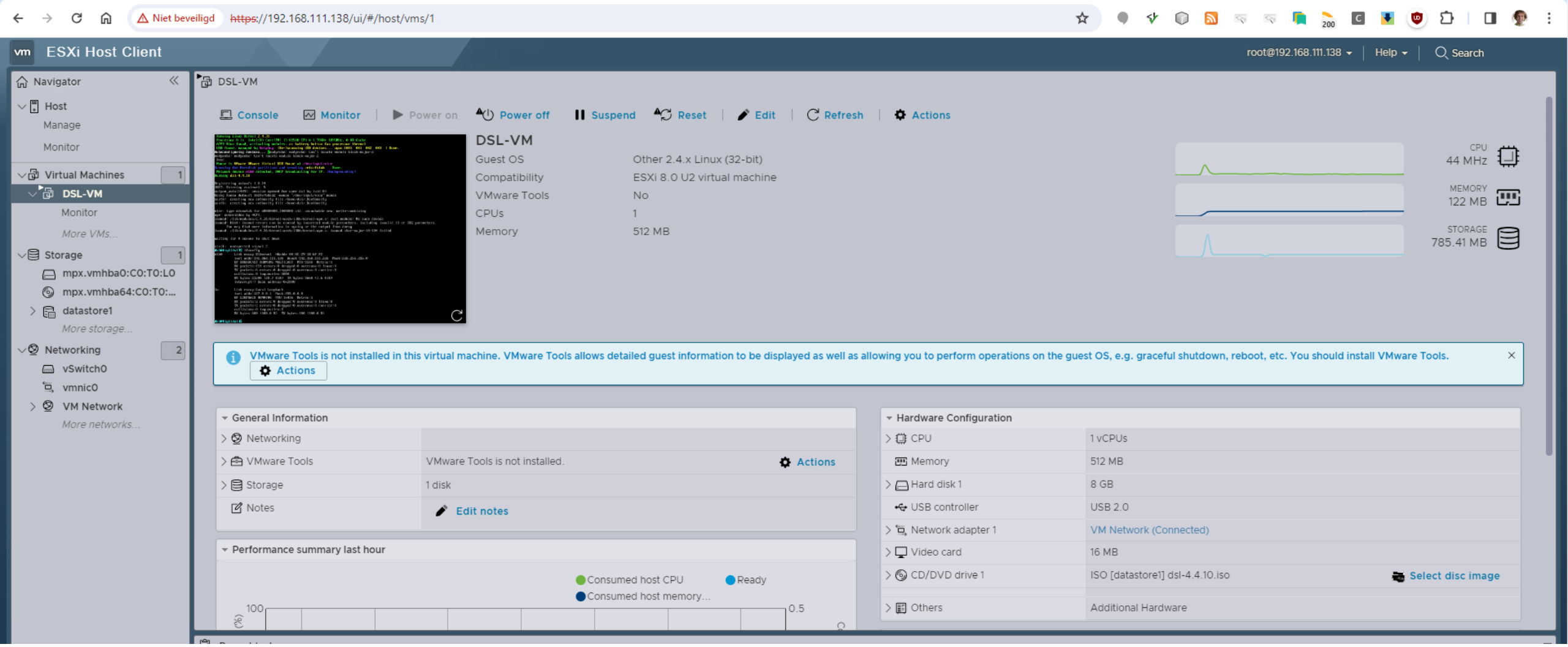
ESXi web interface



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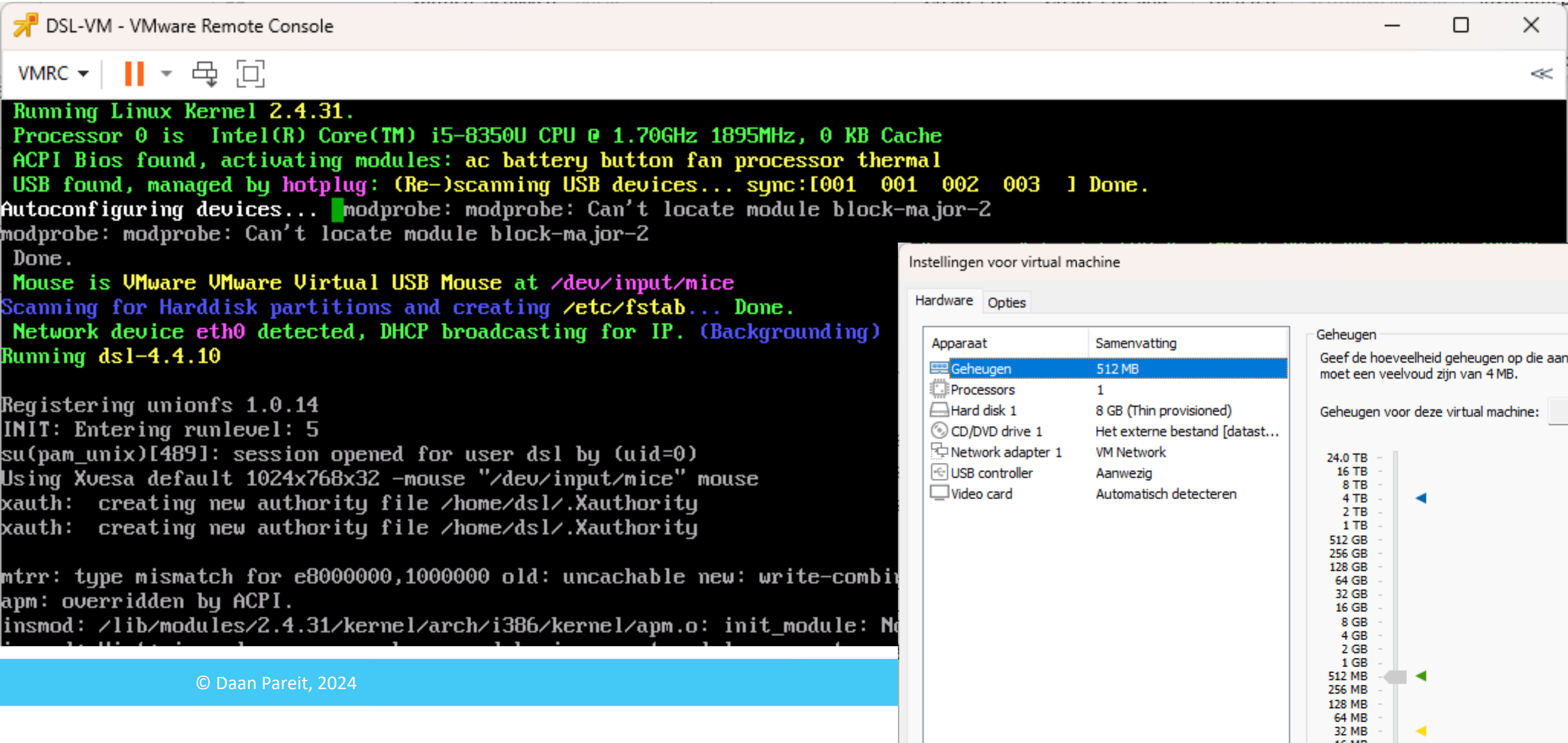
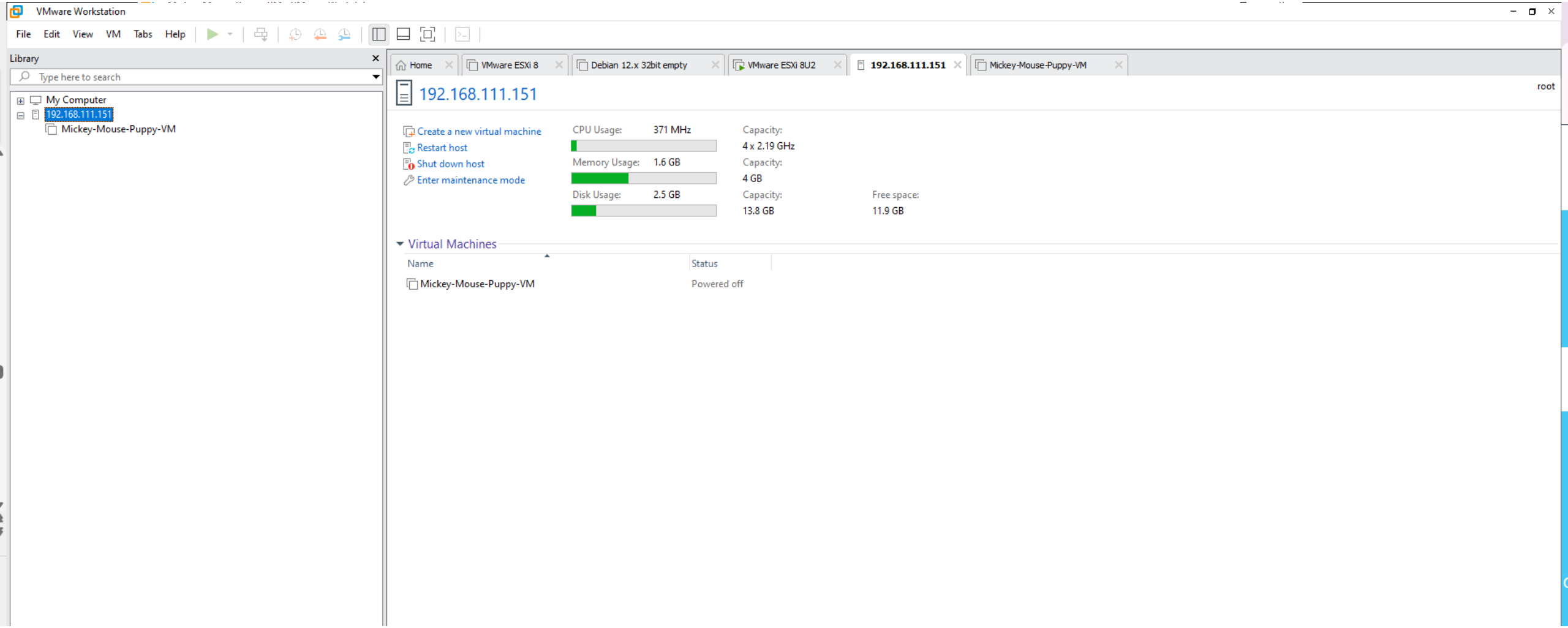
VMware Remote Console



VMware workstation – “Connect to server”



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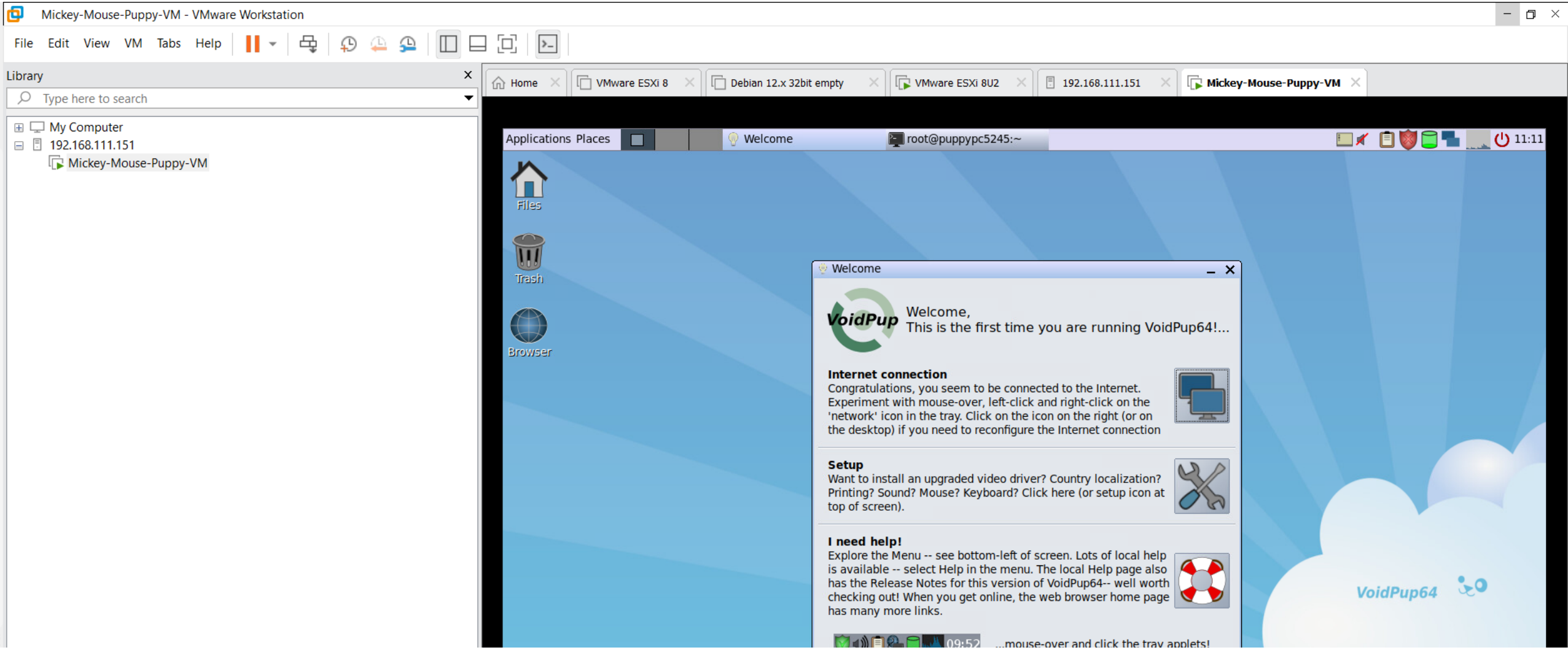
VMware workstation – “Connect to server”



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End Of General Availability of the free vSphere Hypervisor (ESXi 7.x and 8.x)

Article ID: 345098 Updated On: 07-09-2024

Products

VMware vSphere ESXi | VMware vSphere ESXi 6.0 | VMware vSphere ESXi 7.0 | VMware vSphere ESXi 8.0

Issue/Introduction

VMware vSphere Hypervisor (free edition) is no longer available on the VMware website.

Resolution

As part of the transition of perpetual licensing to new subscription offerings, the VMware vSphere Hypervisor (Free Edition) has been marked as EOGA (End of General Availability). At this time, there is not an equivalent replacement product available.

For further details regarding the affected products and this change, we encourage you to review the following blog post: VMware End Of Availability of Perpetual Licensing and SaaS Services.

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https://knowledge.broadcom.com/external/article/345098/end-of-general-availability-of-the-free.html

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Central management in VMware

VMware vSphere Suite

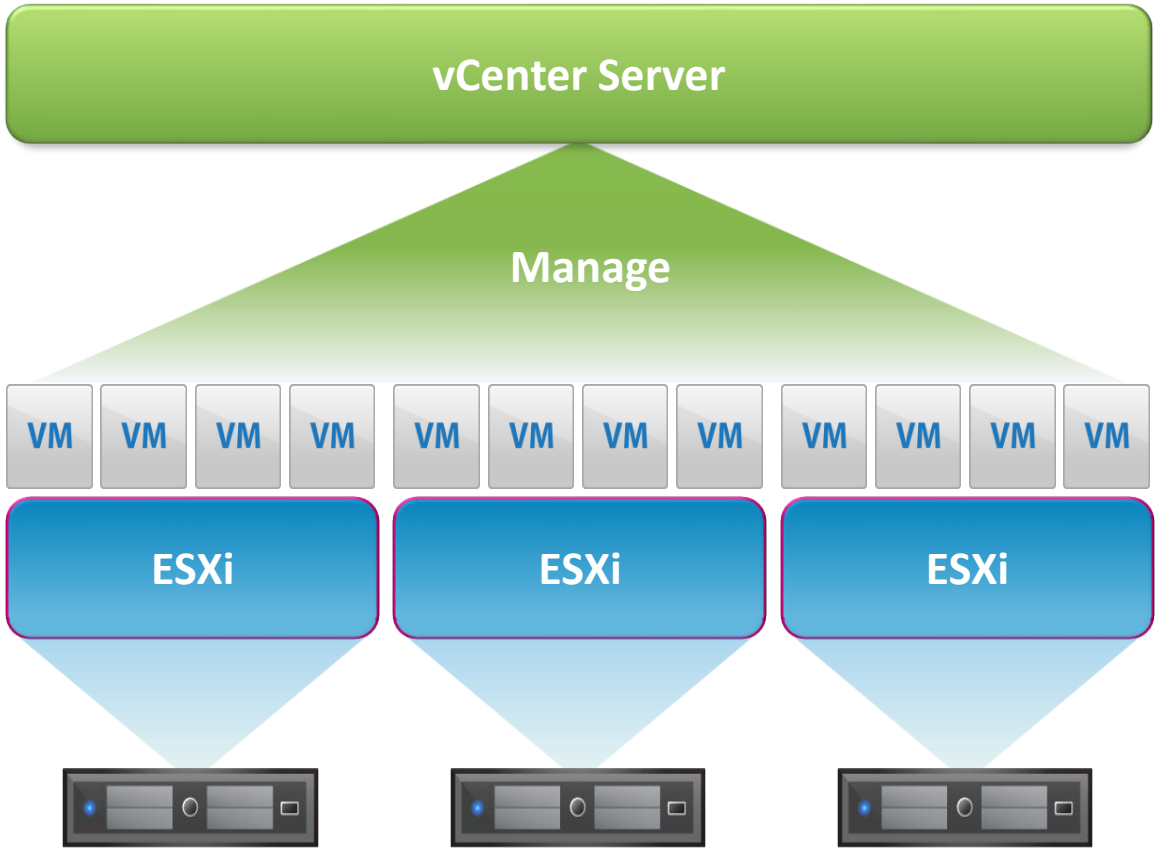
- When managing multiple ESXi hosts, a central management solution is necessary
  - This is called the "**VMware vSphere Suite**"
  - Multiple editions: 'Essentials (Plus)', 'Standard', 'Enterprise Plus', 'Desktop', etc.
- This suite contains multiple products
  - The minimal is "**vSphere Hypervisor (ESXi)**" and "**vCenter Server**"
- **vCenter Server is really a VM or *Appliance***
  - **Installing this is as simple as deploying a ready-made virtual machine**

Essentials	
VMware vSphere Hypervisor (ESXi) 8.0U2	2023-09-21
VMware vCenter Server 8.0U2	2023-09-21
VMware NSX 4.1.1.0 For vShield Endpoint	2023-08-15
VMware Tools 12.3.0	2023-08-31
Essentials Plus	
VMware NSX 4.1.1.0 For vShield Endpoint	2023-08-15
VMware vSphere Hypervisor (ESXi) 8.0U2	2023-09-21
VMware vCenter Server 8.0U2	2023-09-21
VMware vSphere Replication 8.8.0	2023-09-21
VMware Tools 12.3.0	2023-08-31
Standard	
VMware vSphere Hypervisor (ESXi) 8.0U2	2023-09-21
VMware vCenter Server 8.0U2	2023-09-21
VMware vSphere Replication 8.8.0	2023-09-21
VMware Aria Automation Orchestrator 8.13.1	2023-09-07
VMware NSX 4.1.1.0 For vShield Endpoint	2023-08-15
VMware Tools 12.3.0	2023-08-31

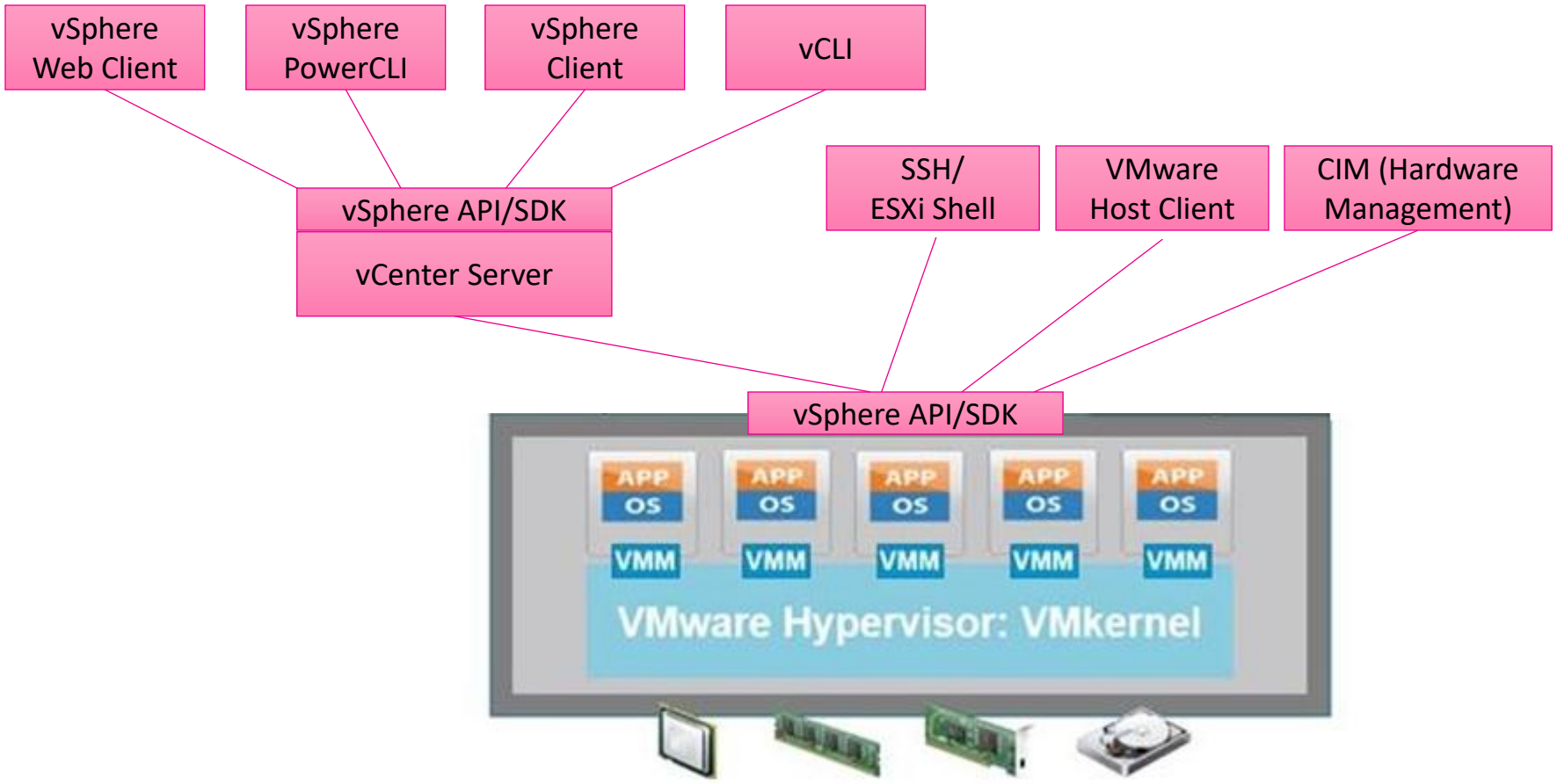
vCenter Server

vCenter Server adds features that are not available in a ~~free~~ standalone ESXi

- Cloning VM's
- Templates
- Updates via GUI
- Replication of VM's
- High Availability (more later)
- DRS / DPM (more later)



vCenter Server



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Managing vCenter Server

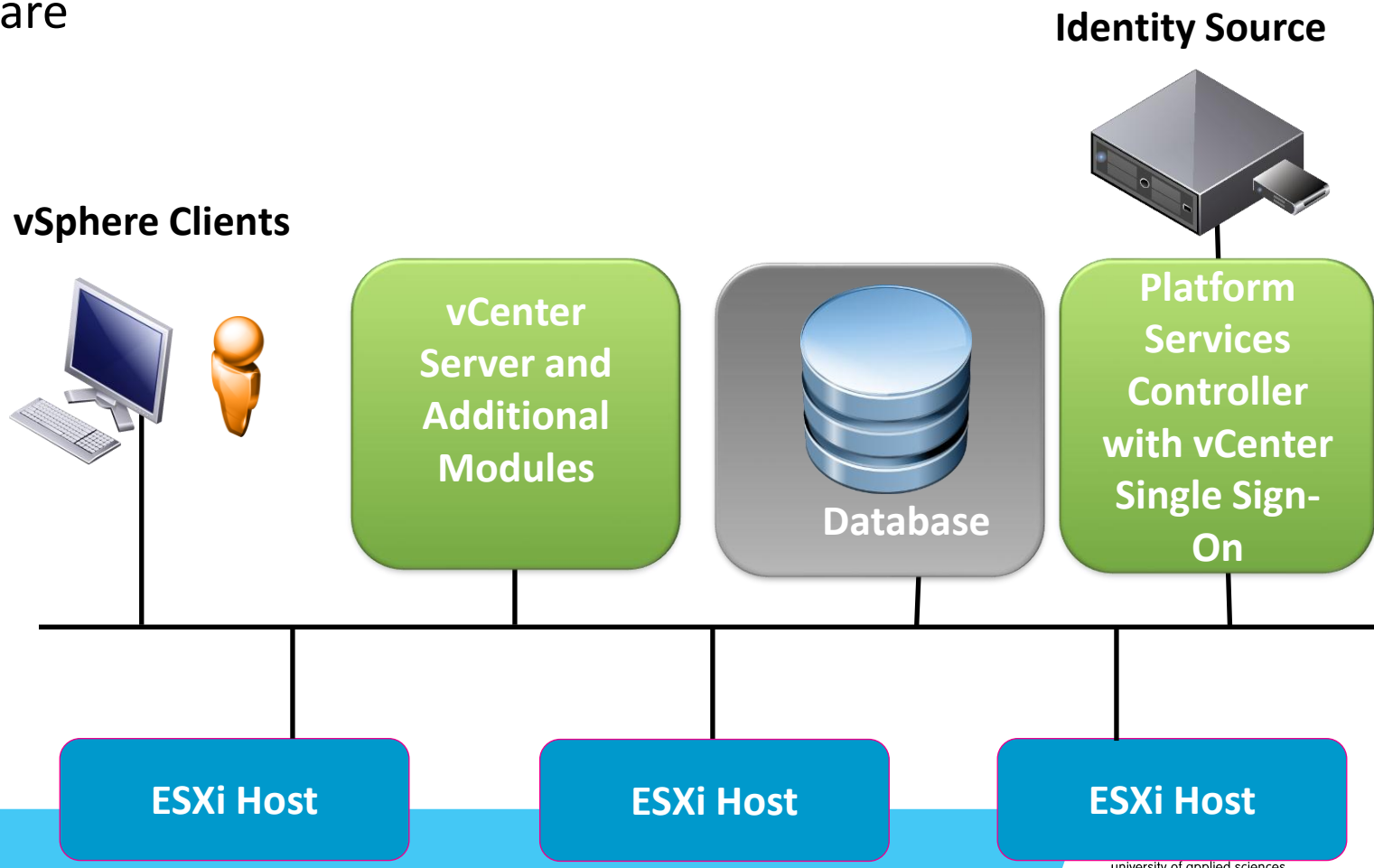
vCenter Server is modular, many third-party vendors have supporting software

- E.g. Dell EMC or HP EVA modules

vCenter can be managed via

- Web interface (HTML5)
- PowerShell
  (Install-Module
  -Name VMware.PowerCLI)

Uses “Single Sign-On” and is usually linked to AD for easy login



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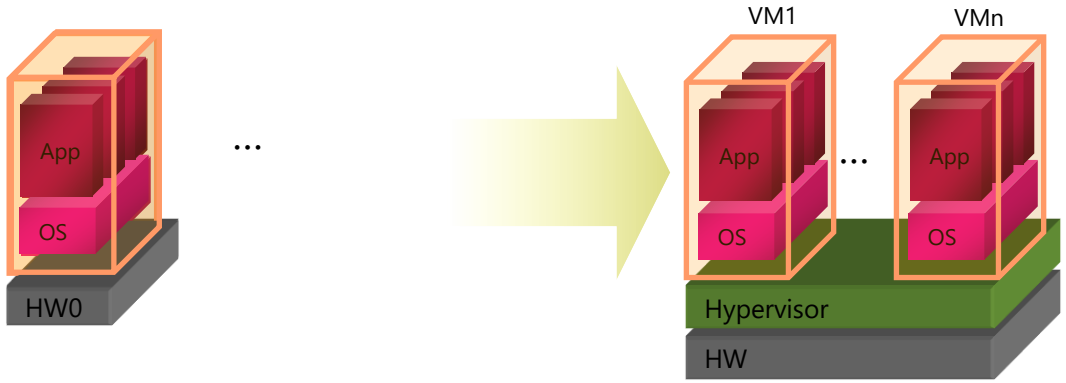
Shared Storage in datacenters

Advanced Features (Bare-Metal only)

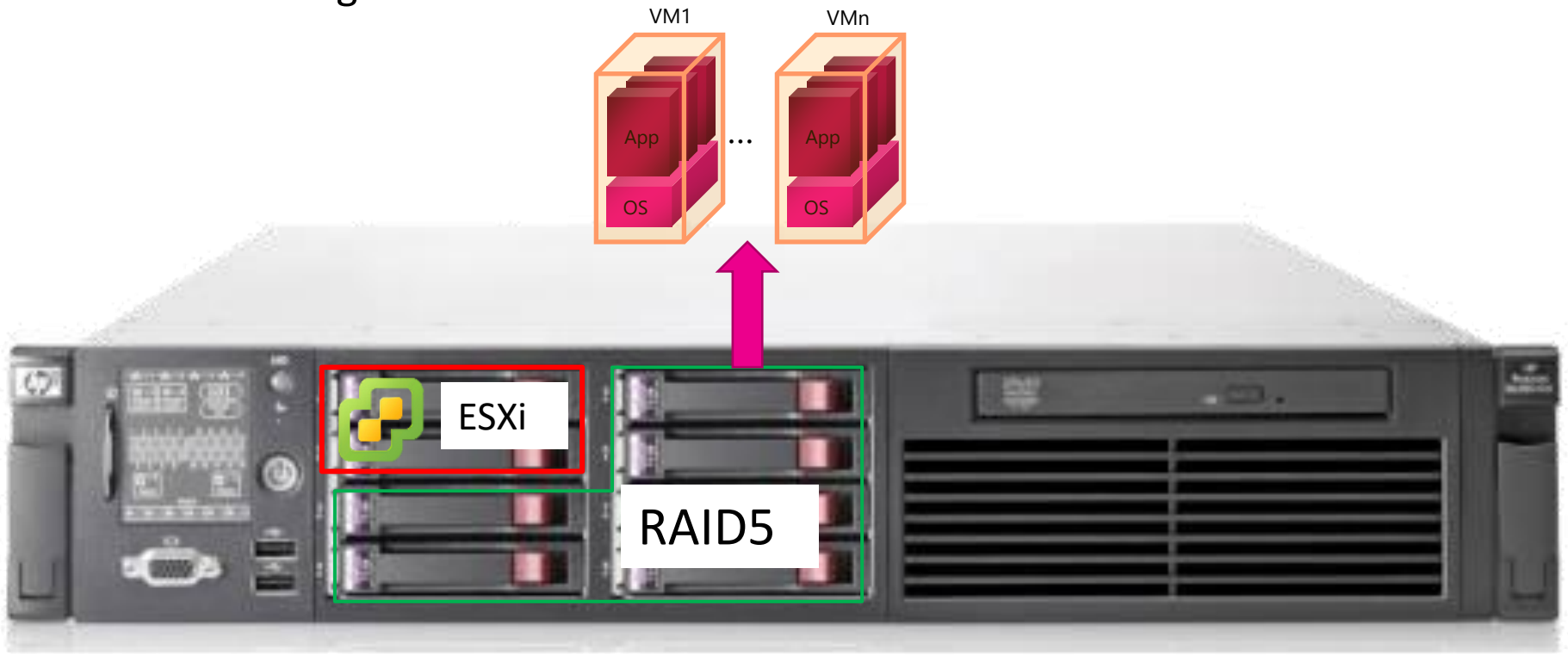
- First phase of Virtualization: **Consolidation**

- Running multiple Operating Systems on a single system



Datacenters “think” differently

- By using **Shared Storage**
- Datacenters are moving from here:



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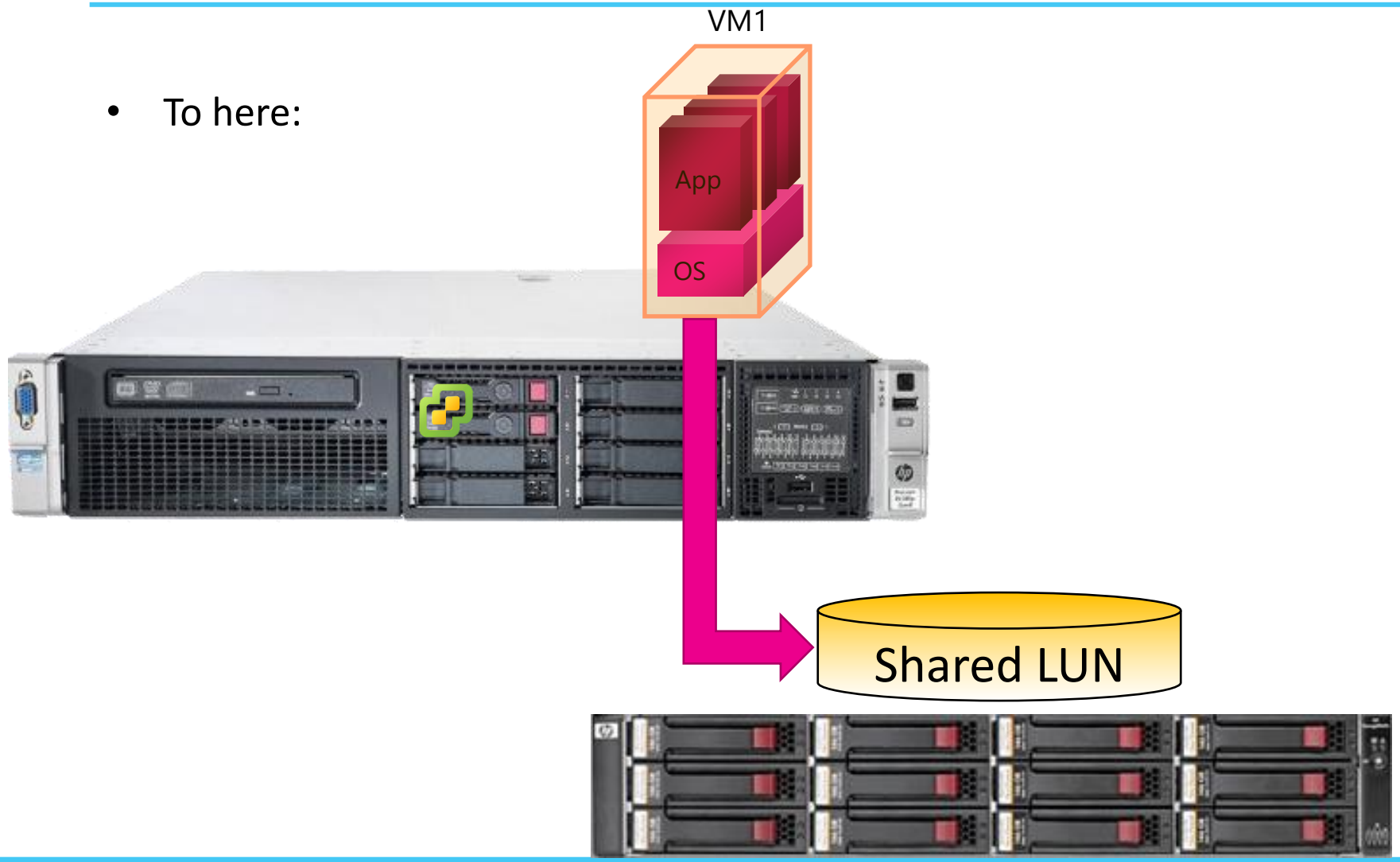
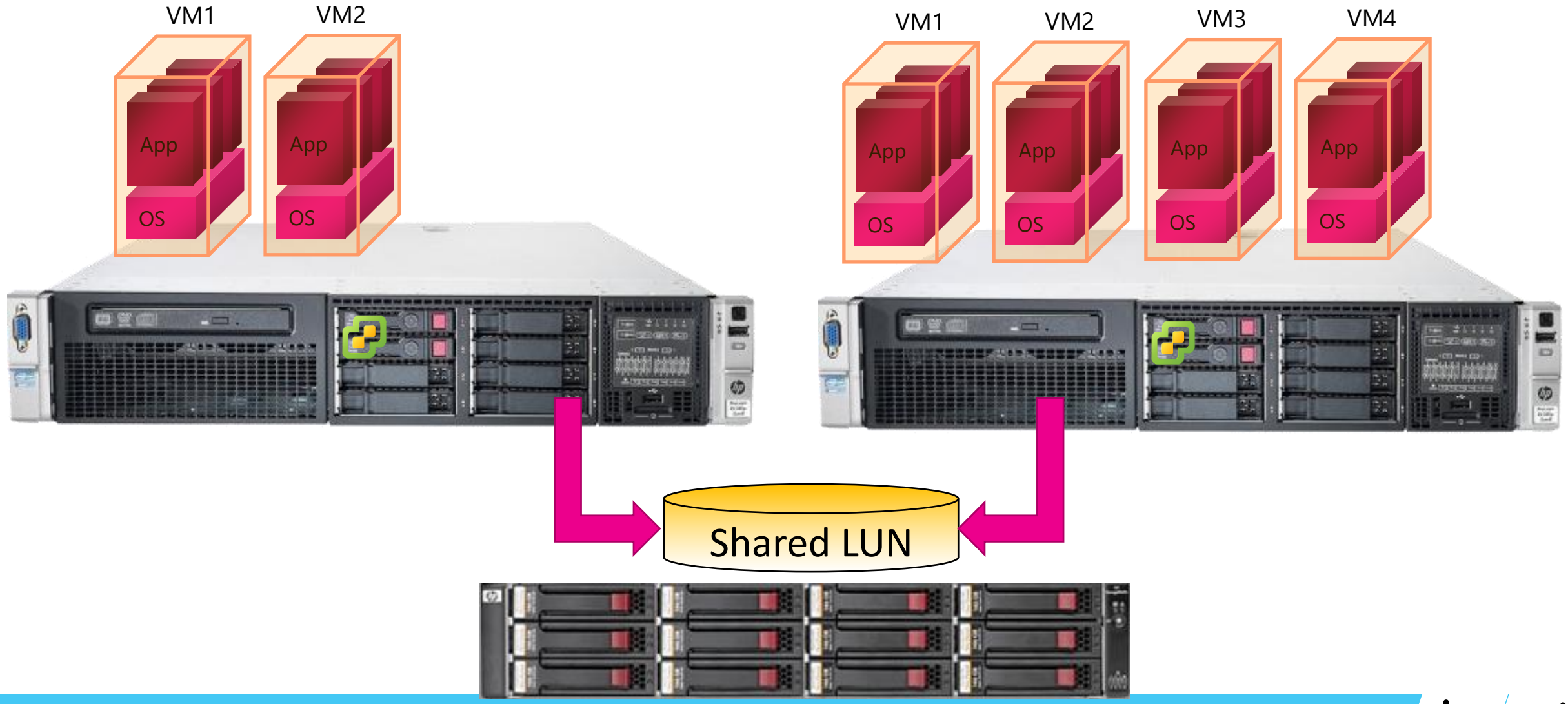
Shared Storage

- To here:



Movement 1: High Availability



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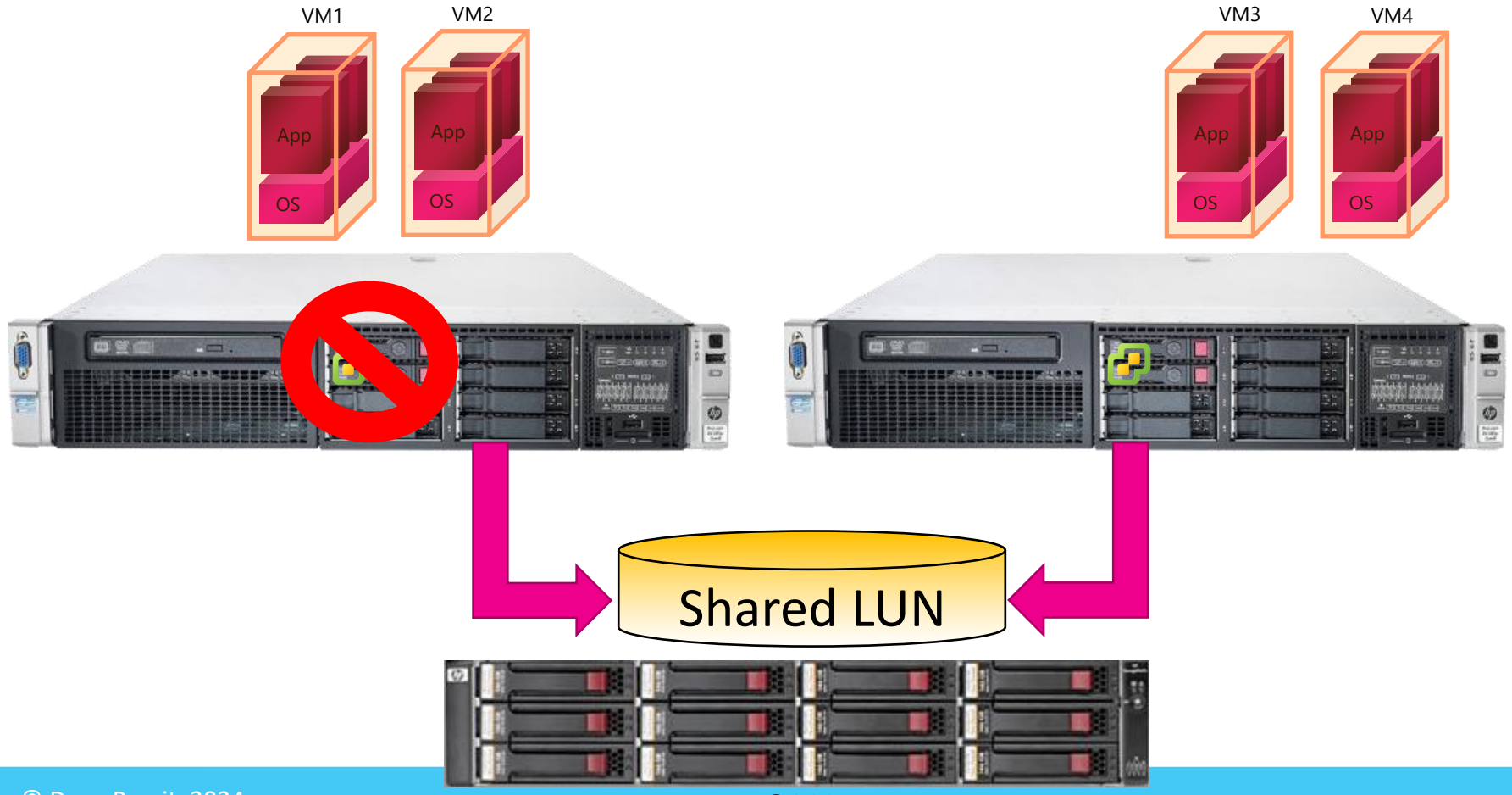
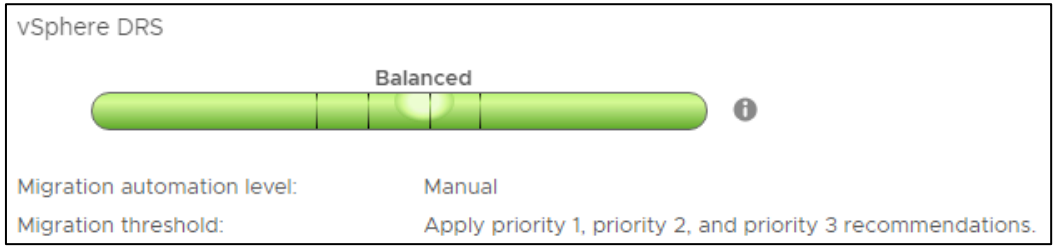
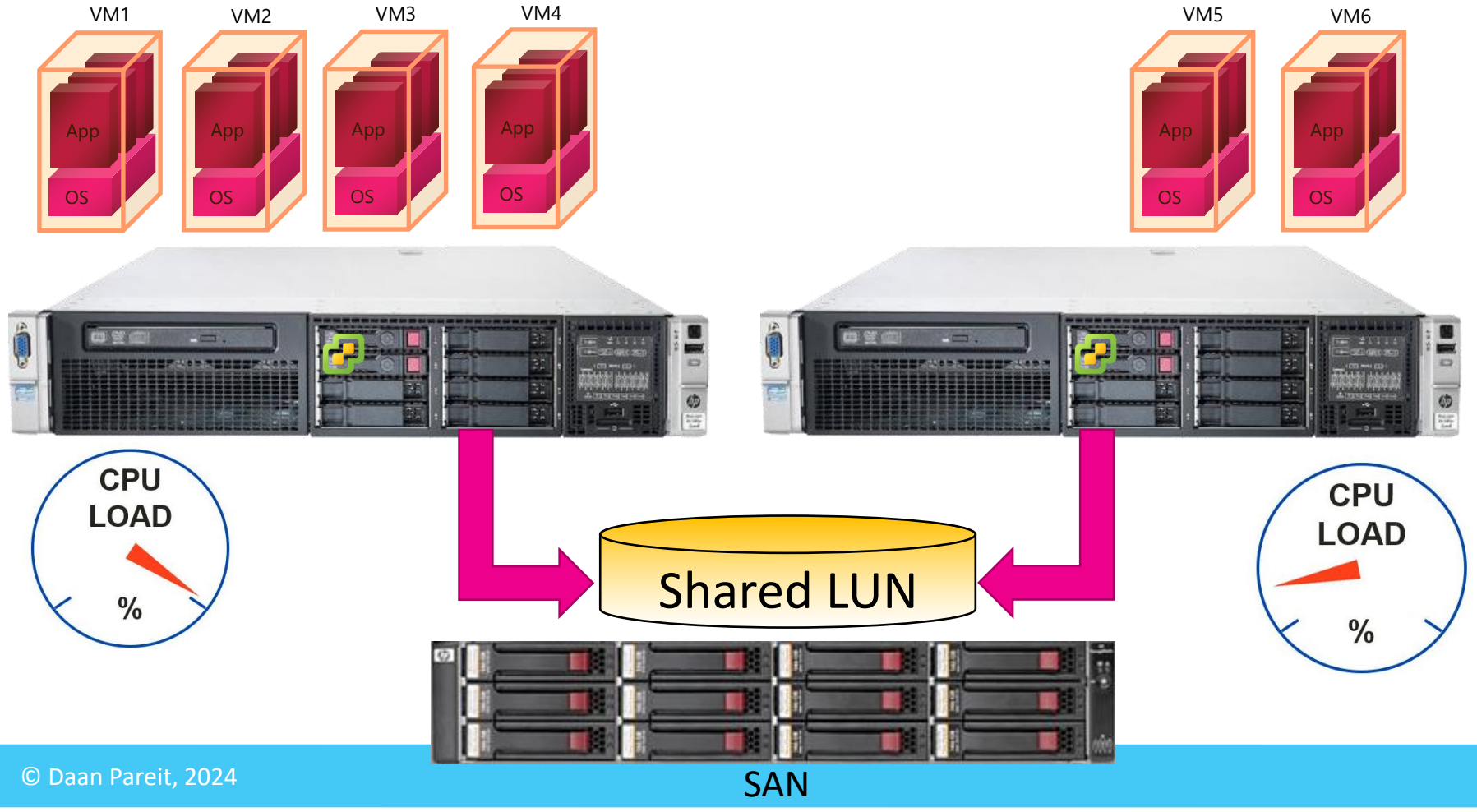
Movement 2: vMotion (~2010)

Or: *Migration without downtime*



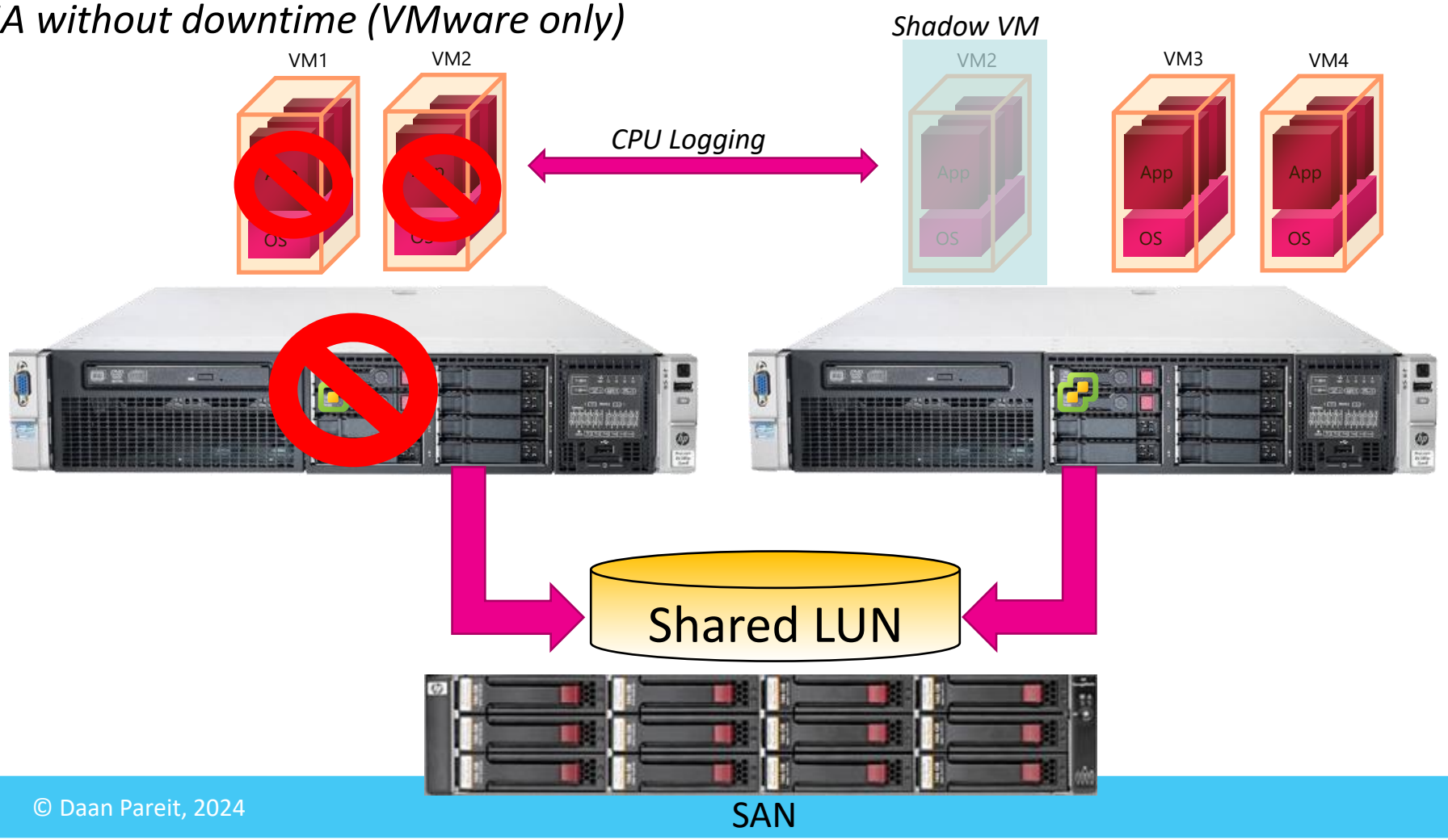
Dynamic Resource Scheduling





Movement 3: Fault Tolerance (~2012)

Or: *HA without downtime (VMware only)*



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Vmware alternatives

Mostly used alternatives

- VMware workstation
  - Oracle virtual box (vm not directly accessible though NAT)
- ESXI
  - Linux KVM (also used by Oracle Linux)
  - Hyper-V (Microsoft)
  - Openshift (RedHat)
- Vsphere
  - Proxmox -> used in our Labo’s
  - Openstack -> more Cloud based
- But the future : Containers

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The Lab: VMware Virtualization

Hosted virtualization (Workstation / Fusion)

+

Bare-metal virtualization (ESXi)

Lab

- Remember: in datacenters, ESXi is installed on powerful servers (which meet the supported hardware compatibility list, HCL) as its dedicated operating system

- Big surprise: we can't donate a server to every student 🤷 . You'll thus have to install ESXi within your Workstation/Fusion
  - Realization 1: you're installing a type 1 hypervisor within your type 2 host virtualization 😱
  - Realization 2: you will be running VMs in ESXi, which itself is a VM in your Workstation/Fusion
    ➔ **nested virtualization**

- Note: Hypervisor VMs on Workstation are only possible if Hyper-V extensions are disabled on the host
  - more details in the lab and in 'hyperv-vs-vmware.txt' on Leho