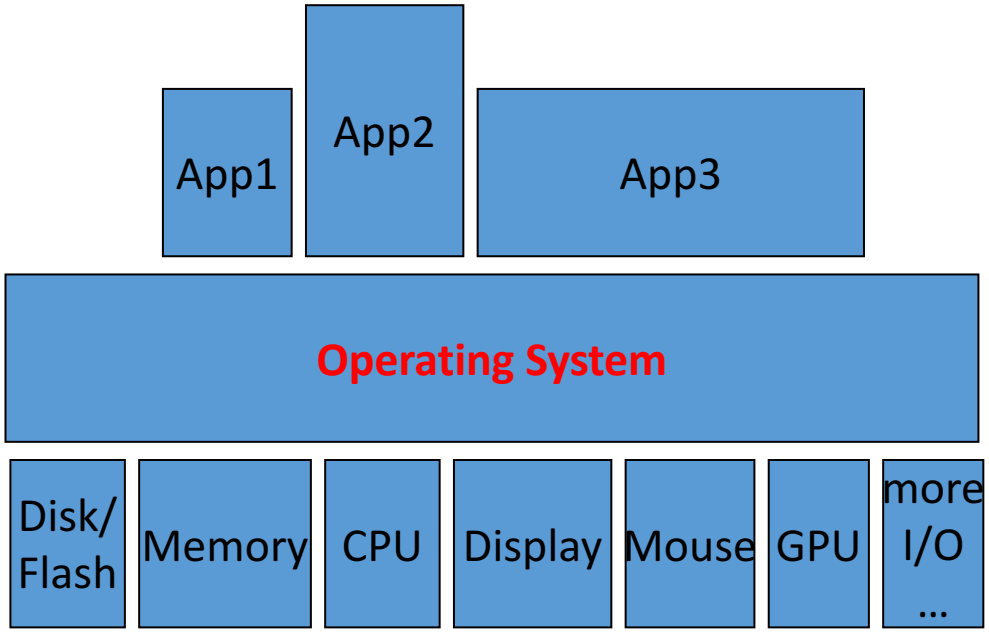
Lecture 26
Virtualization

What does Operating System provide?

Definition: An operating system is a layer of software between *many* applications and *diverse* hardware that

1. Provides a ***hardware abstraction*** so an application doesn't have to know the details about the hardware.



E.g. An application saving a file to disk doesn't have to know how the disk operates

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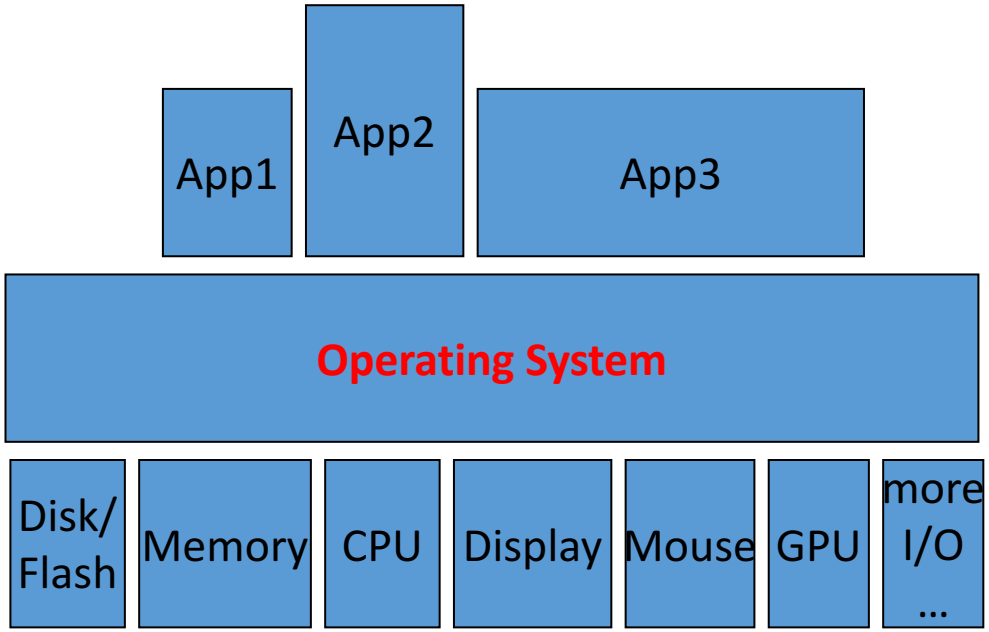
2. **Arbitrates access** to resources among multiple applications:
   + Sharing of resources.

E.g. Sharing a Printer among applications



What does Operating System provide?

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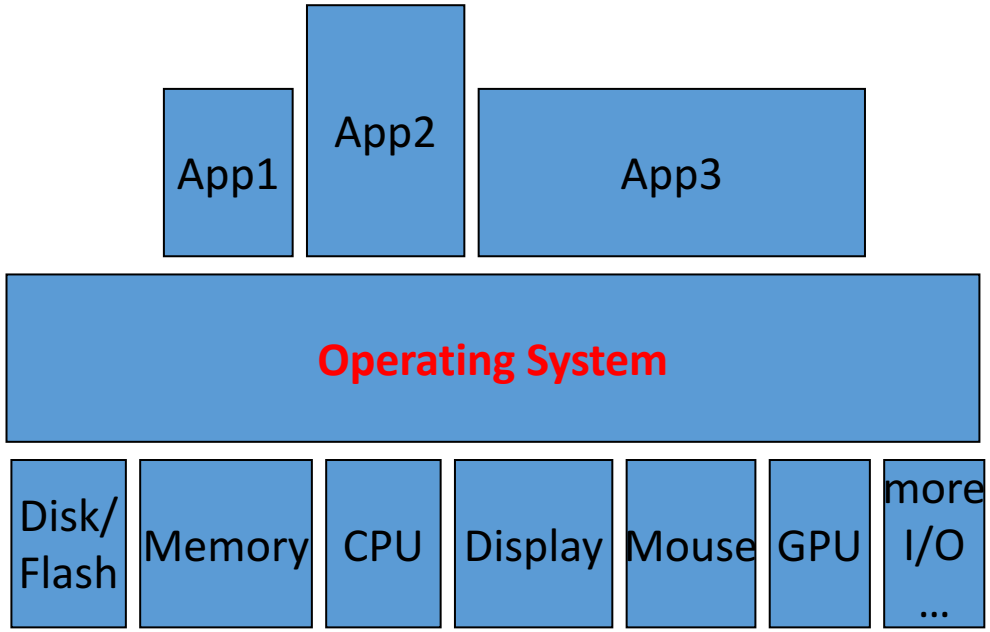
3 . **Provide protections**:

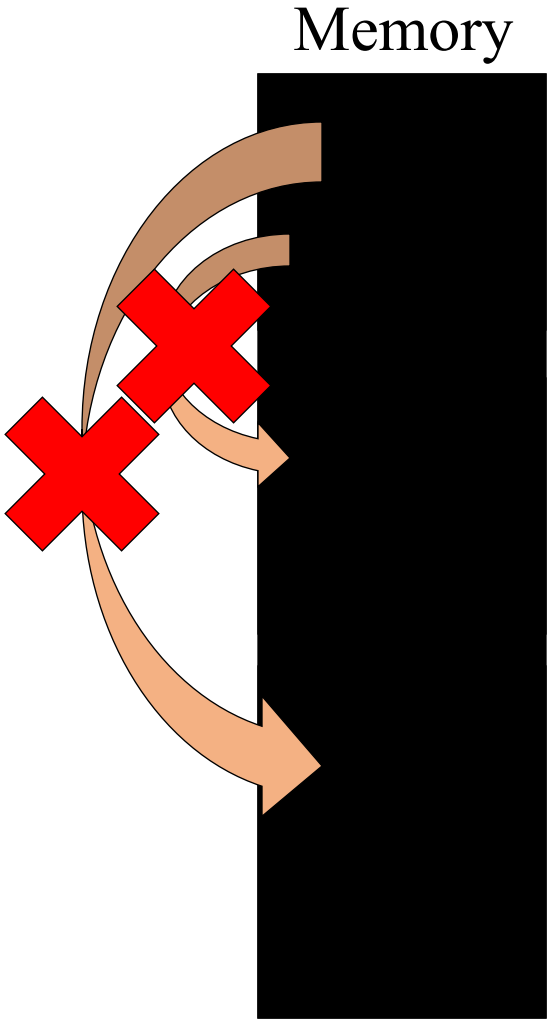
- *Isolation* protects **app's from each other**
- *Isolation* also to protect the **OS from applications**
- *Isolation* to **limit resource consumption by any one app**



Protection in Operating Systems

1. Prevent applications from writing into privileged memory
   – e.g. of another app or OS kernel

2. Prevent applications from invoking privileged functions
   – e.g. OS kernel functions

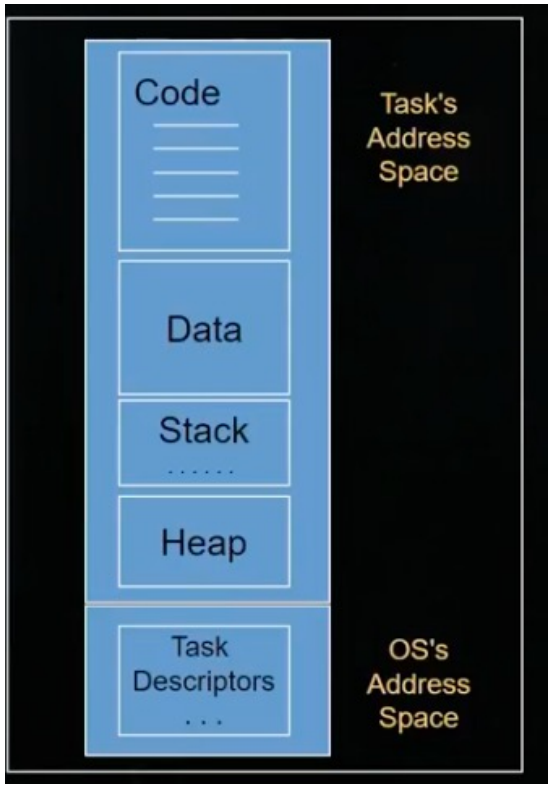


Privileged Instruction Examples

- Memory address mapping
- Flush or invalidate data cache
- Invalidate TLB (Translation Lookaside Buffer) entries
- Load and read system registers
- Change processor modes from K to U
- Change the voltage and frequency of processors
- Halt/reset processor
- Perform I/O operations

What is an unit of work for an OS?

- Application
- Task
- Job
- Process

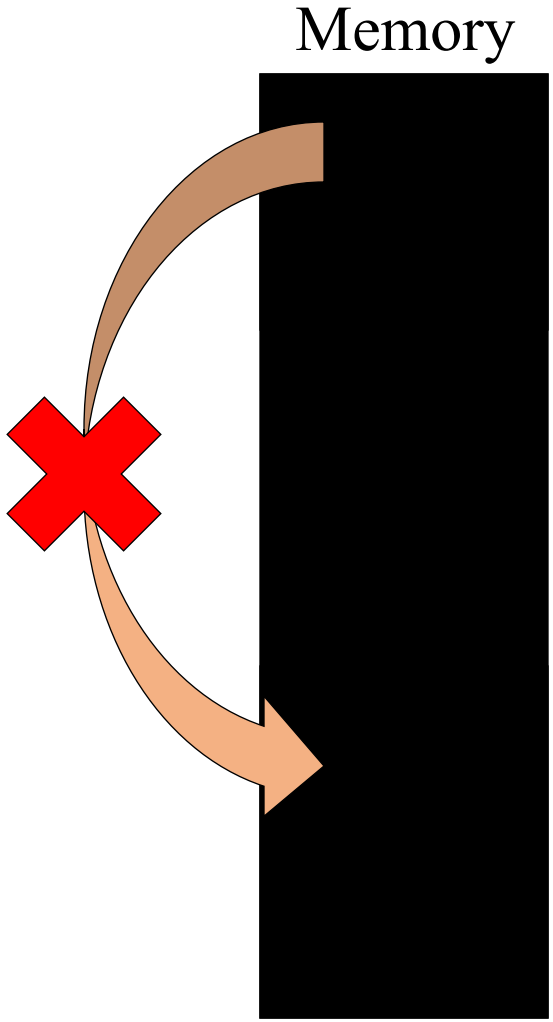


What does a TASK consist of?

- Code – placed into memory
- Data – stored in memory
- OS data for task – task descriptors

How can we access the OS functionality?

- **Problem:** If a task is protected from getting into the OS code and data, OS functionality are restricted from these tasks
- How does CPU know if a certain instruction should be allowed?
- How does OS grant a task access to certain OS data structures but not the other?
- How to switch from running the task's code to running OS's code
- Need to use a hardware assistant called **mode bit**

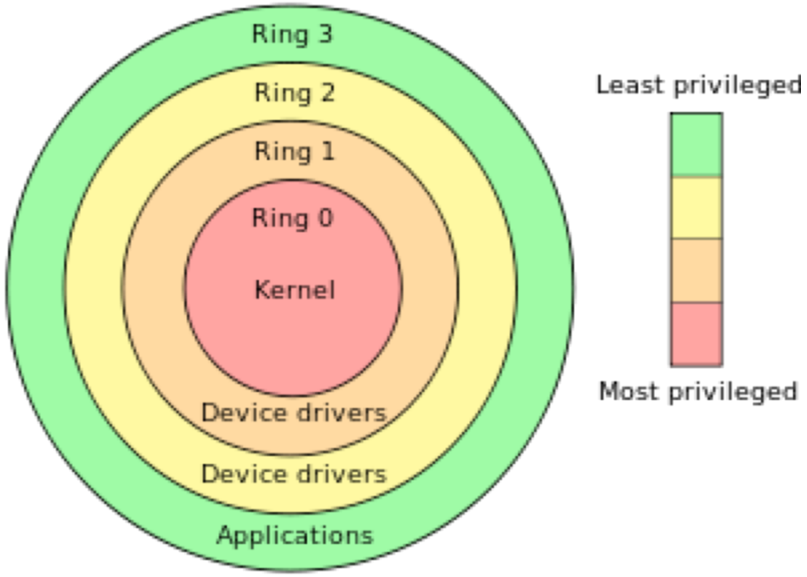


Kernel Mode vs User Mode

- Processors include a hardware *mode* bit that identifies whether the system is in *user* mode or *supervisor/kernel* mode
  - Requires extra support from the CPU hardware for this OS feature
- Supervisor or kernel mode (mode bit = 0)
  - Can execute all machine instructions, including privileged instructions
  - Can reference all memory locations
  - Kernel executes in this mode
- User mode (mode bit = 1)
  - Can only execute a subset of non-privileged instructions
  - Can only reference a subset of memory locations
  - All applications run in user mode

Multiple Rings/Modes of Privilege

- Intel x86 CPUs support four modes or rings of privilege
- Common configuration:
  - OS like Linux or Windows runs in ring 0 (highest privilege), Apps run in ring 3, and rings 1-2 are unused



- **Virtual machines (one possible configuration)**
  - **VM's hypervisor runs in ring 0, guest OS runs in ring 1 or 2, Apps run in ring 3**

What is a Virtual Machine?

- An simulated computer running within a real computer
- The virtual computer runs an operating system that can be different than the host operating
- All the requests to access real hardware are routed to the appropriate host hardware, then virtual operating system or applications don’t know they are virtual
- Similar to a person embedded in the Matrix (virtual people)

Virtual X concept.

- A process already is given the illusion that it has its
  - Own memory, via virtual memory
  - Own CPU, via time slicing
- Virtual machine extends this idea to give a process the illusion that it also has its own hardware
  - Moreover, extend the concept from a process to an entire OS being given the illusion that it has its own memory, CPU, and I/O devices

Virtual Machines

- Benefits include:
  - Can run multiple OS's simultaneously on the same host
  - Fault isolation if an OS fails – doesn't crash another VM. This is also useful for debugging a new OS.
  - Easier to deploy applications – can deploy an app within a VM instance that is customized for the app, rather than directly deploying the app itself and worrying about compatibility with the target OS – useful for cloud server deployments

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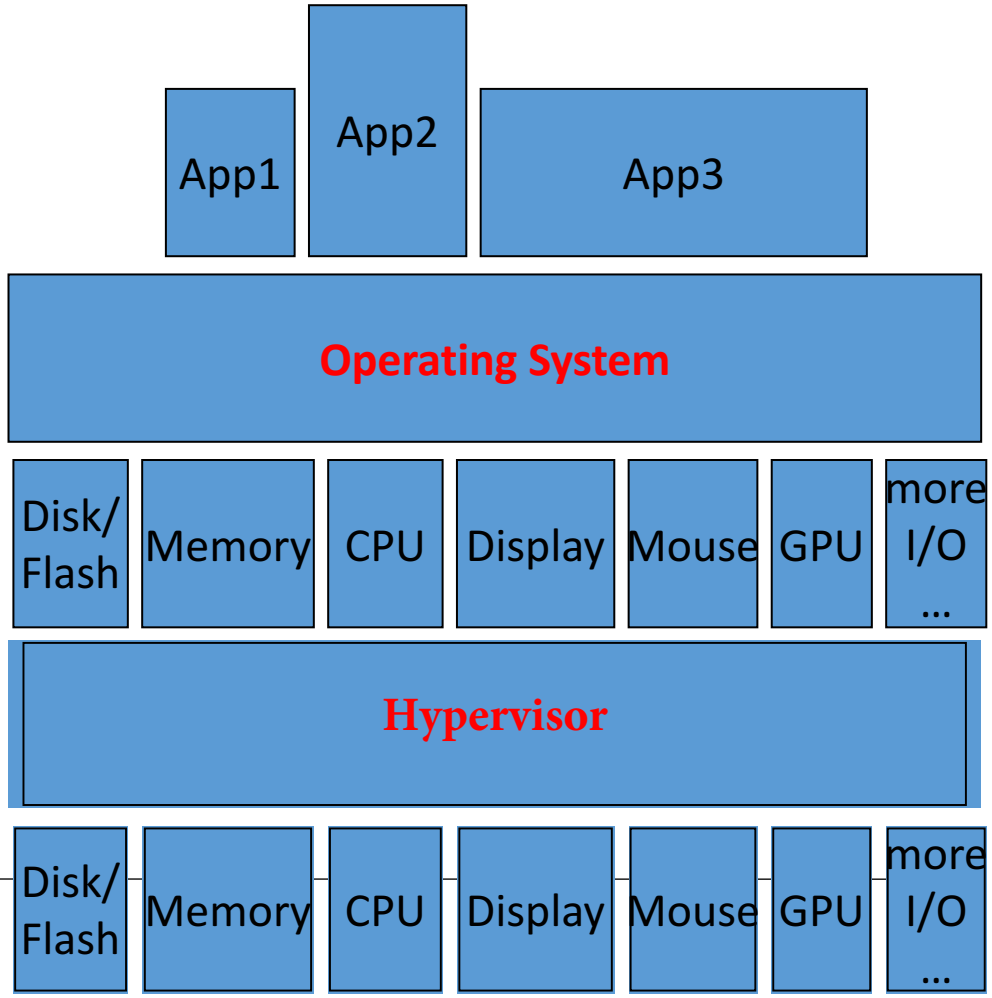
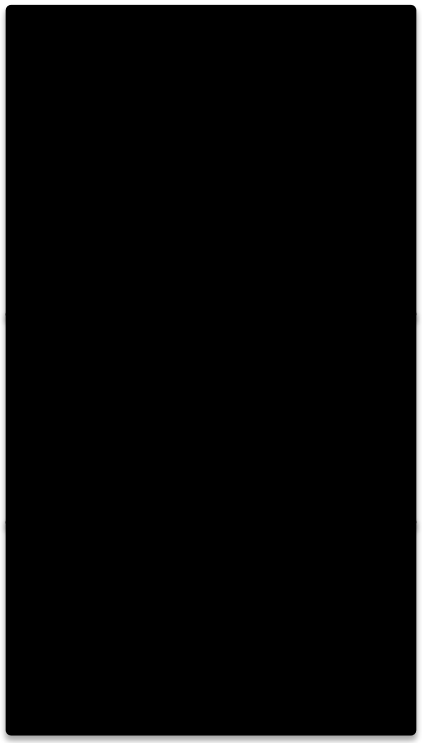
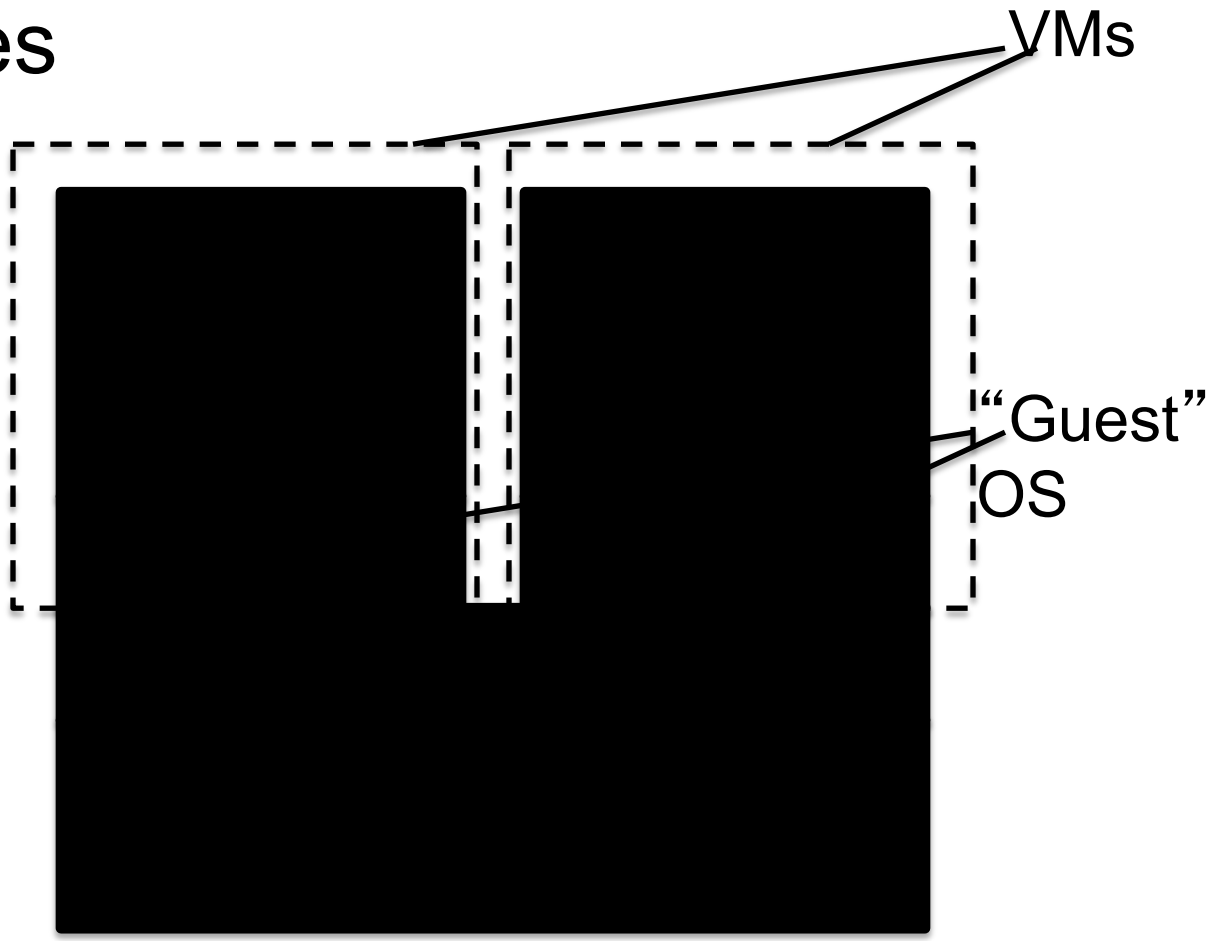


Virtual Machines



Traditional OS



A Type 1 *Hypervisor* provides a virtualization layer for guest OSs and resides just above the hardware.

Virtual Machines

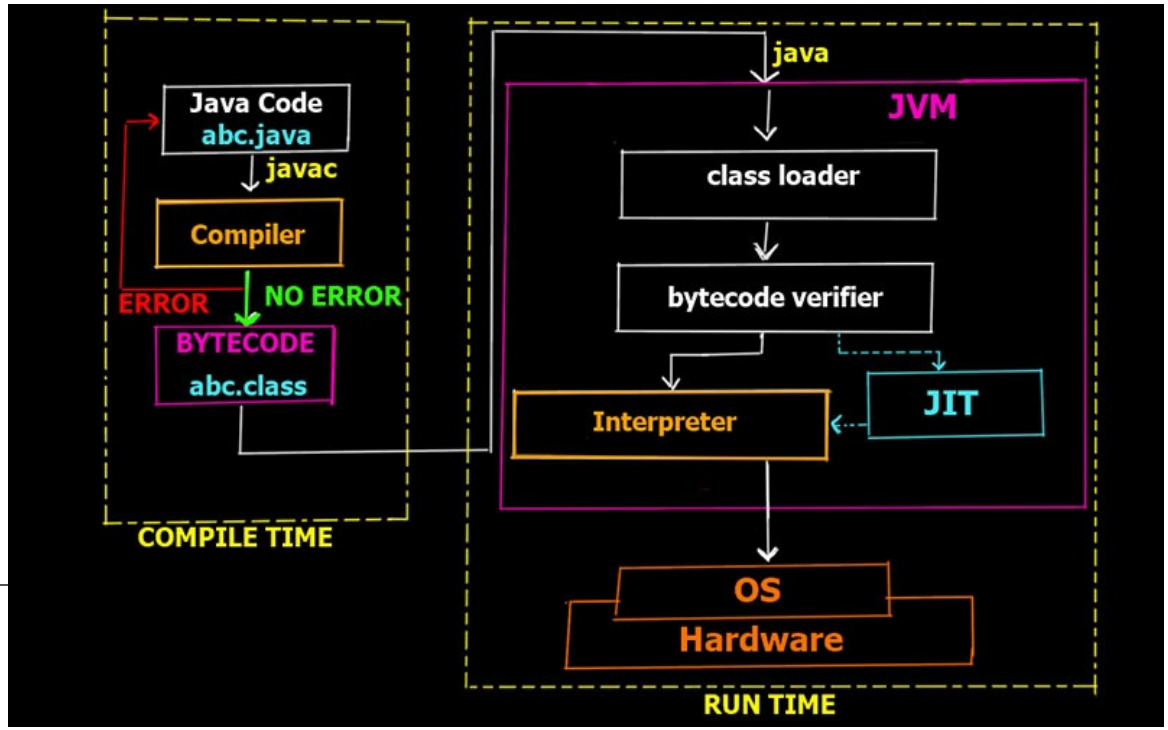
- How it basically works:
  - Goal: want to create a virtual machine that executes at close to native speeds on a CPU, so emulation and interpreting instruction by instruction are not good options – too much software overhead
  - Solution: have the guest OS execute normally, directly on the CPU, except that it is not in kernel mode.
    Therefore, any special privileged instructions invoked by the guest OS will be trapped to the hypervisor, which is in kernel mode.
  - The hypervisor then emulates only these privileged instructions and when done passes control back to the guest OS, also known as a "VM entry"
  - This way, most ordinary (non-privileged) instructions operate at full speed, and only privileged instructions incur the overhead of a trap, also known as a "VM exit", to the hypervisor/VMM.
  - This approach to VMs is called *trap-and-emulate*

Virtual Machines

- Cloud Computing
  - Very easy to provision and deploy VM instances on the cloud
  - E.g. Amazon's Elastic Compute Cloud (EC2) uses Xen virtualization
    - There are different types of VMs or instances that can be deployed:
      - Standard, High-Memory, High-CPU
    - Users can create and reboot their own VMs
    - To store data persistently, need to supplement EC2 with an additional cloud service, e.g. Amazon's Simple Storage Service (S3)

Java Virtual Machines

- Process VMs, e.g. Java VMs
  - Differ from System VMs in that the goal is NOT to try to run multiple OSs on the same host, but to **provide portable code execution** of a single application across different hosts
- Java applications are compiled into Java byte code that can be run on any Java VM
  - Java VM acts as an *interpreter* of byte code, translating each byte code instruction into a local action on the host OS



Java Virtual Machines

- Just in time compilation can be used to speed up execution of Java code
  - Java byte code is compiled at run time into native machine code that is executed directly on the hardware, rather than being interpreted instruction by instruction
- Note Java VMs virtualize an abstract machine, not actual hardware, unlike system VMs
  - i.e. the target machine that Java byte code is being compiled for is a software specification