6.033 Spring 2021

Lecture #6: Virtual Machines and Performance

wrapping up operating systems

Katrina LaCurts | lacurts@mit.edu | 6.033 2021

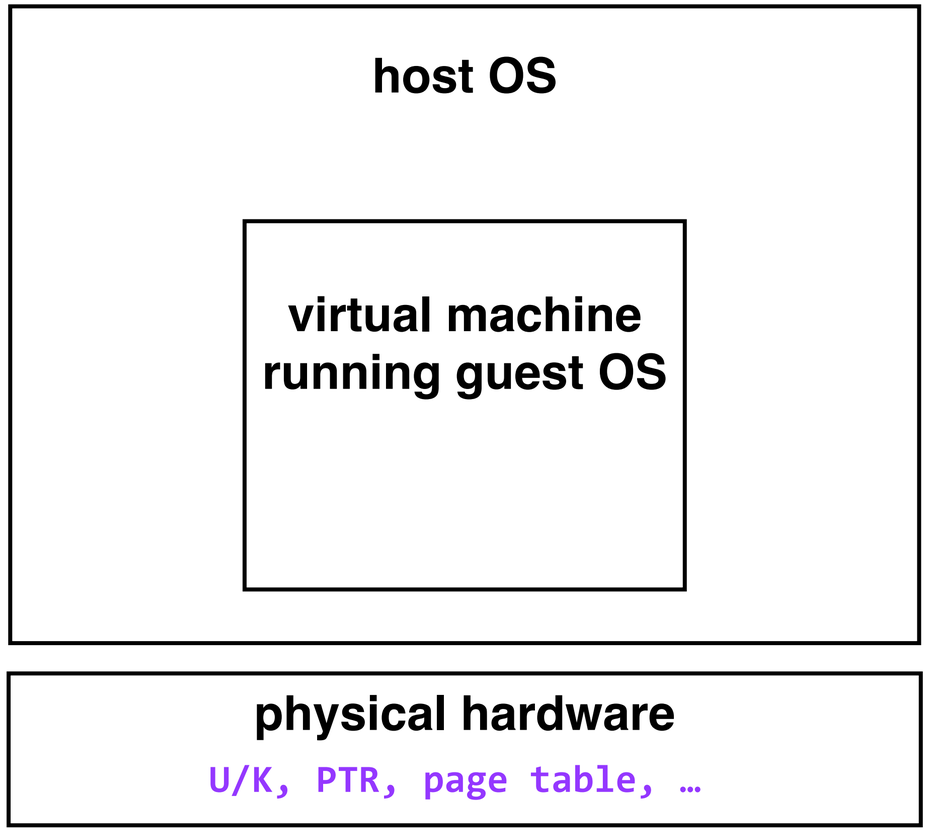
operating systems enforce modularity on a single machine using **virtualization**

in order to enforce modularity + have an effective operating system, a few things need to happen

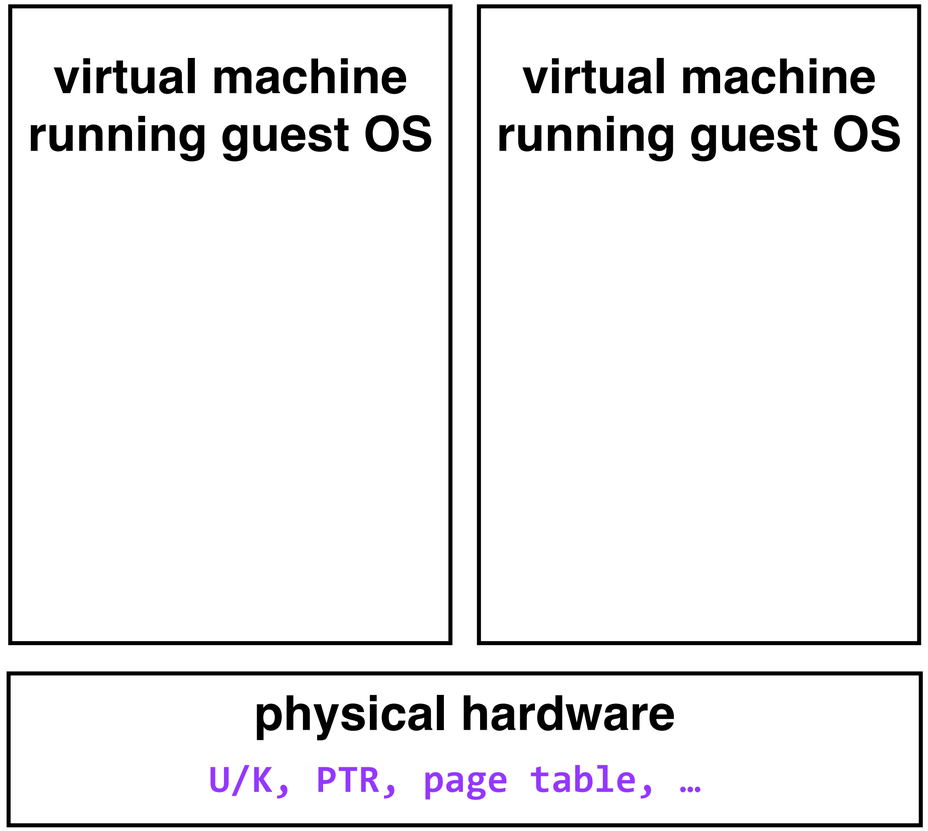
1. programs shouldn't be able to refer to (and corrupt) each others' **memory** → **virtual memory**
2. programs should be able to **communicate** with each other → **bounded buffers** (virtualize communication links)
3. programs should be able to **share a CPU** without one program halting the progress of the others → **threads** (virtualize processors)

today's goal: run multiple operating systems at once

common computing environment: running multiple OSes on a single physical machine

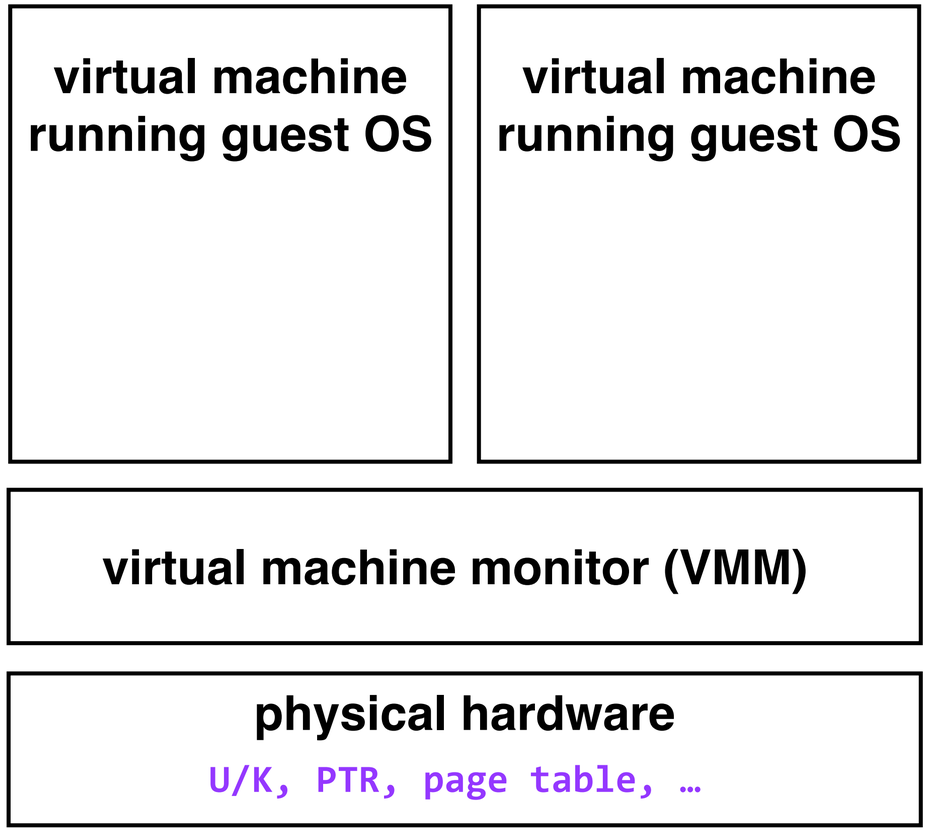


common computing environment: running multiple OSes on a single physical machine



problem: how to (safely) share physical hardware?

virtual machine monitor: virtualizes the physical hardware for the guest OSes



guest OSes run in user mode

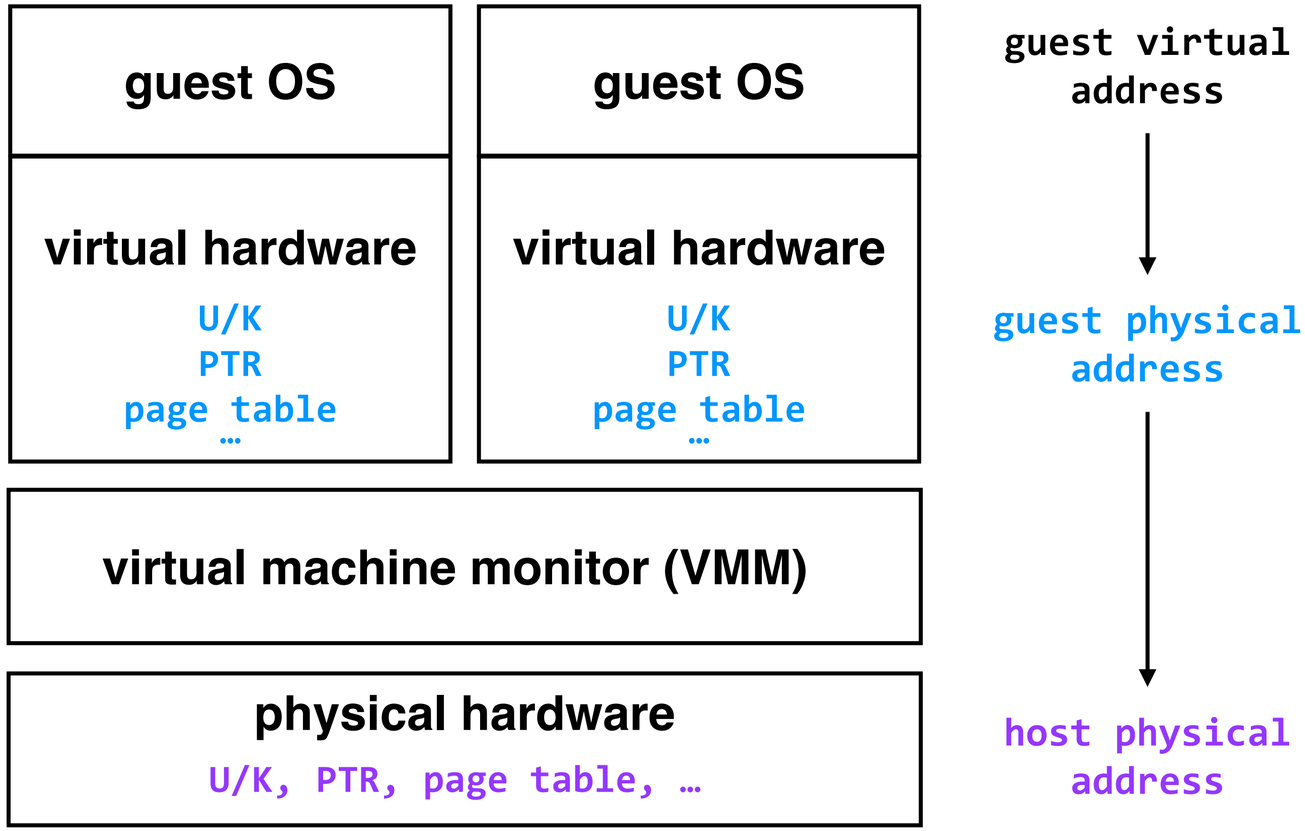
privileged instructions in guest OS will cause an exception, which the VMM will intercept ("**trap**") and **emulate**

if the VMM *can't* emulate an instruction, it will send the exception back to the guest OS for handling

first question: what does it mean to emulate?

virtual machine monitor: virtualizes the physical hardware for the guest OSes

first example: virtualizing memory (again)

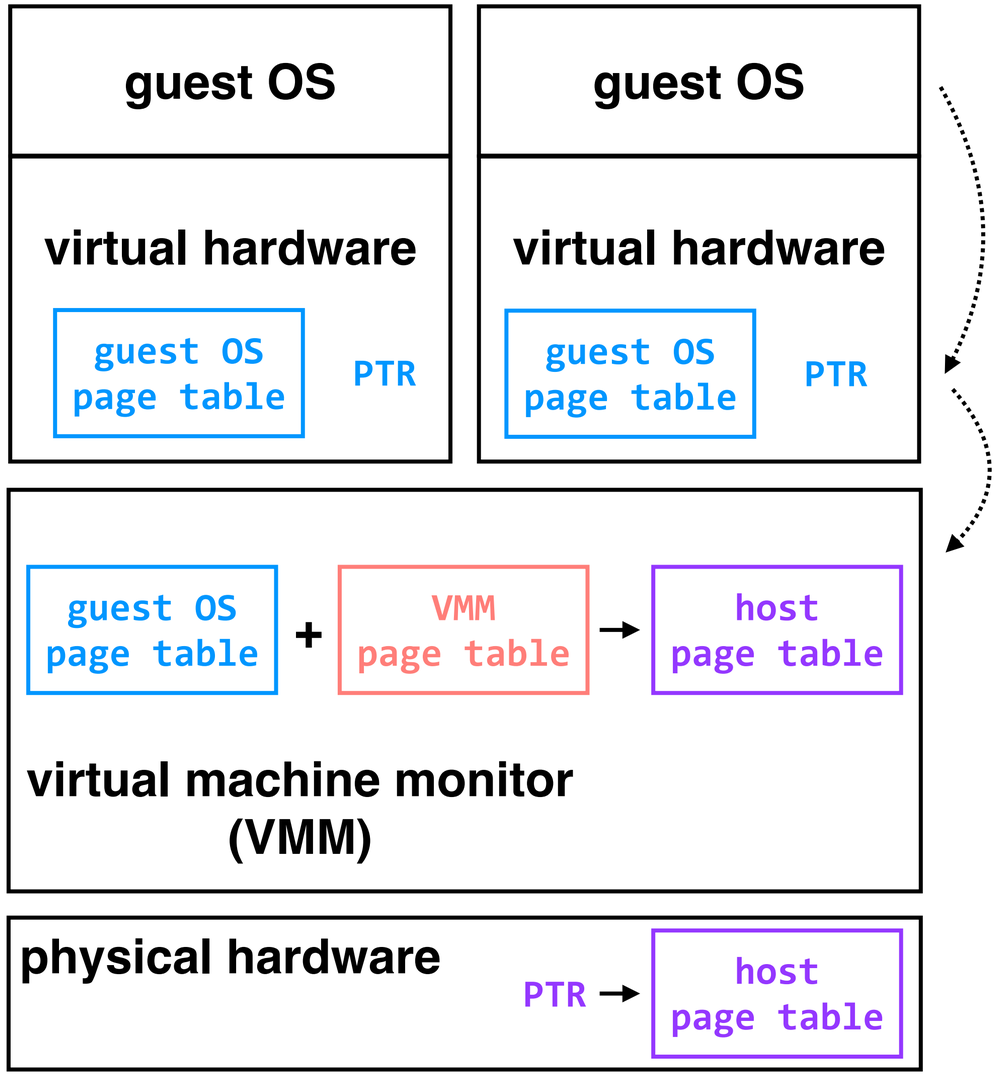


first question: what does it mean to emulate?

in this example, it means that the VMM needs to step in and translate guest physical addresses to host physical addresses

virtual machine monitor: virtualizes the physical hardware for the guest OSes

first example: virtualizing memory (again)



1. guest OS loads its PTR, which triggers an exception; the VMM intercepts

2. VMM combines the guest page table with its own page table to create a host page table

3. physical hardware uses the host page table

guest OS page table

guest virtual → guest physical

VMM page table

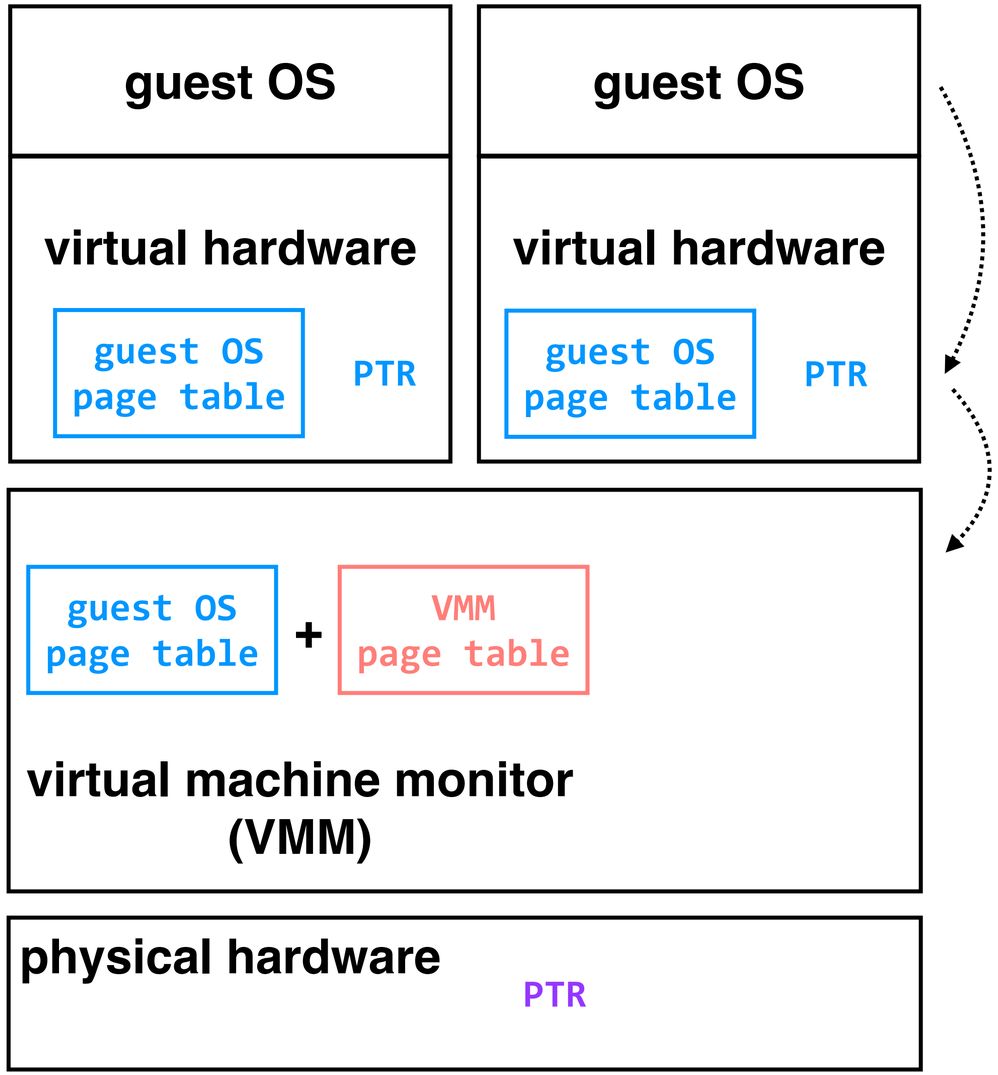
guest physical → host physical

host page table

guest virtual → host physical

virtual machine monitor: virtualizes the physical hardware for the guest OSes

first example: virtualizing memory (again)



1. guest OS loads its PTR, which triggers an exception; the VMM intercepts

in modern hardware, the physical hardware is aware of both page tables, and performs the translation from guest virtual to host physical itself

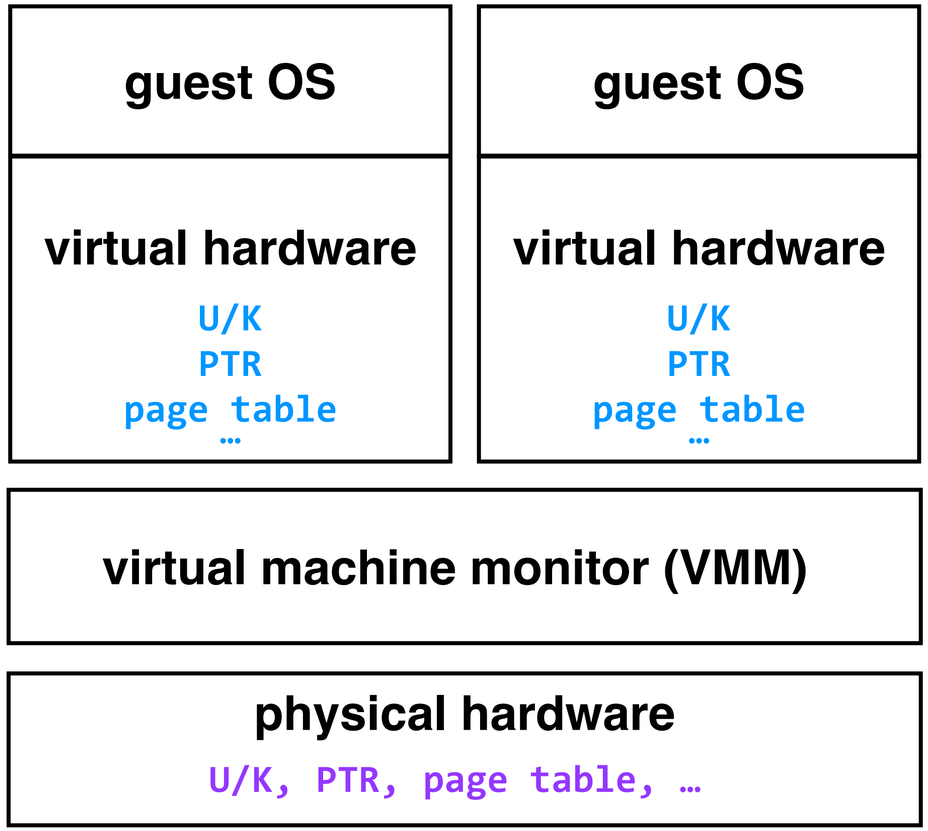
guest OS page table

guest virtual → guest physical

VMM page table

guest physical → host physical

virtual machine monitor: virtualizes the physical hardware for the guest OSes



guest OSes run in user mode

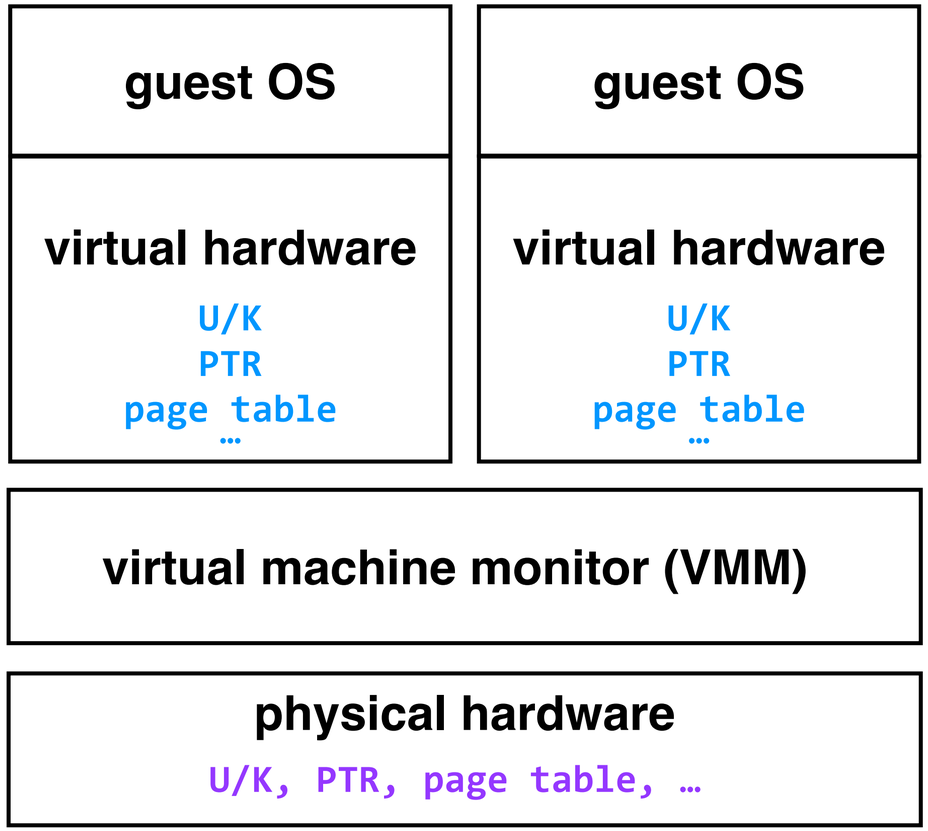
privileged instructions in guest OS will cause an exception, which the VMM will intercept ("**trap**") and **emulate**

if the VMM *can't* emulate an instruction, it will send the exception back to the guest OS for handling

second question: what about when the VMM needs to emulate an instruction that doesn't trigger an exception?

virtual machine monitor: virtualizes the physical hardware for the guest OSes

second example: virtualizing the U/K bit



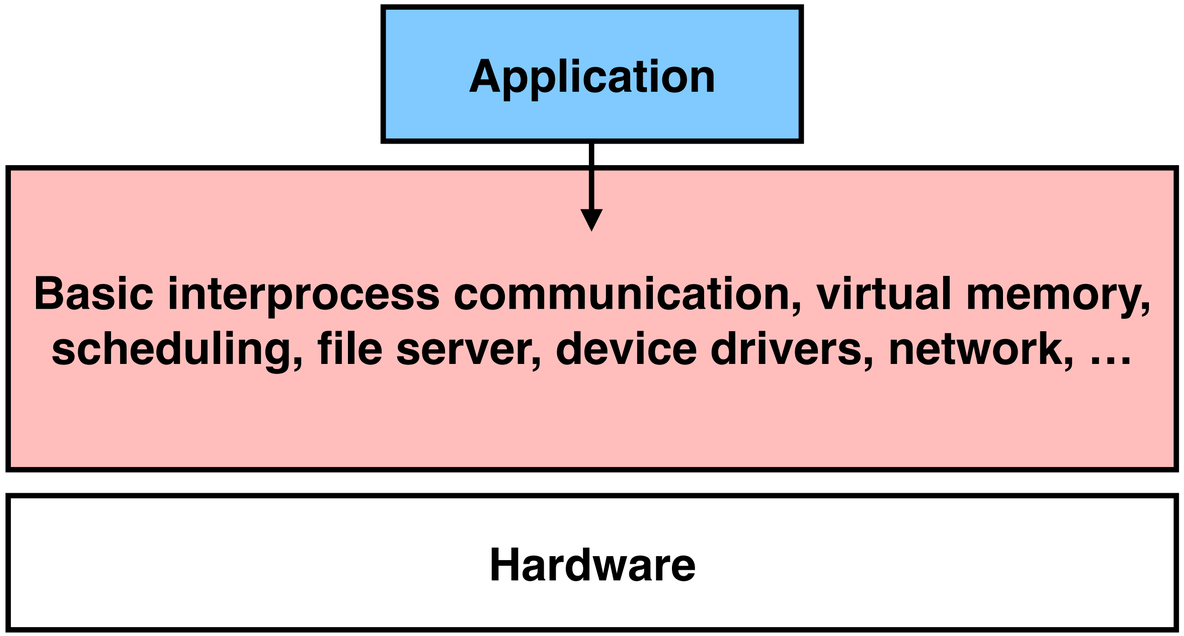
para-virtualization: modify guest OS slightly

binary translation: VMM replaces problematic instructions with ones that it can trap and emulate

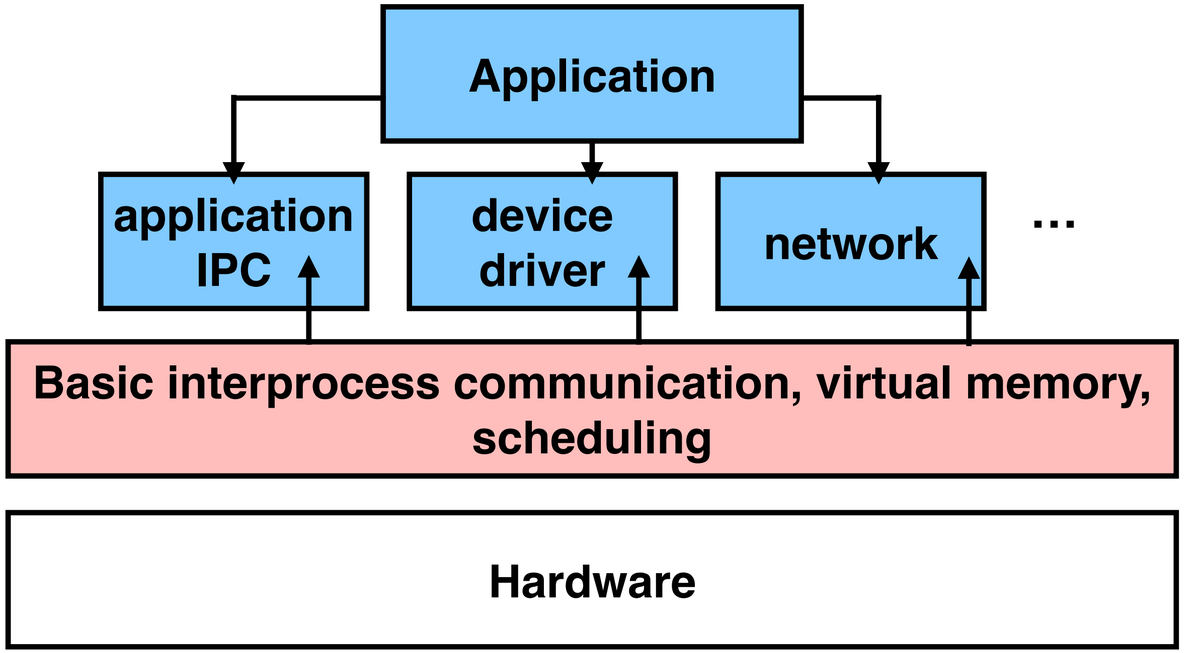
hardware support: architecture provides a special operating mode for VMMs in addition to user mode, kernel mode

second question: what about when the VMM needs to emulate an instruction that doesn't trigger an exception?

monolithic kernel: no enforced modularity within the kernel itself



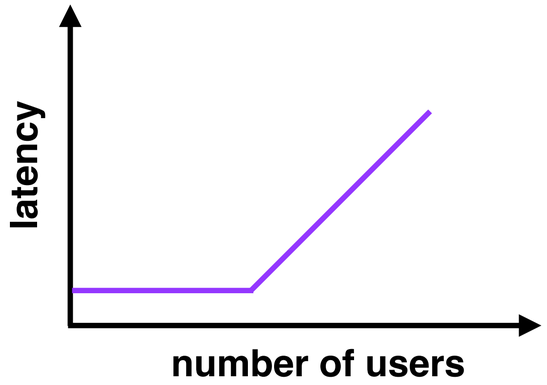
microkernels: enforce modularity by putting subsystems in user programs



performance: performance issues have influenced a lot of the system designs you've seen so far

latency: how long does it take to complete a single request?

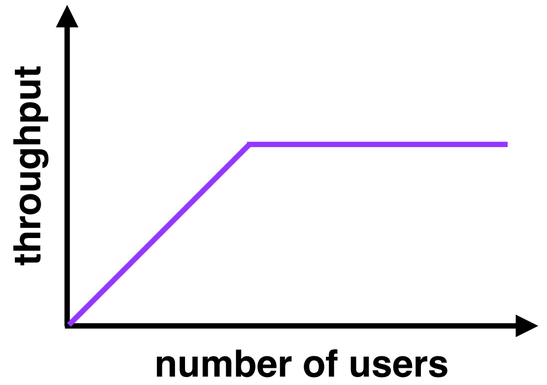
example: how long does it take to retrieve a particular piece of memory in an OS?



often we see latency remain low until the system is heavily utilized, and then it rises.

throughput: how many requests per unit of time?

example: how many reads or writes can a system do to a disk at once?



throughput, on the other hand, increases as requests increase, and maxes out when the system is fully utilized

utilization: what fraction of resources are being utilized? this puts our performance measurements in context

virtual machines allow us to run multiple **isolated** OSes on a single physical machine, similar to how we used an OS to run multiple programs on a single CPU.

monolithic kernels provide no enforced modularity within the kernel. **microkernels** do, but redesigning monolithic kernels as microkernels is challenging

performance affects all aspects of system design. **throughput**, **latency**, and **utilization** are important metrics (but not the only ones), and we have general, systems-level techniques for attempting to improve them (e.g., caching, batching). knowing when to apply them requires a solid understanding of the system itself and how it's used