Virtualization

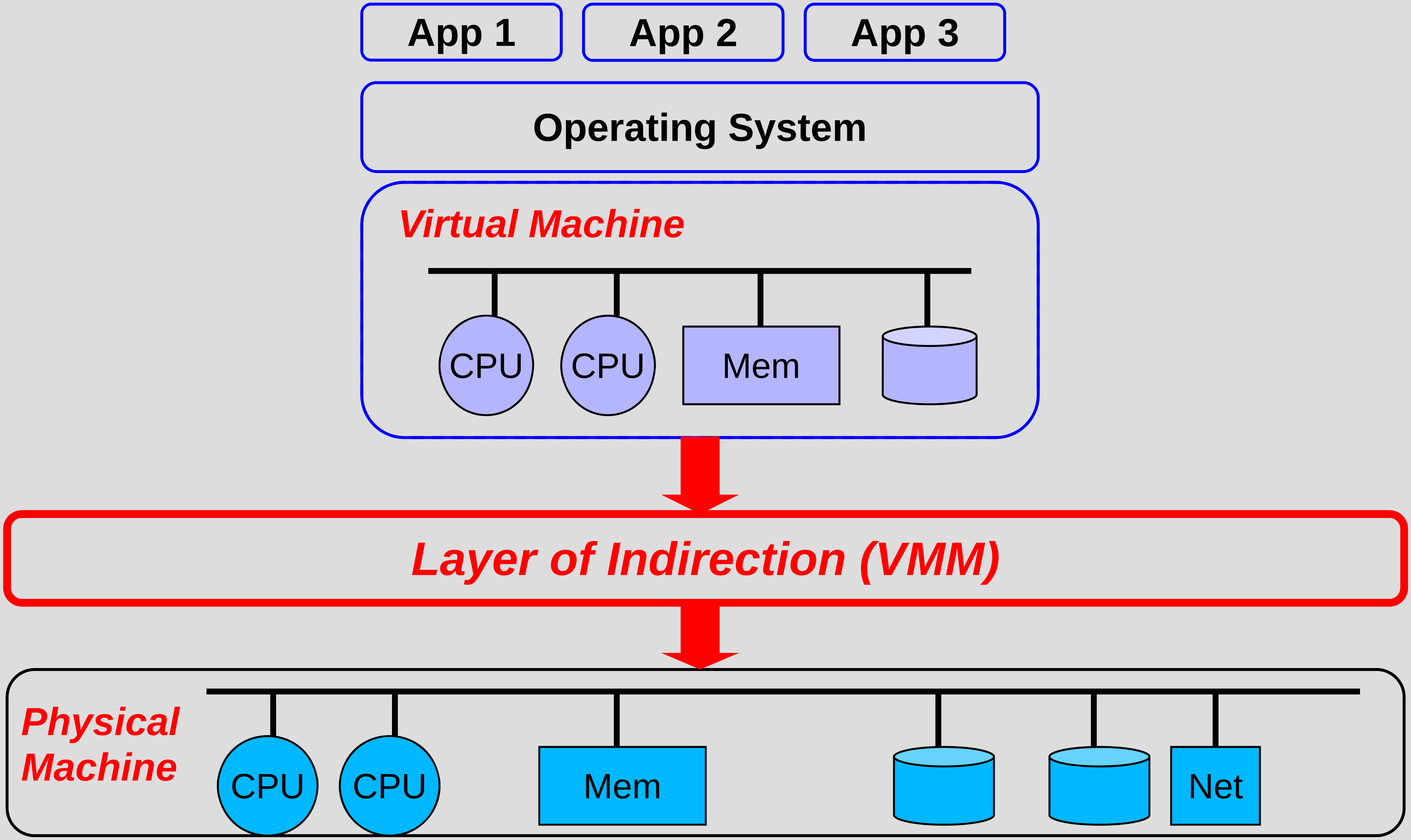
Resource Virtualization

- Separating the abstract view of computing resources from the implementation of these resources

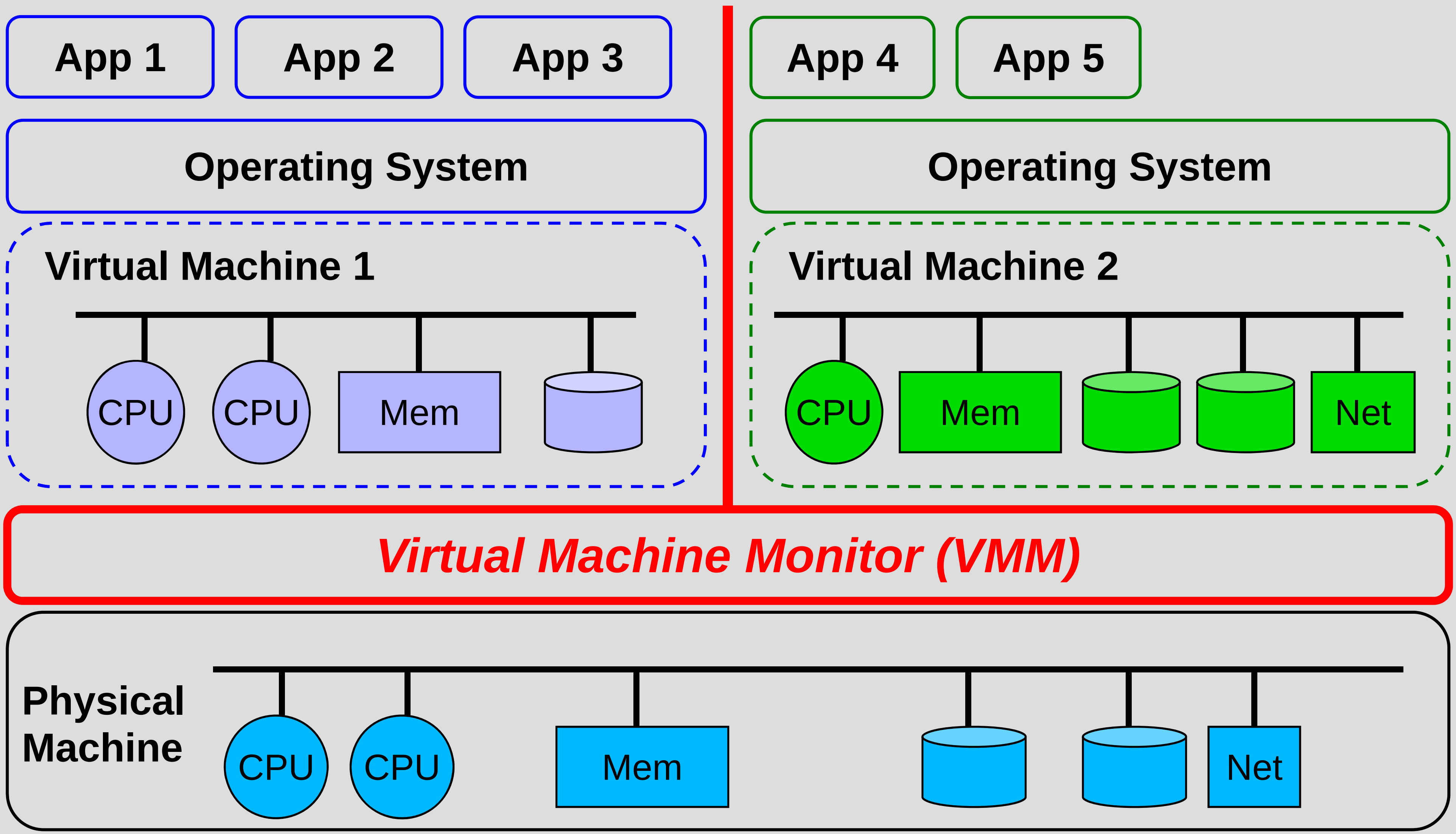
- ***A layer of indirection between abstract view and implementation***
  - Hides implementation details
  - Controls mapping from abstract view to implementation

"*any problem in computer science can be solved with another layer of indirection*"
– David Wheeler

Virtual Machines



Virtual Machines



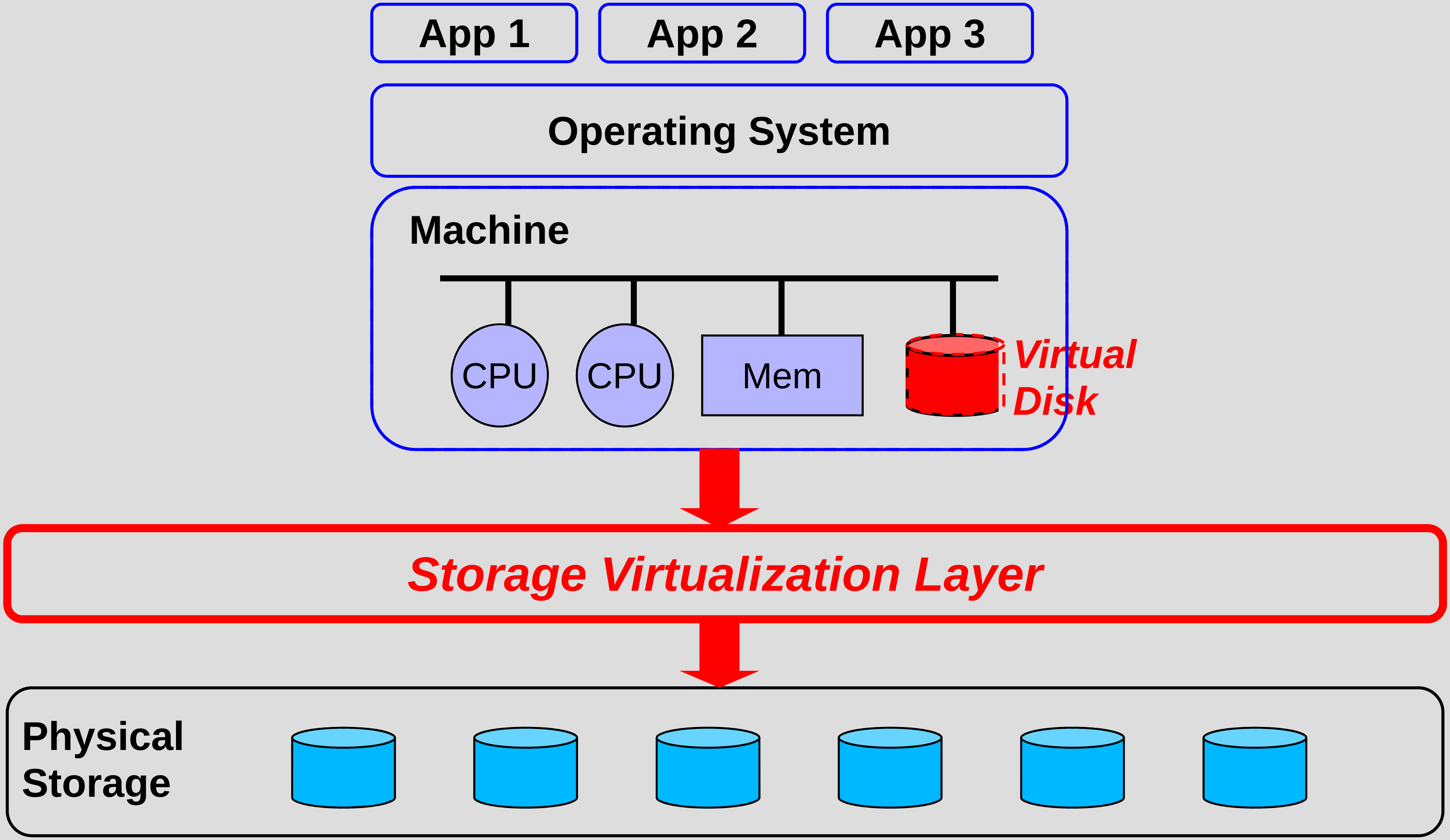
Machine Virtualization

- A ***virtual machine*** abstracts the computing resources of a physical machine into virtual resources
- End users only see the virtual resources
  - Can install their operating systems and run their applications on the virtual machines
- A ***Virtual Machine Monitor*** (or ***Hypervisor***) is a software layer that implements the mapping from virtual resources to physical resources

Virtual Machine Monitors

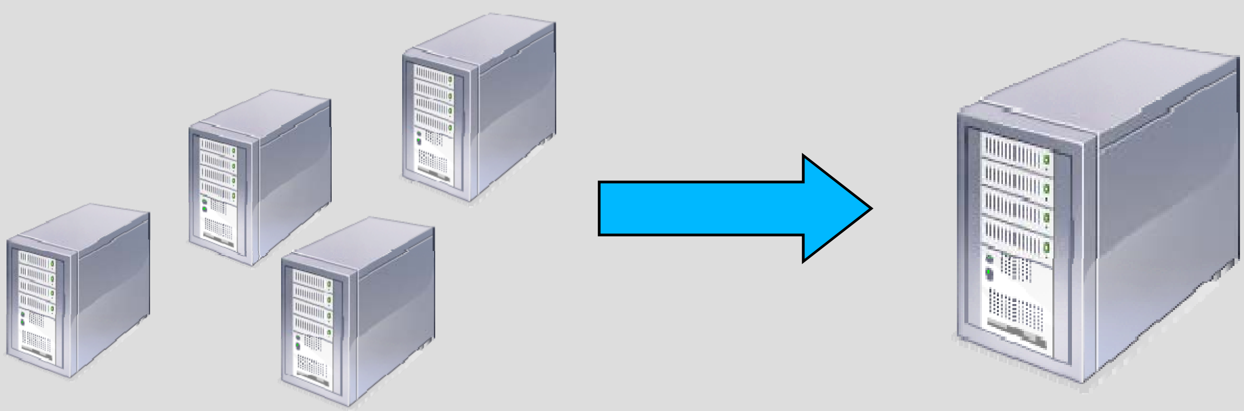
- ***Strong isolation*** between virtual machines
- ***Flexible mapping*** between virtual resources and physical resources
  - Can have more virtual resources than the corresponding physical resources
  - Can reallocate physical resources among VMs
- Pause, resume, checkpoint, and migrate virtual machines

Virtual Storage

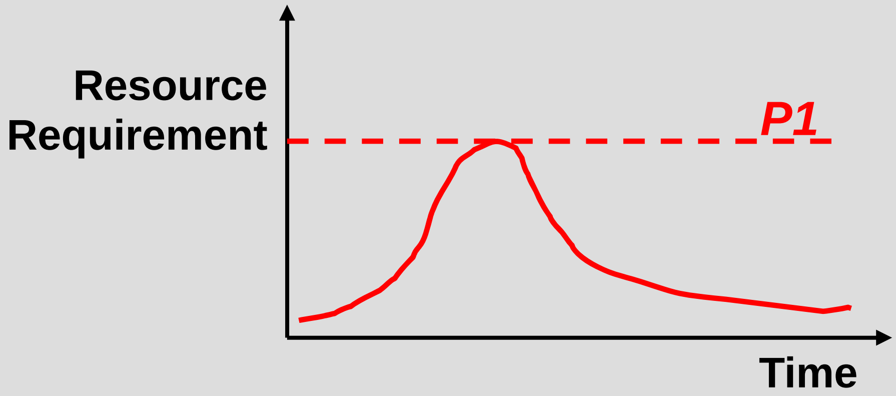


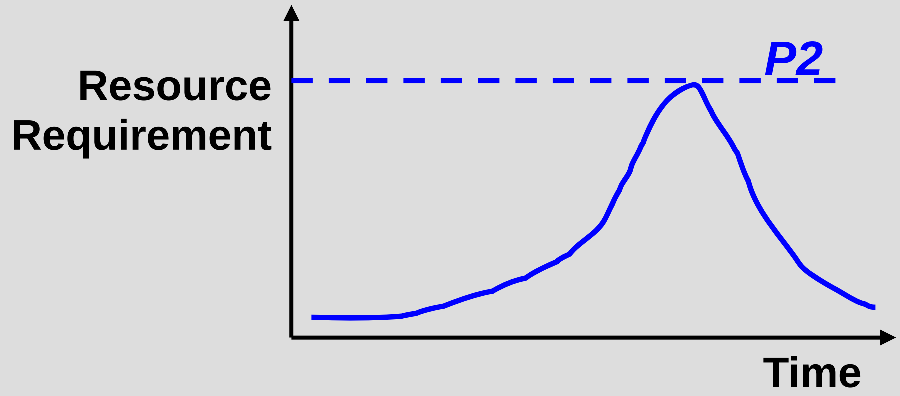
Why Use Virtual Machines?

- Server consolidation
  - Traditional IT setup: one machine per application (DBMS, web server, mail server, …)
  - Provisioned for peak load. Usually under-utilized
  - Instead, can run multiple applications on virtual machines that share the same physical machine
  - Save hardware costs and administration/operation costs



Server Consolidation





P12 < P1 + P2

- Consolidate onto a single machine
  - Easier to manage
  - Less total capacity than the original two
  - Better utilization than the original two

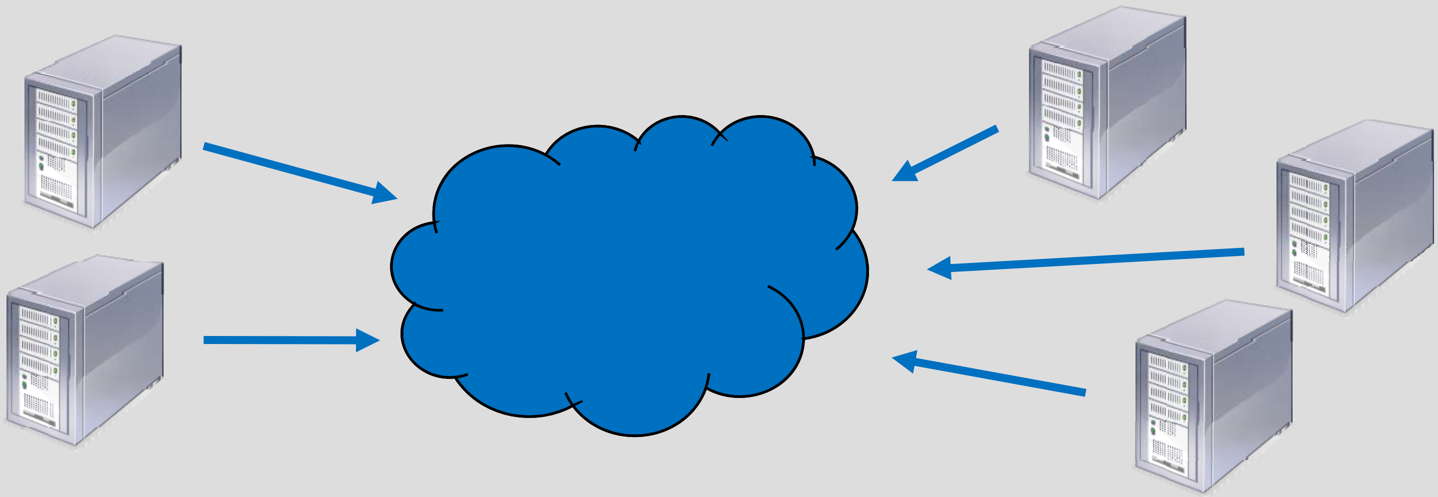
Consolidation

- ***Economies of scale***
  - Cheaper provisioning, administration, power, networking, and cooling
- Users benefit too
  - Efficient access to a larger pool of resources with better manageability and fault tolerance

Worldwide spending on servers in 2007: US$200 billion
(30% new servers, 10% power and cooling, 60% administration)
Source: IDC, 2008

Cloud Computing

- Consolidation on massive, shared, hosted computer clusters



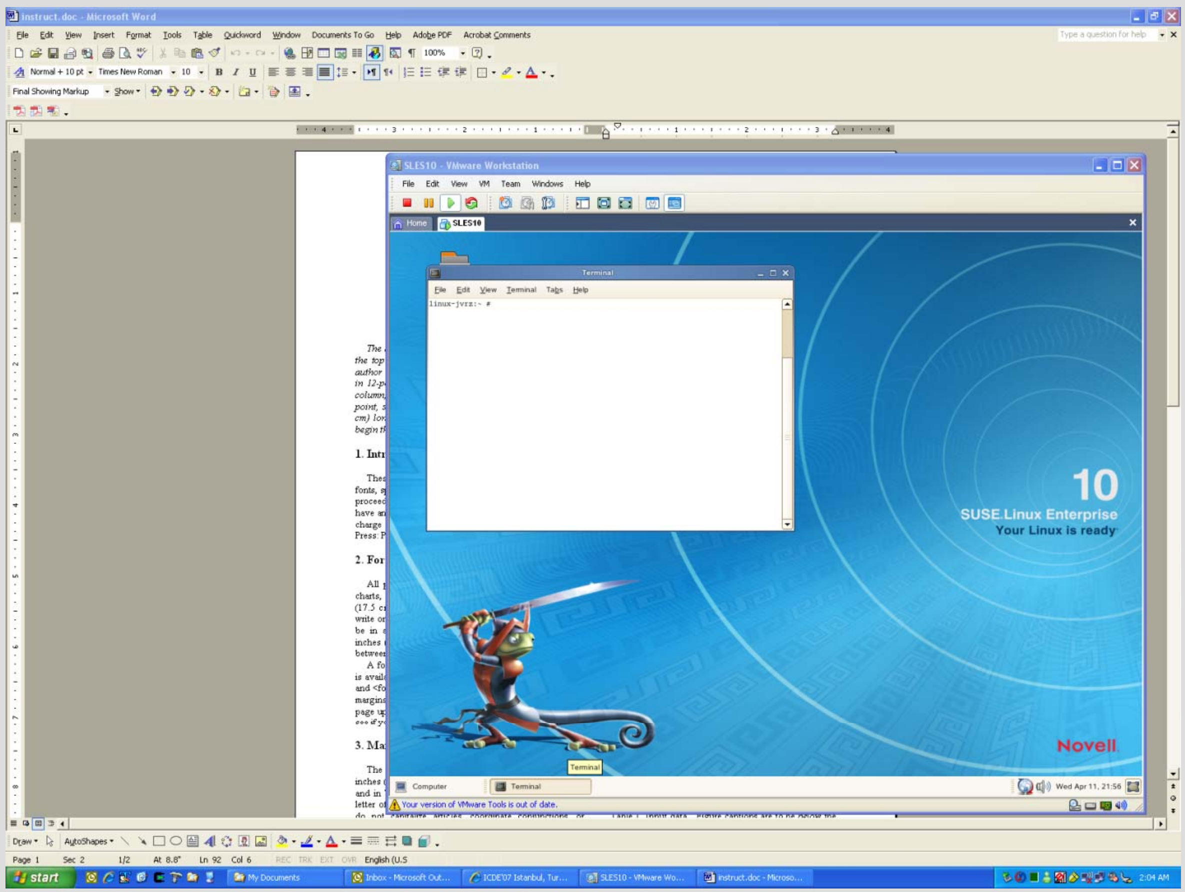
Why Use Virtual Machines?

- Improved manageability
  - Dynamic provisioning of resources to VMs
  - Migration of VMs for load balancing
  - Migration of VMs to avoid down time during upgrades

- Isolation between VMs
  - Security
  - Privacy
  - Fault tolerance

Why Use Virtual Machines?

- Application compatibility
  - Different environments for different applications

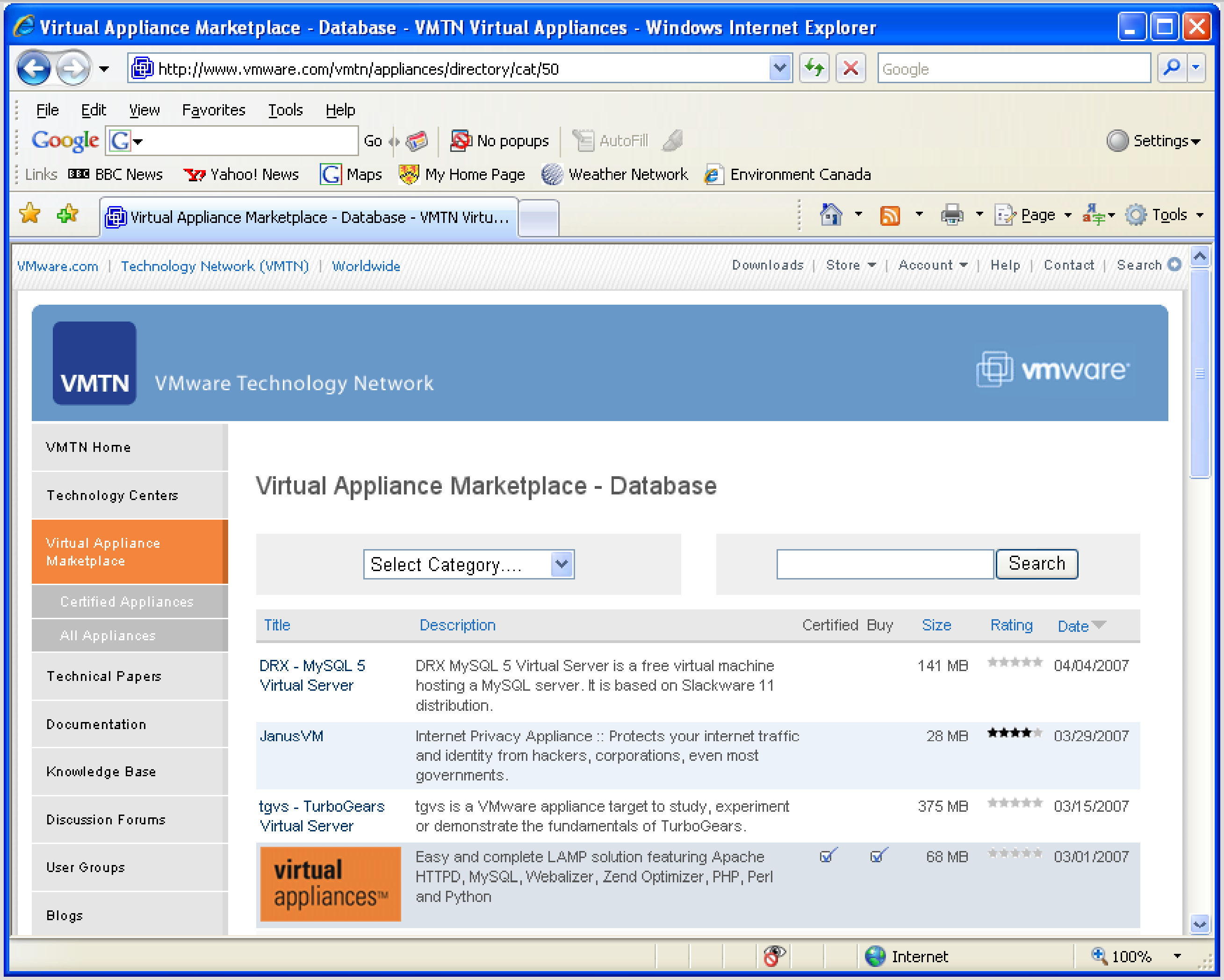


Why Use Virtual Machines?

- Software development and testing
  - Multiple environments for development and testing

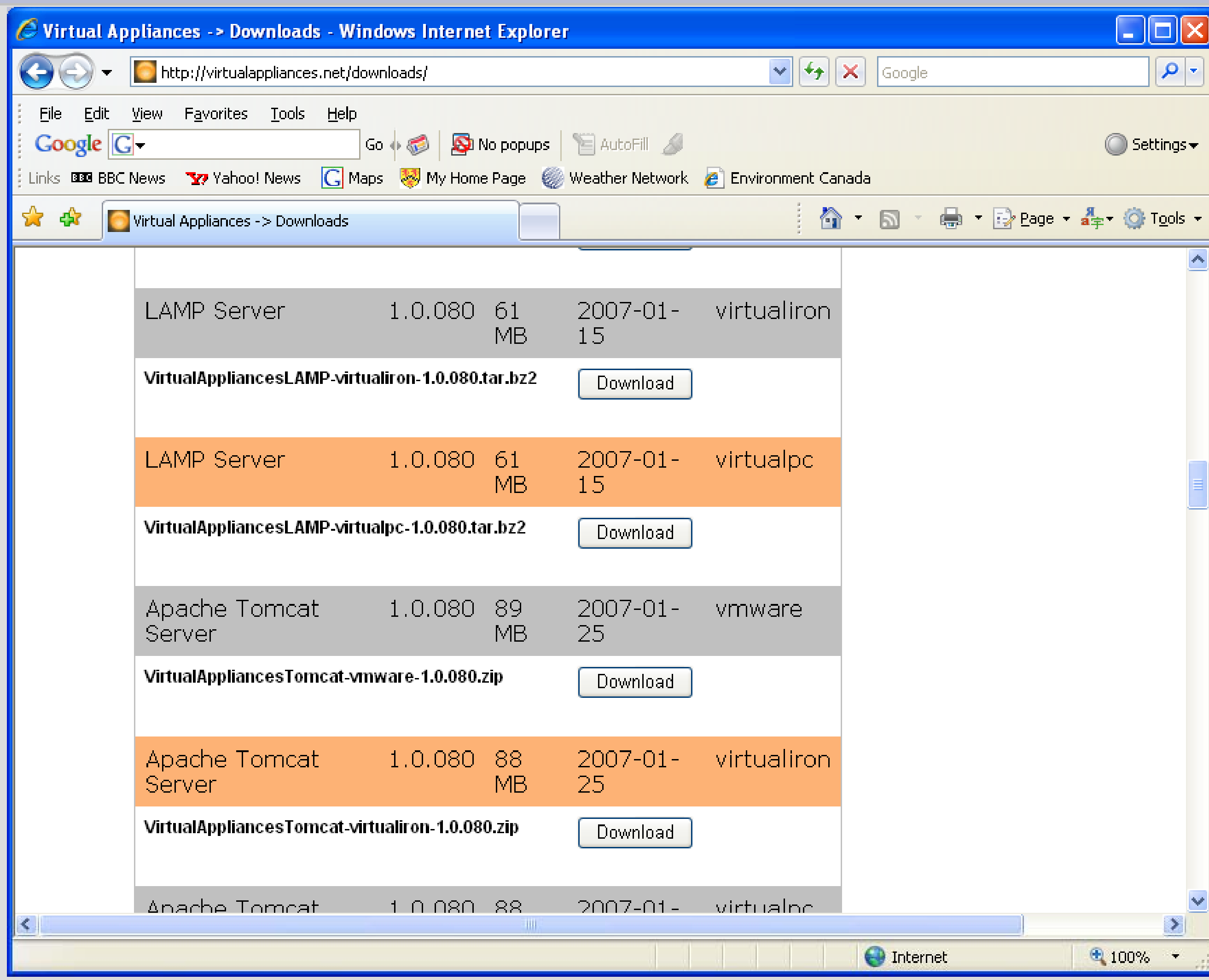
- Software deployment
  - Preconfigured ***virtual appliances***
  - Repositories of virtual appliances on the web

Virtual Appliances



http://www.vmware.com/vmtn/appliances

Virtual Appliances

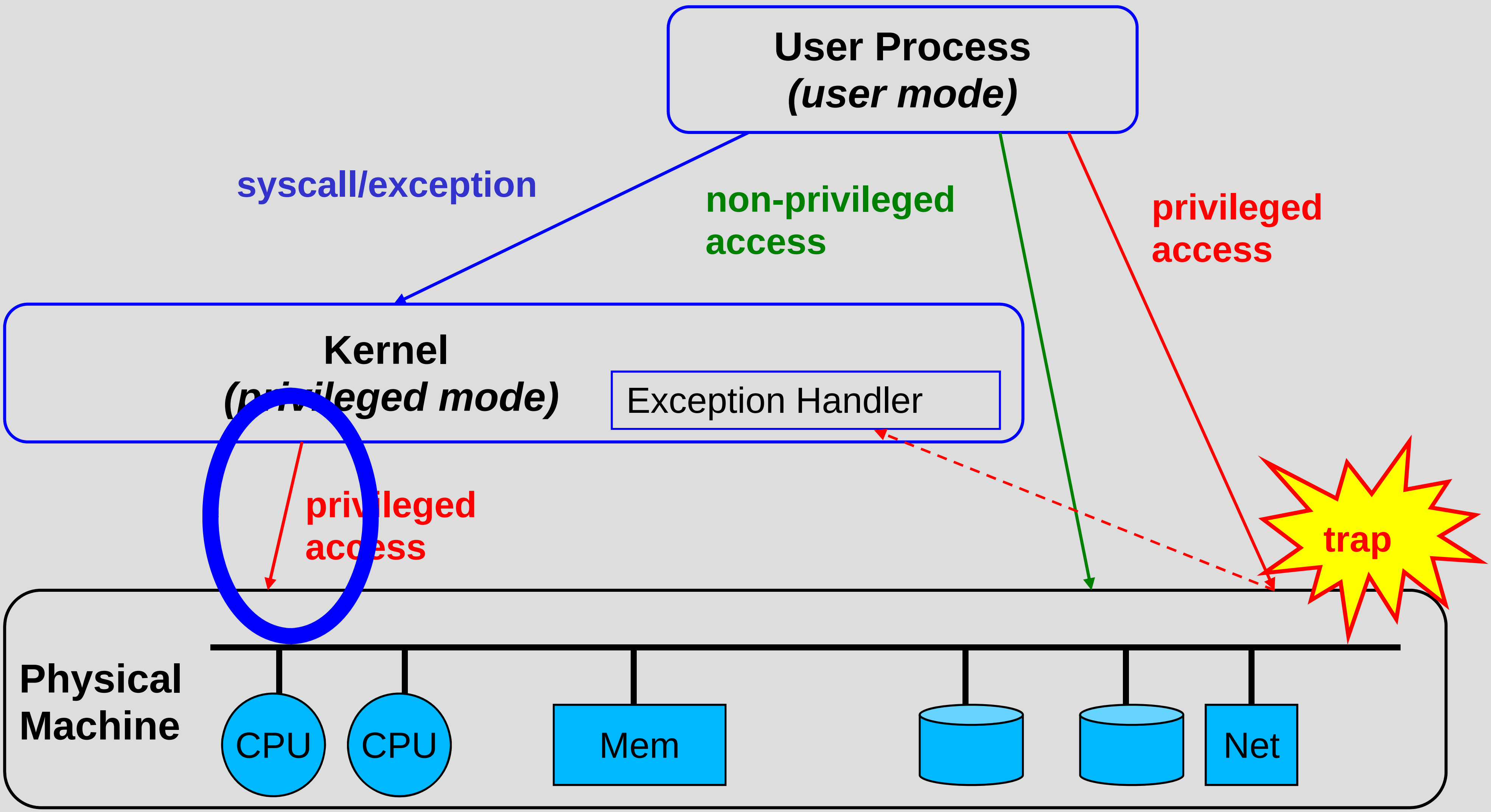


http://virtualappliances.net/downloads/

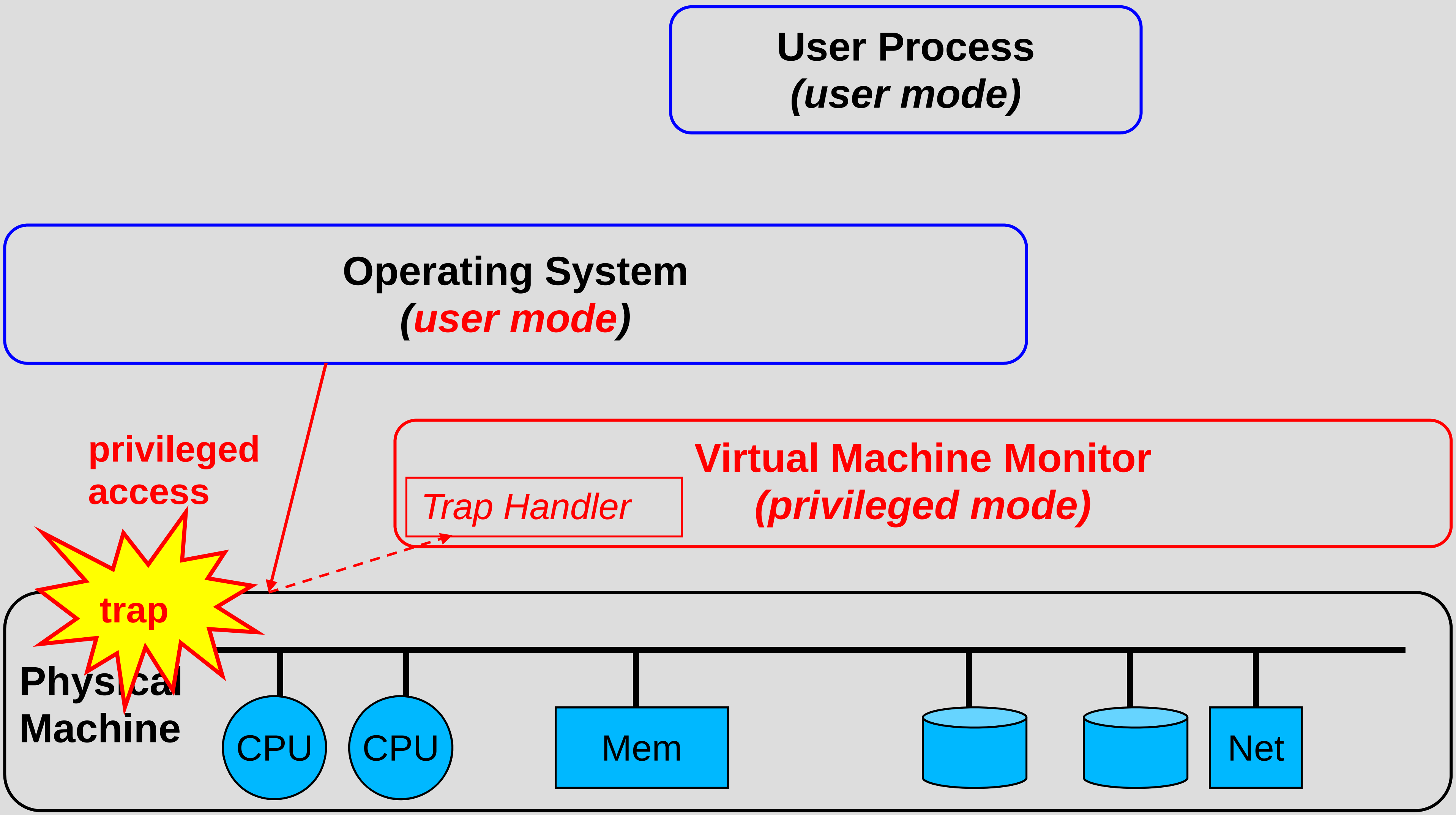
Why Not Use Virtual Machines?

- ***Performance penalty***
  - Indirection through VMM adds overhead
- ***Hiding details of physical resources***
  - Some applications make decisions based on assumptions about the physical resources

Basic Approach to Virtualization



Trap-and-Emulate Virtualization



Trap-and-Emulate Virtualization

- Run VMM in privileged mode
- Run OS in user mode
- Privileged operations by the OS will trap
- Trap handler in VMM emulates these operations as if they were run on the virtual machine
- Non-privileged operations can proceed as before with no intervention from the VMM

Architectural Obstacles

- Some machine architectures are not easy to virtualize
  - Notable example: ***x86***
- Not all privileged operations trap when run in user mode
  - Example: `popf` (pop stack into flags)
    Privileged mode: change user and system flags
    User mode: change user flags only, no trap
- Some privileged state is visible in user mode
  - Example: Machine status word
- For an architecture like x86, ***trap-and-emulate alone will not work***

Virtualization Approaches

- ***Binary rewriting***
  - Operating system running in VM is ***unmodified***
  - VMM scans ***Guest OS*** memory for problematic instructions and rewrites them
  - Example: VMware Workstation

- ***Paravirtualization***
  - Software interface to VMM is ***not identical to hardware***
  - Operating systems need to be ***ported*** to run on VMM
  - Simpler VMM and ***faster virtual machines*** than with trap-and-emulate
  - Example: Xen

Hardware Virtualization for x86

- Intel and AMD have both introduced processor extensions to help virtualization (Intel VT, AMD-V)

- Processor is aware of multiple ***virtual machine contexts*** (like process control blocks, but for entire operating system)
- New instructions to ***start/resume*** a VM
- New ***privilege level*** for VMM
- VMM selects which events should ***trap*** (`vmexit`)
  - Manipulating interrupt state, interacting with TLB, accessing control registers, …