

CSC 112: Computer Operating Systems

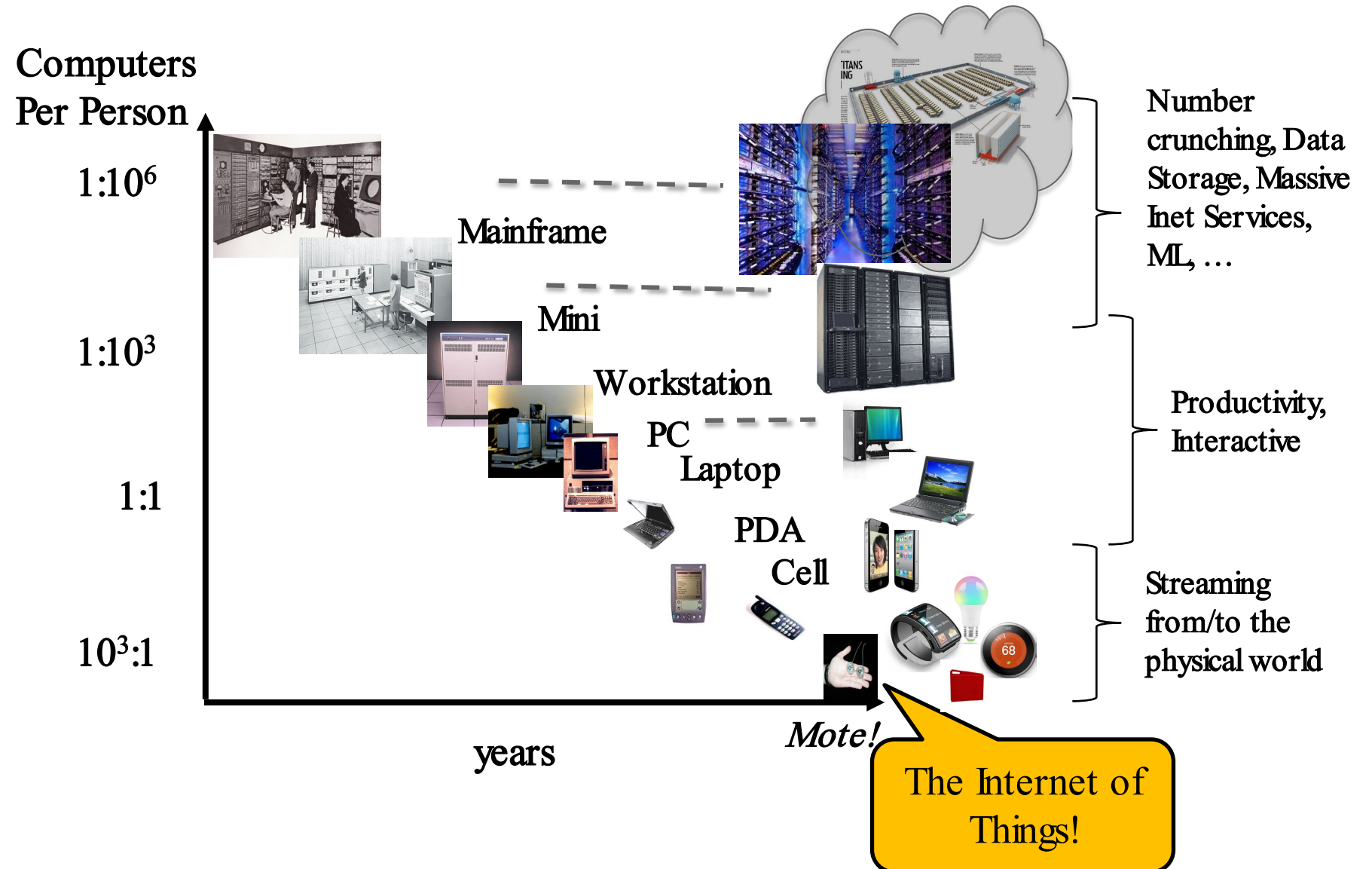
Lecture 1

What is an Operating System?

Department of Computer Science,
Hofstra University

Across Incredible Diversity

**Bell's Law: New
computer class
every 10 years**



And Range of Timescales

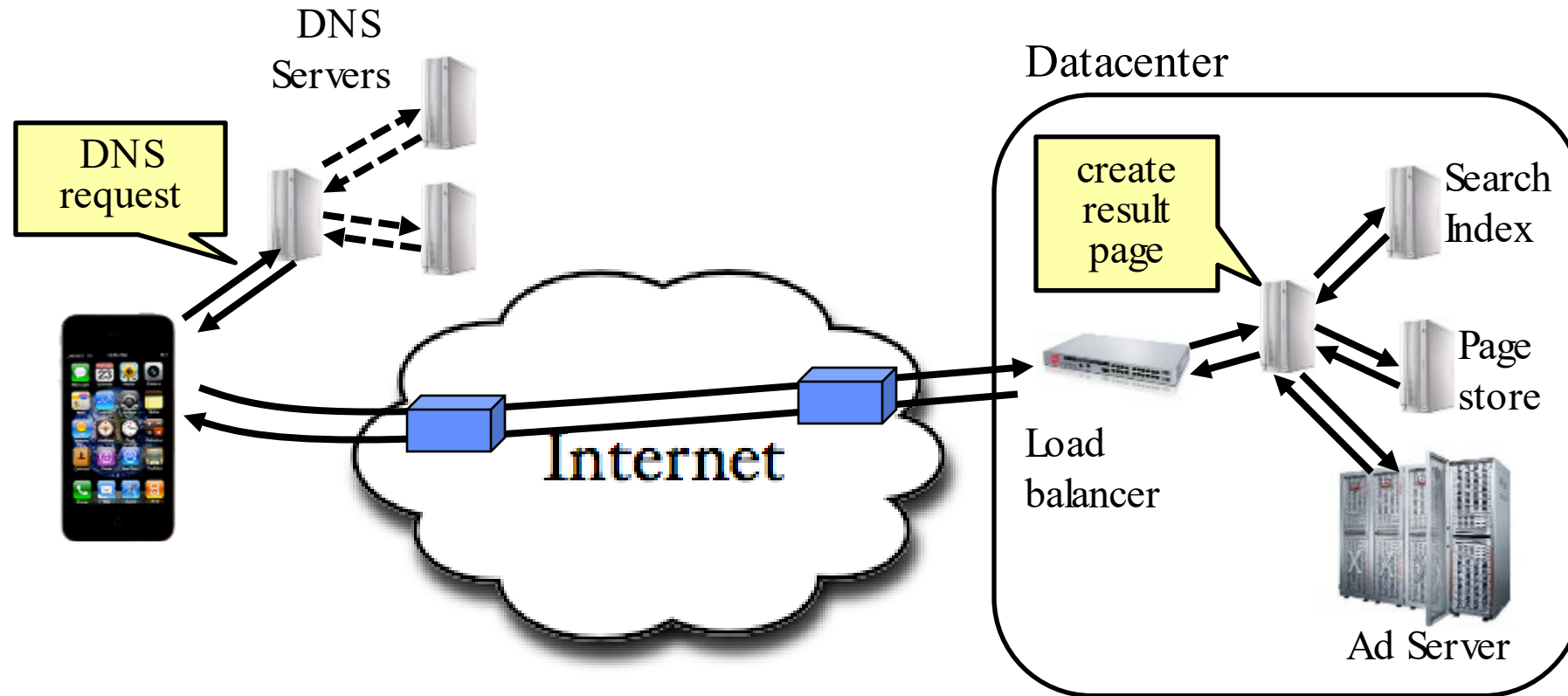
**Jeff Dean: “Numbers
Everyone Should Know”**

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns

Operating Systems are at the Heart of it All!

- Make the incredible advance in the underlying technology available to a rapidly evolving body of applications
 - Provide **consistent abstractions** to applications, even on different hardware
 - Manage **sharing of resources** among multiple applications
- The key building blocks:
 - Processes
 - Threads, Concurrency, Scheduling, Coordination
 - Address Spaces
 - Protection, Isolation, Sharing, Security
 - Communication, Protocols
 - Persistent storage, transactions, consistency, resilience
 - Interfaces to all devices

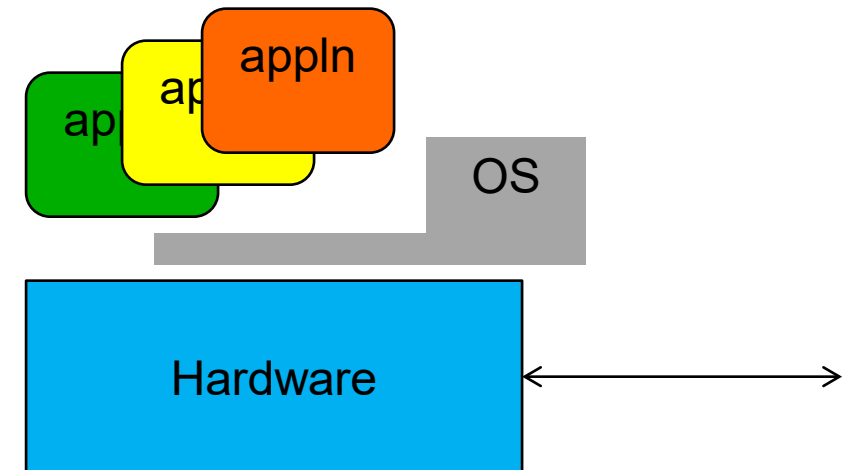
Example: What's in a Search Query?



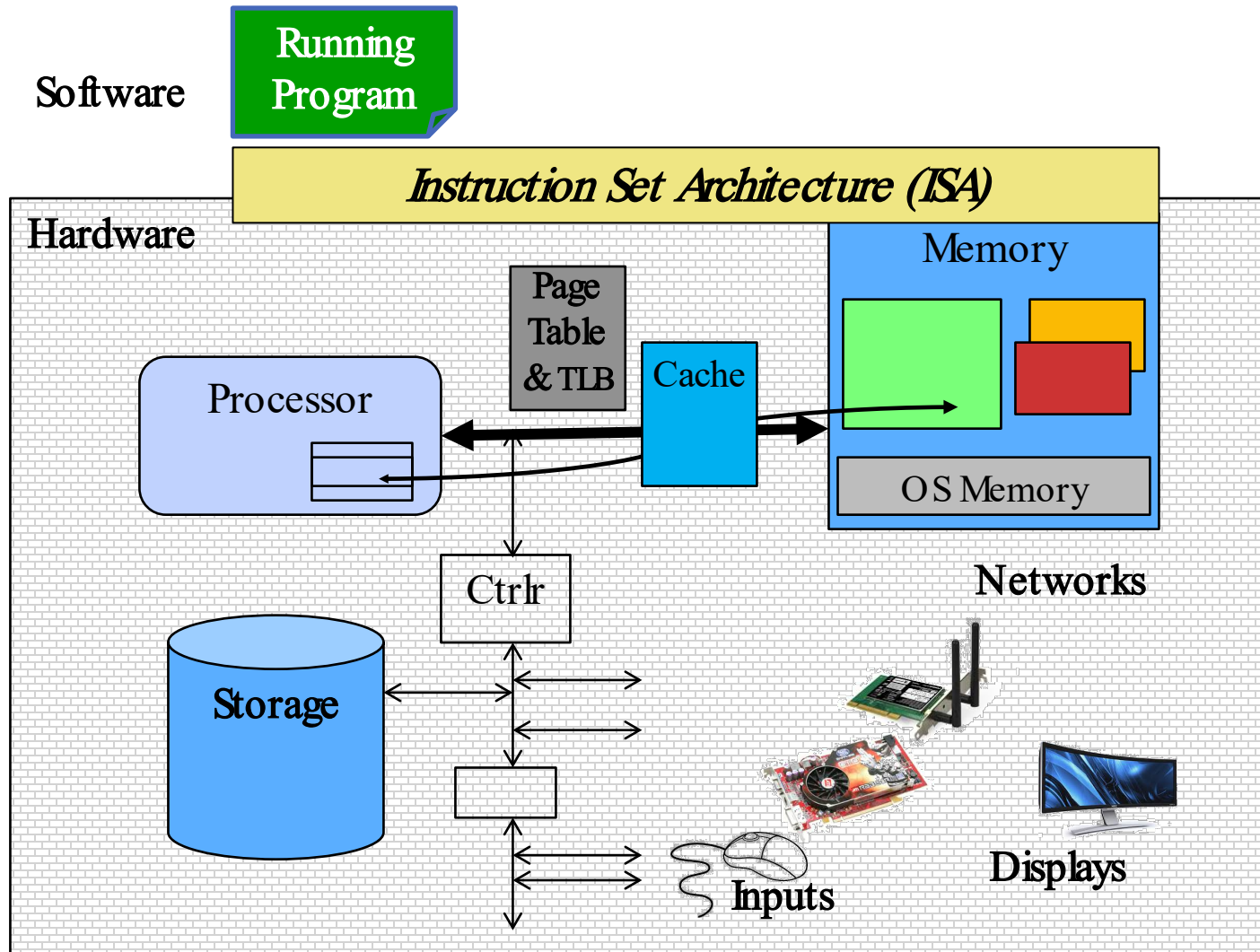
- Complex interaction of multiple components in multiple administrative domains
 - Systems, services, protocols, ...

One Definition of an Operating System

- Special layer of software that provides application software access to hardware resources
 - Convenient abstraction of complex hardware devices
 - Protected access to shared resources
 - Security and authentication
 - Communication



Hardware/Software Interface



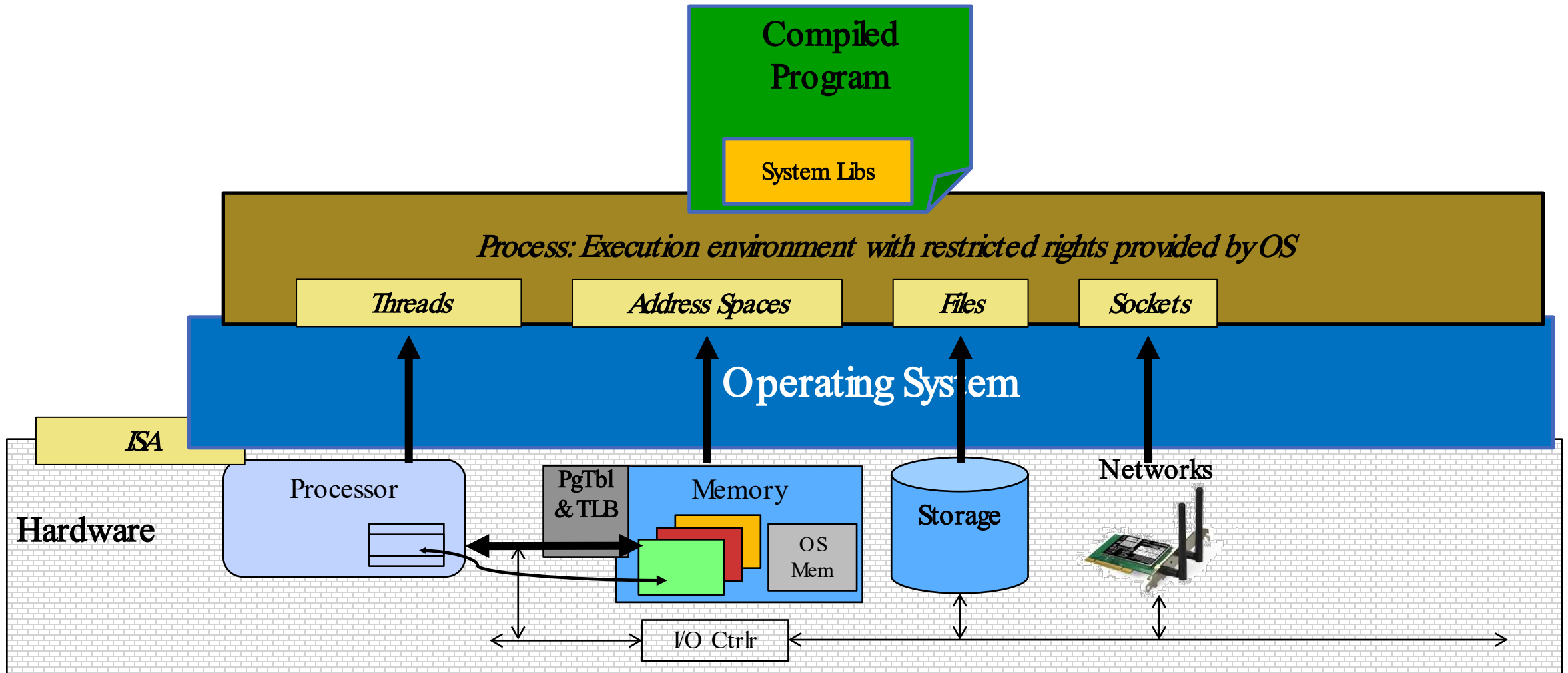
The OS *abstracts* these hardware details from the application

What is an Operating System?

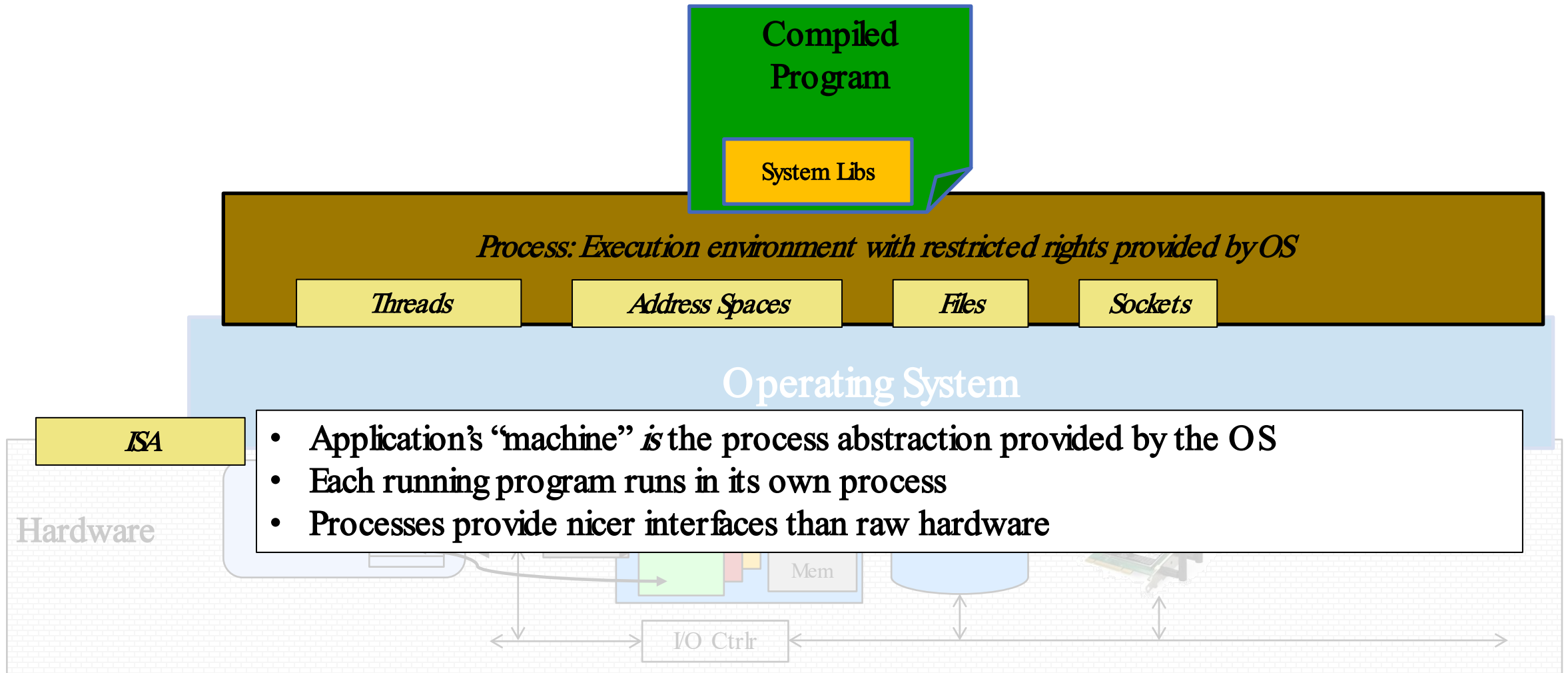


- Illusionist
 - Provide clean, easy-to-use abstractions of physical resources
 - » Infinite memory, dedicated machine
 - » Higher level objects: files, users, messages
 - » Masking limitations, virtualization

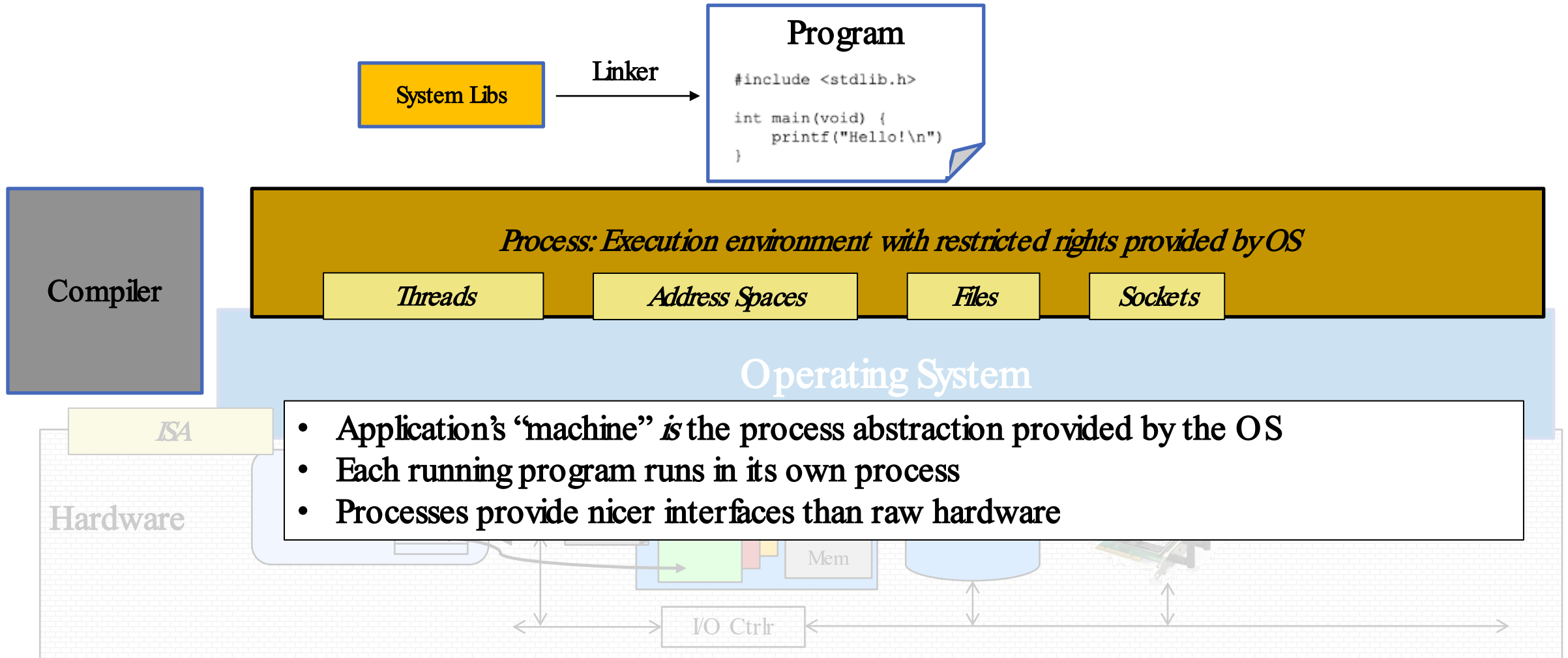
OS Basics: Virtualizing the Machine



Compiled Program's View of the World



System Programmer's View of the World

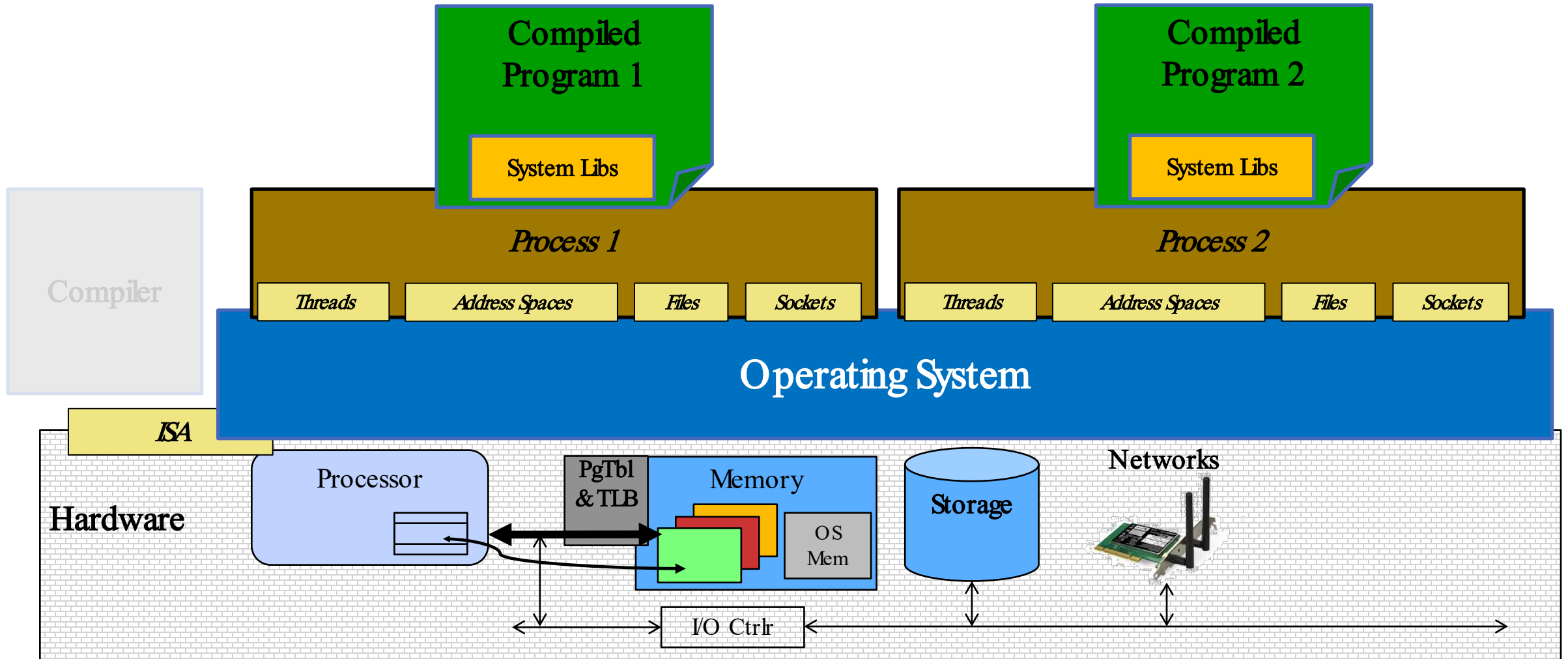


What's in a Process?

A process consists of:

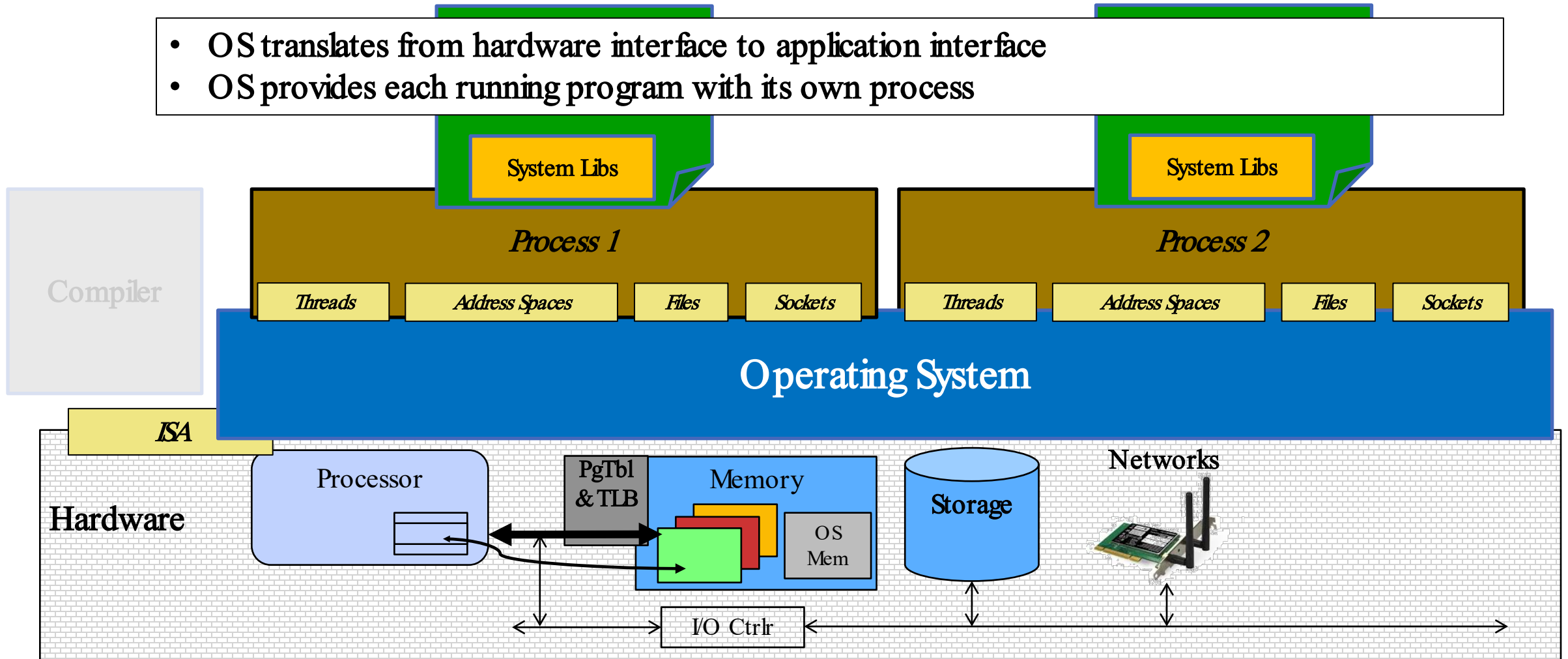
- Address Space
- One or more threads of control executing in that address space
- Additional system state associated with it
 - Open files
 - Open sockets (network connections)
 - ...

Operating System's View of the World



Operating System's View of the World

- OS translates from hardware interface to application interface
- OS provides each running program with its own process

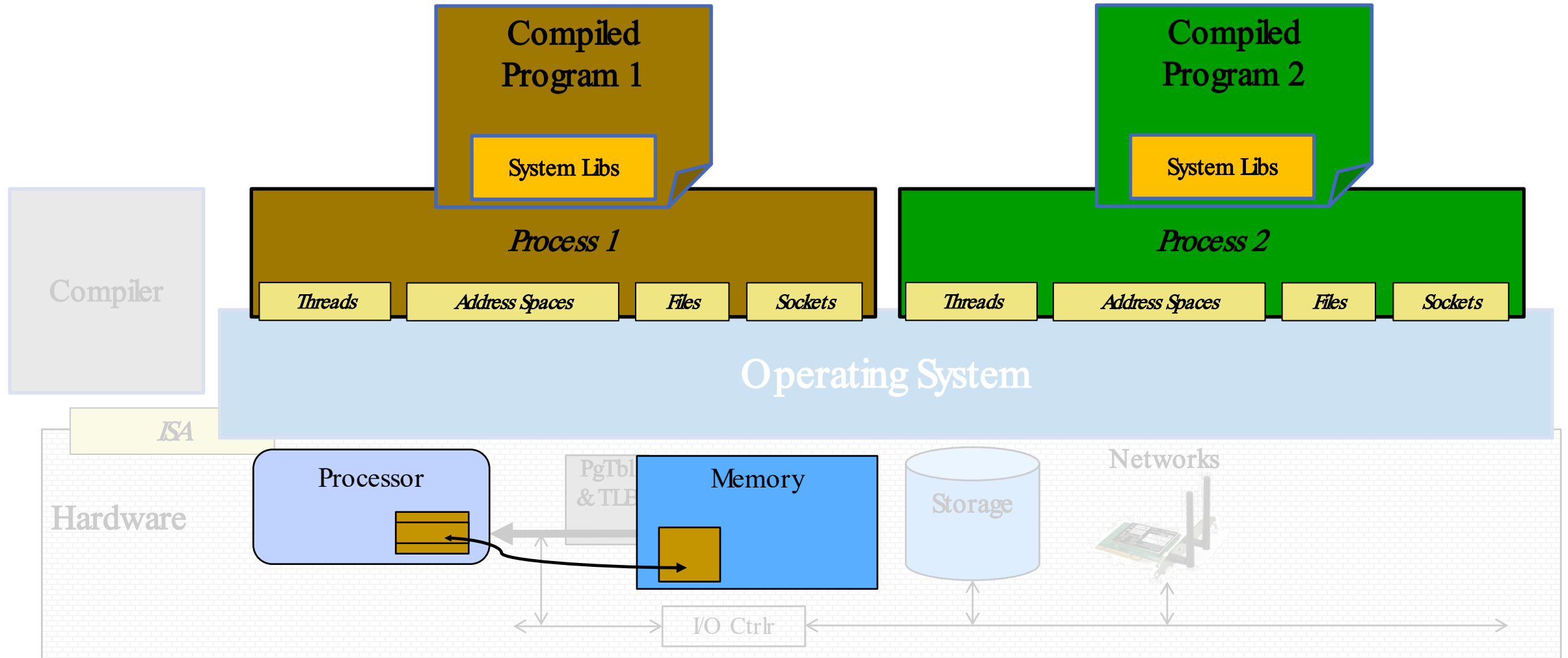


What is an Operating System?

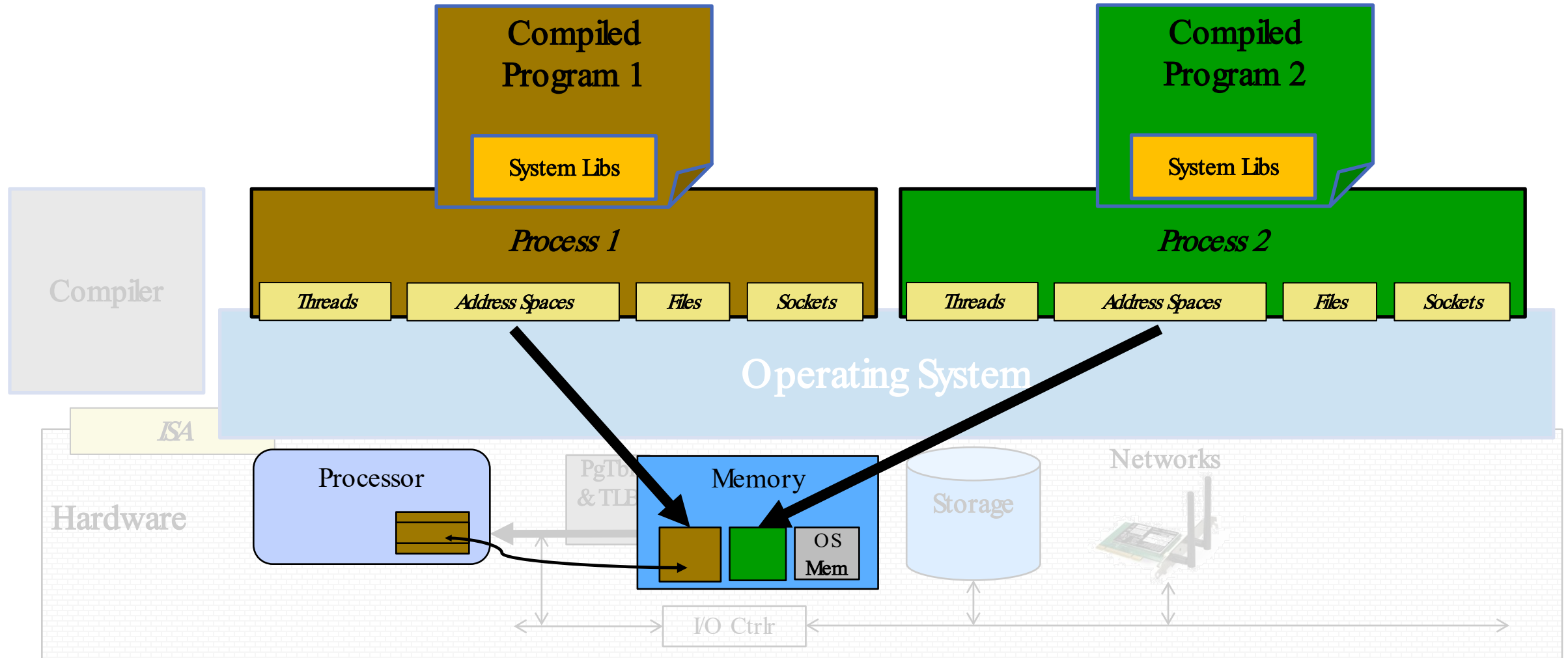


- Illusionist
 - Provide clean, easy-to-use abstractions of physical resources
 - » Infinite memory, dedicated machine
 - » Higher level objects: files, users, messages
 - » Masking limitations, virtualization
- Referee
 - Manage protection, isolation, and sharing of resources
 - » Resource allocation and communication

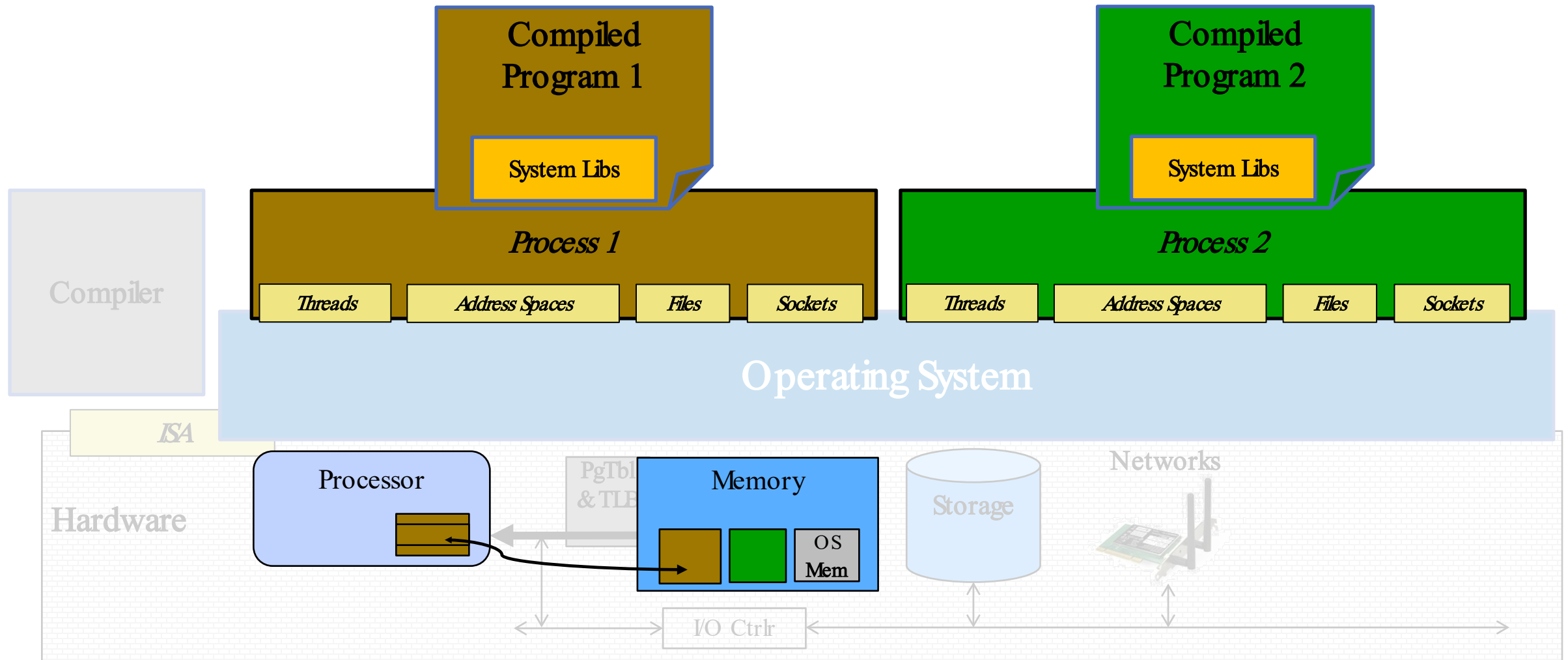
OS Basics: Running a Process



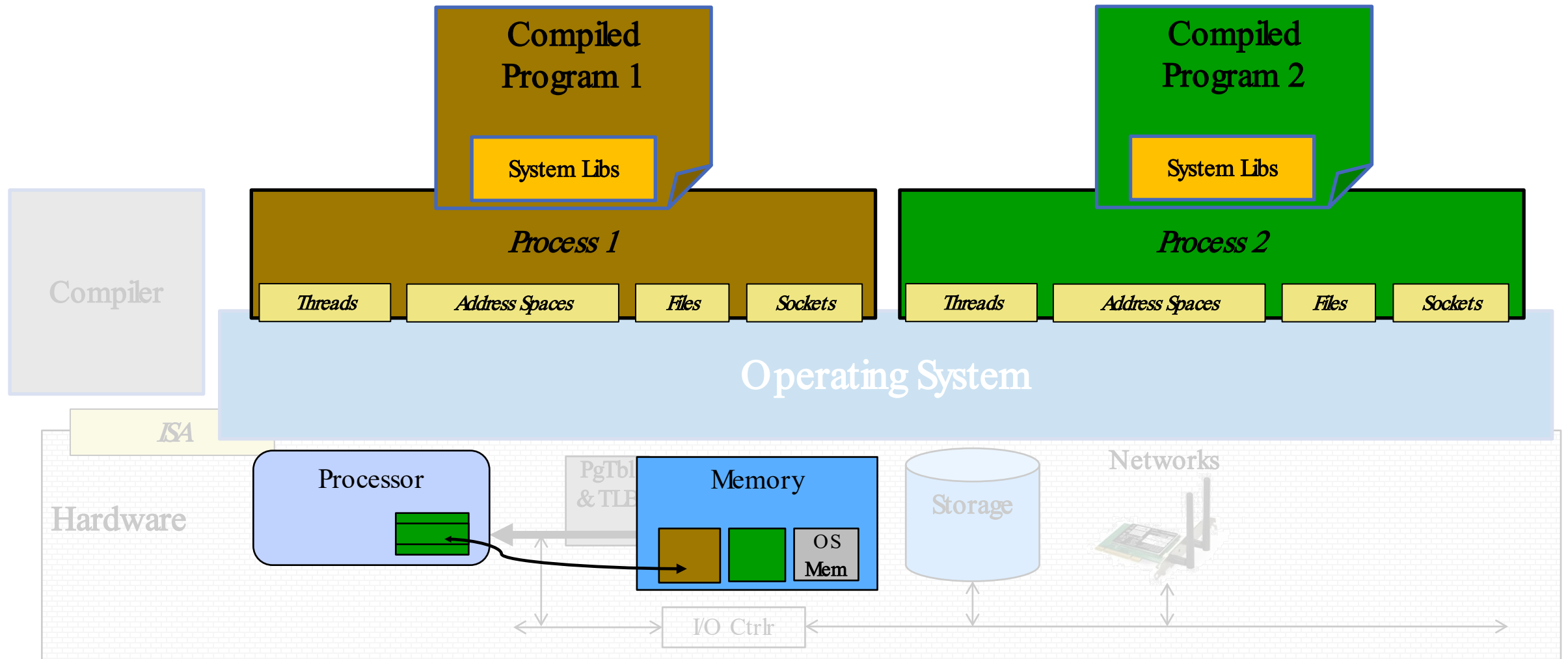
OS Basics: Switching Processes



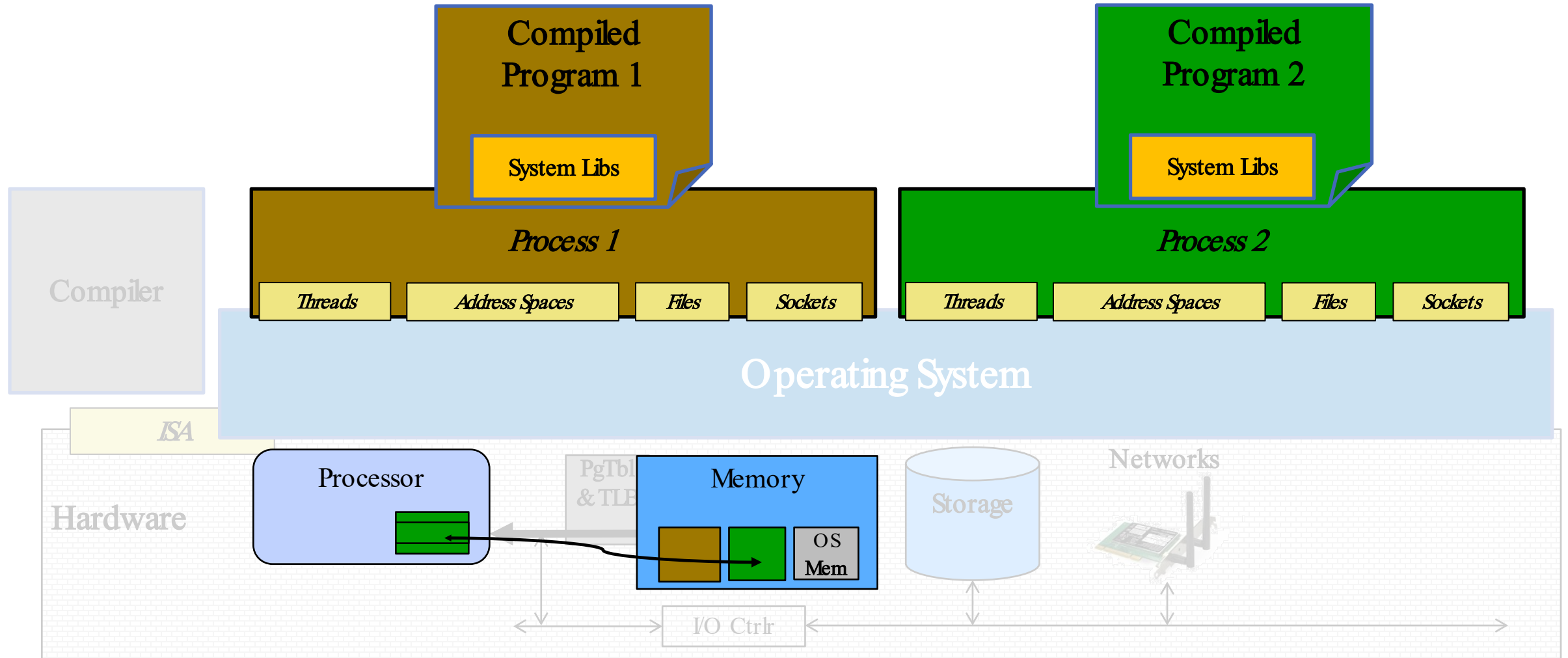
OS Basics: Switching Processes



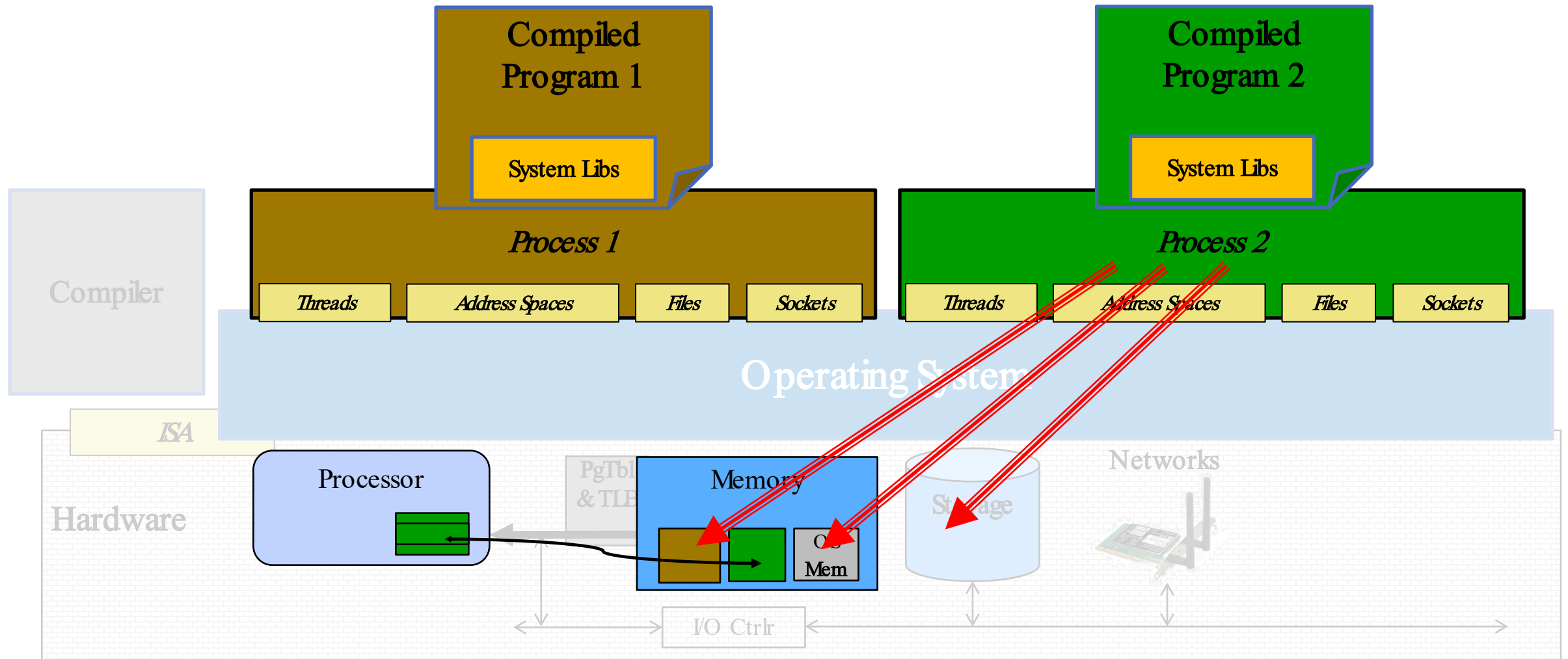
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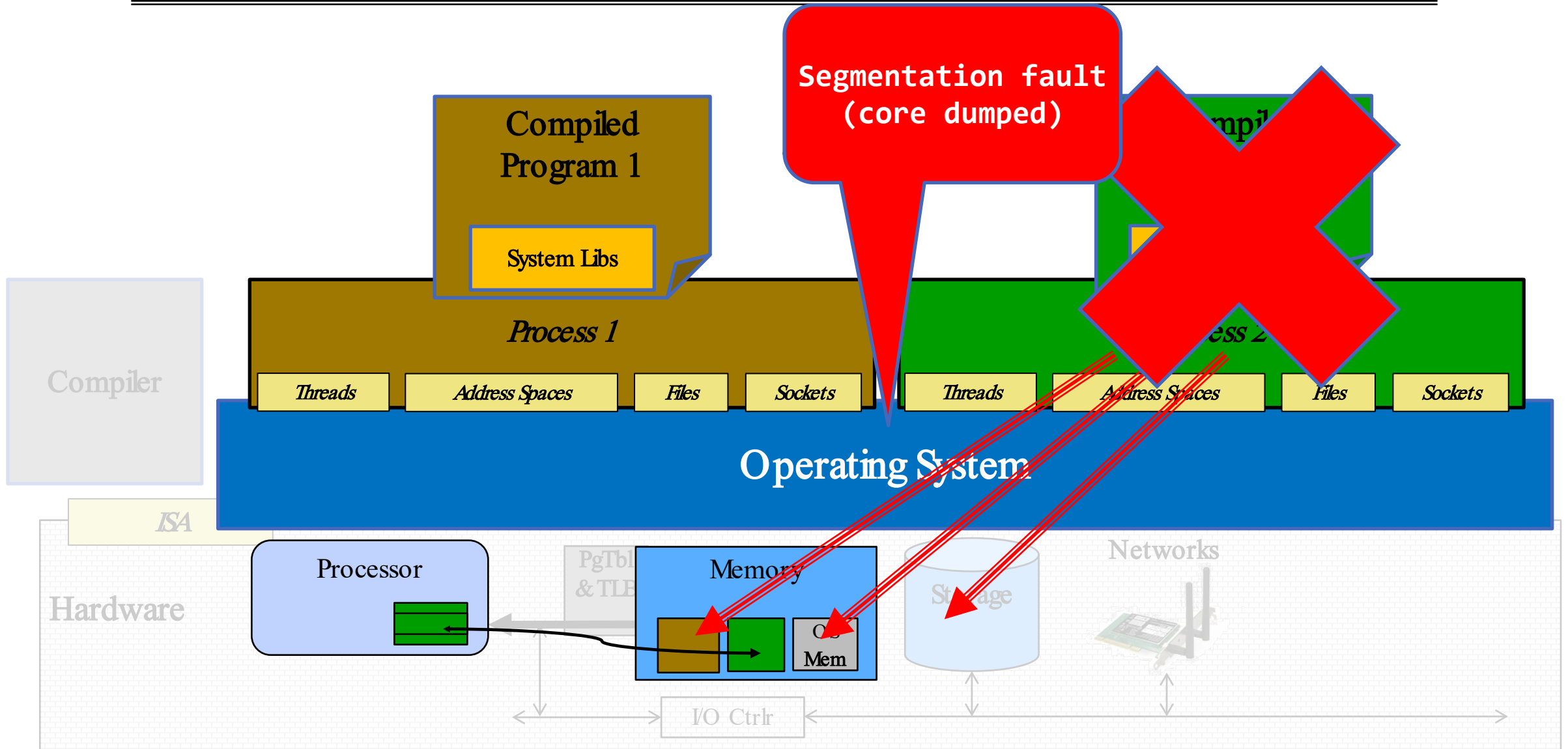
OS Basics: Switching Processes



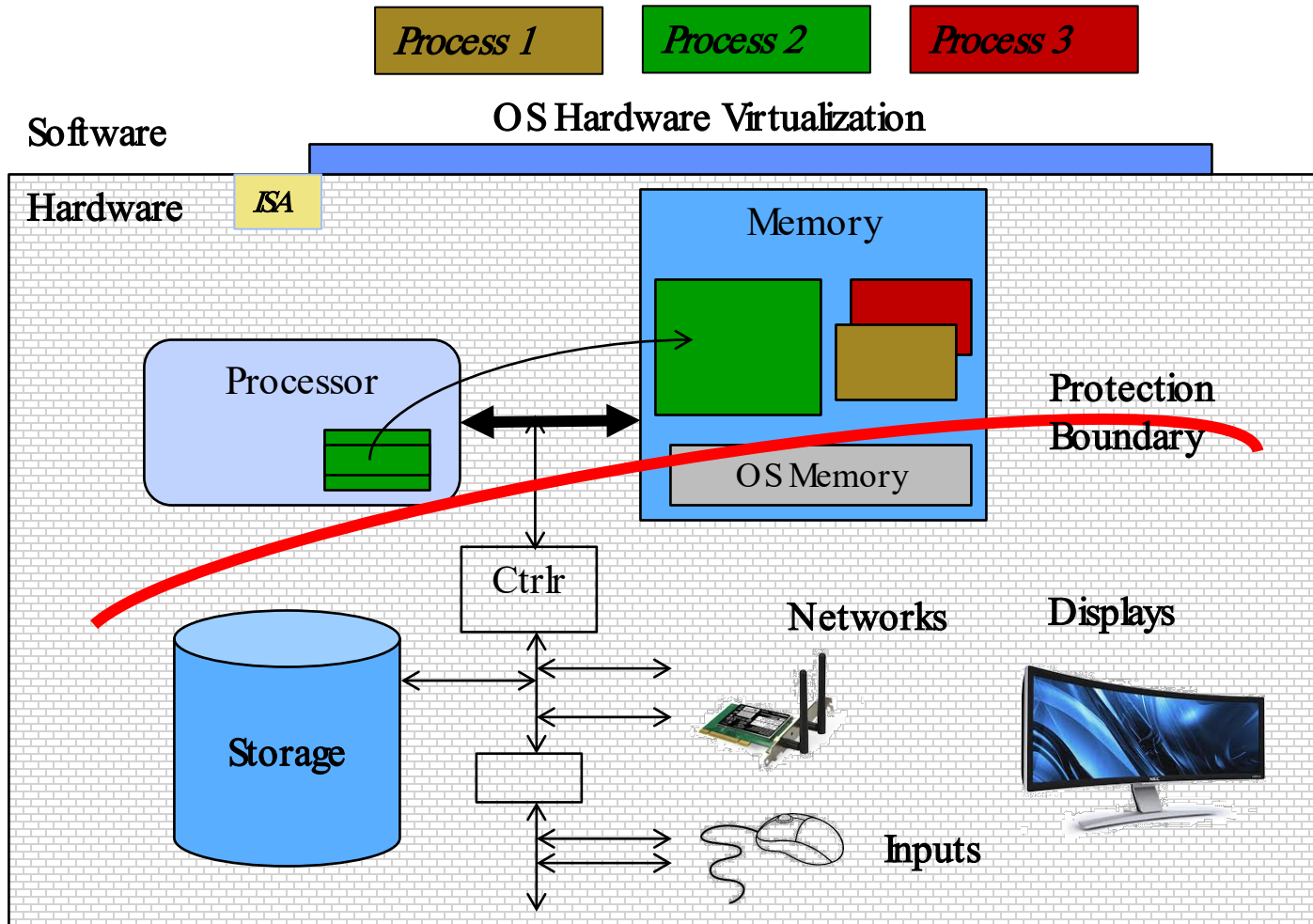
OS Basics: Protection



OS Basics: Protection

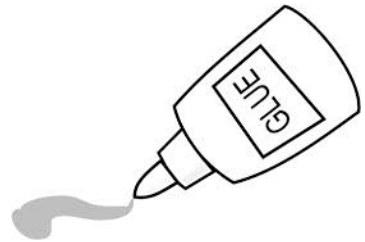


OS Basics: Protection



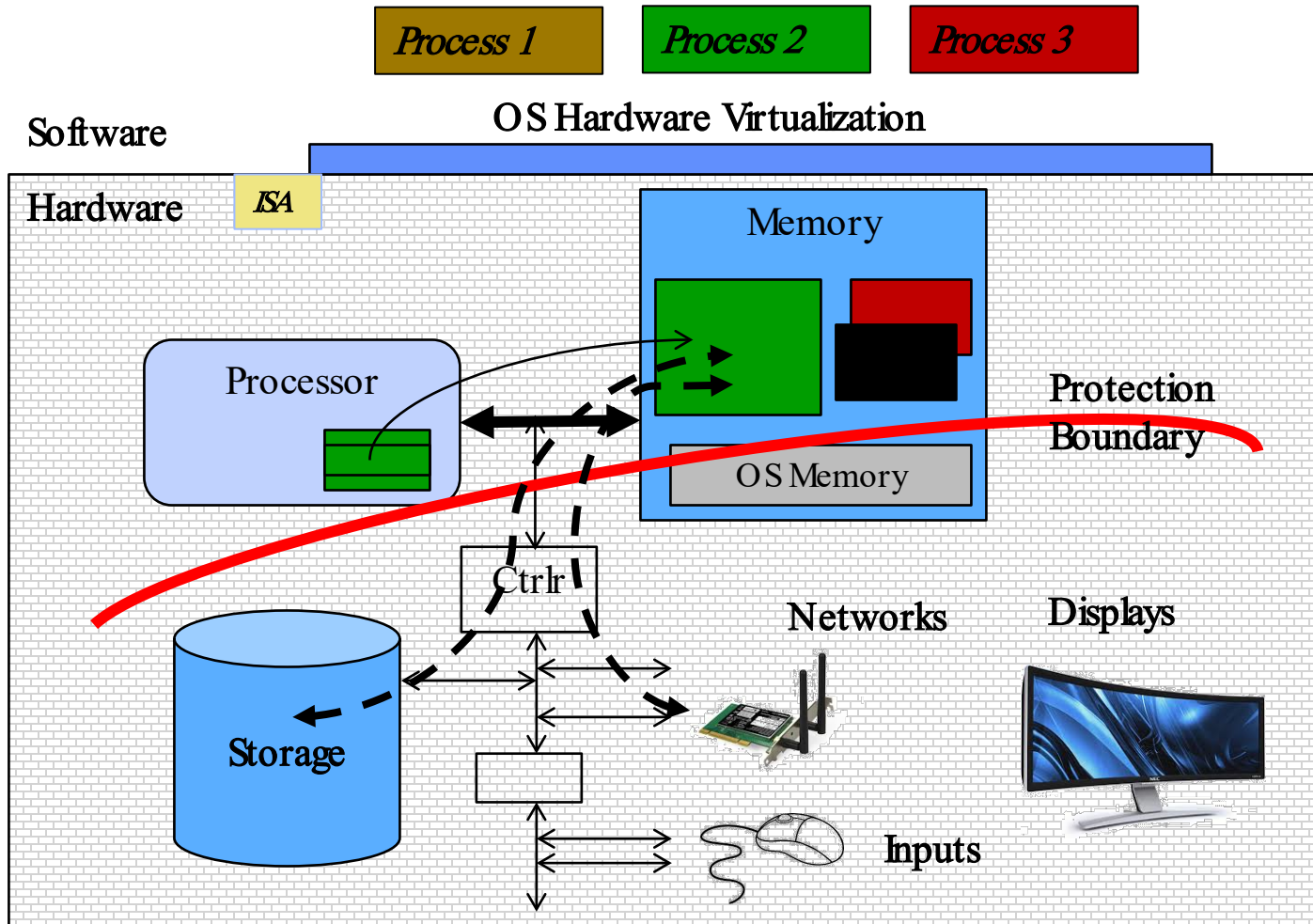
- OS *isolates* processes from each other
- OS *isolates* itself from other processes
- ... even though they are actually running on the same hardware!

What is an Operating System?



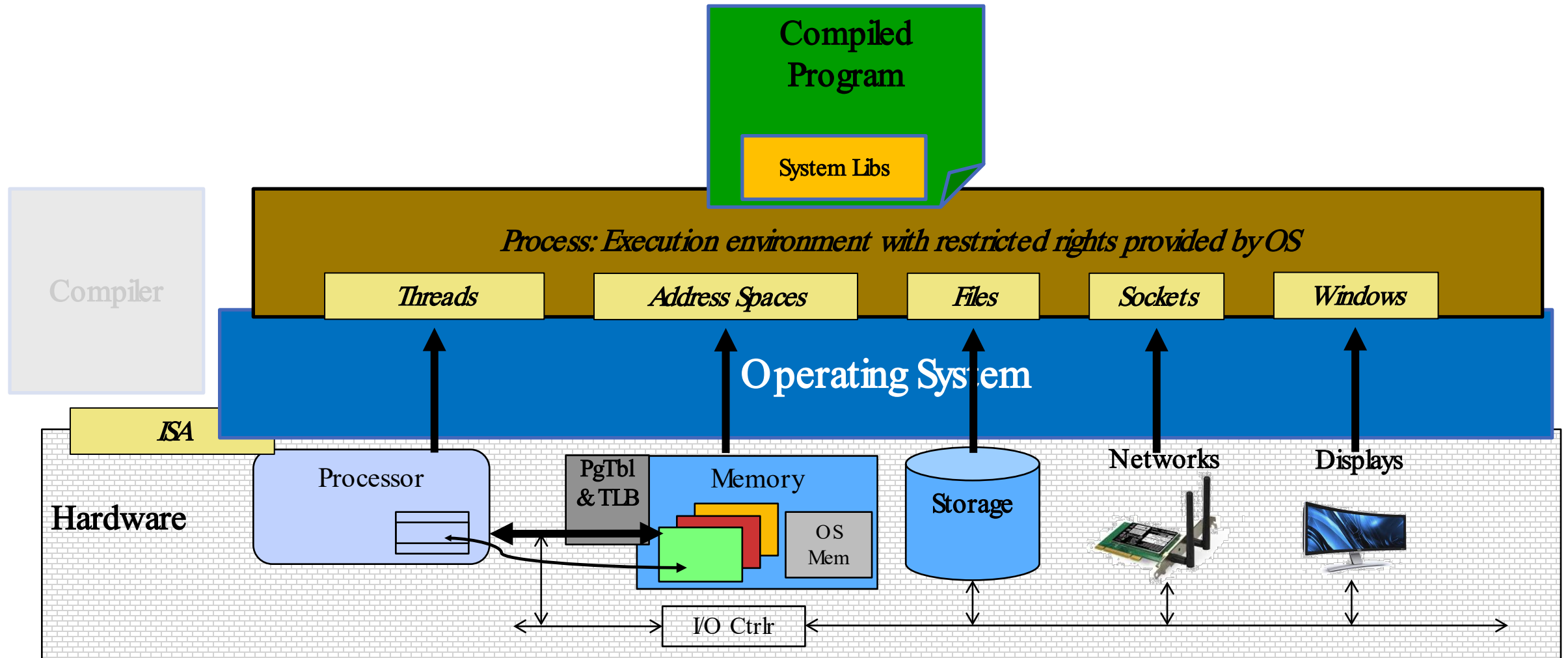
- Illusionist
 - Provide clean, easy-to-use abstractions of physical resources
 - » Infinite memory, dedicated machine
 - » Higher level objects: files, users, messages
 - » Masking limitations, virtualization
- Referee
 - Manage protection, isolation, and sharing of resources
 - » Resource allocation and communication
- Glue
 - Common services
 - » Storage, Window system, Networking
 - » Sharing, Authorization
 - » Look and feel

OS Basics: I/O

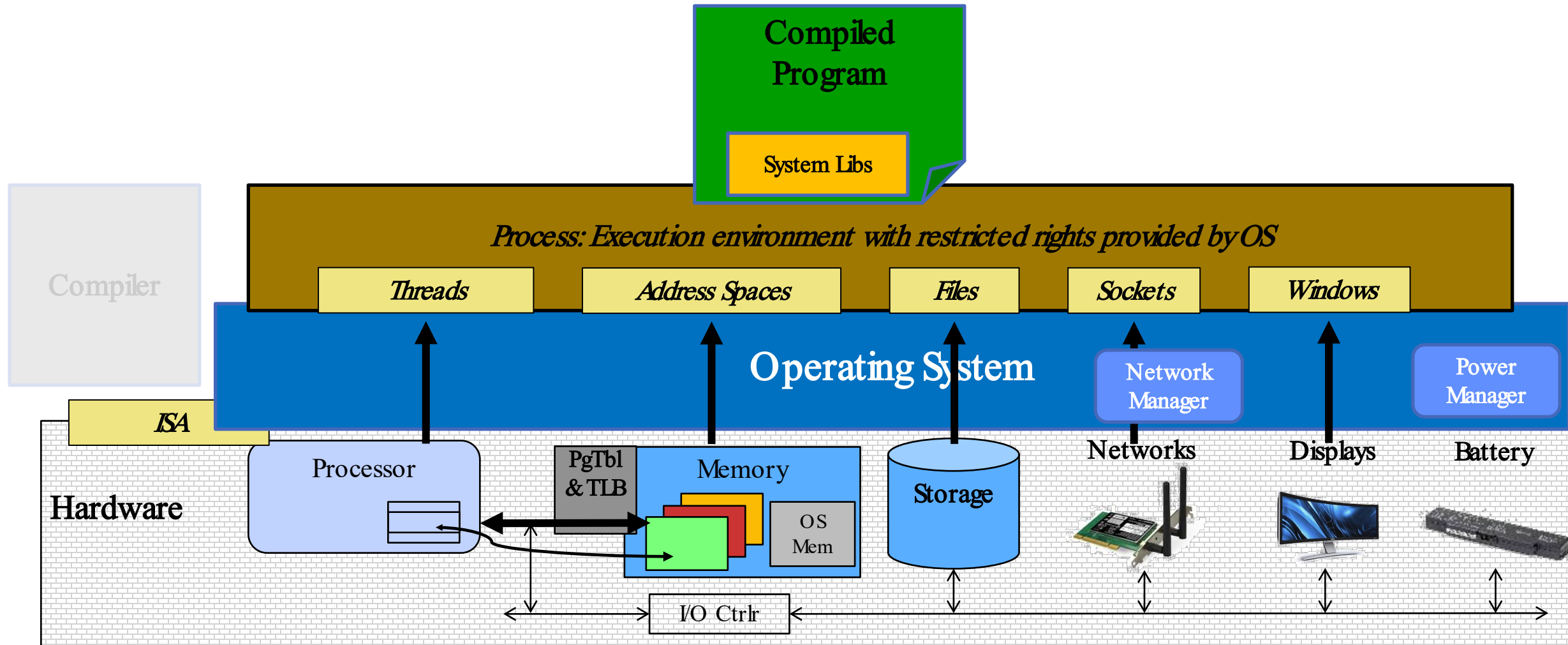


- OS provides common services in the form of I/O

OS Basics: Look and Feel



OS Basics: Background Management



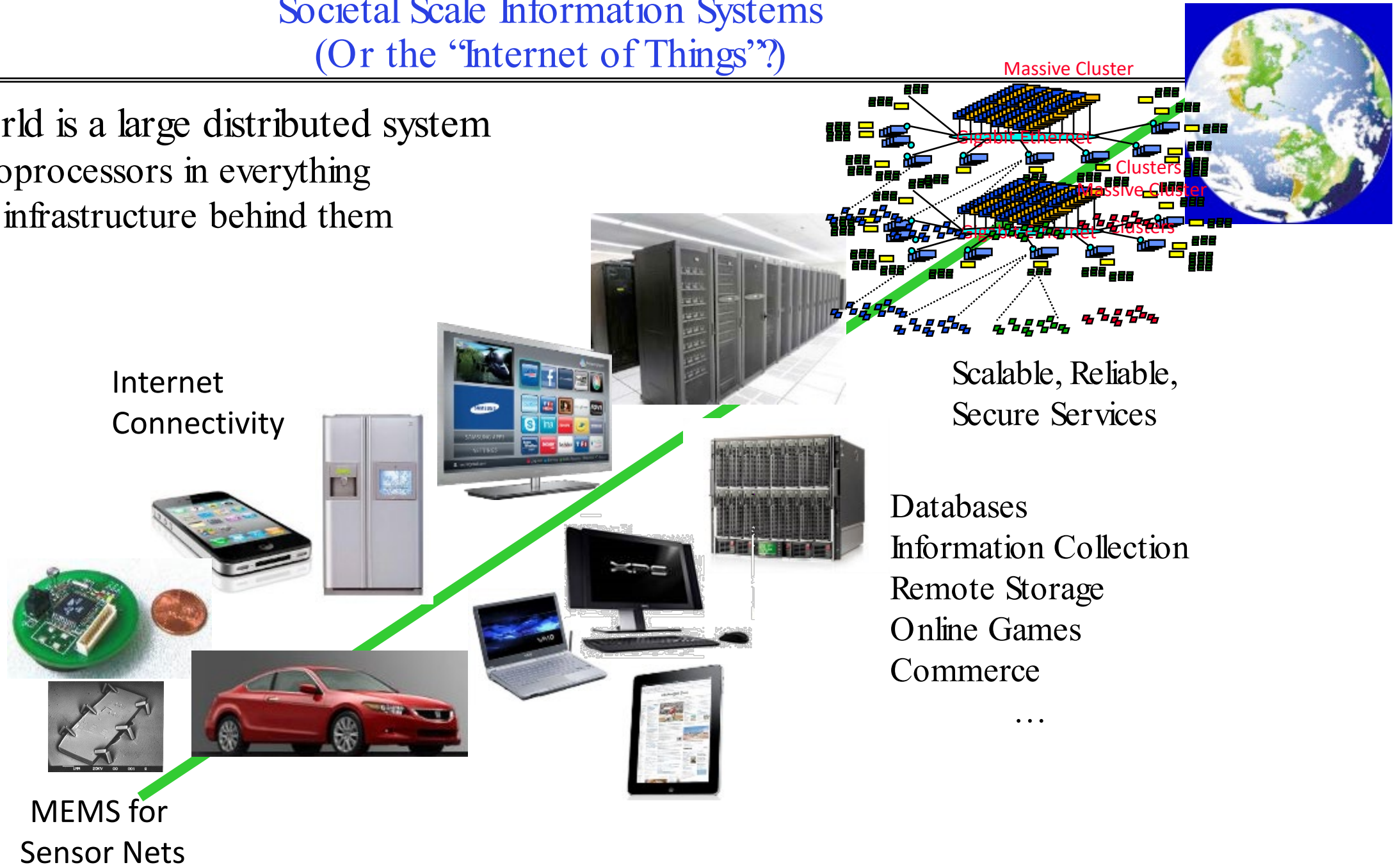
Why take CSC112?

- Some of you will design and build operating systems or components of them.
 - Perhaps more now than ever for embedded systems
- Many of you will create systems that utilize the core concepts in operating systems.
 - Whether you build software or hardware
 - The concepts and design patterns appear at many levels
- All of you will build applications, etc. that utilize operating systems
 - The better you understand their design and implementation, the better use you'll make of them.

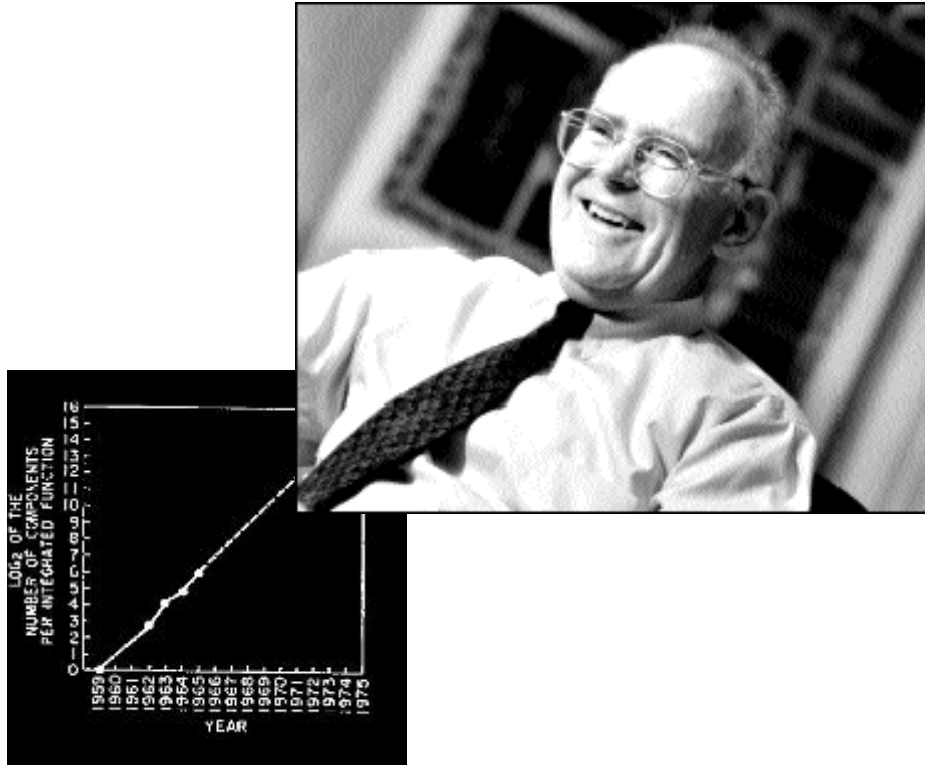
What makes Operating Systems Exciting and Challenging?

Societal Scale Information Systems (Or the ‘Internet of Things’?)

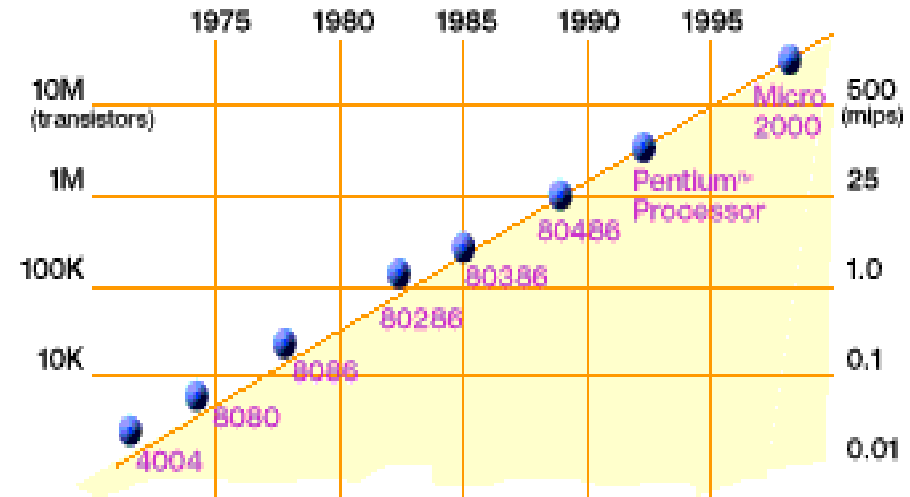
- The world is a large distributed system
 - Microprocessors in everything
 - Vast infrastructure behind them



Technology Trends: Moore's Law



Gordon Moore (co-founder of Intel) predicted in 1965 that the transistor density of semiconductor chips would double roughly every 18 months

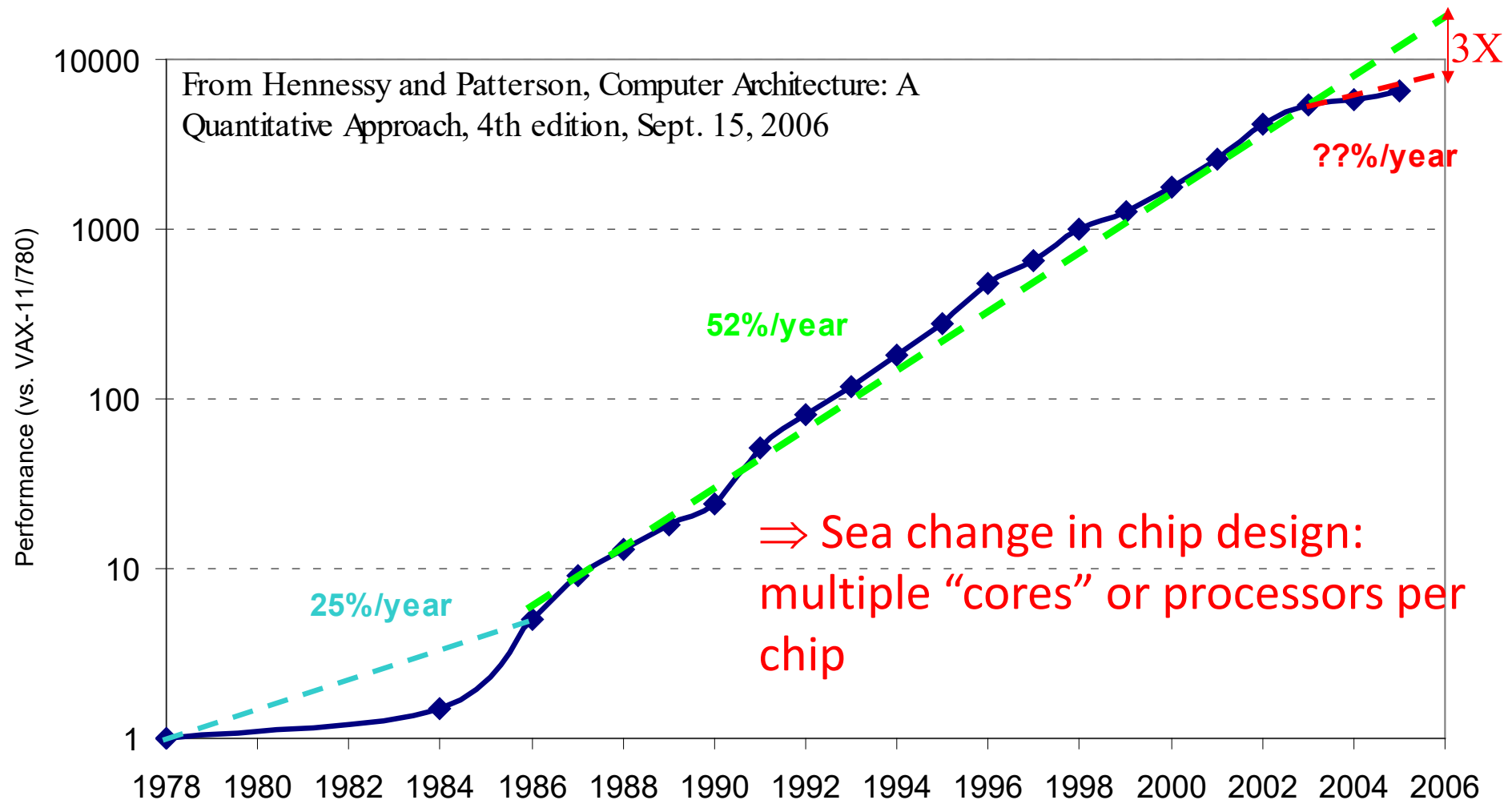


2X transistors/Chip Every 1.5 years

Called “Moore’s Law”

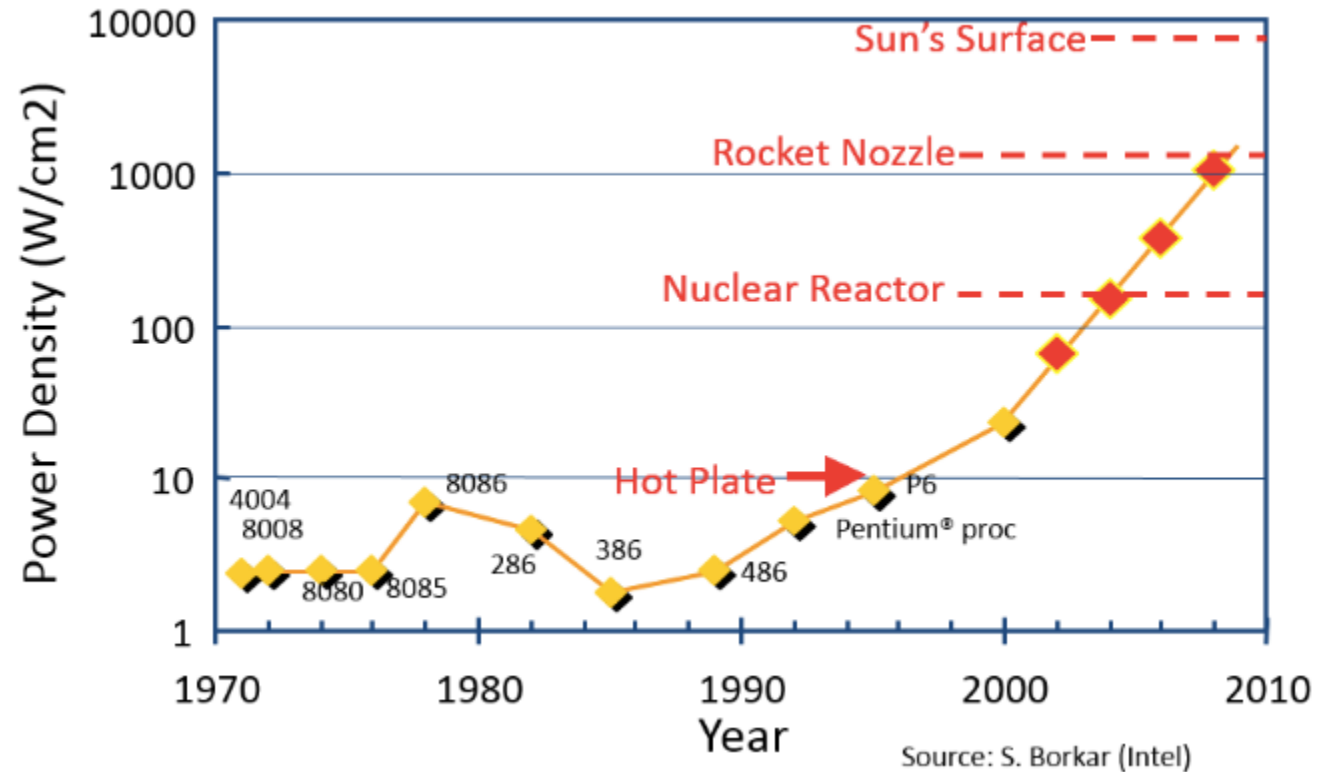
Microprocessors have become smaller, denser, and more powerful

Big Challenge: Slowdown in Jy's law of Performance



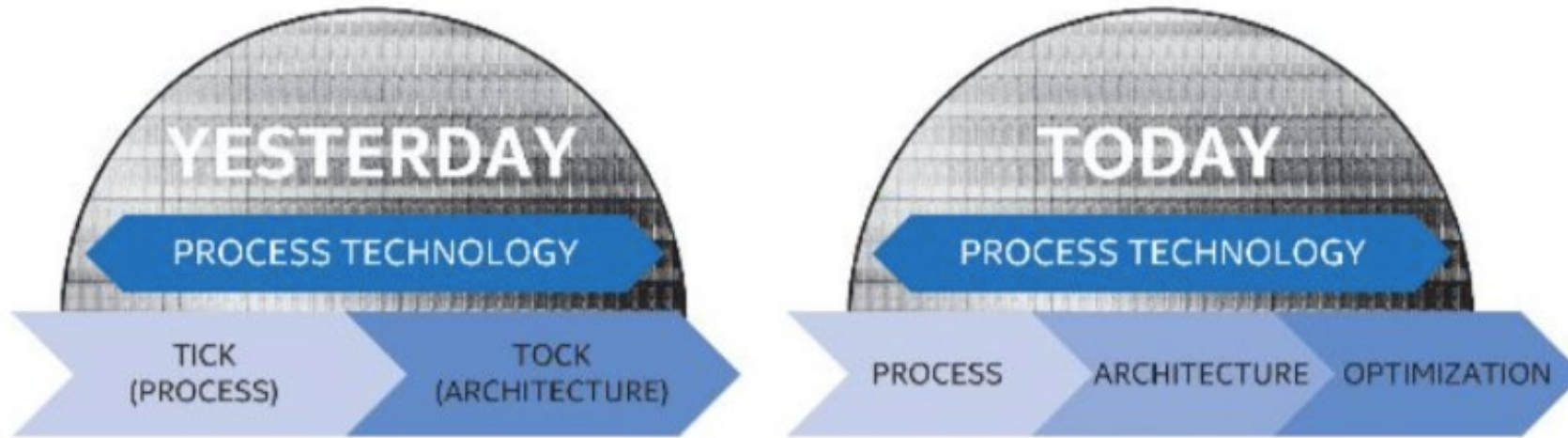
- VAX : 25%/year 1978 to 1986
- RISC + x86 : 52%/year 1986 to 2002
- RISC + x86 : ??%/year 2002 to present

Another Challenge: Power Density



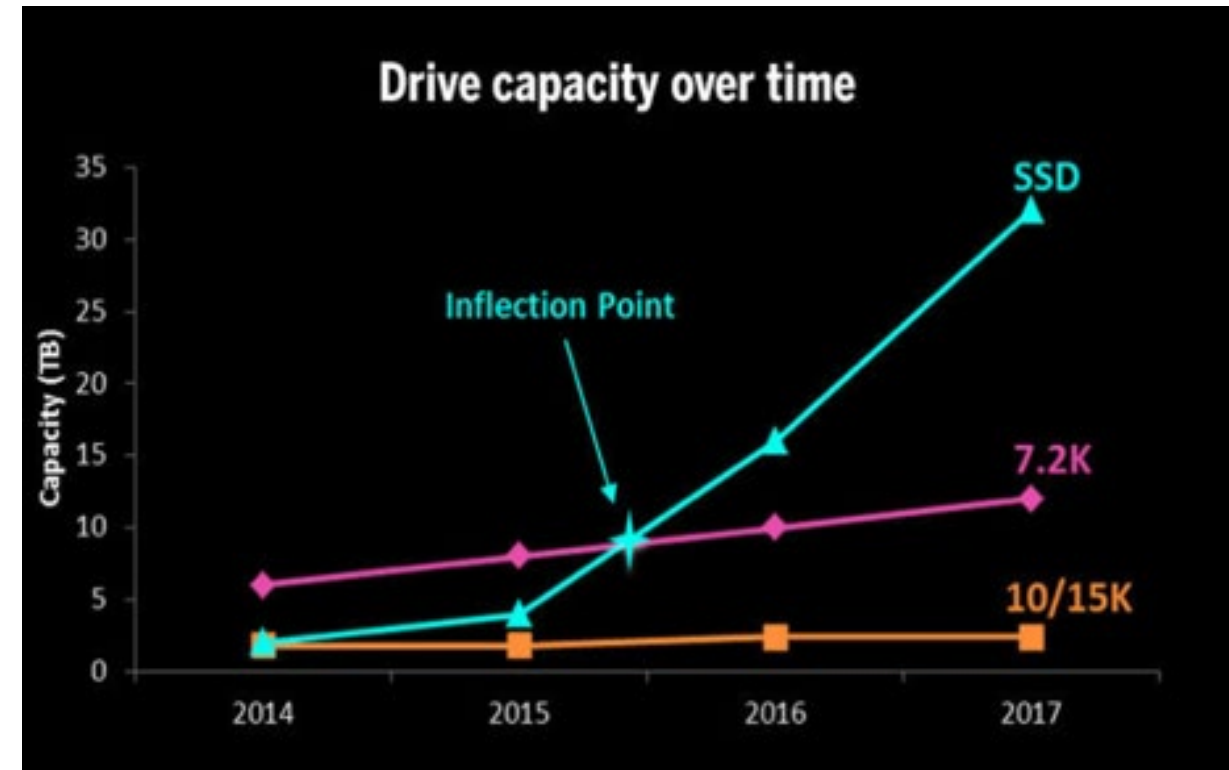
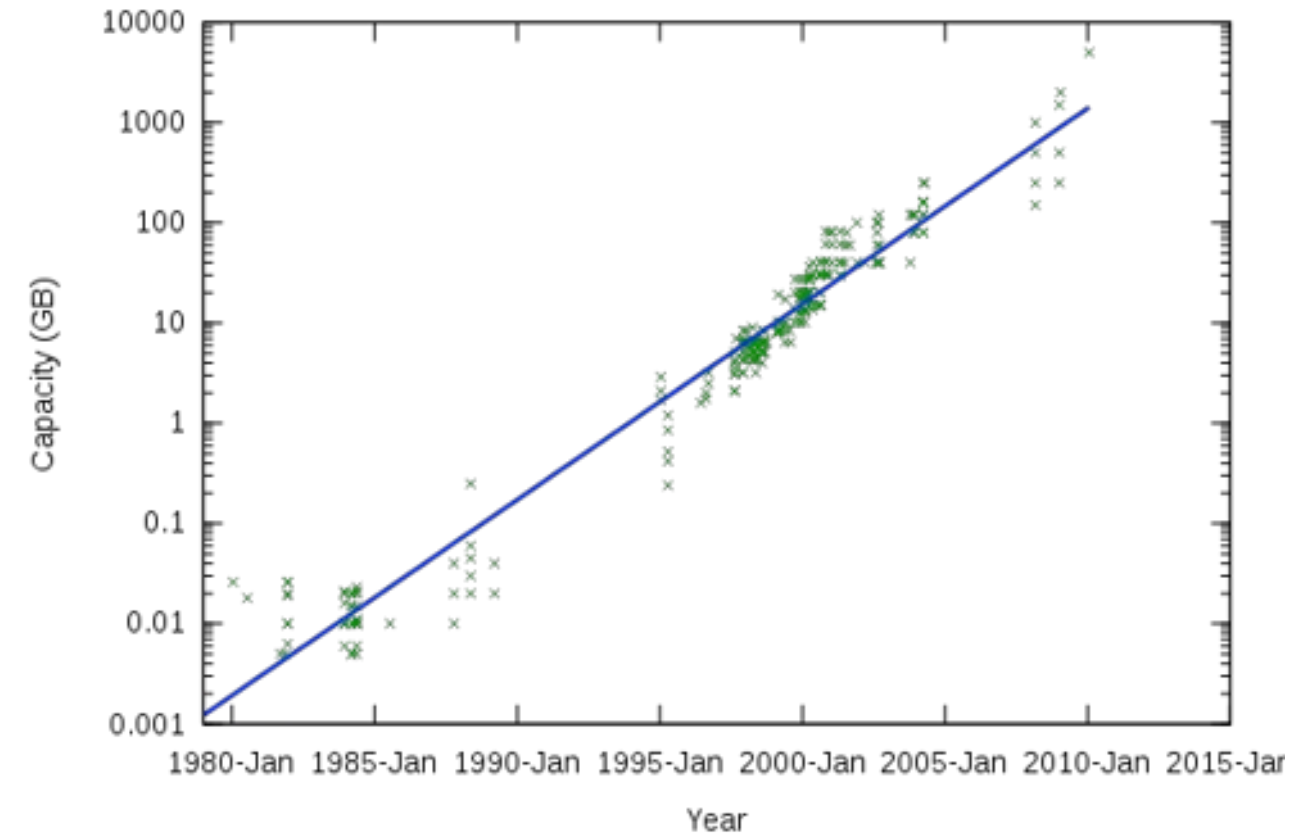
- Moore's law extrapolation
 - Potential power density reaching amazing levels!
- Flip side: battery life very important
 - Moore's law yielded more functionality at equivalent (or less) total energy consumption

But then Moore's Law Ended...

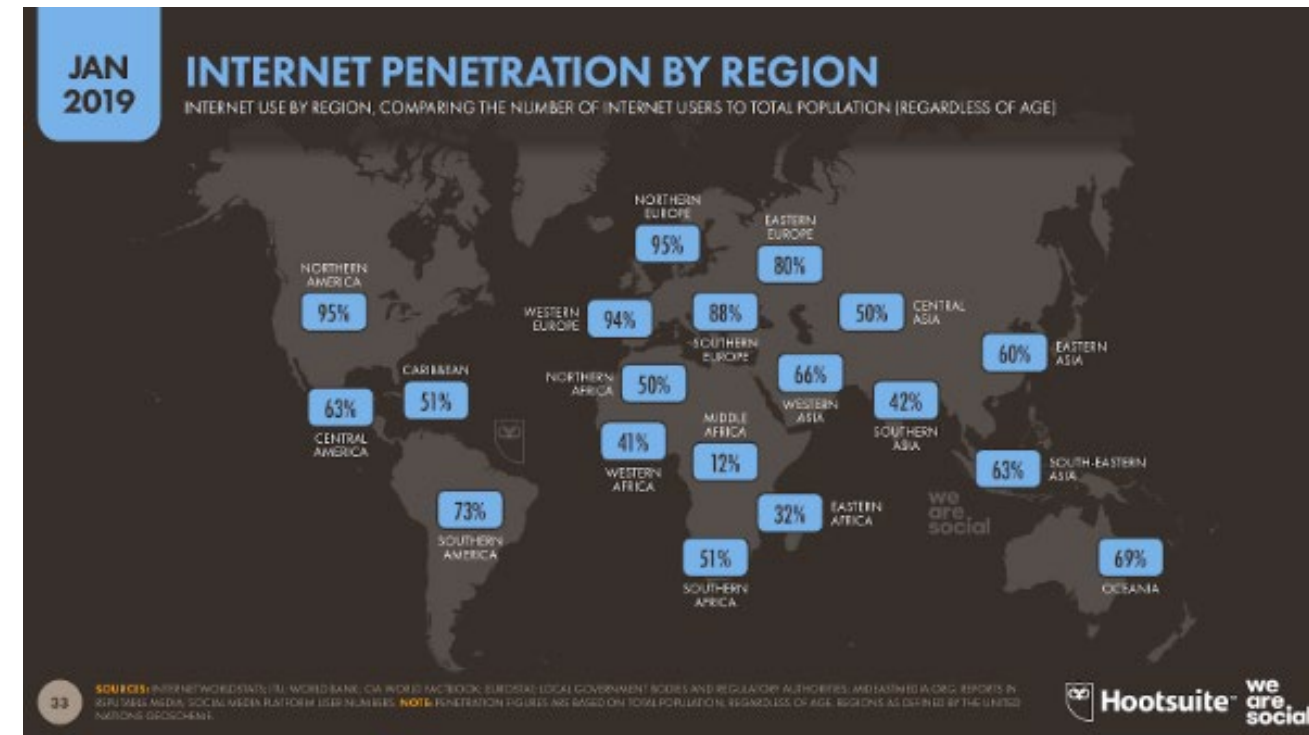


- Moore's Law has (officially) ended -- Feb 2016
 - No longer getting 2 x transistors/chip every 18 months...
 - or even every 24 months
- May have only 2-3 smallest geometry fabrication plants left:
 - Intel and Samsung and/or TSMC
- Vendors moving to 3D stacked chips
 - More layers in old geometries

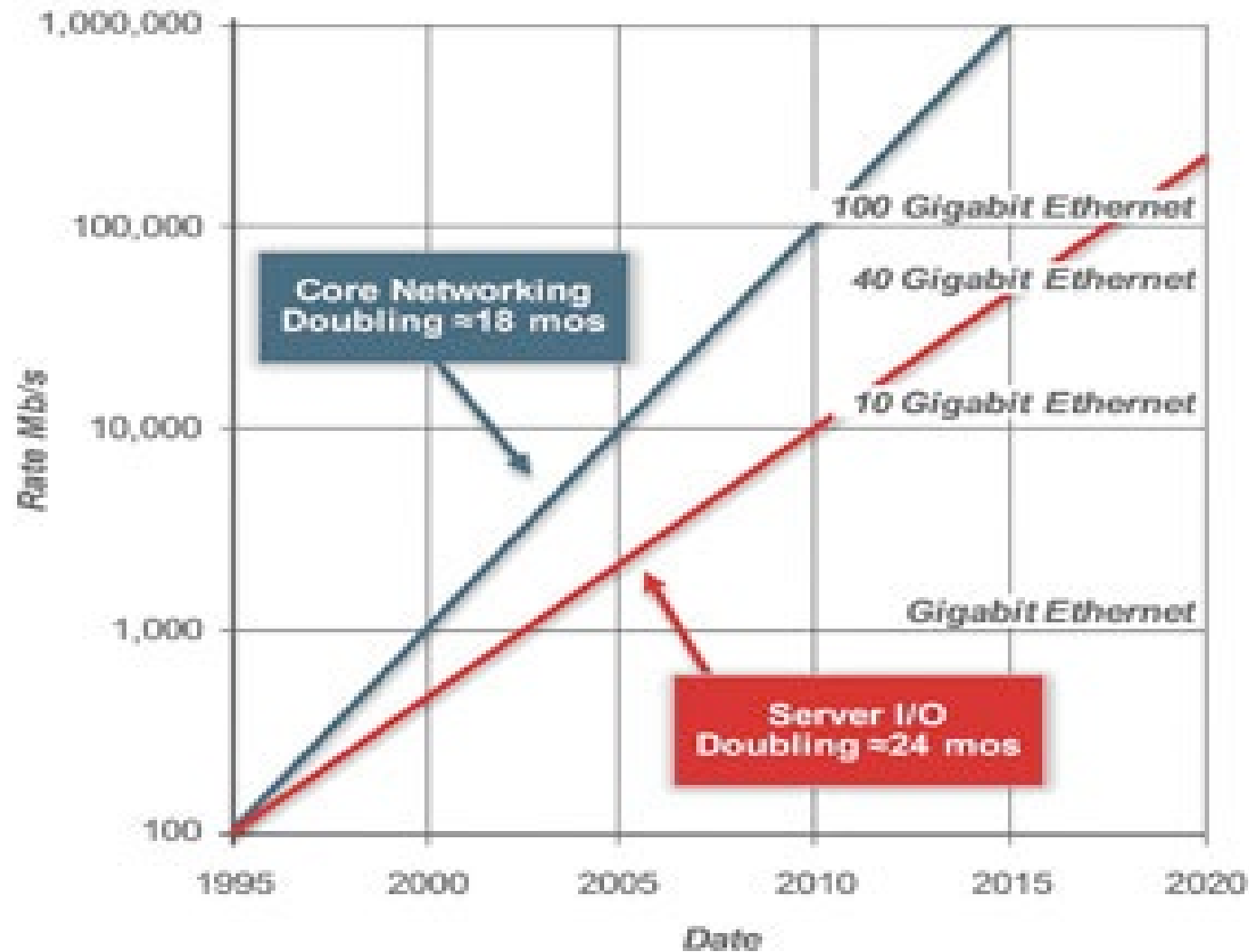
Storage Capacity is Still Growing!



Society is Increasingly Connected...



Network Capacity Still Increasing



(source: <http://www.ospmag.com/issue/article/Time-Is-Not-Always-On-Our-Side>)

Not Only PCs connected to the Internet

- In 2011, smartphone shipments exceeded PC shipments!

- 2011 shipments:

- 487M smartphones
- 414M PC clients
 - » 210M notebooks
 - » 112M desktops
 - » 63M tablets
- 25M smart TVs

1.53B in 2017

262.5M in 2017

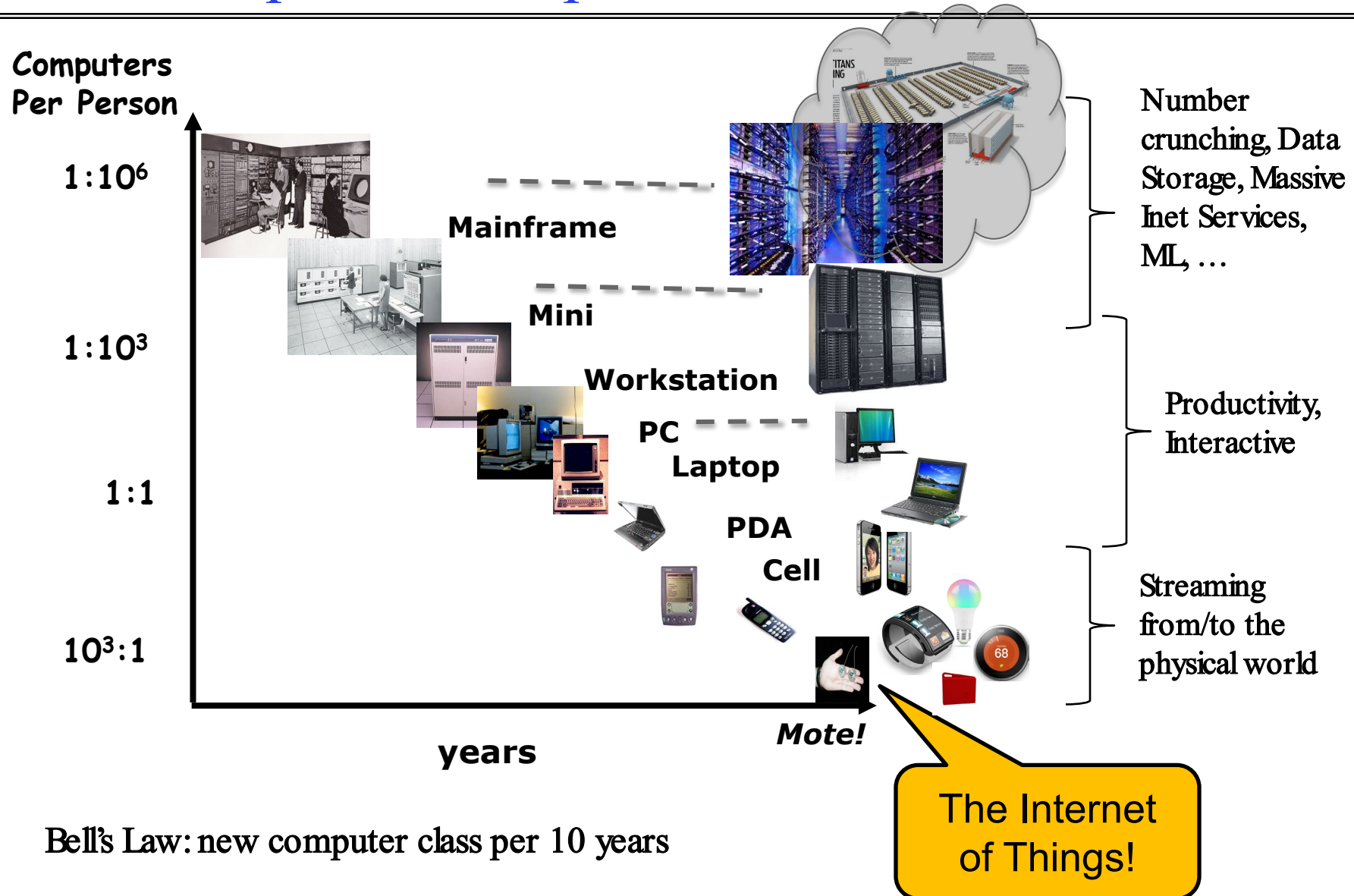
164M in 2017

39.5M in 2017



- 4 billion phones in the world → smartphones over next few years
- Then...

People-to-Computer Ratio Over Time

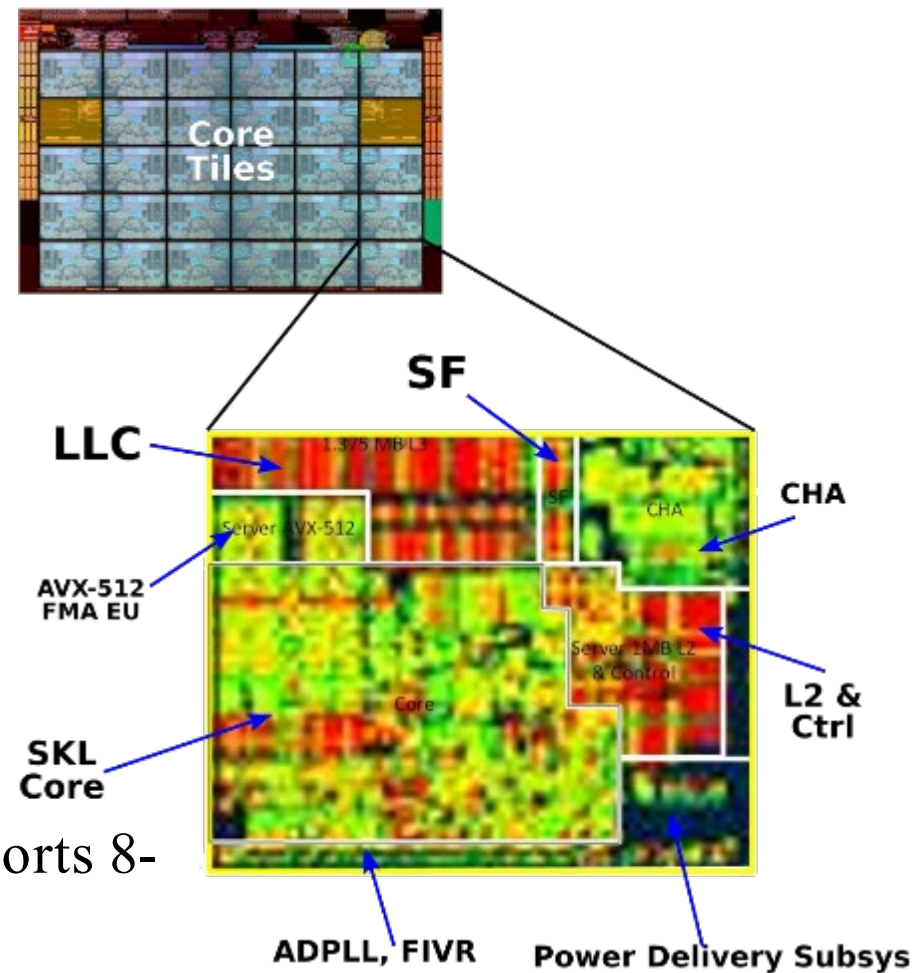


Challenge: Complexity

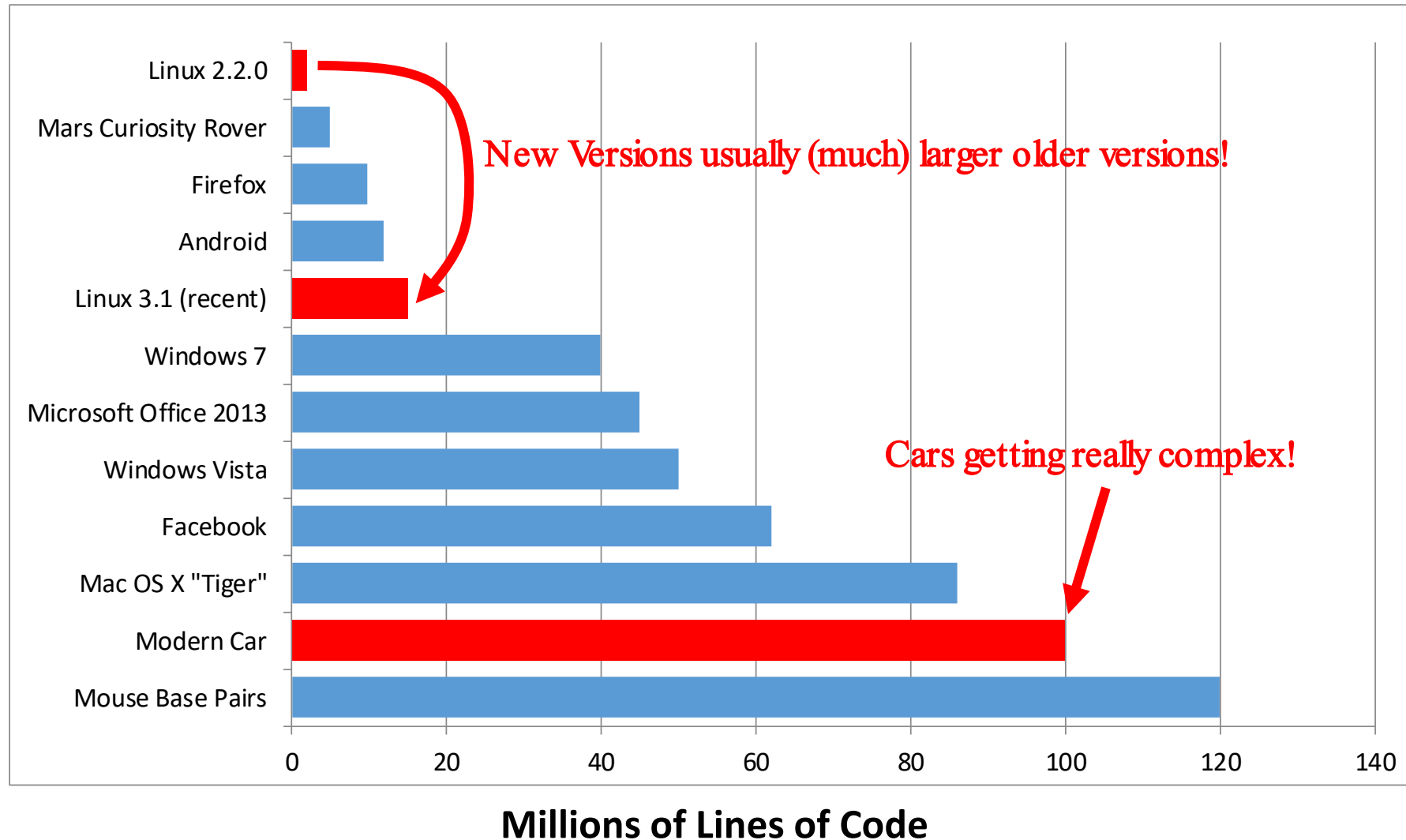
- Applications consisting of...
 - ... a variety of software modules that ...
 - ... run on a variety of devices (machines) that
 - » ... implement different hardware architectures
 - » ... run competing applications
 - » ... fail in unexpected ways
 - » ... can be under a variety of attacks
- Not feasible to test software for all possible environments and combinations of components and devices
 - The question is not whether there are bugs but how serious are the bugs!

The World Is Parallel: Intel SkyLake (2017)

- Up to 28 Cores, 56 Threads
 - 694 mm² die size (estimated)
- Many different instructions
 - Security, Graphics
- Caches on chip:
 - L2: 28 MiB
 - Shared L3: 38.5 MiB (non-inclusive)
 - Directory-based cache coherence
- Network:
 - On-chip Mesh Interconnect
 - Fast off-chip network directly supports 8-chips connected
- DRAM/chips
 - Up to 1.5 TiB
 - DDR4 memory



Recall: Increasing Software Complexity



(source <https://informationisbeautiful.net/visualizations/million-lines-of-code/>)

Example: Some Mars Rover (“Pathfinder”) Requirements

- Pathfinder hardware limitations/complexity:
 - 20Mhz processor, 128MB of DRAM, VxWorks OS
 - cameras, scientific instruments, batteries, solar panels, and locomotion equipment
 - Many independent processes work together
- Can’t hit reset button very easily!
 - Must reboot itself if necessary
 - Must always be able to receive commands from Earth
- Individual Programs must not interfere
 - One buggy module should not crash critical modules, e.g., antenna positioning software!
- Further, all software may crash occasionally
 - Automatic restart with diagnostics sent to Earth
 - Periodic checkpoint of results saved?
- Certain functions time critical:
 - Need to stop before hitting something
 - Must track orbit of Earth for communication
- A lot of similarity with the Internet of Things?
 - Complexity, QoS, Inaccessibility, Power limitations ... ?



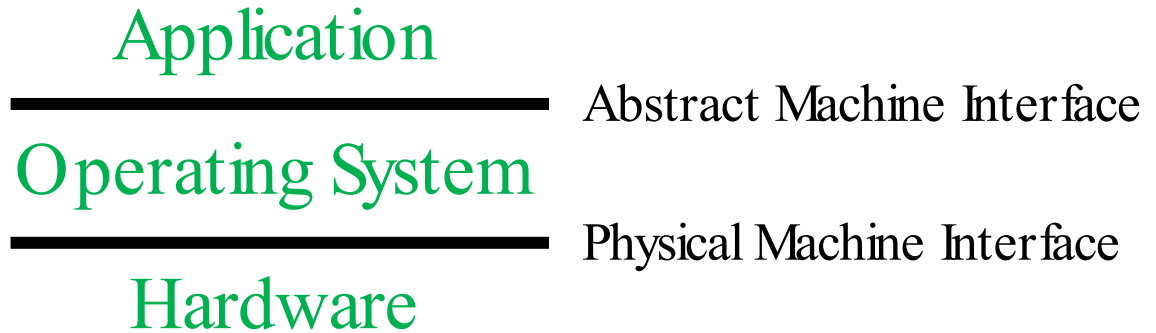
Questions

- Does the programmer need to write a single program that performs many independent activities?
- Does every program have to be altered for every piece of hardware?
- Does a faulty program crash everything?
- Does every program have access to all hardware?

No. Operating Systems help the programmer write robust programs!

OS Abstracts the Underlying Hardware

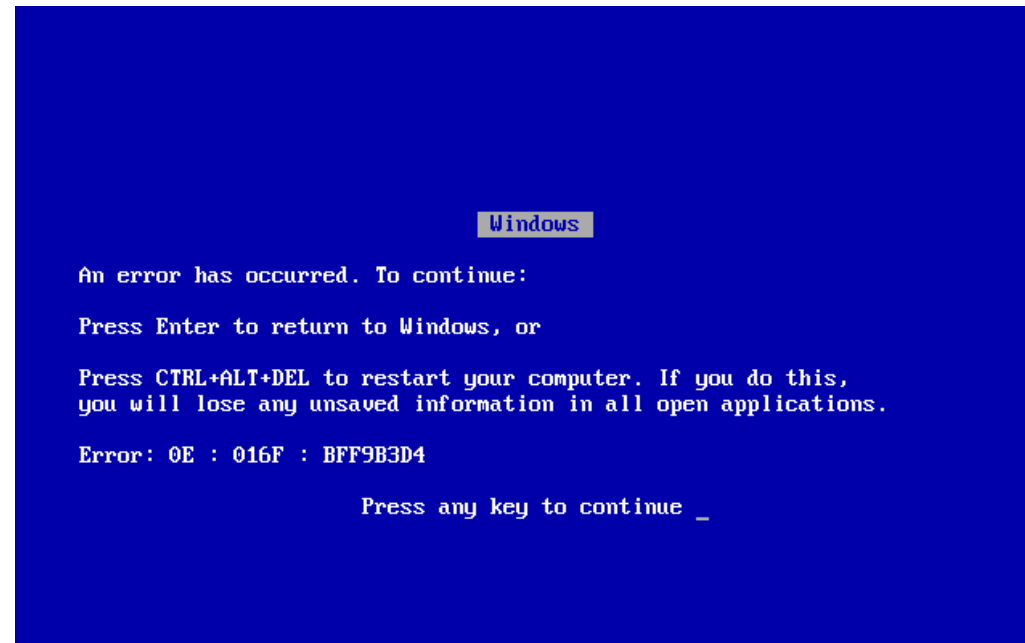
- Processor → Thread
- Memory → Address Space
- Disks, SSDs, ... → Files
- Networks → Sockets
- Machines → Processes



- OS as an Illusionist:
 - Remove software/hardware quirks (fight complexity)
 - Optimize for convenience, utilization, reliability, ... (help the programmer)
- For any OS area (e.g. file systems, virtual memory, networking, scheduling):
 - What hardware interface to handle? (physical reality)
 - What's software interface to provide? (nicer abstraction)

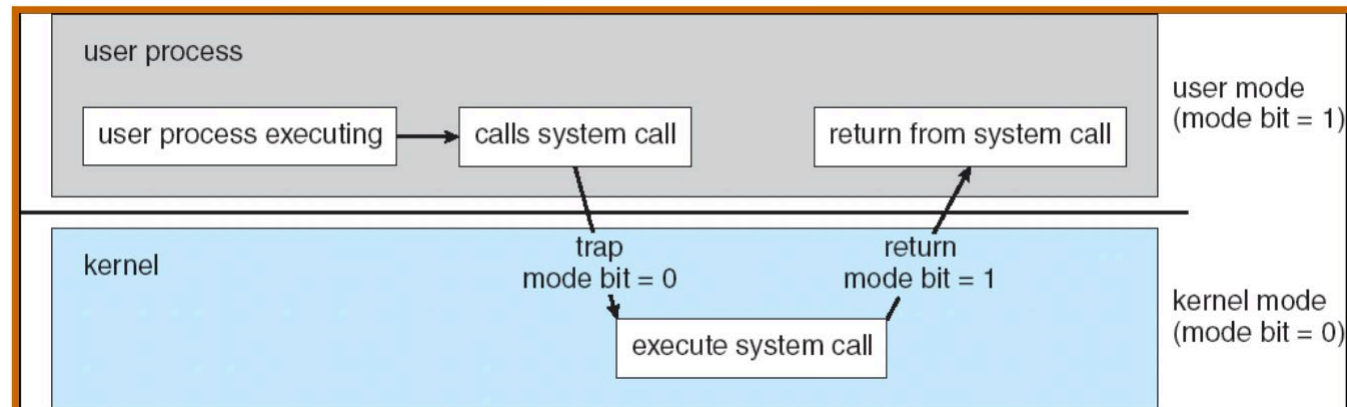
OS Protects Processes and the Kernel

- Run multiple applications and:
 - Keep them from interfering with or crashing the operating system
 - Keep them from interfering with or crashing each other

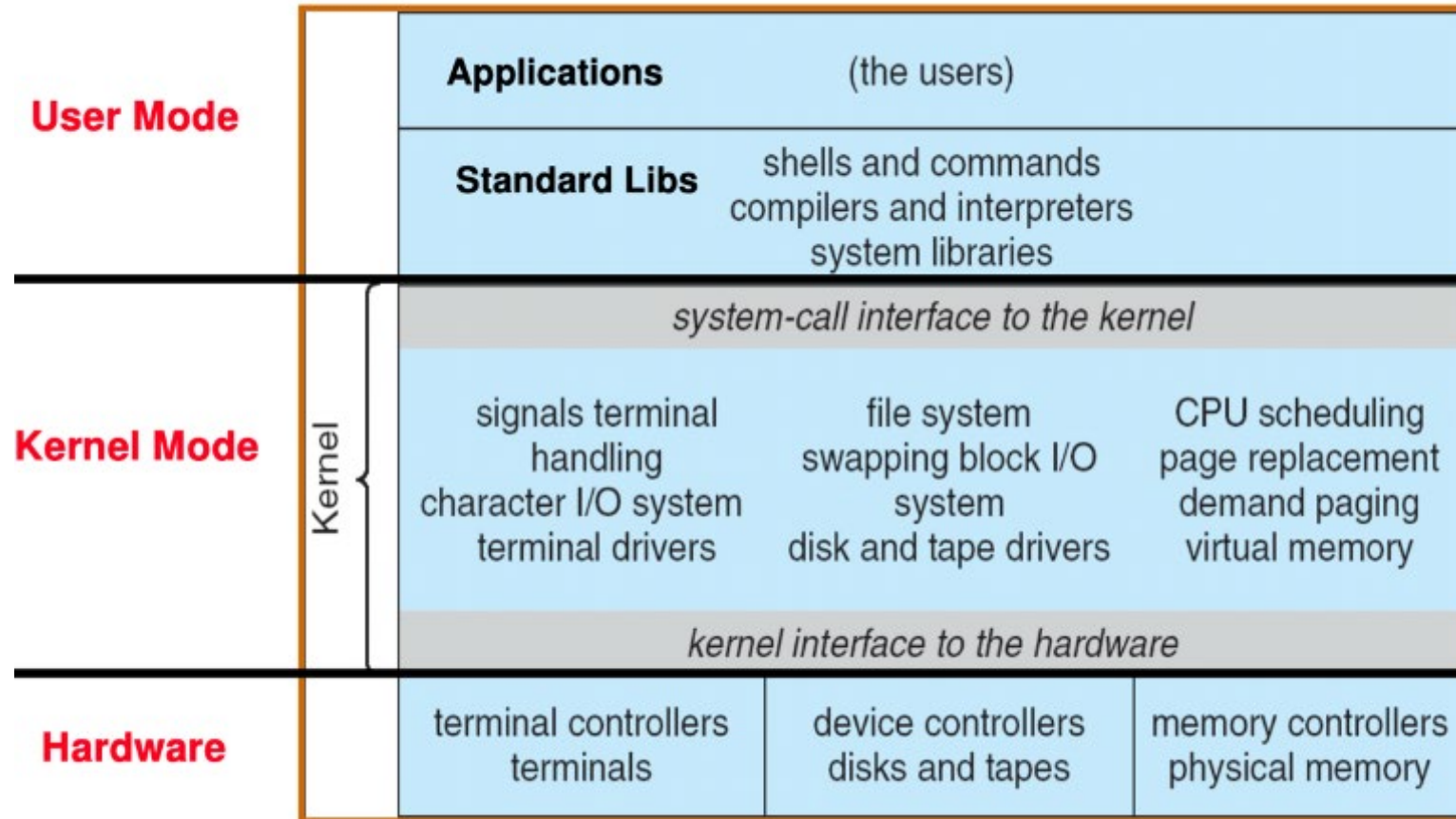


Basic Tool: Dual-Mode Operation

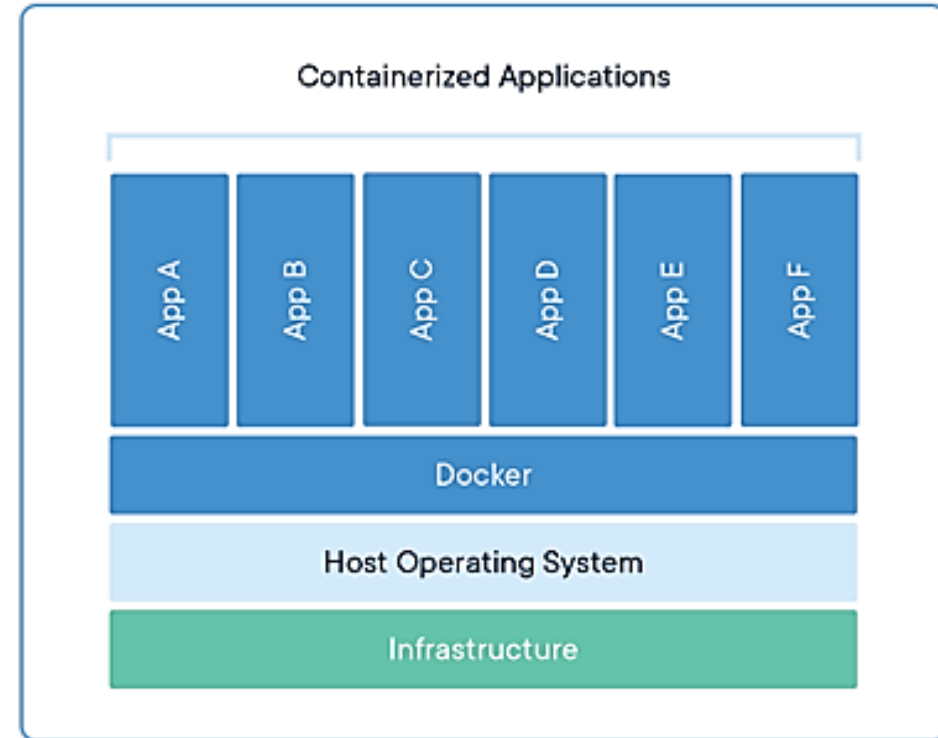
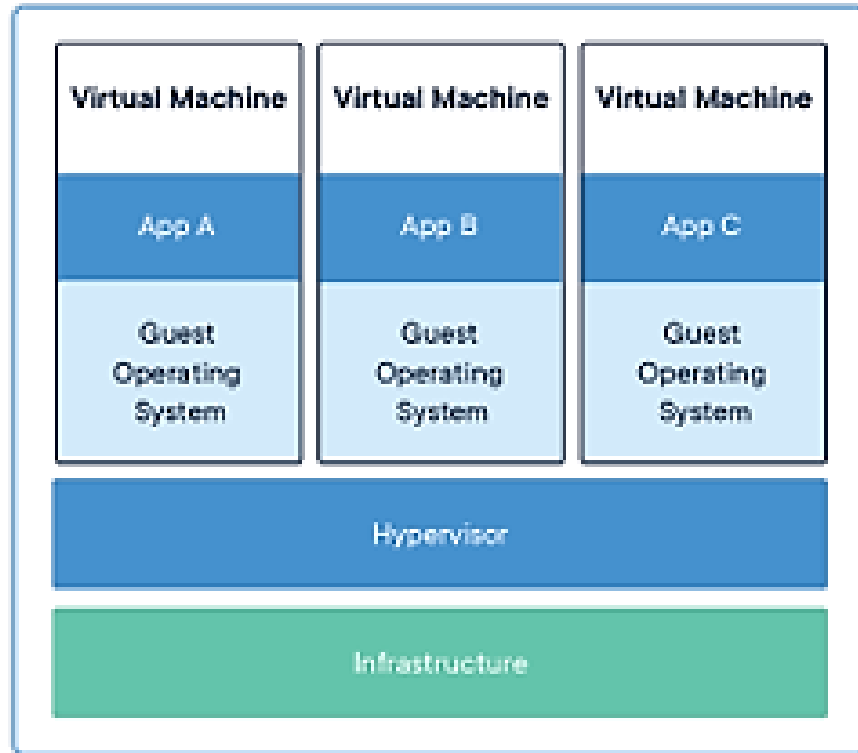
- Hardware provides at least two modes:
 1. Kernel Mode (or “supervisor” mode)
 2. User Mode
- Certain operations are **prohibited** when running in user mode
 - Changing the page table pointer, disabling interrupts, interacting directly w/ hardware, writing to kernel memory
- Carefully controlled transitions between user mode and kernel mode
 - System calls, interrupts, exceptions



UNIX System Structure



Virtualization: Execution Environments for Systems



Additional layers of protection and isolation can help further manage complexity

What is an Operating System,... Really?

- Most Likely:
 - Memory Management
 - I/O Management
 - CPU Scheduling
 - Communications? (Does Email belong in OS?)
 - Multitasking/multiprogramming?
- What about?
 - File System?
 - Multimedia Support?
 - User Interface?
 - Internet Browser?

Operating System Definition (Cont.)

- No universally accepted definition
- “Everything a vendor ships when you order an operating system” is good approximation
 - But varies wildly
- “The one program running at all times on the computer” is the **kernel**
 - Everything else is either a system program (ships with the operating system) or an application program

‘In conclusion...Operating Systems:’

- Provide convenient abstractions to handle diverse hardware
 - Convenience, protection, reliability obtained in creating the illusion
- Coordinate resources and protect users from each other
 - Using a few critical hardware mechanisms
- Simplify application development by providing standard services
- Provide fault containment, fault tolerance, and fault recovery