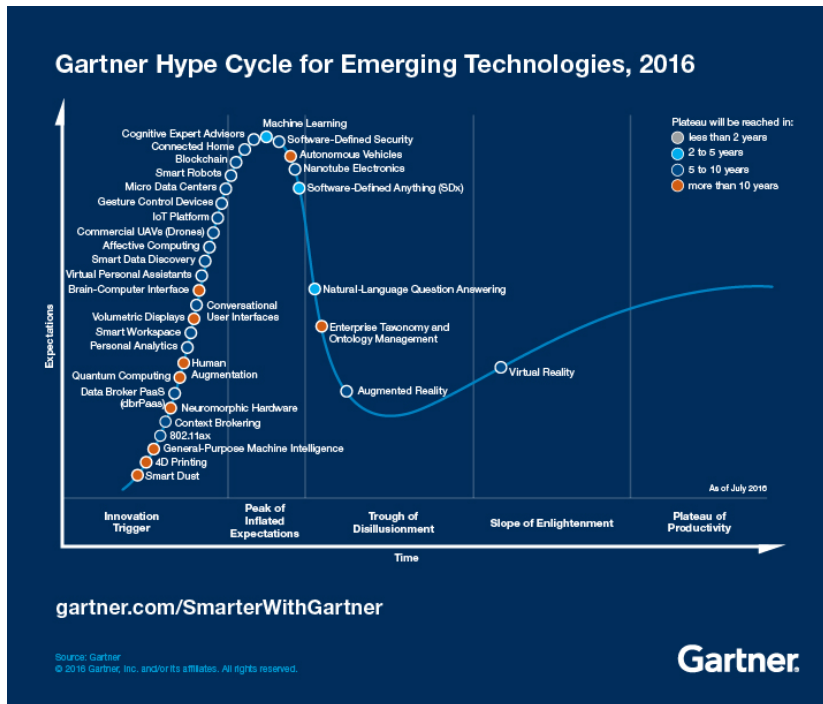


## Module: Distributed and Cloud Computing

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The Gartner Hype Cycle of New Technologies



<sup>1</sup> <http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp>

### Scalable Computing Trends and New Paradigms

- Several predictable trends in technology are known to drive computing applications.
  - Jim Gray's paper, "Rules of Thumb in Data Engineering,"<sup>2</sup>
  - Moore's law indicates that processor speed doubles every 18 months.
  - Gilder's law indicates that network bandwidth has doubled each year in the past.

<sup>2</sup> [http://research.microsoft.com/pubs/68636/ms\\_tr\\_99\\_100\\_rules\\_of\\_thumb\\_in\\_data\\_engineering.pdf](http://research.microsoft.com/pubs/68636/ms_tr_99_100_rules_of_thumb_in_data_engineering.pdf)

### Degrees of Parallelism

- 50 years ago
  - bit-level parallelism (BLP) converts bit-serial processing to word-level processing gradually.
- 30 years ago to present

- 4-bit microprocessors to 8-,16-, 32-, and 64-bit CPU
  - \* instruction-level parallelism (ILP), processor executes multiple instructions simultaneously
  - \* For the past 30 years, we have practiced ILP through pipelining, superscalar computing, VLIW (very long instruction word) architectures, and multithreading
- Data-level parallelism (DLP) was made popular through SIMD (single instruction, multiple data) and vector machines
- multicore processors and chip multiprocessors (CMPs) give us task-level parallelism (TLP)
- Moving parallel processing to distributed processing, we see an increase in computing granularity to job-level parallelism (JLP).

### *The Internet of Things and Cyber-Physical Systems*

#### *The Internet of Things*

- The concept of the IoT was introduced in 1999 at MIT
- The IoT refers to the networked interconnection of everyday objects, tools, devices, or computers.
- One can view the IoT as a wireless network of sensors that interconnect all things in our daily life.
- IoT researchers have estimated that every human being will be surrounded by 1,000 to 5,000 objects.

#### *Cyber-Physical Systems*

- A cyber-physical system (CPS) is the result of interaction between computational processes and the physical world.
- A CPS integrates “cyber” (heterogeneous, asynchronous) with “physical” (concurrent and information-dense) objects.
- A CPS merges the “3C” technologies of computation, communication, and control into an intelligent closed feedback system between the physical world and the information world
- The IoT emphasizes various networking connections among physical objects, while the CPS emphasizes exploration of virtual reality (VR) applications in the physical world.

## Multicore CPUs and Multithreading Technologies

### Advances in CPU Processors

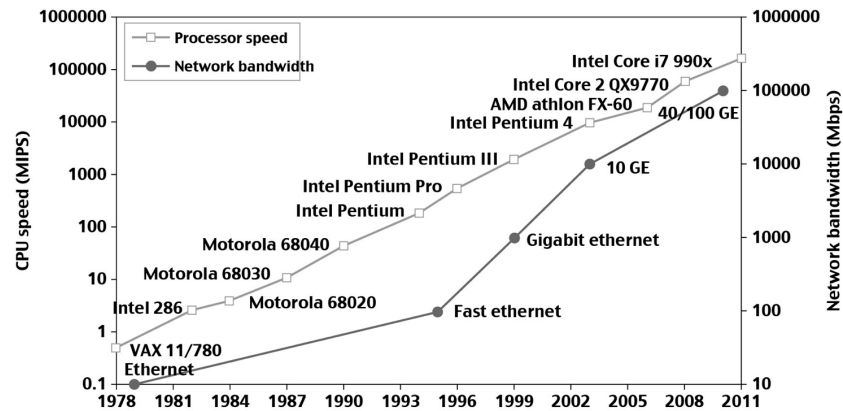


Figure 1: 33 years of improvement in processor and network technology

### Modern Multi-core CPU Chip

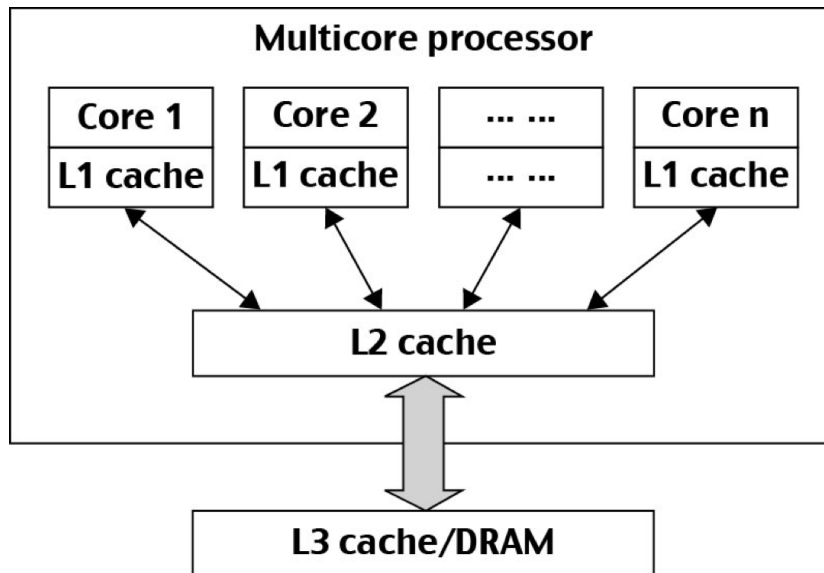


Figure 2: Modern Multi-core CPU Chip

### Multicore CPU and Many-Core GPU Architectures

- Multicore CPUs may increase from the tens of cores to hundreds or more in the future.

- but CPU has reached its limit in terms of exploiting massive DLP due to the memory wall problem<sup>3</sup>
  - This has triggered the development of many-core GPUs with thousands or more thin cores
  - Many RISC processors have been replaced with multicore x-86 processors and many-core GPUs in the Top 500 systems.
  - The GPU also has been applied in large clusters to build supercomputers in MPPs

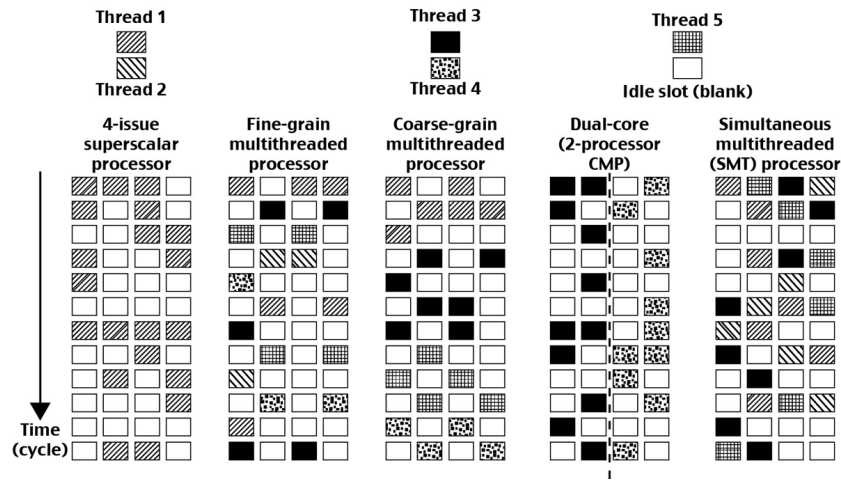
<sup>3</sup> <http://www.di.unisa.it/~vitsca/SC-2011/DesignPrinciplesMulticoreProcessors/Wulf1995.pdf>

### *Multithreading Technology*

- 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.

## CPU and GPU based Architectures

### 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 Computing to Exascale and Beyond

- A GPU is a graphics coprocessor or accelerator mounted on a computer's graphics card or video card. A GPU offloads the CPU from tedious graphics tasks in video editing applications
- Unlike CPUs, GPUs have a throughput architecture that exploits massive parallelism by executing many concurrent threads slowly, instead of executing a single long thread in a conventional micro-processor very quickly
- General-purpose computing on GPUs, known as GPGPUs, have appeared in the HPC field and power exascale<sup>4</sup>
- NVIDIA's CUDA model was for HPC using GPGPUs

<sup>4</sup> Exascale computing refers to computing systems capable of at least one exaFLOPS, or a billion billion calculations per second. Such capacity represents a thousandfold increase over the first petascale computer that came into operation in 2008.

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

#### NVIDIA Fermi GPU

#### Power Efficiency of the GPU

Bill Dally of Stanford University considers power and massive parallelism as the major benefits of GPUs over CPUs for the future

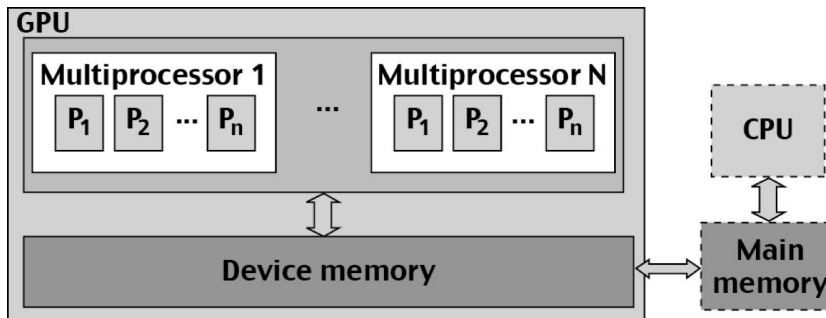


Figure 3: Architecture of A Many-Core Multiprocessor GPU interacting with a CPU Processor

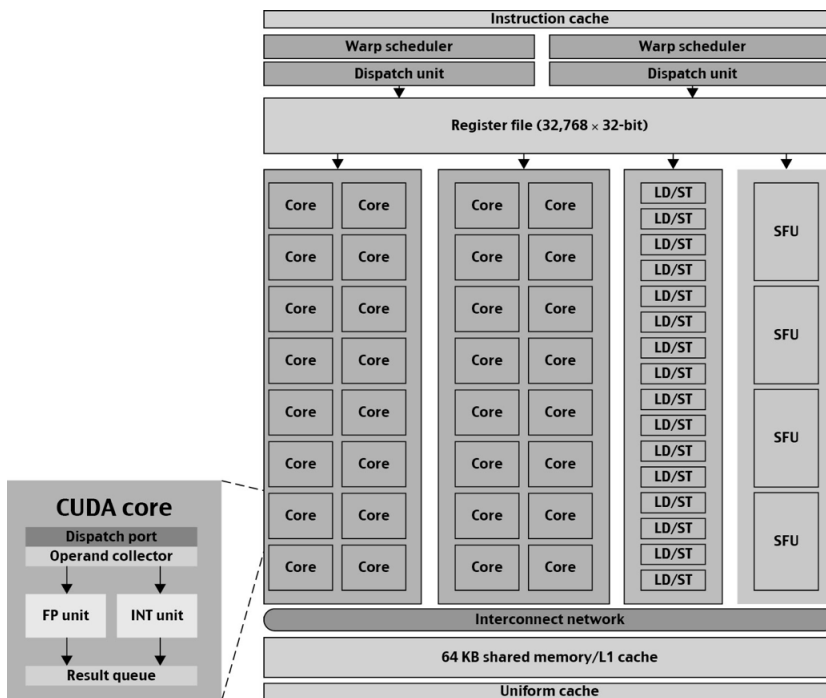


Figure 4: NVIDIA Fermi GPU

## GPU Performance

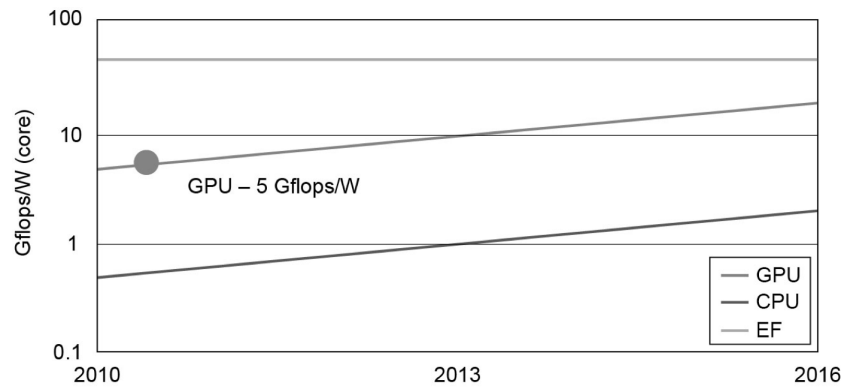


Figure 5: GPU Performance

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

## Memory, Storage, and Wide-Area Networking

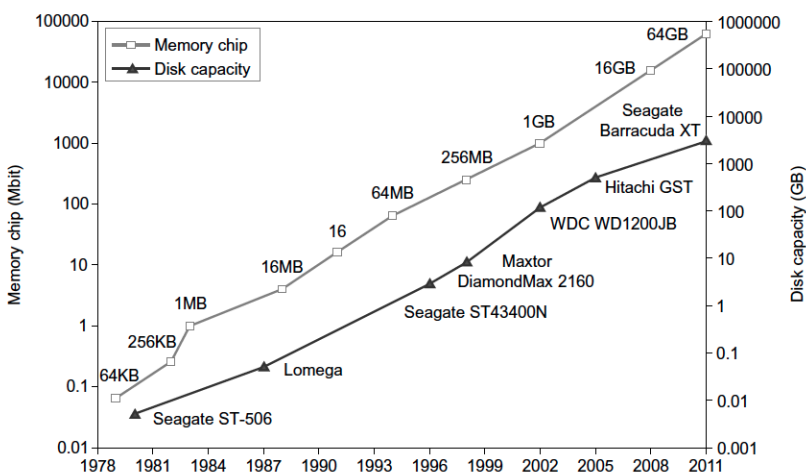


Figure 6: disk and memory capacity

## System-Area Interconnects

### Network Interconnections

### Network Interconnections

- SAN (storage area network) - connects servers with disk arrays

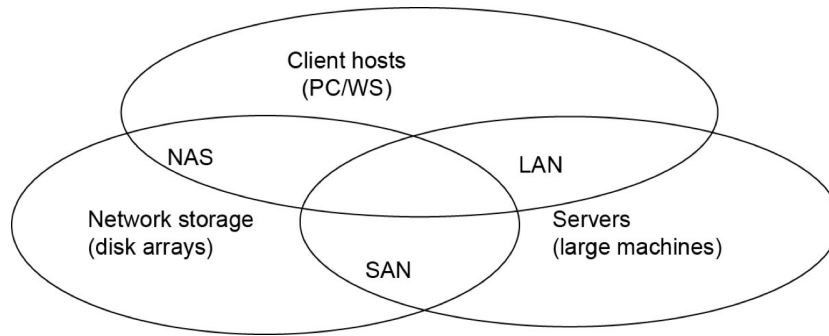


Figure 7: Network Interconnections

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

### Wide Area Networking

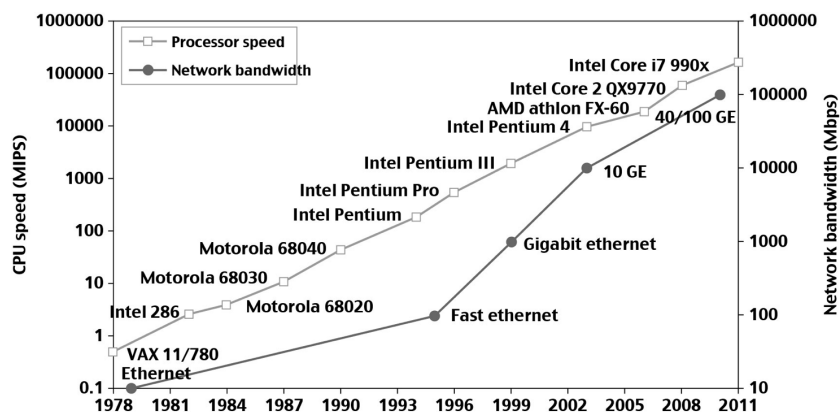


Figure 8: 33 years of improvement in processor and network technology

### Wide Area Networking

- The lower curve here plots the rapid growth of Ethernet bandwidth from 10 Mbps in 1979 to 1 Gbps in 1999, and 40 ~ 100 GE in 2011.
- We have recently seen a 255Tbps link created in 2014<sup>5</sup>

<sup>5</sup> <http://bit.ly/cnsm4dcc-255tbps>



## Virtualisation

### Virtual Machines and Virtualization Middleware

- A conventional computer has a single OS image. This offers a rigid architecture that tightly couples application software to a specific hardware platform.
- Some software running well on one machine may not be executable on another platform with a different instruction set under a fixed OS.
- Virtual machines (VMs) offer novel solutions to underutilized resources, application inflexibility, software manageability, and security concerns in existing physical machines.

### VM Architectures

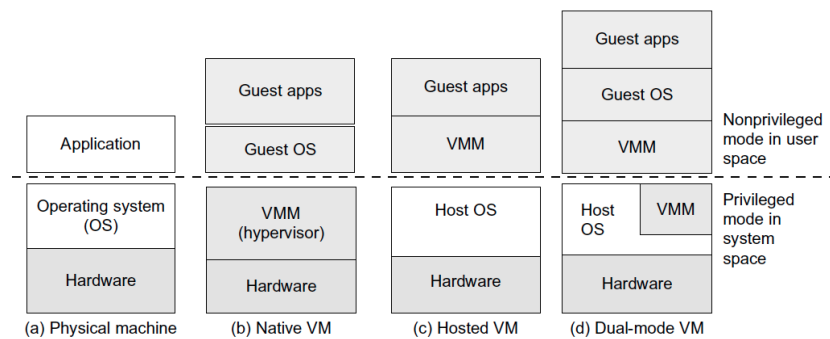


Figure 9: VM Architectures

## VM Operations

### Next Lesson

- Cloud Centres
  - What are they ?
  - Are they all the same ?
  - Whats different about them ?

Thank You

Questions?

### References

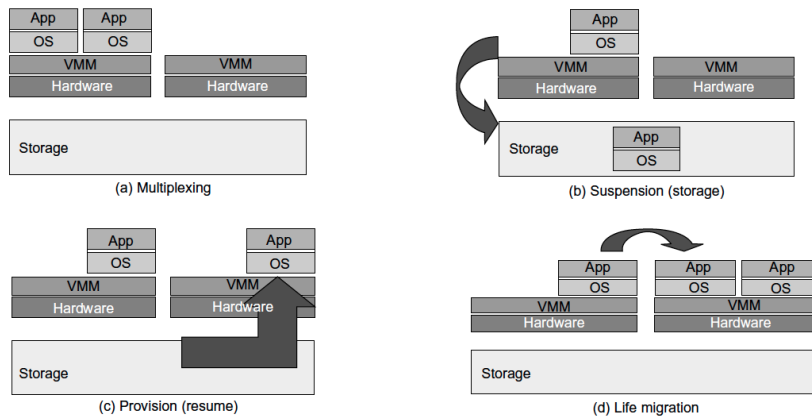


Figure 10: VM Management