Enabling Technologies for Network – Based Systems

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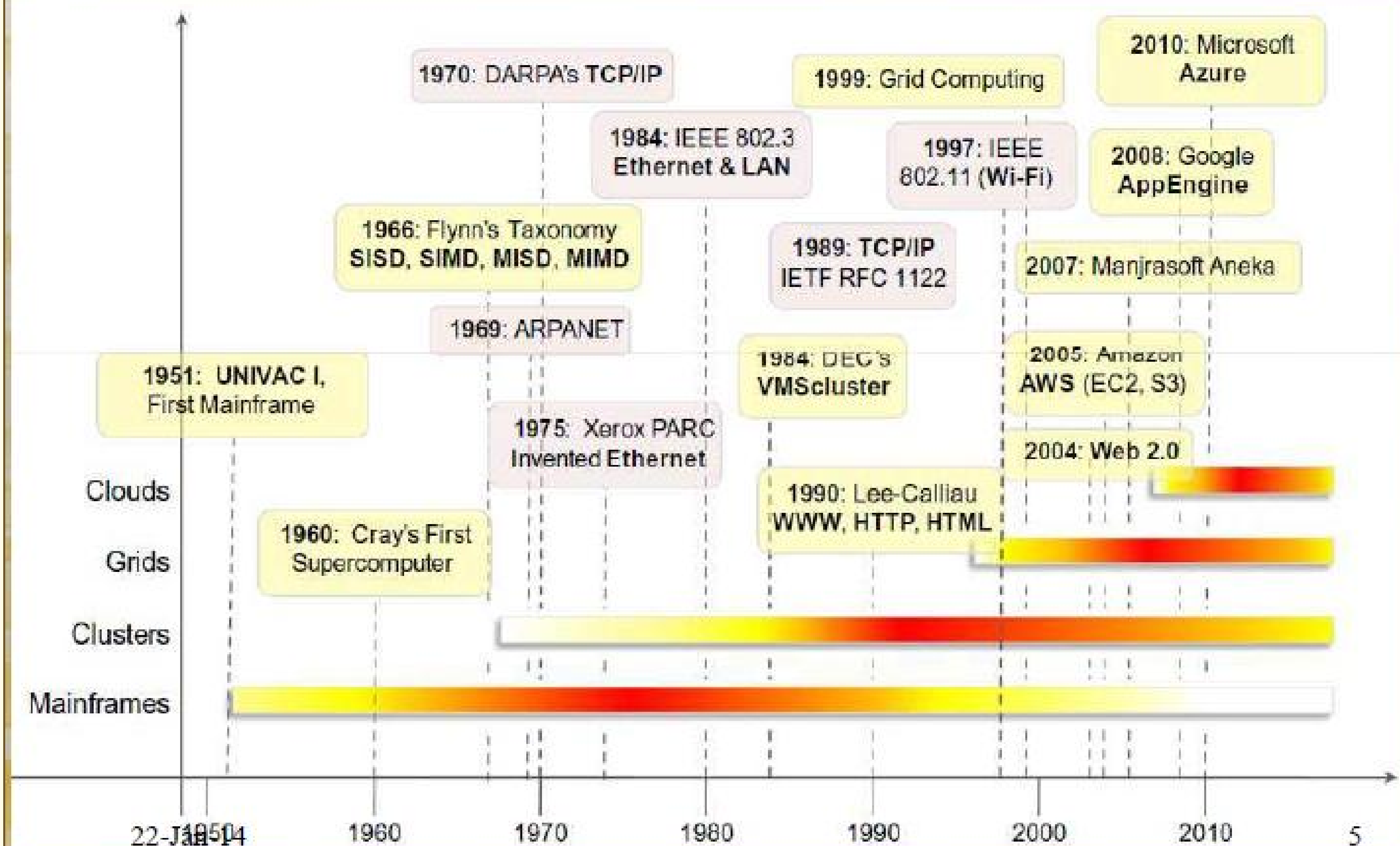
Reference: Distributed and Cloud Computing
K. Hwang, G. Fox and J. Dongarra

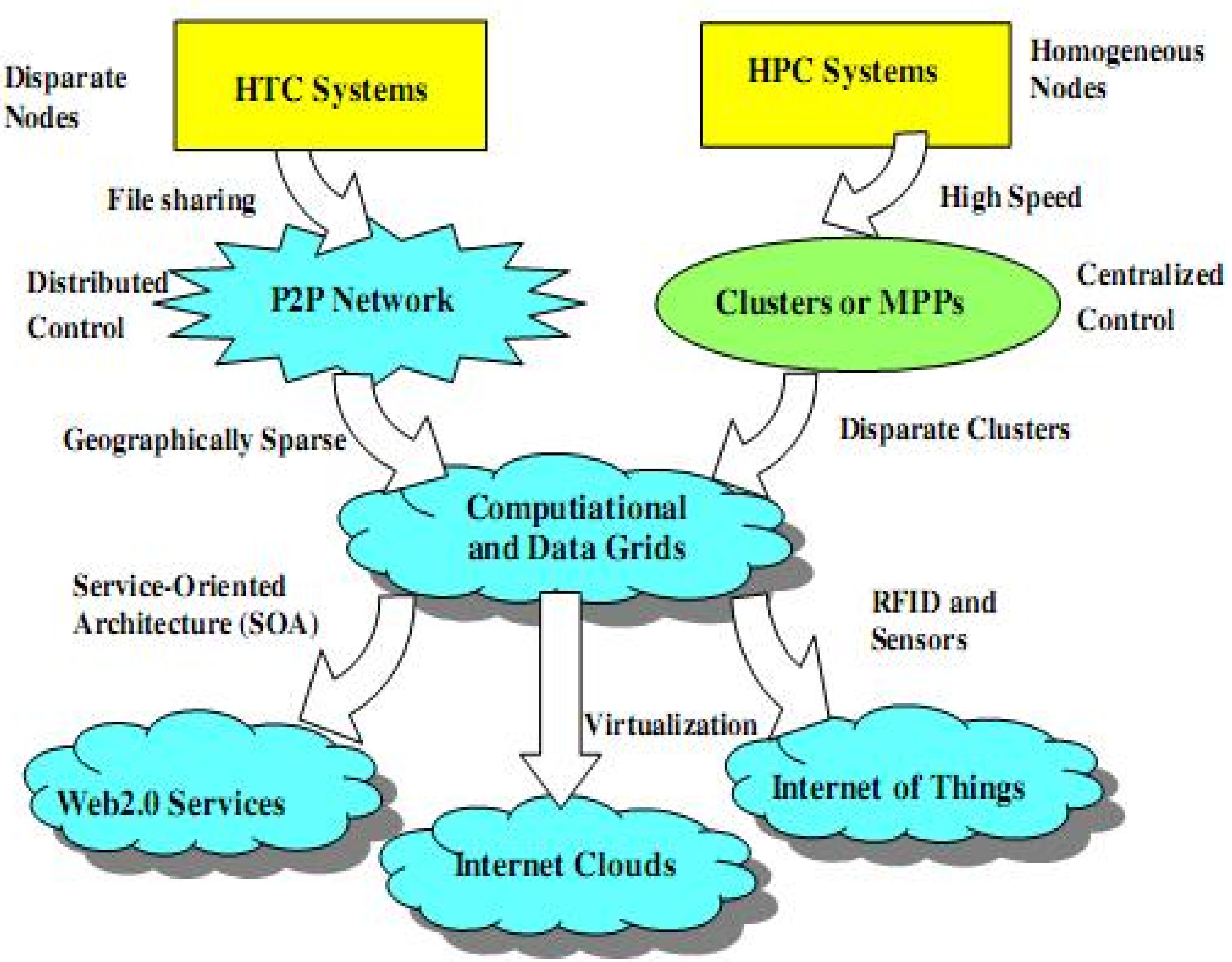
Overview

- Different hardware, software and network Technologies
  - Multi-core CPU and multi-threading
  - GPU computing
  - Memory, Storage and WAN
  - Virtual Machines and Virtualization Middleware
  - Data center virtualization

The Evolution of Distributed Computing Technologies, 1950s–2010s



Clouds and Internet of Things



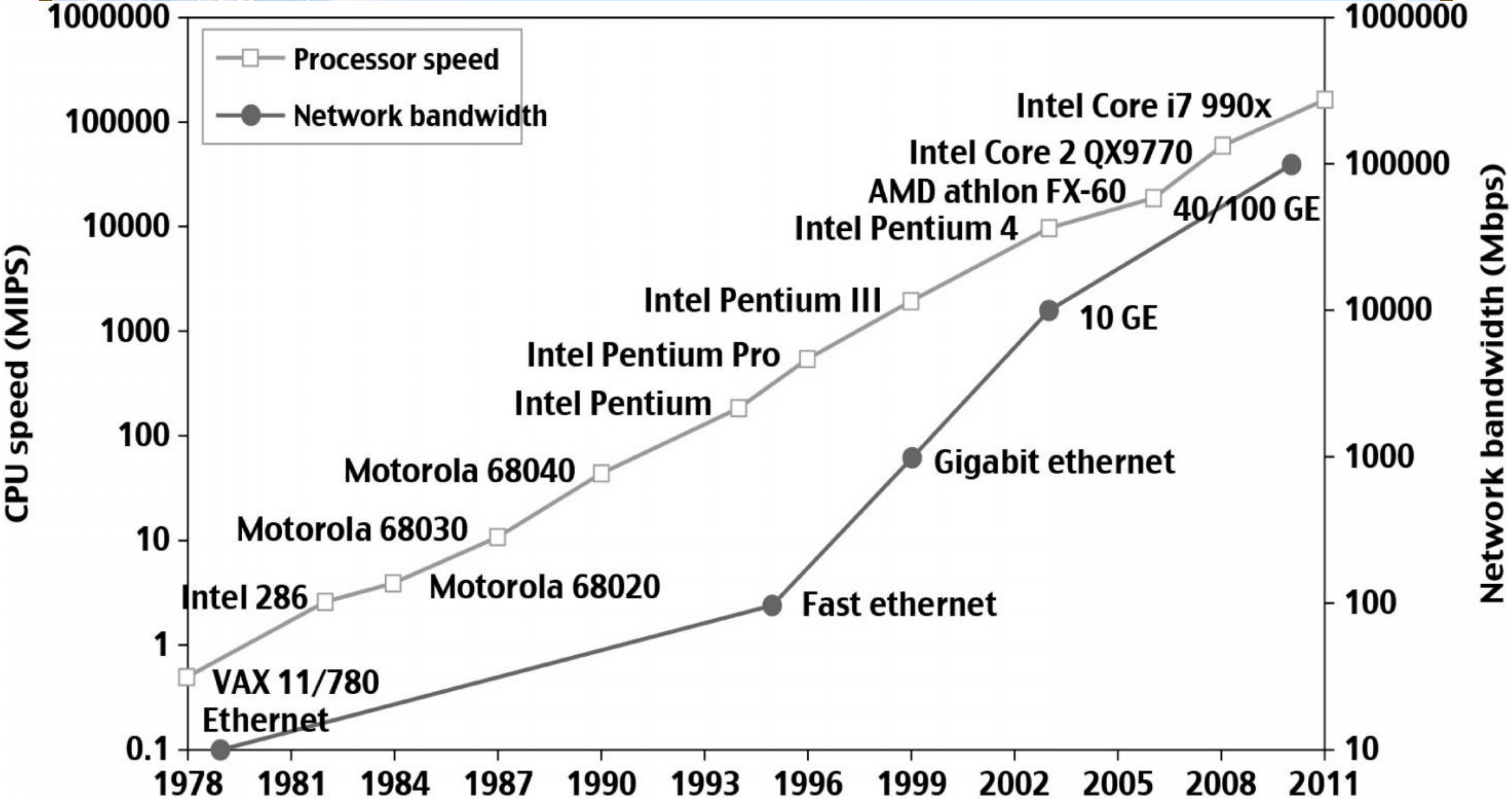
HPC: High-Performance Computing

HTC: High-Throughput Computing

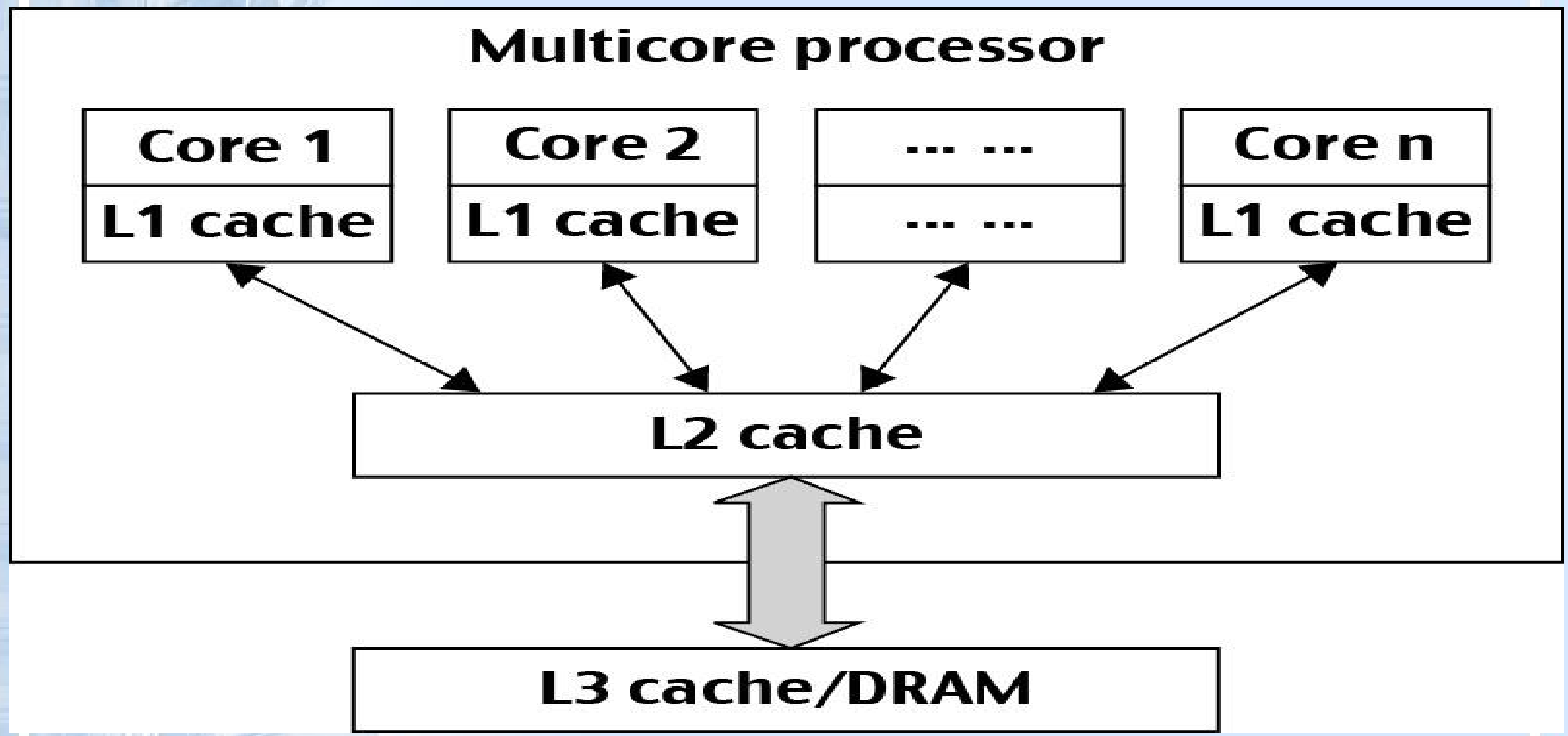
P2P: Peer to Peer

MPP: Massively Parallel Processors

33 year Improvement in Processor and Network Technologies



Modern Multi-core CPU Chip

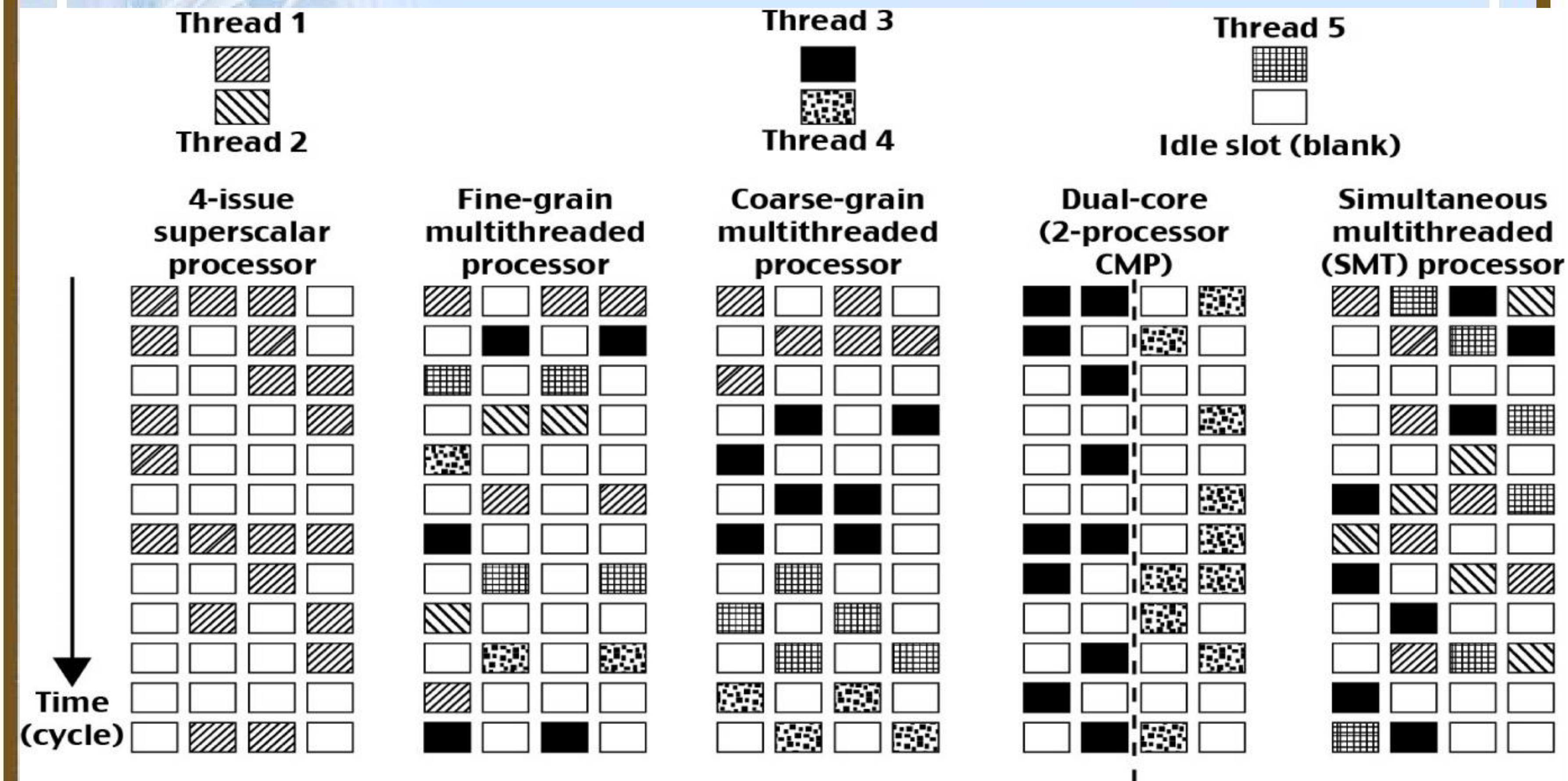


L1 cache is private to each core, on-chip L2 cache is shared and L3 cache or DRAM is off the chip.

Multi-threading Processors

- **Four-issue superscalar (e.g. Sun Ultrasparc I)**
  - Implements instruction level parallelism (ILP) within a single processor.
  - Executes more than one instruction during a clock cycle by sending multiple instructions to redundant functional units.
- **Fine-grain multithreaded processor**
  - Switch threads after each cycle
  - Interleave instruction execution
  - If one thread stalls, others are executed
- **Coarse-grain multithreaded processor**
  - Executes a single thread until it reaches certain situations
- **Simultaneous multithread processor (SMT)**
  - Instructions from more than one thread can execute in any given pipeline stage at a time.

5 Micro-architectures of CPUs



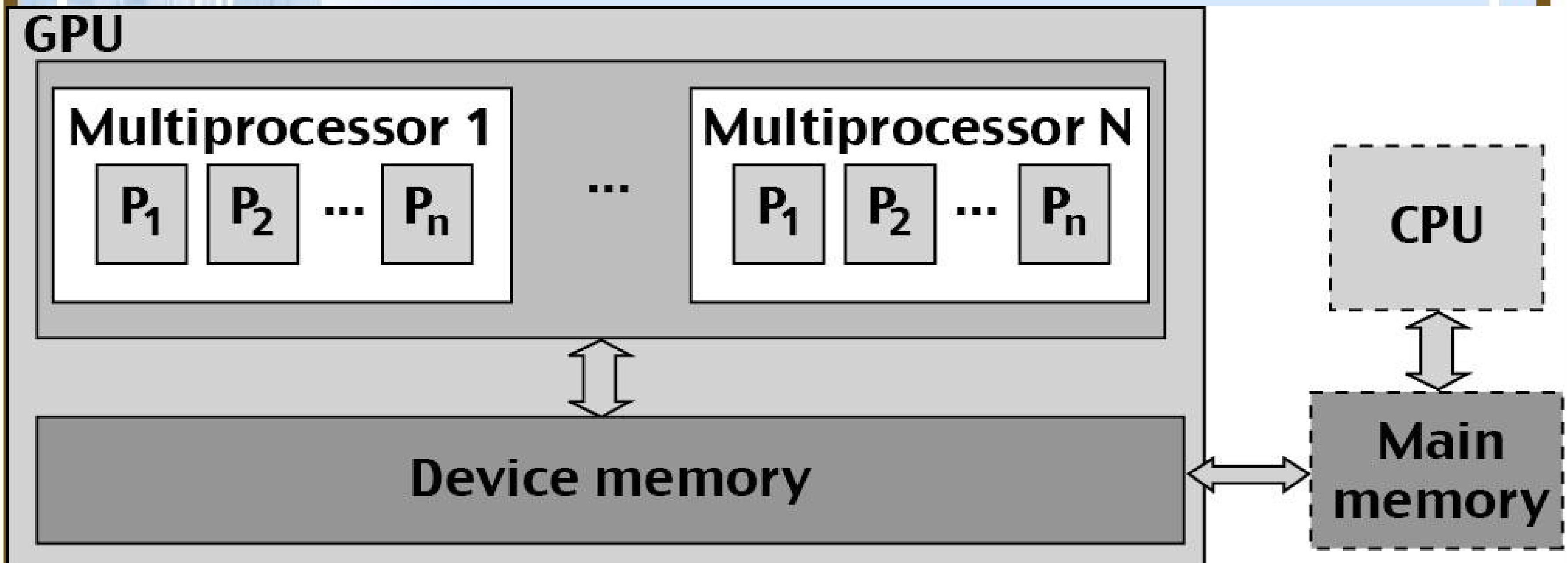
Each row represents the issue slots for a single execution cycle:

- A filled box indicates that the processor found an instruction to execute in that issue slot on that cycle;
- An empty box denotes an unused slot.

GPU and its working

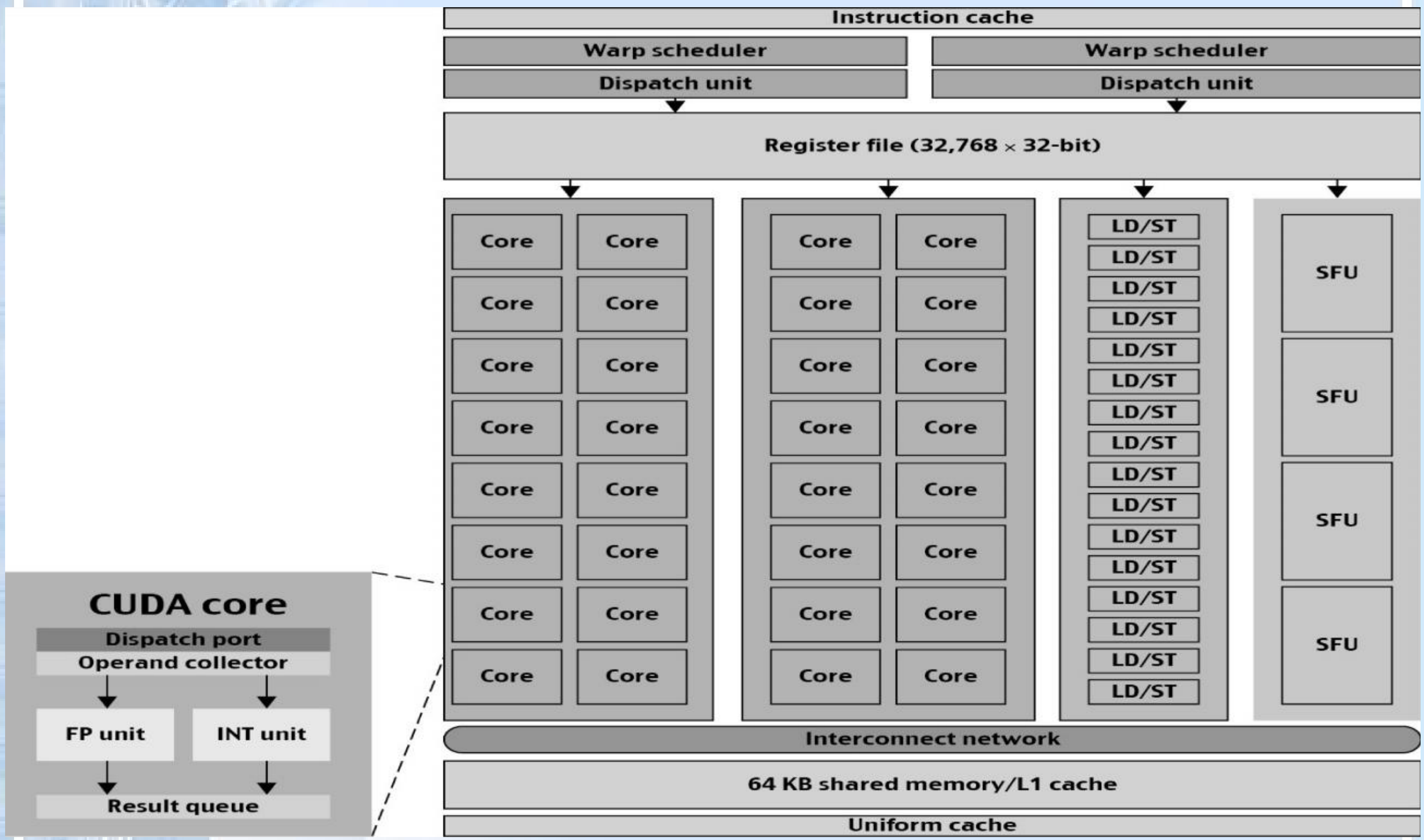
- GPU adopts many-core architecture with hundreds to thousands of simple cores.
- GPU (Graphics Processing Unit) is a graphics coprocessor or accelerator mounted on a computer's graphics card or video card.
- A GPU offloads the CPU from tedious graphics task in video editing applications.
- GPU are used in HPC systems to power supercomputers with massive parallelism at multi-core and multithreading levels
- GPUs are designed to handle large number of floating point operations in parallel.
- CPU's floating point computation role is largely offloaded to many-core GPU.

Architecture of A Many-Core Multiprocessor GPU interacting with a CPU Processor



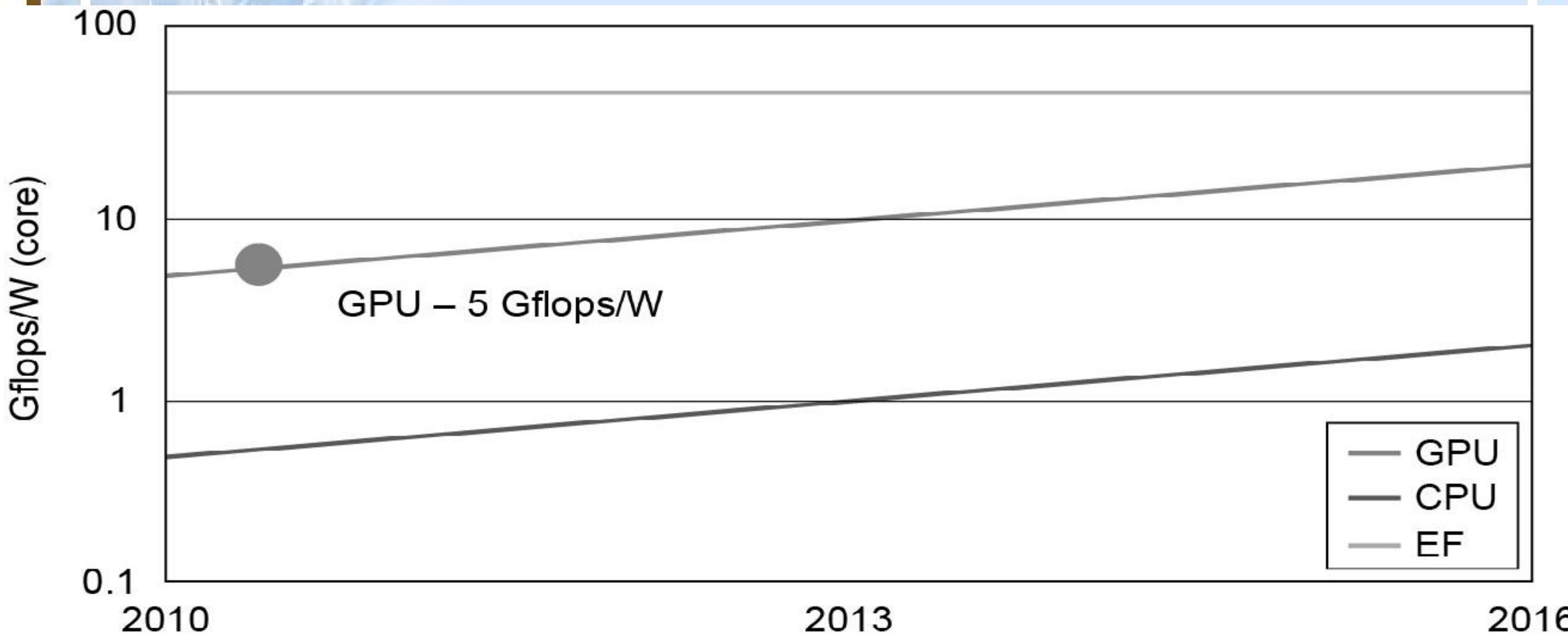
The use of a GPU along with a CPU for massively parallel execution in hundreds or thousands of processing cores

NVIDIA Fermi GPU



NVIDIA Fermi GPU built with 16 streaming multiprocessors (SMs) of 32 CUDA cores each; only one SM Is shown.

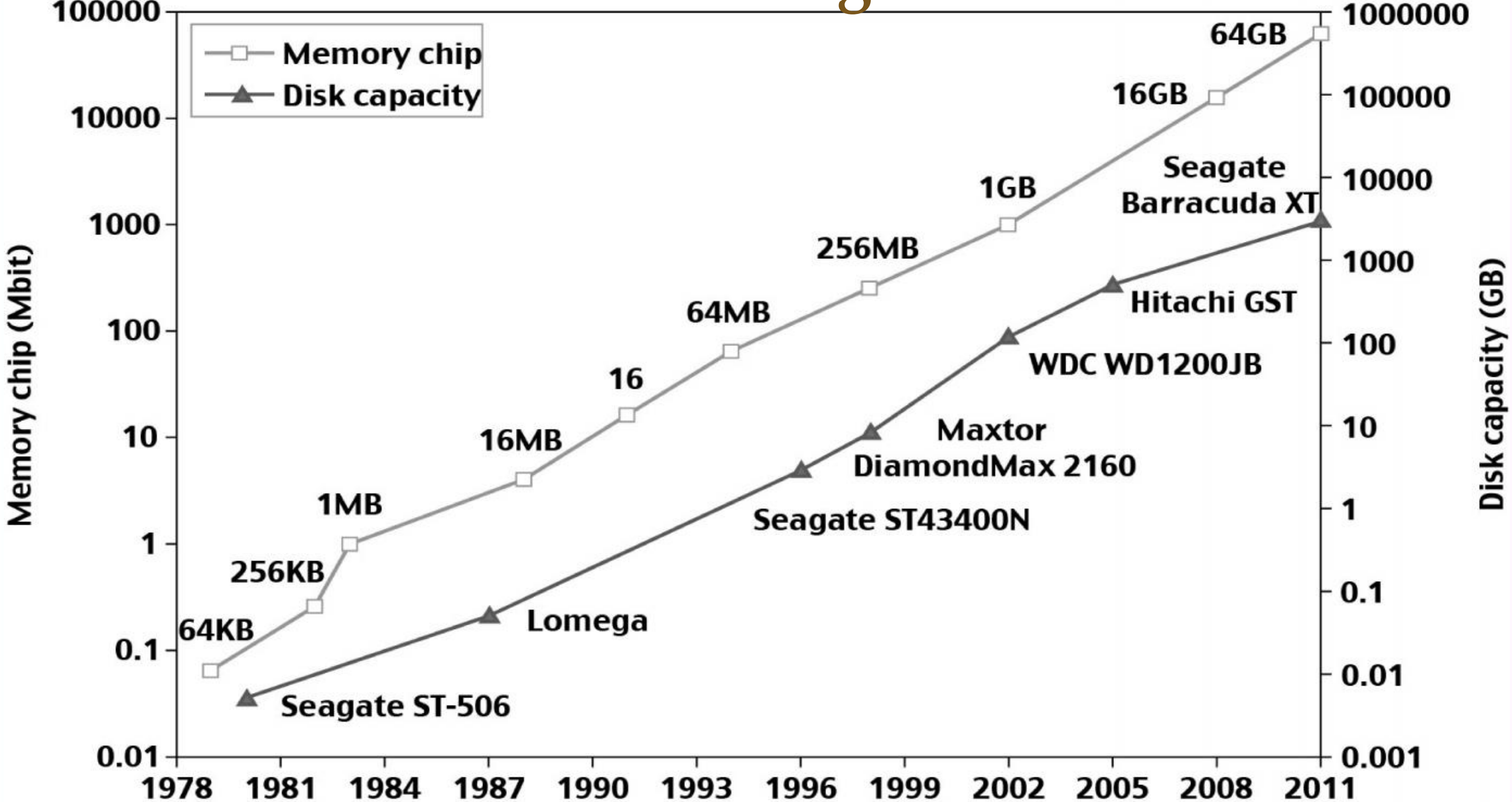
GPU Performance



The GPU performance (middle line, measured 5 Gflops/W/core in 2011), compared with the lower CPU performance (lower line measured 0.8 Gflops/W/core in 2011) and the estimated 60 Gflops/W/core performance in 2011 for the Exascale (EF in upper curve) in the future.

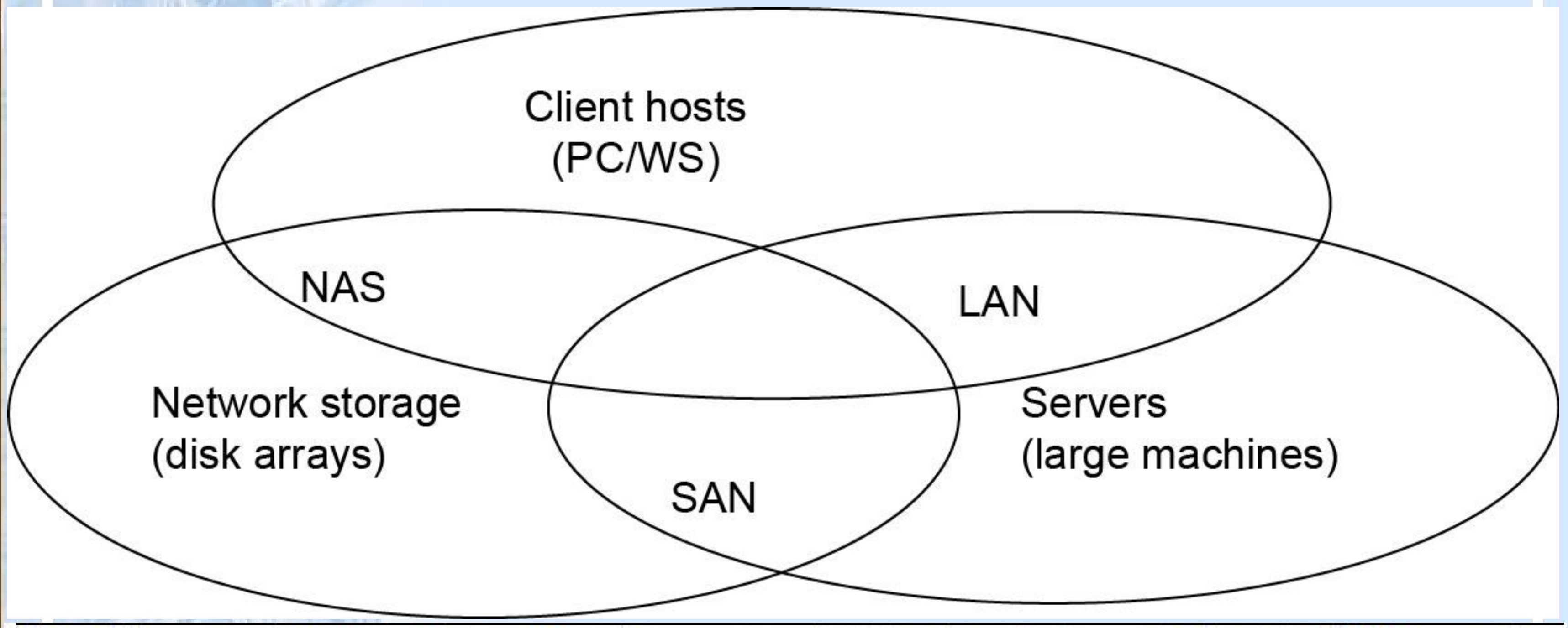
Bottom – CPU - 0.8 Gflops/W/Core (2011)
Middle – GPU - 5 Gflops/W/Core (2011)
Top - EF – Exascale computing (10^18 Flops)

33 year Improvement in Memory and Disk Technologies



Improvement in memory and disk technologies over 33 years. The Seagate Barracuda XT disk has a capacity of 3 TB in 2011.

Interconnection Networks



Three interconnection networks for connecting servers, client hosts, and storage devices; the LAN connects client hosts and servers, the SAN connects servers with disk arrays, and the NAS connects clients with large storage systems in the network environment.

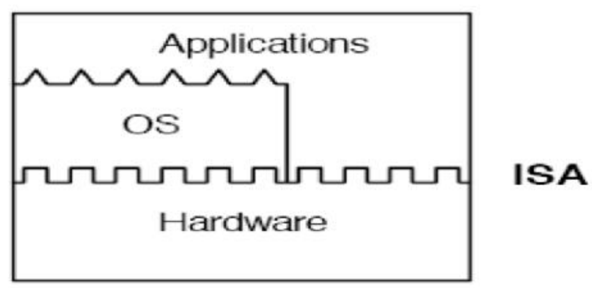
- SAN (storage area network) - connects servers with disk arrays
- LAN (local area network) – connects clients, hosts, and servers
- NAS (network attached storage) – connects clients with large storage systems

Virtual Machines

- Conventional computers has a single OS image.
- This couples application software to a specific hardware.
- Virtual machine adds software to a physical machine to give it the appearance of a different platform or multiple platforms.
- To build large clusters, grid and clouds, we need large amount of computing, storage and networking resources in virtualized manner
- Cloud will rely on virtualization of processors, memory and I/O facilities dynamically.

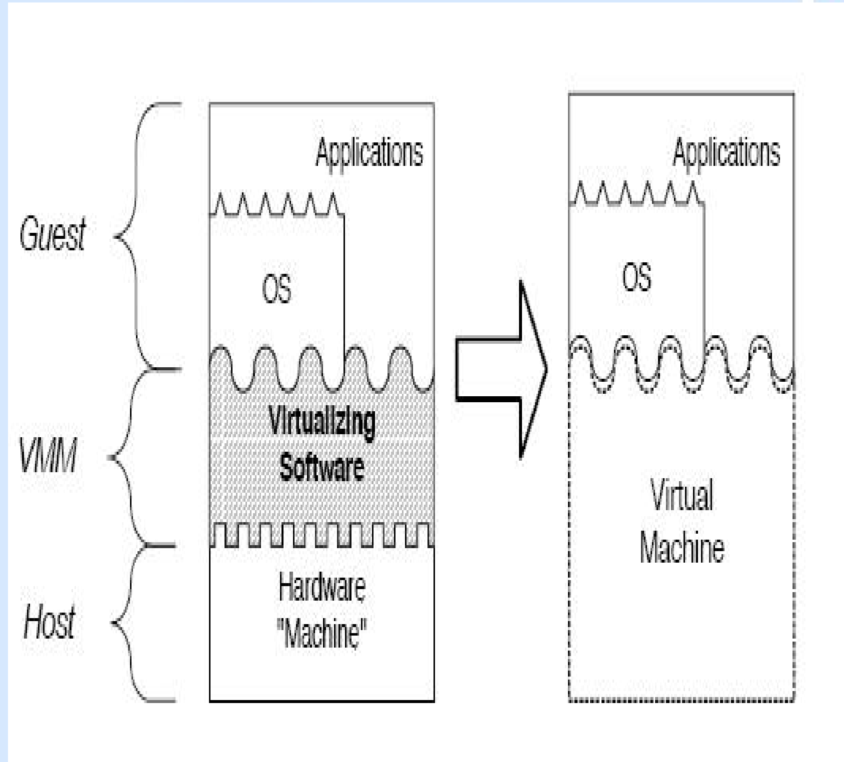
Initial Hardware Model

- All applications access hardware resources (i.e. memory, i/o) through system calls to operating system (privileged instructions)
- Advantages
  - Design is decoupled (i.e. OS people can develop OS separate of Hardware people developing hardware)
  - Hardware and software can be upgraded without notifying the Application programs
- Disadvantage
  - Application compiled on one ISA will not run on another ISA..
    - Applications compiled for Mac use different operating system calls then application designed for windows.
  - ISA's must support old software
    - Can often be inhibiting in terms of performance
  - Since software is developed separately from hardware… Software is not necessarily optimized for hardware.

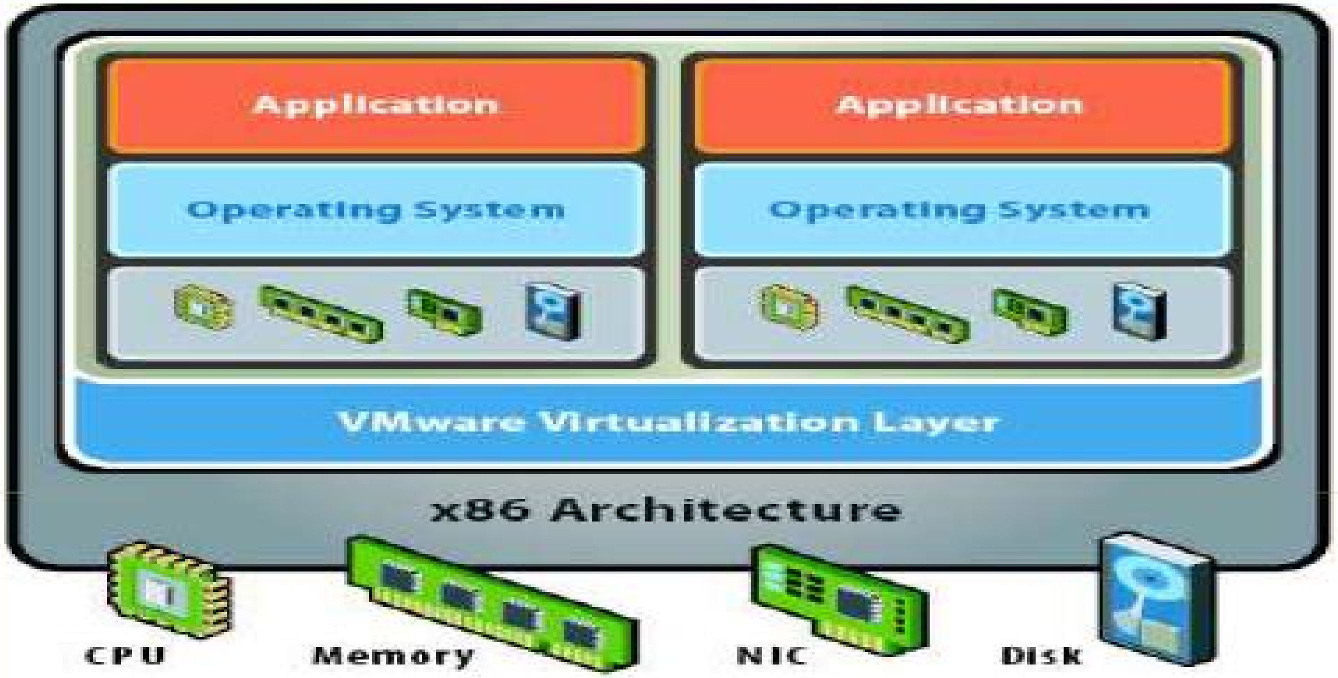


Virtual Machine Basics

- Virtual software placed between underlying machine and conventional software
  - Conventional software sees different ISA from the one supported by the hardware
- Virtualization process involves:
  - Mapping of virtual resources (registers and memory) to real hardware resources
  - Using real machine instructions to carry out the actions specified by the virtual machine instructions



Virtual Machine Architecture



After Virtualization:

- Hardware-independence of operating system and applications
- Virtual machines can be provisioned to any system
- Can manage OS and application as a single unit by encapsulating them into virtual machines

Virtual Machines and Virtualization Middleware

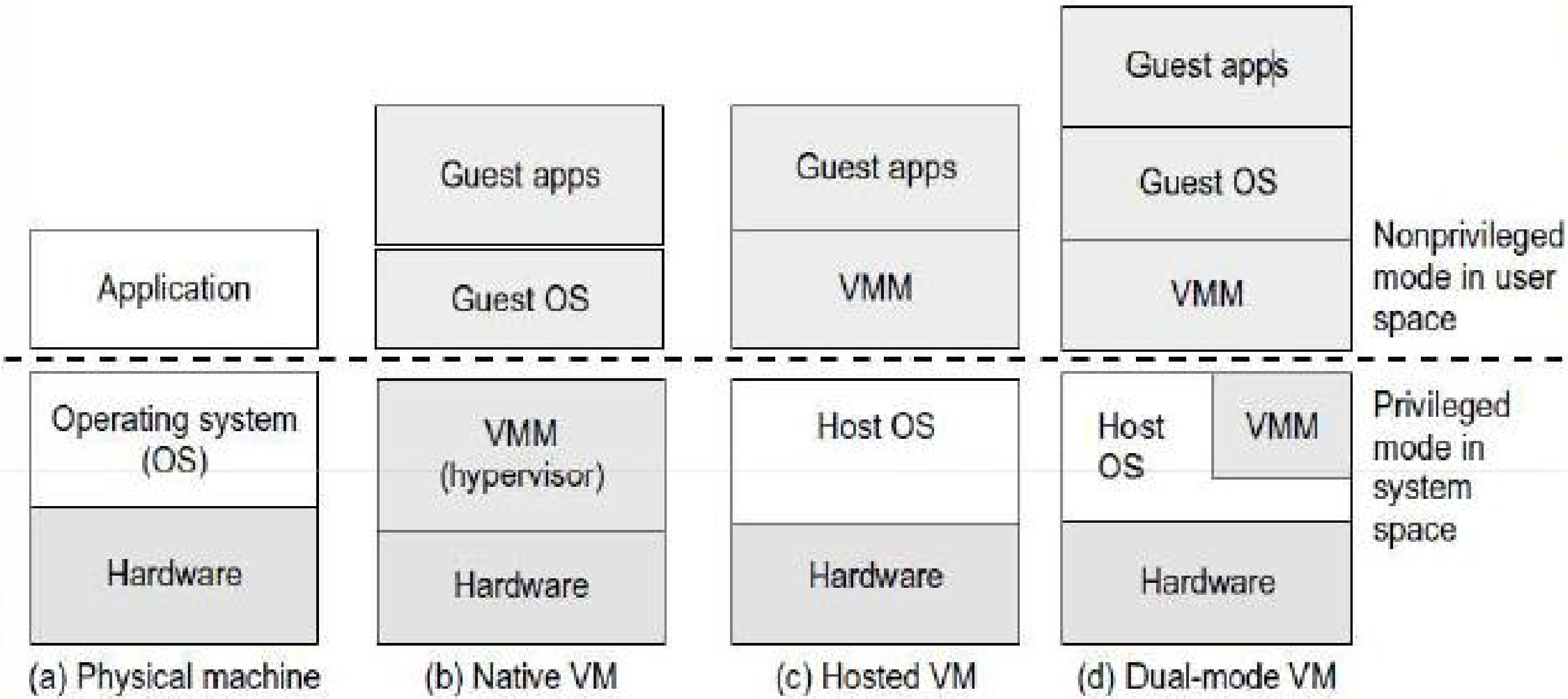


FIGURE 1.12

Three VM architectures in (b), (c), and (d), compared with the traditional physical machine shown in (a).

Three VM Architectures

Primitive Operations in Virtual Machines

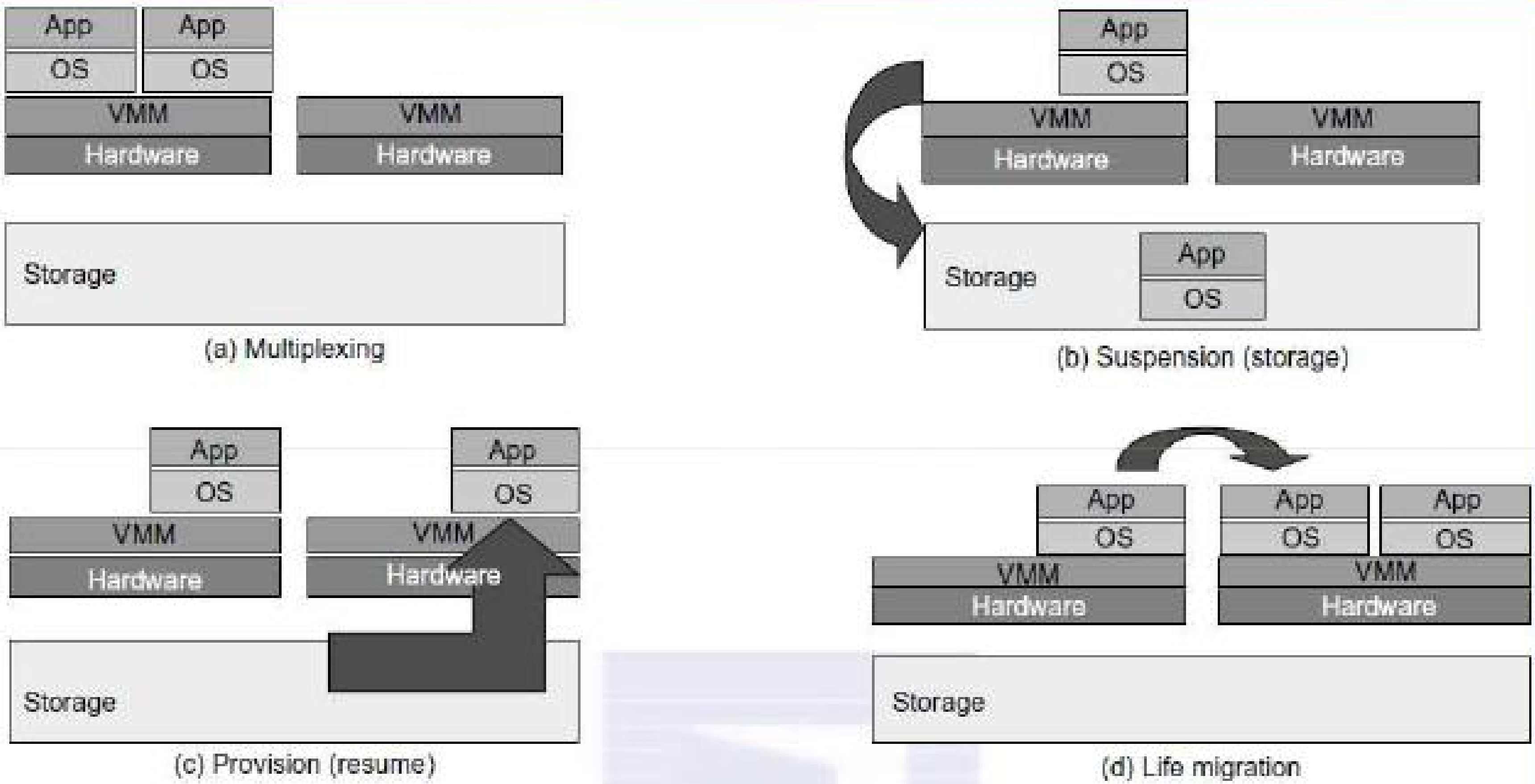


FIGURE 1.13

VM multiplexing, suspension, provision, and migration in a distributed computing environment.

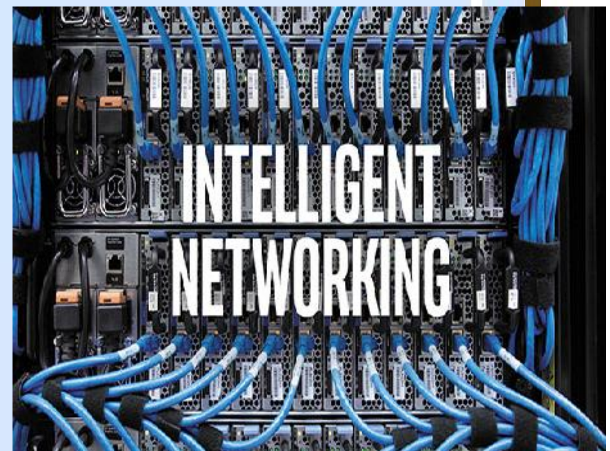
Virtual Machines Benefits

- Eliminate real machine constraint
  - Increases portability and flexibility
- **Benefits**
  - Cross platform compatibility
  - Increase Security
  - Enhance Performance
  - Simplify software migration
- **Virtual Machines (VMs) offers solutions to**
  - underutilized resources,
  - application inflexibility,
  - Software manageability
  - Security concerns in physical machines.

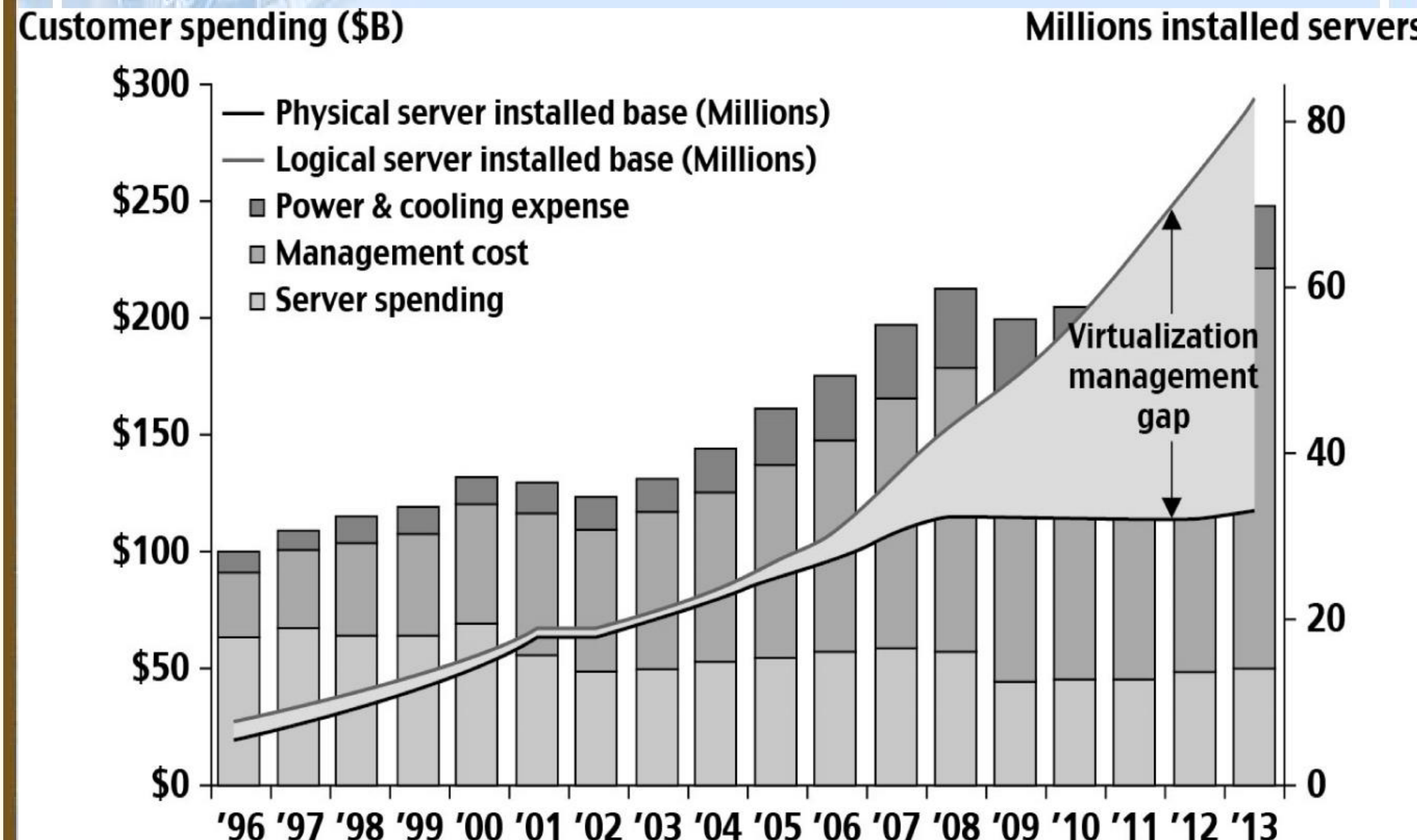
Data center virtualization

- Data center virtualization is the process of designing, developing and deploying a data center on virtualization and cloud computing technologies.
- It primarily enables virtualizing physical servers in a data center facility along with storage, networking and other infrastructure devices and equipments.
- A data center can host multiple virtualized data centers on the same physical infrastructure, which can simultaneously be used by separate applications and/or organizations.

Data center virtualization



Datacenter and Server Cost Distribution



Summary

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- Data center virtualization

Four Reference Books:

1. K. Hwang, G. Fox, and J. Dongarra, *Distributed and Cloud Computing: from Parallel Processing to the Internet of Things Morgan Kauffmann Publishers*, 2011

2. R. Buyya, J. Broberg, and A. Goscinski (eds), Cloud Computing: Principles and Paradigms, ISBN-13: 978-0470887998, Wiley Press, USA, February 2011.

3. T. Chou, *Introduction to Cloud Computing: Business and Technology,* Lecture Notes at Stanford University and at Tsinghua University, Active Book Press, 2010.

4. T. Hey, Tansley and Tolle (Editors), *The Fourth Paradigm : Data-Intensive Scientific Discovery*, Microsoft Research, 2009.