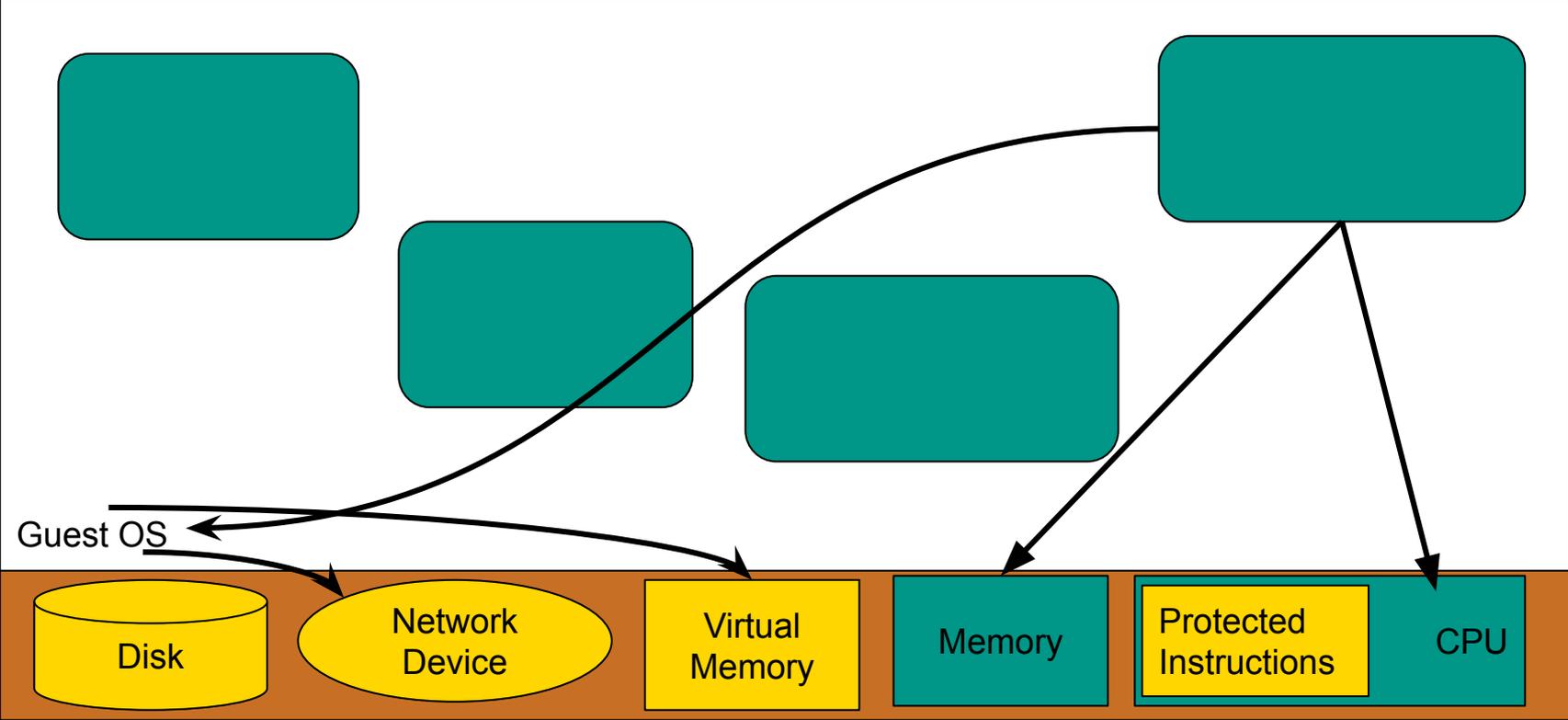


Virtual Machines

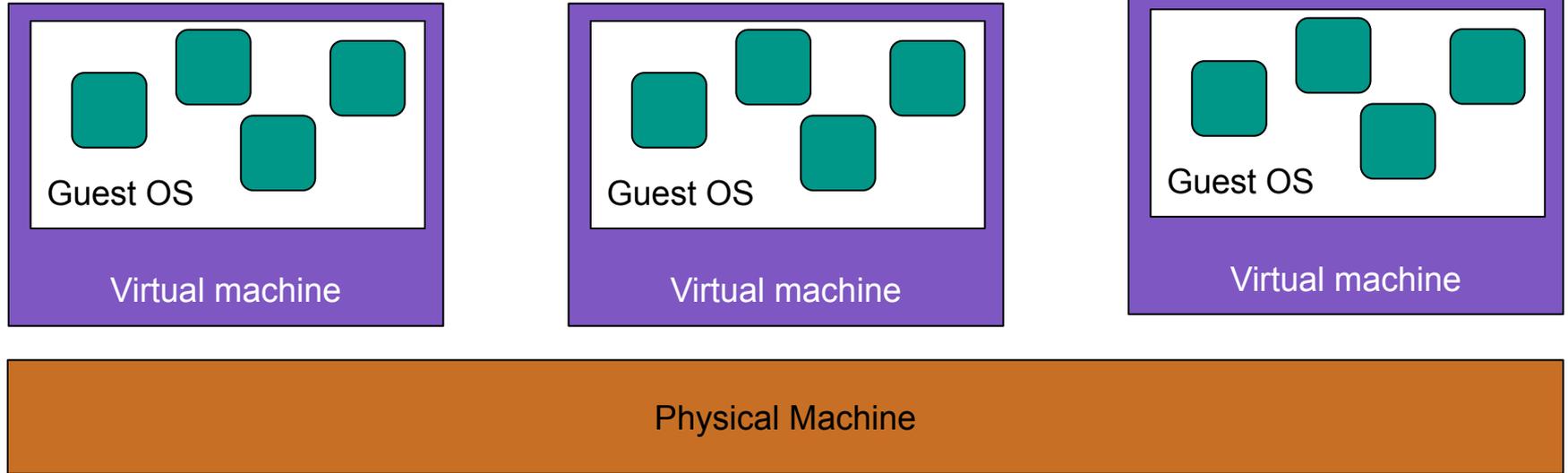
COS 316 Lecutre 18



Physical Machines



Virtual Machines



Virtualization

presents a physical machine as though many guest OSs had exclusive access

Virtual Machines vs. Processes?

	Virtual Machine Interface	Process Interface
<i>Network</i>	Network device (ethernet, WiFi, etc...)	TCP & UDP sockets
<i>Storage</i>	Block device	File System
<i>Compute</i>	CPU	Unprivileged subset of CPU (x86/ARM/RISC-V...)
<i>Memory</i>	Virtual & physical memory addresses	Virtual addresses only

Why Virtual Machines?

Scalability: Disco (1997)

“[W]e examine the problem of extending modern operating systems to run efficiently on large-scale shared-memory multiprocessors without a large implementation effort. [...] We use virtual machines to run multiple commodity operating systems on a scalable multiprocessor.”

“Disco: Running Commodity Operating Systems on Scalable Multiprocessors”

Edouard Bugnion, Scott Devine, Kinshuk Govil, and Mendel Rosenblum

Ed, Scott & Mendel (along with Diane Green) founded VMWare a year later
in October 1998

Scalability: Disco (1997)

From Edouard Bugnion's job talk at EPFL in 2014:

“First, Disco ran commodity operating systems on scalable MIPS multiprocessors. [...] Second, VMware Workstation is a successful commercial product that allows...”

Work by a few grad students

(along with Diane Gre

Work by 10,000s of employees
at a \$70B Company

SAME!

Flexibility: VMWare Workstation, Parallels

1999-~2006

Use virtual machines alongside physical machines

Run Windows apps on Linux, and Linux apps on Windows

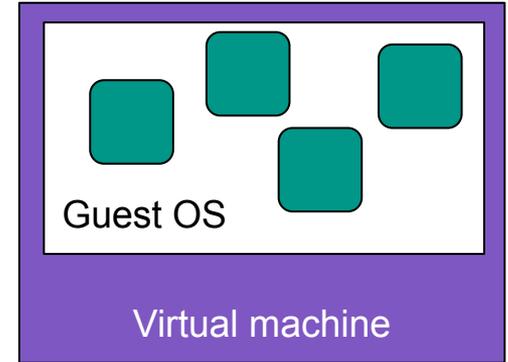
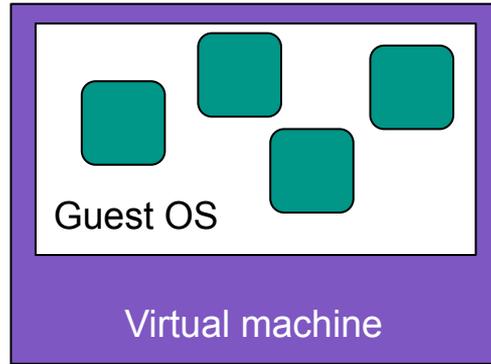
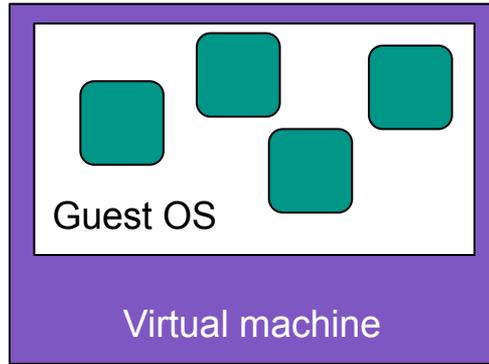
Cloud Computing: Amazon EC2

“Before the advent of Amazon EC2, you had to buy or rent sufficient servers to cover your present needs, and you also had to be able to anticipate [and] forecast [...] for enough hardware to accomodate(*sic*) [...] growth as well as bursts of traffic [...]

With Amazon EC2, you don't need to acquire hardware in advance of your needs. Instead, you simply turn up the dial, spawning more virtual CPUs, as your processing needs grow.”

-Amazon EC2 Announcement, August 25th 2006 *Jeff Barr*

Virtual Machines



Physical Machine

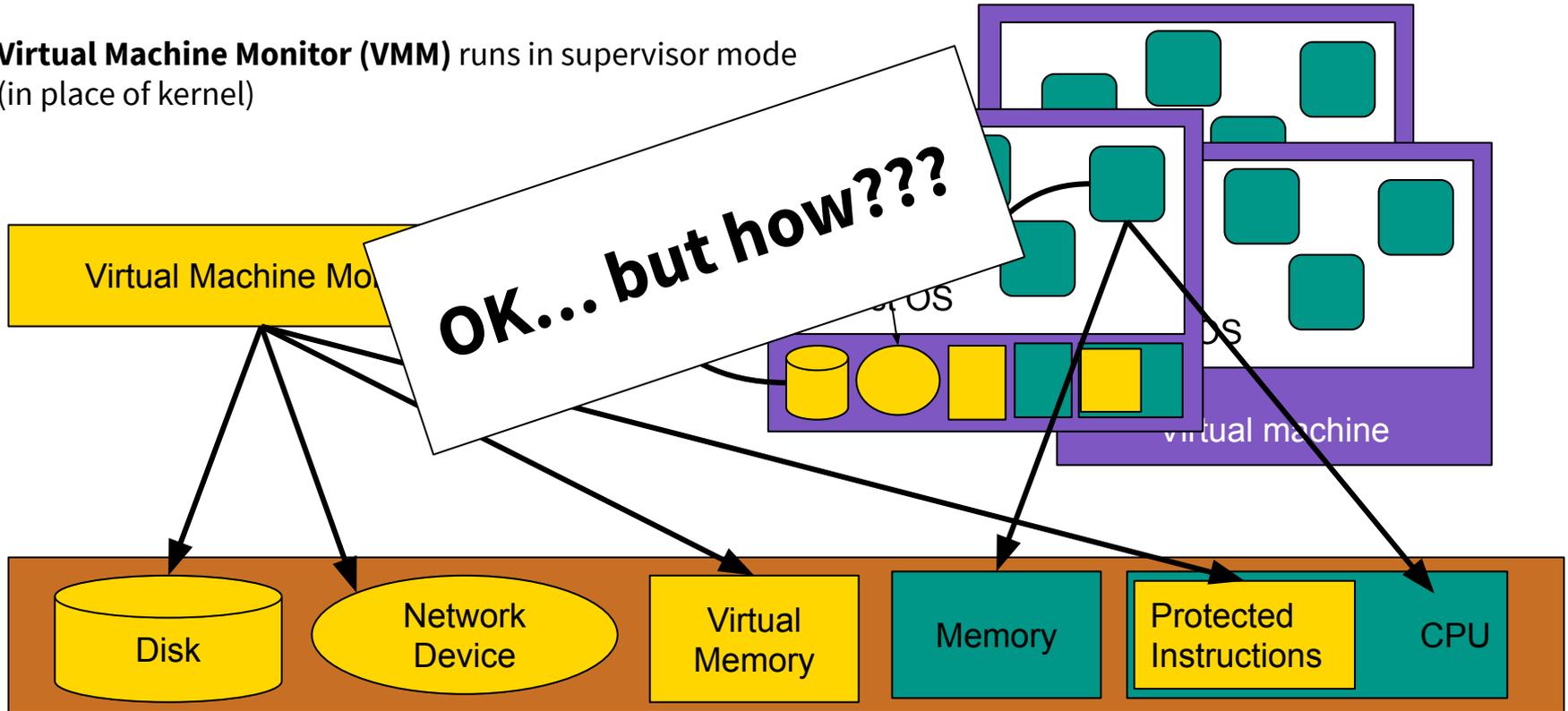
Virtualization

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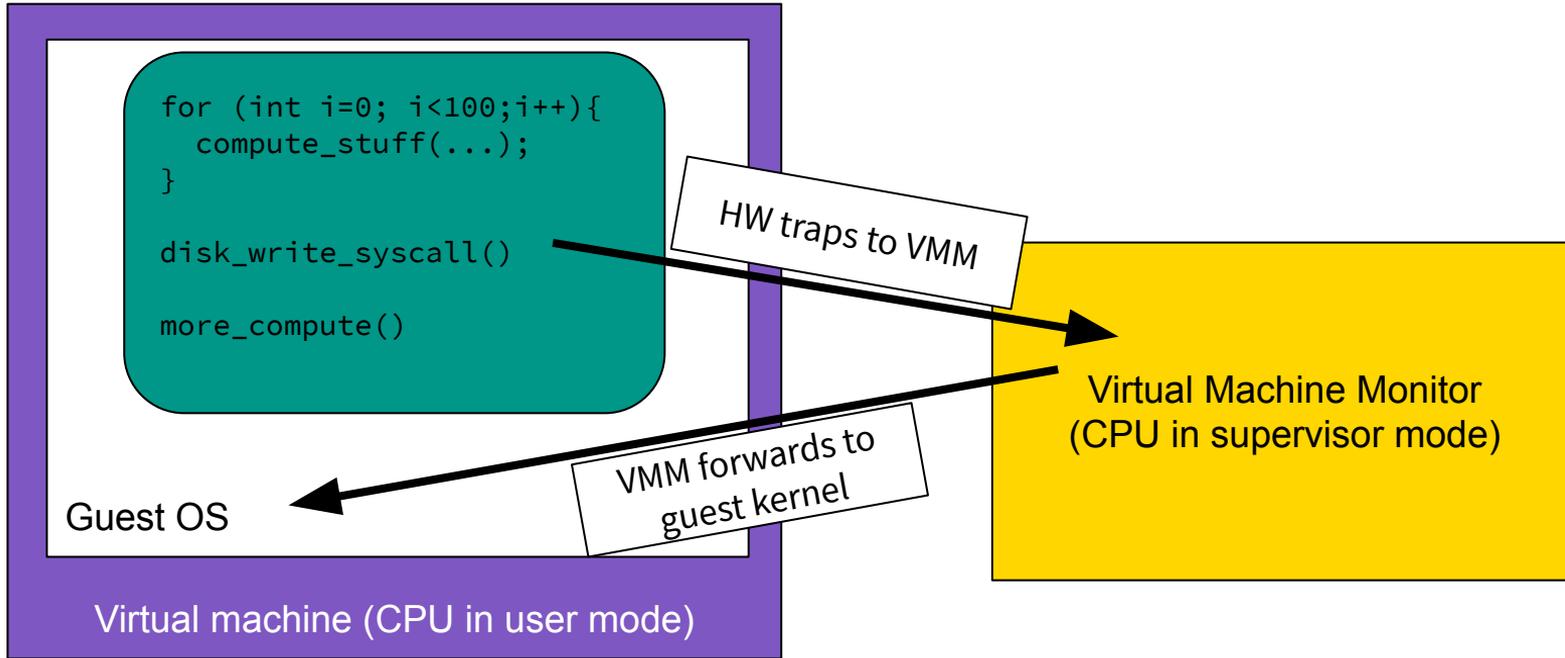
But How??

Virtual Machines

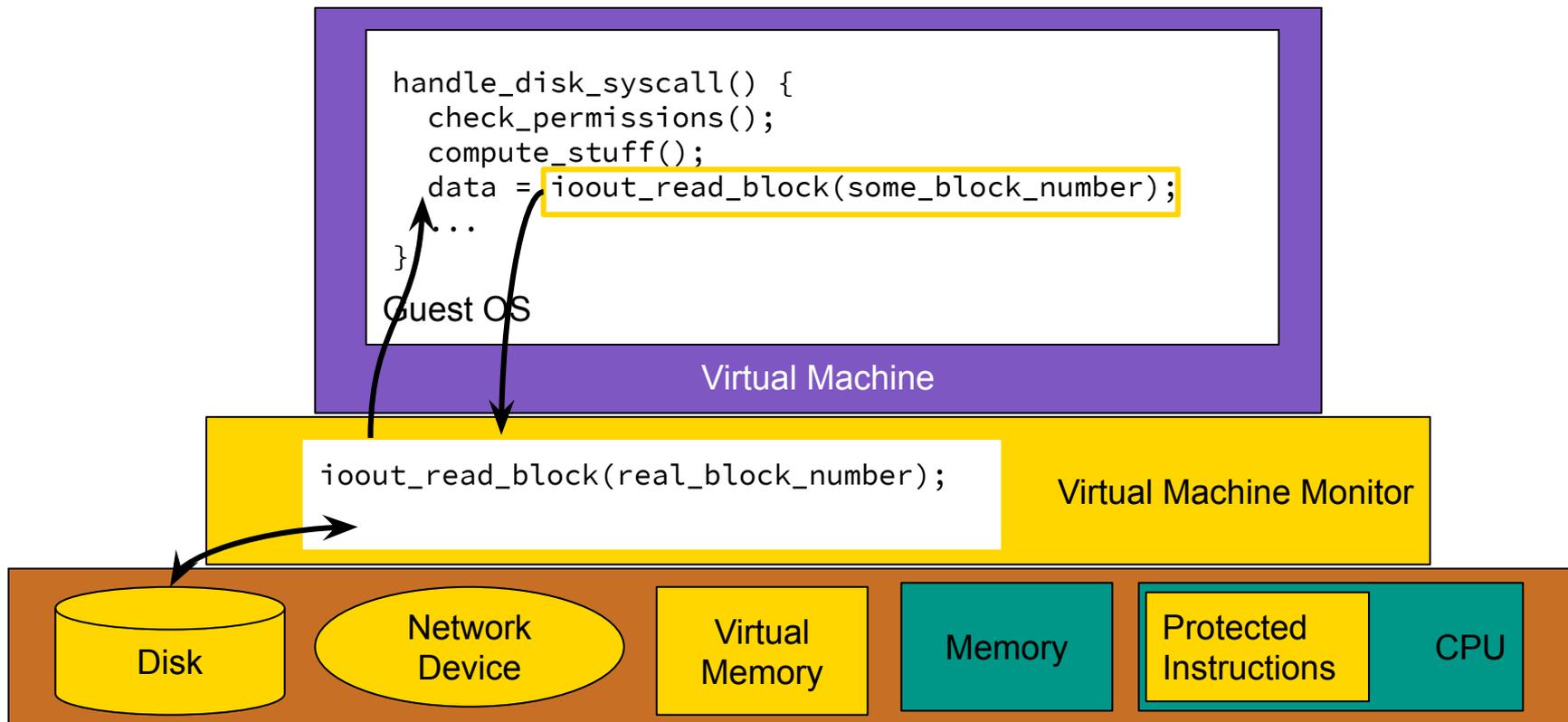
Virtual Machine Monitor (VMM) runs in supervisor mode
(in place of kernel)



Trap-and-Emulate: System Calls



Trap-and-Emulate: I/O



What if we *can't* trap-and-emulate?

x86 didn't fault when some protected instructions were executed by user programs.

E.g. setting interrupt flags with Pop-Flags (POPFL) instruction silently fails

- Binary translation
 - Before running VM code for the first time, translate it to replace with explicit calls to VMM
 - Disco & early VMWare
- Para-virtualization
 - Modify guest OSs to detect if they are running inside a VM and use different instructions
 - Xen (2003) & most VMMs since
- Modify the hardware
 - Intel VT-X, APICV, VT-d, SR-IOV, GVT-d, and on and on... starting 2005

Isn't a VMM just an Operating System?

- Yes!
- No: API is hardware resources (disk, network card), not abstract interfaces (file system, socket)

Next up

- Problem set due tomorrow
- Assignment 5 due Tuesday, December 3rd
- Next & last section of course is on access control