Operating System (OS)

National Tsing Hua University

2021, Fall Semester

Historical Prospective

- Mainframe Systems
- Computer-system architecture
- Special-purpose Systems

System Category

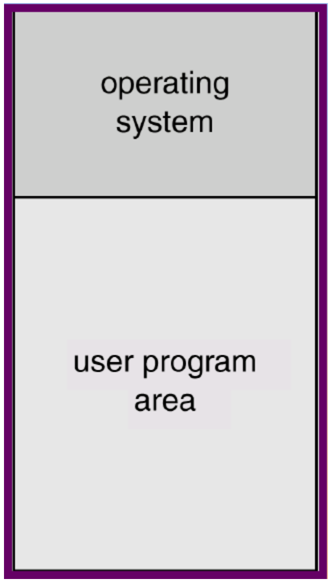
- Mainframe Systems
  - Batch
  - Multi-programming
  - Time-sharing
- Computer-system architecture
- Special-purpose Systems

Mainframe Systems

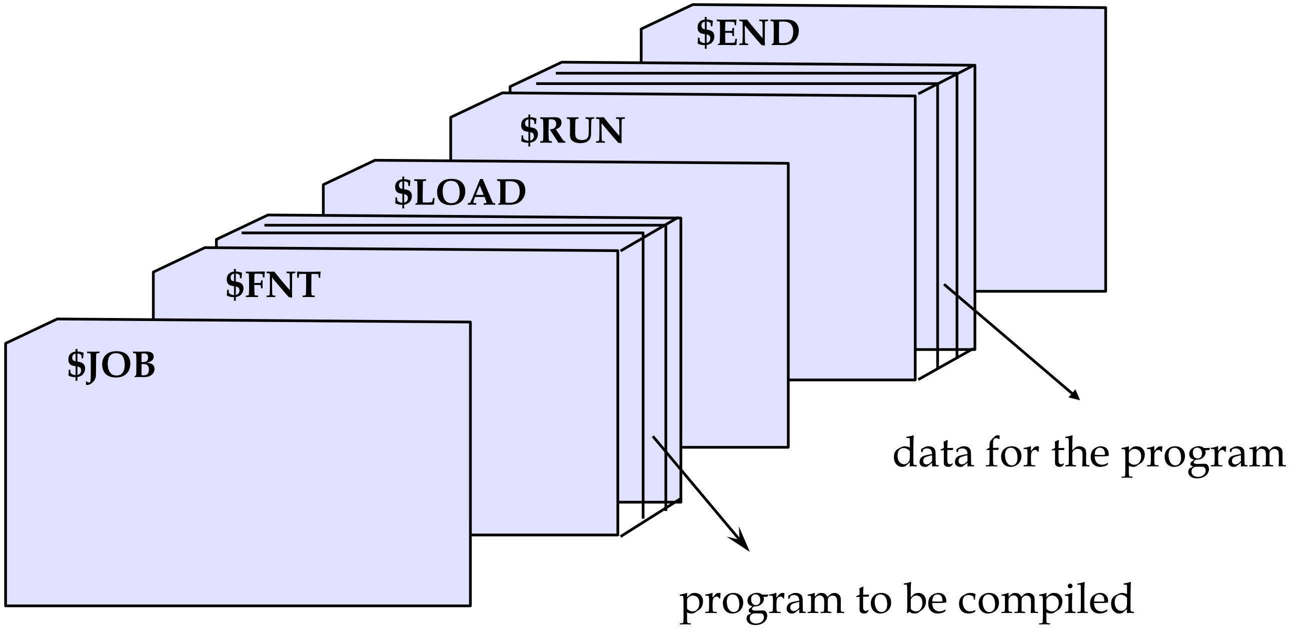
- One of the earliest computers
  - Slow I/O devices: card reader/printer, tape drivers
- Evolution:
  - Batch ➔ Multi-programming ➔ Time-shared
- Still exists in today's world…
  - For critical application with better **reliability & security**
  - Bulk data processing
  - Widely used in hospitals, banks

IBM 704 mainframe in 1954

Mainframe: Batch Systems



Memory layout



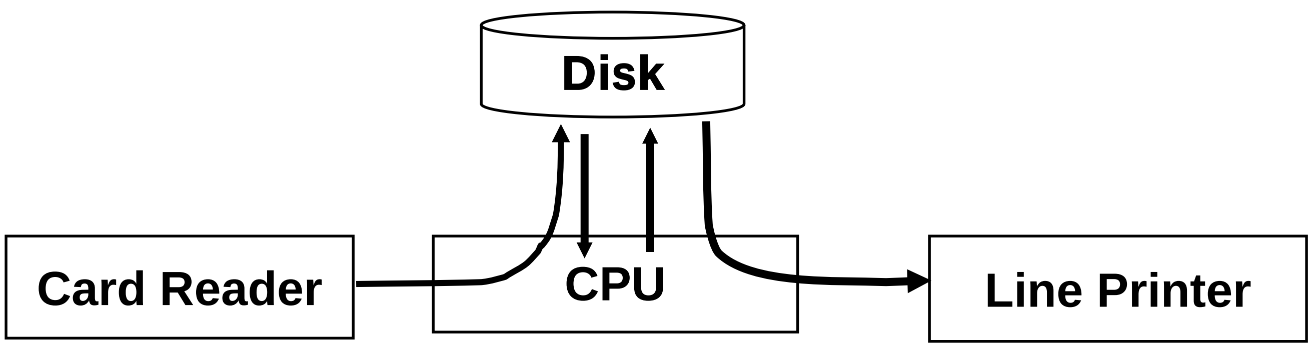
- Processing steps:
  - Users submit jobs (program, data, control card)
  - Operator sort jobs with similar requirements
  - OS simply transfer control from one job to the next

Mainframe: Batch Systems

- Drawbacks:
  - One job at a time
  - No interaction between users and jobs
  - CPU is often idle
    - I/O speed << CPU speed (at least 1:1000)
- OS doesn’t need to make any decision

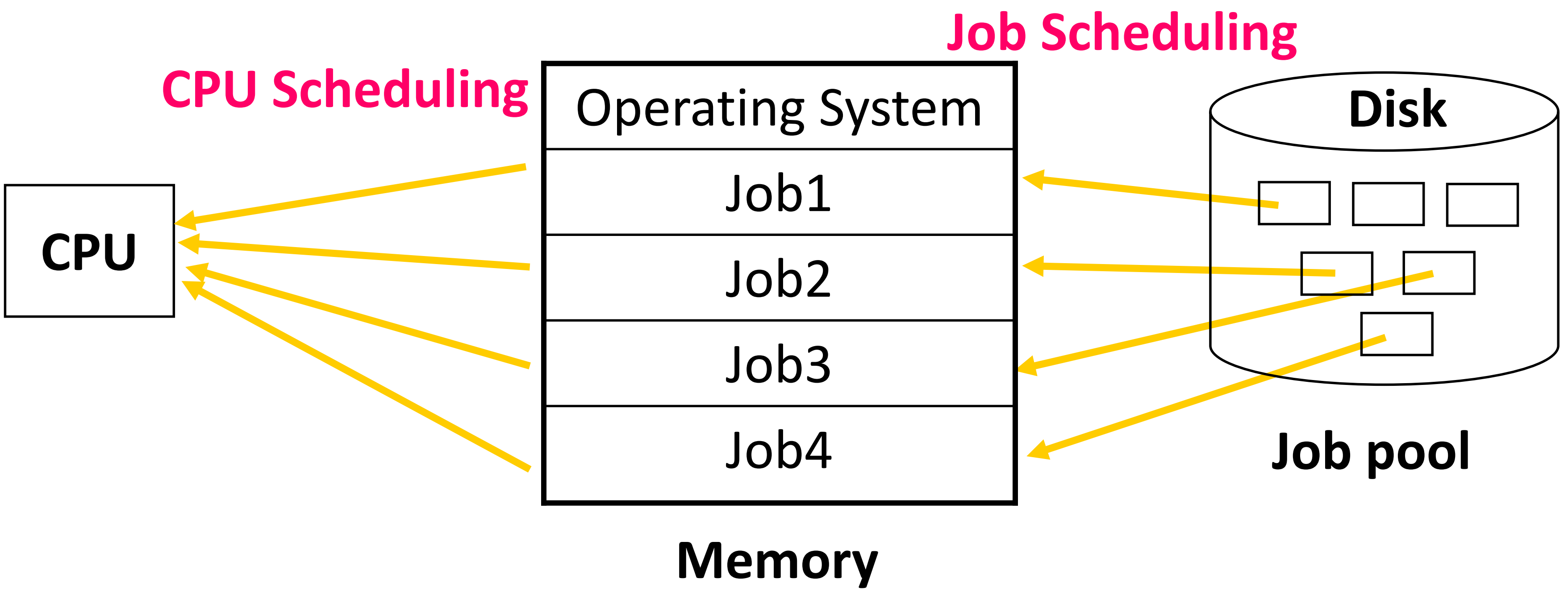
Mainframe: Multi-programming System

- Overlaps the I/O and computation of jobs
  - Keeps both CPU and I/O devices working at higher rates
- **Spooling** (Simultaneous Peripheral Operation On-Line)
  - I/O is done with no CPU intervention
  - CPU just needs to be notified when I/O is done



Mainframe: Multi-programming System

- Several jobs are kept in main memory at the same time, and the CPU is multiplexed among them



Mainframe: Multi-programming System

- OS tasks
  - Memory management (chap 9) – the system must allocate the memory to several jobs
  - CPU scheduling (chap6) – the system must choose among several jobs ready to run.
  - I/O system (chap13) – I/O routine supplied by the system, allocation of devices

Mainframe: Time-sharing System (Multi-tasking System)

- An interactive system provides direct communication between the users and the system
  - CPU switches among jobs so frequently that users may interact with programs
  - Users can see results immediately (response time < 1s)
  - Usually, keyboard/screen are used
- Multiple users can share the computer simultaneously
- Switch job when
  - finish
  - waiting I/O
  - a short period of time

Mainframe: Time-sharing System (Multi-tasking System)

- OS tasks
  - Virtual memory (chap 10) – jobs swap in and out of memory to obtain reasonable response time
  - File system and disk management (chap11,12) – manage files and disk storage for user data
  - Process synchronization and deadlock (chap7,8) – support concurrent execution of programs

Mainframe System Summary

	Batch	Multi-programming	Time-sharing (Multi-tasking)
System Model	Single user Single job	Multiple prog.	Multiple users Multiple prog.
Purpose	Simple	Resource utilization	Interactive Response time
OS features	N.A	CPU scheduling Memory Mgt. I/O system	File system Virtual memory Synchronization Deadlock

System Category

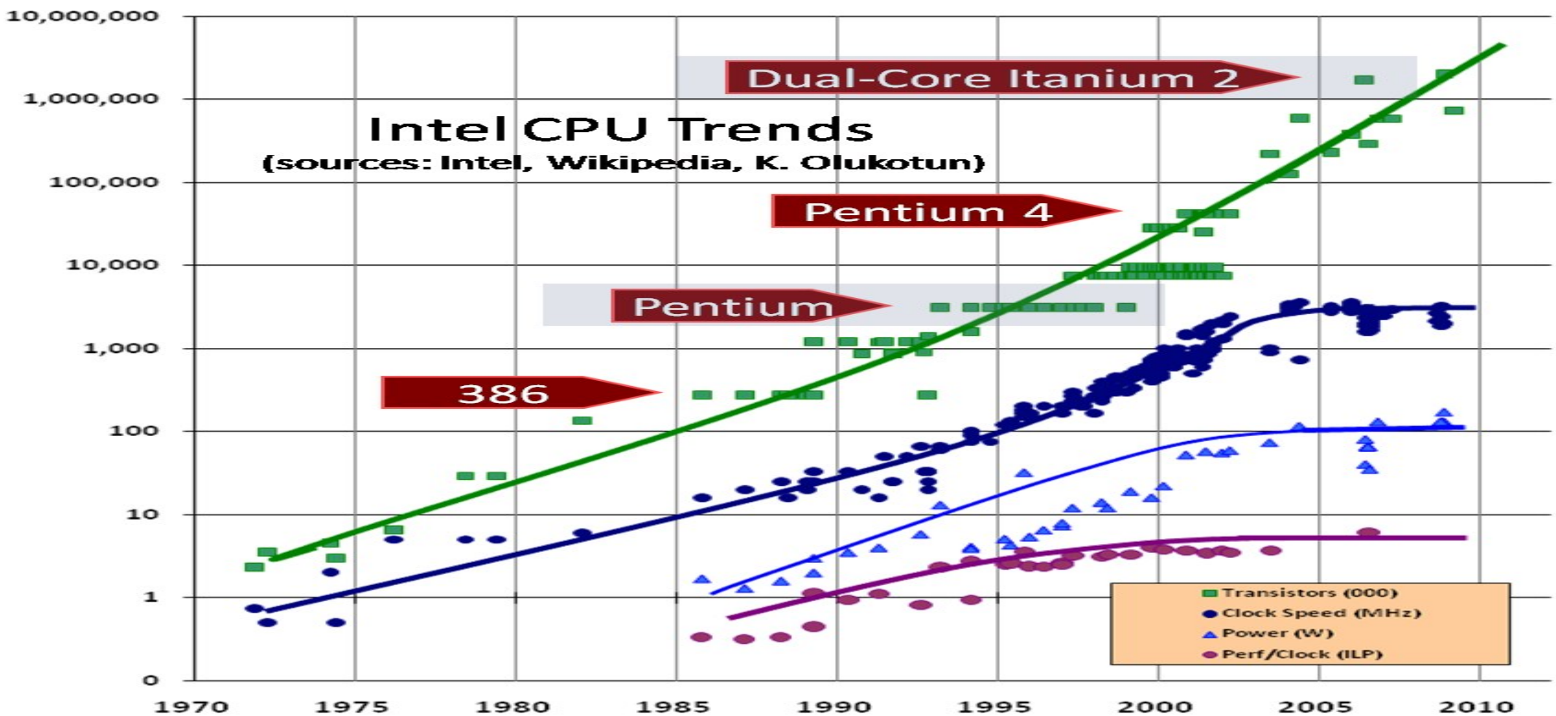
- Mainframe Systems
- Computer-system architecture
  - Desktop Systems: single processor
  - Parallel Systems: tightly coupled
  - Distributed Systems: loosely coupled
- Special-purpose Systems

Desktop Systems: Personal Computers

- Personal computers (PC) – computer system dedicated to a single user
- User convenience and responsiveness – GUI
- I/O devices – keyboards, mice, screens, printers
- Several different types of operating systems
  - Windows, MacOS, Unix, Linux
- Lack of file and OS protection from users
  - Worm, Virus

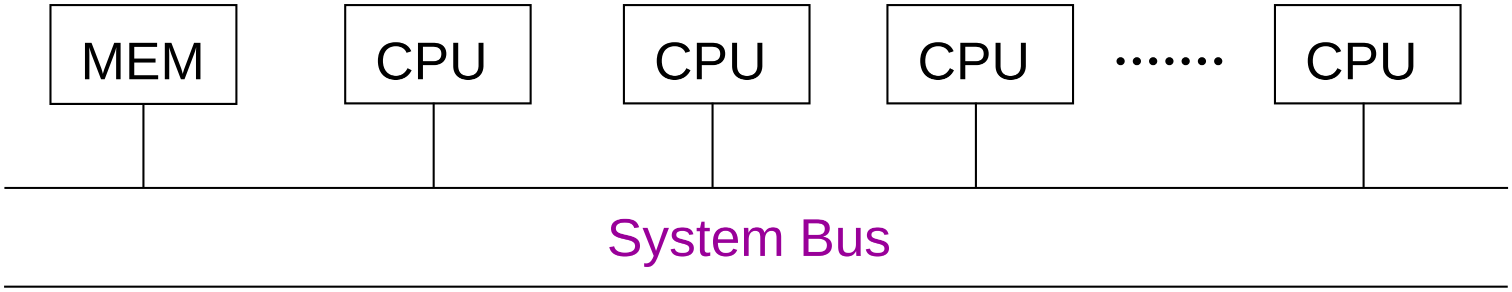
The Death of CPU Scaling

- Increase of transistor density ≠ performance
  - The power consumption and clock speed improvements collapsed
  - Non-CPU bottleneck: memory and disk access speed



Parallel Systems

- A.k.a multiprocessor or ***tightly*** *coupled system*
  - More than one CPU/core in close communication
  - Usually communicate through **shared memory**
- Purposes
  - ***Throughput***, **Economical**

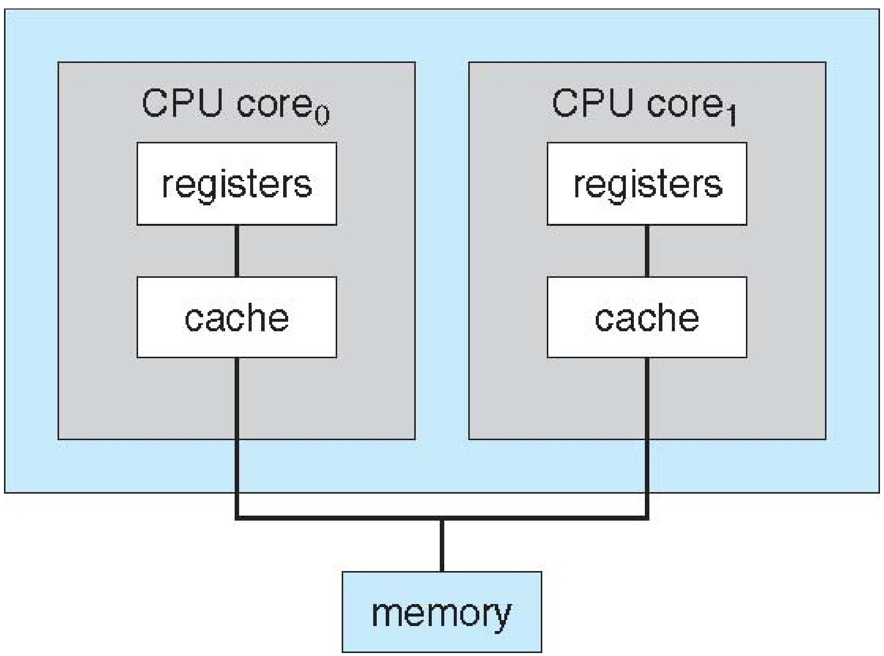


Parallel Systems

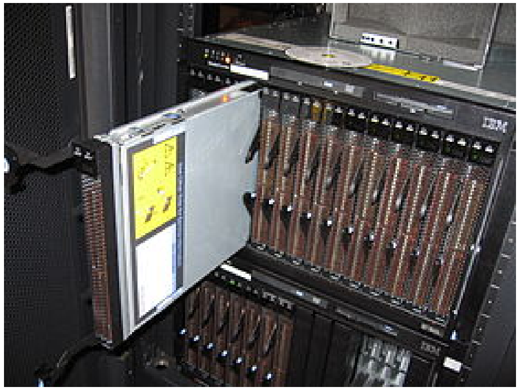
- Symmetric multiprocessor system (SMP)
  - Each processor runs the same OS
  - Most popular multiple-processor architecture
  - Require extensive synchronization to protect data integrity
- Asymmetric multiprocessor system
  - Each processor is assigned a specific task
  - One Master CPU & multiple slave CPUs
  - More common in extremely large systems

Multi-Core Processor

- A CPU with multiple cores on the same die (chip)
- On-chip communication is faster than between-chip communication
- One chip with multiple cores uses significantly less power than multiple single-core chips

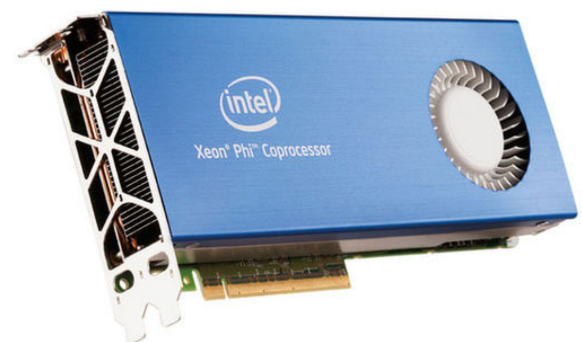


blade servers:
Each blade–processor board boots independently and run its own OS



Many-Core Processor

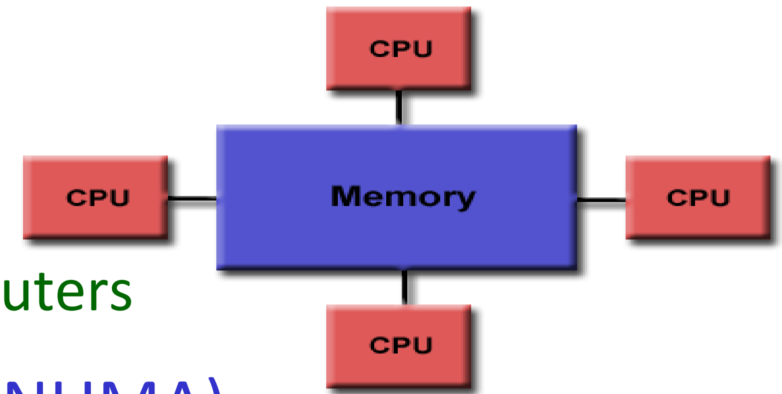
- Nvidia General-Purpose GPU
  - First release in Apr. 2008
  - High degree of parallelism
    - 2,880 thread processor
    - **Single Instruction Multiple Data (SIMD)**
  - Higher Performance per Watt
    - **1.43TFlops (x200 faster than a single Intel Core i7)**
    - **245 WATTS**
  - Lower clock frequency: 600~750 MHz
  - **$3000 USD**



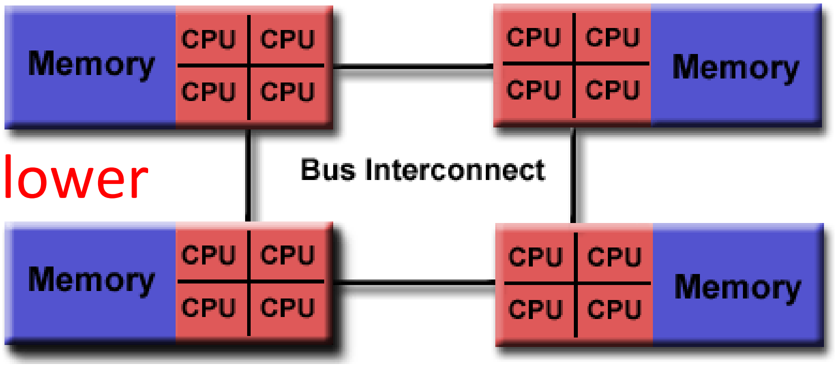
- Intel Xeon Phi
  - First release in Nov. 2012
  - A coprocessor computer architecture based on Intel Many Integrated Core (MIC)
  - 61 cores , 1.2TFlops, 300WATTS
  - It runs **Intel assembly code** just like the main CPU in your computer
  - Can be used as a **standalone CPU**

Memory Access Architecture

- Uniform Memory Access (UMA):
  - Most commonly represented today by Symmetric Multiprocessor (SMP) machines
  - Identical processors
  - Equal access times to memory
  - Example: most commodity computers



- Non-Uniform Memory Access (NUMA):
  - Often made by physically linking two or more SMPs
  - One SMP can directly access memory of another SMP
  - Memory access across link is slower
  - Example: IBM Blade server

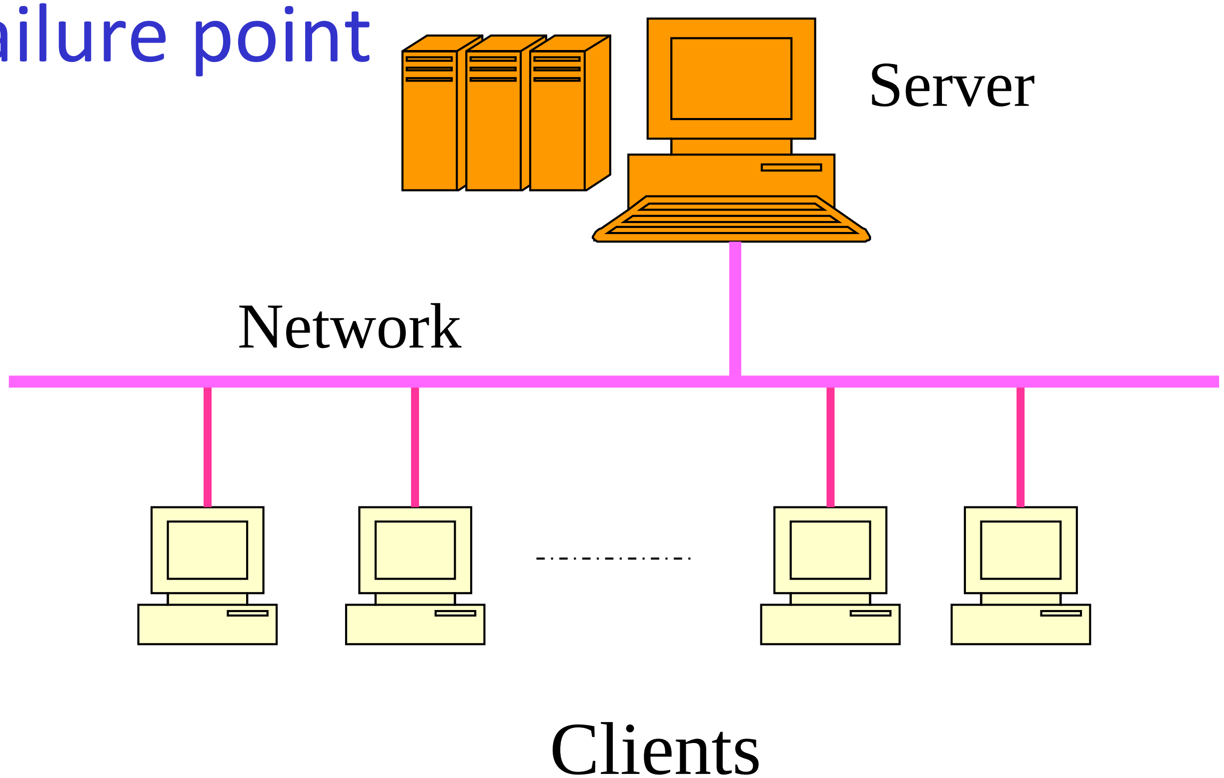


Distributed Systems

- Also known as ***loosely** coupled system*
  - Each processor has its own **local memory**
  - processors communicate with one another through various communication lines (I/O bus or **network**)
  - Easy to scale to large number of nodes (hundreds of thousands, e.g. Internet)
- Purposes
  - Resource sharing
  - Load sharing
  - Reliability
- Architecture: peer-to-peer or client-server

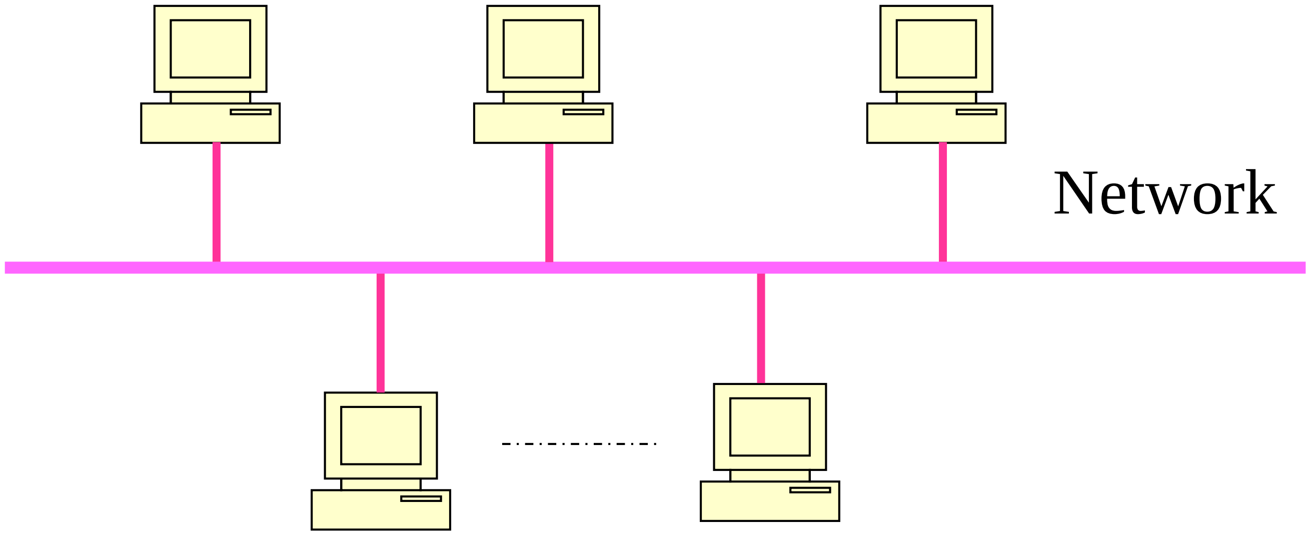
Client-Server Distributed System

- Easier to manage and control resources
- But, server becomes the bottleneck and single failure point



Peer-to-Peer Distributed System

- Every machine is identical in its role in the distributed system – decentralized
- Example: ppStream, bitTorrent, Internet



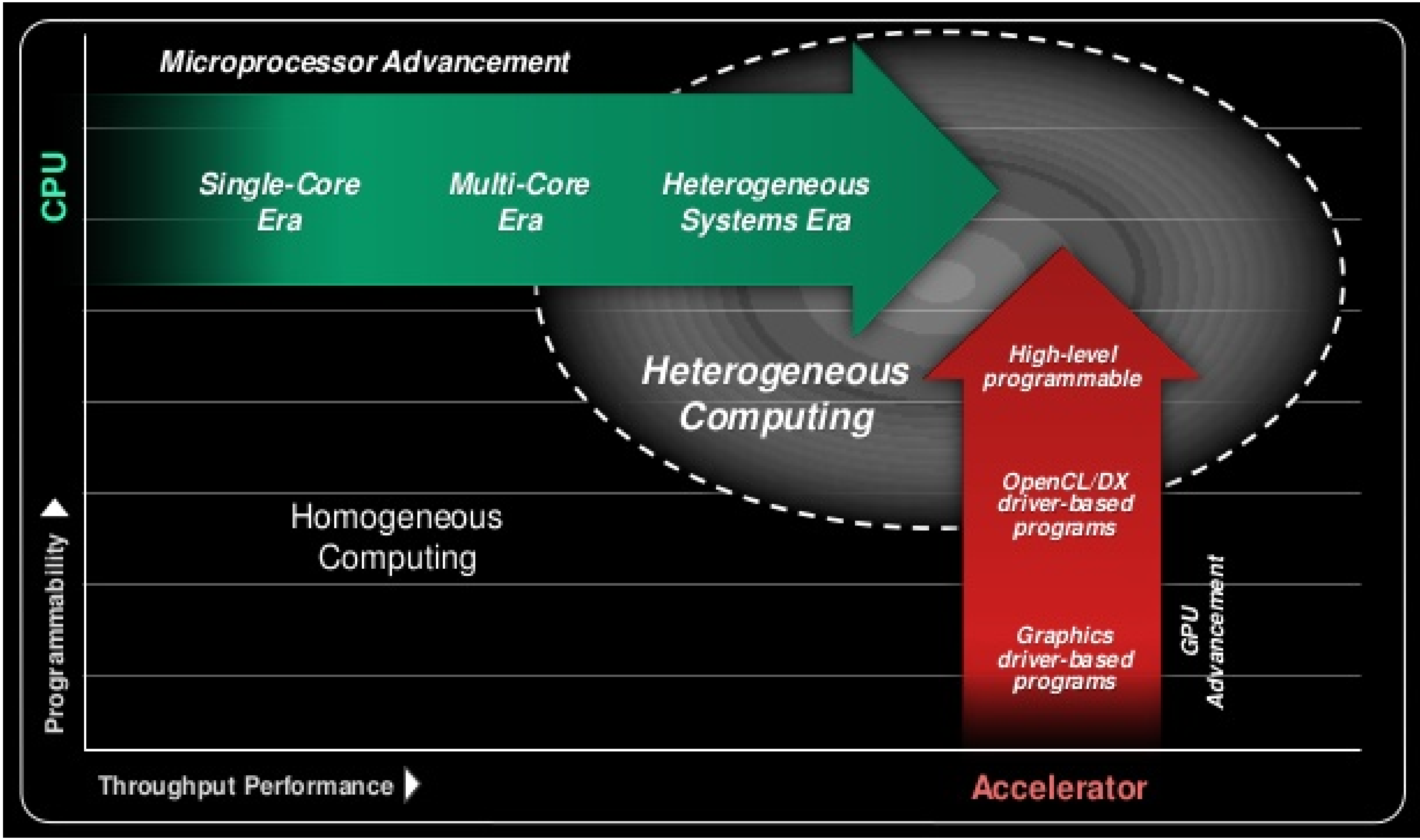
Clustered Systems

- Definition:
  - Cluster computers share storage and are closely linked via a local area network (LAN) or a faster interconnect, such as InfiniBand (up to 300Gb/s).
- *Asymmetric clustering*: one server runs the application while other servers standby
- *Symmetric clustering*: two or more hosts are running application and are monitoring each other

Heterogeneous Computing

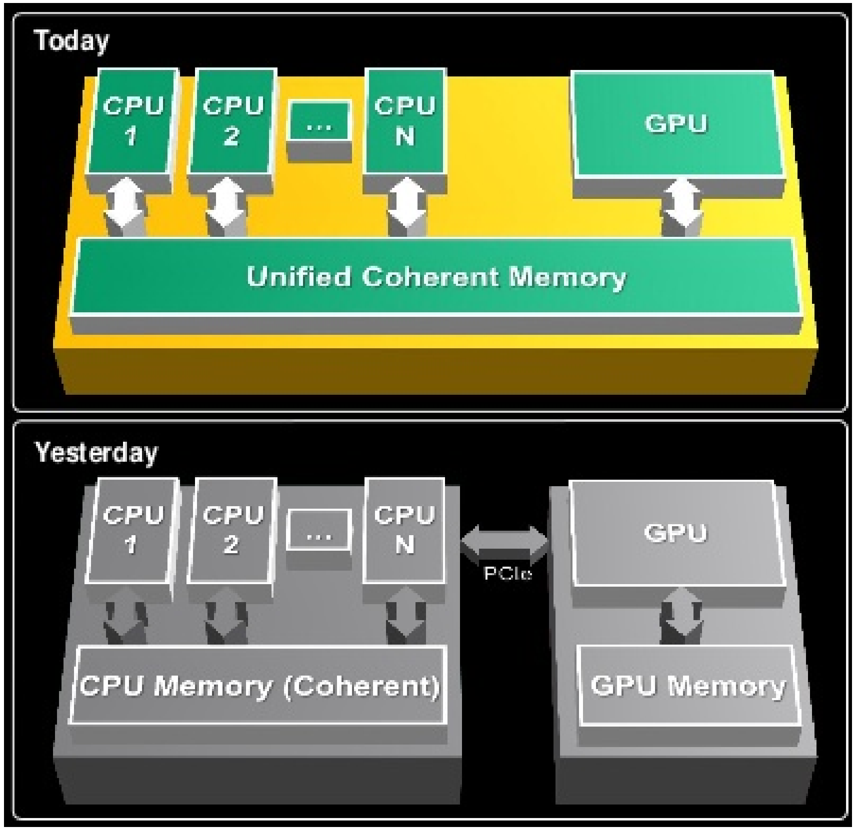
- Heterogeneous computing is an integrated system that consists of different types of (programmable) computing units.
  - DSP (digital signal processor)
  - FPGA (field-programmable gate array)
  - ASIC (application-specific integrated circuit)
  - GPU (graphics processing unit)
  - Co-processor (Intel Xeon Phi)
- A system can be a cell phone or a supercomputer

Shift of Computing Paradigm



Heterogeneous System Architecture (HSA)

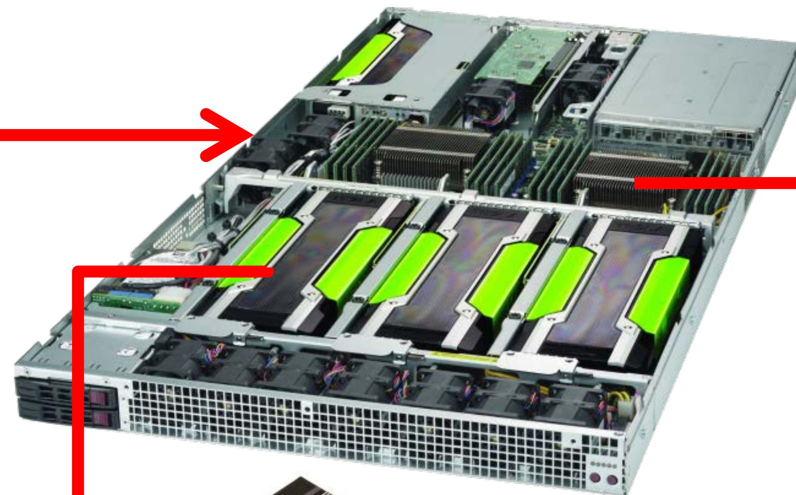
- Aim to provide a common system architecture for designing higher-level programming models for all devices
- Unified coherent memory
  - Single virtual memory address space
  - Prevent memory copy

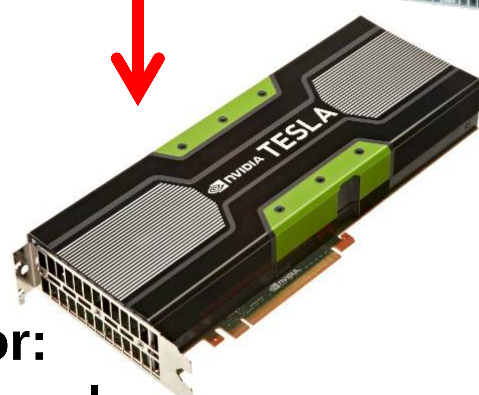


Today’s Typical Parallel Computers

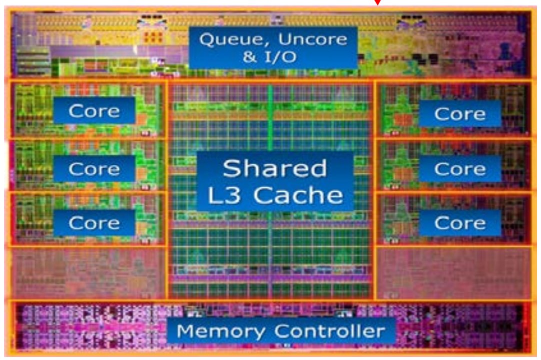
Racks: 16~42U

Node/Server: 1~4U





Multi-core Processor:
100x cores/1000xthreads



Co-Processor: 4~12 cores

Supercomputers

- Definition: A computer with a high-level computational capacity compared to a general-purpose computer
- Its performance is measured in floating-point operations per second (FLOPS) instead of million instructions per second (MIPS)
- Ranked by the TOP500 list since 1993
  - According to the HPL benchmark results
  - Announced twice a year at ISC and SC conferences

TOP500 List (2021 June)

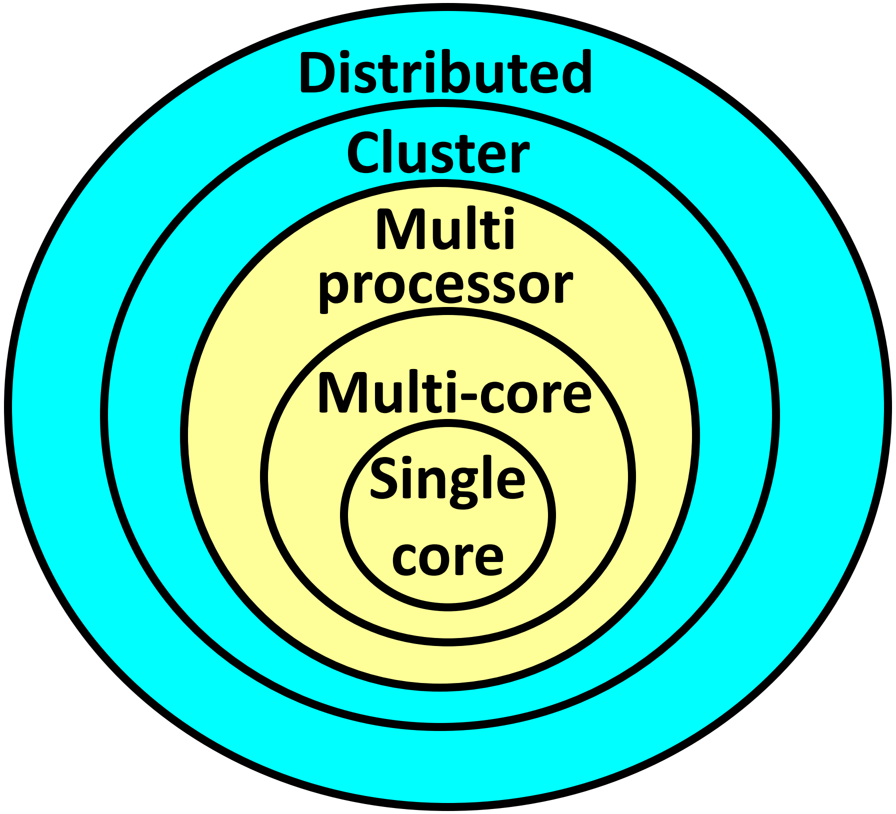
	Country	System	Vendor	Power (kW)	#cores	Accelerator	Rmax	Rpeak (PFLOPS)
1	Japan	Fugaku	Fujitsu	29,899	7.6M		442.0	537.2
2	US	Summit	IBM	10,096	2.4M	Volta V100	148.6	200.8
3	US	Sierra	IBM	7,438	1.5M	Volta V100	94.6	125.7
4	China	TaihuLight	NRCPC	15,371	10.6M		93.0	125.4
5	US	Perlmutter	Cray	2,528	706K	Volta A100	64.6	90.0
15	Swiss	Piz Daint	Cray	2,384	387K	Volta P100	21.2	27.1

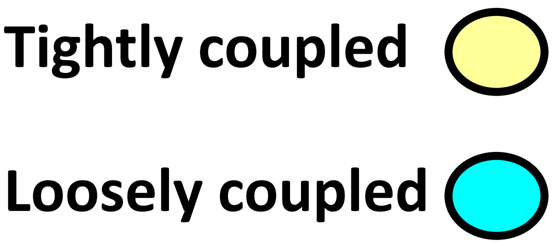
2016 June

8	Swiss	Piz Daint	Cray	2,325	116K	Tesla K20X	6.2	7.8

- Accelerators/Many-core processors provide huge computing power with better energy efficiency
  - **Fugaku** is the first processor to use the ARMv8.2-A Scalable Vector Extension SIMD instruction set
  - **TaihuLight** uses manycore 64-bit RISC processors
  - **Perlmutter** uses the latest A100 GPUs to have highest power efficiency

System Architecture Summary





Trend of Parallel Computers/Computing

Single-Core Era

Enabled by:
- Moore's Law
- Voltage Scaling

Constraint by:
- Power
- Complexity

Assembly → C/C++ → Java …

Muti-Core Era

Enabled by:
- Moore's Law
- SMP

Constraint by:
- Power
- Parallel SW
- Scalability

Pthread → OpenMP …

Distributed System Era

Enabled by:
- Networking

Constraint by:
- Synchronization
- Comm. overhead

MPI → MapReduce …

Heterogeneous Systems Era

Enabled by:
- Abundant data parallelism
- Power efficient GPUs

Constraint by:
- Programming models
- Comm. overhead

Shader → CUDA → OpenCL …

System Category

- Mainframe Systems
- Computer-system architecture
- Special-purpose Systems
  - Real-Time Systems
  - Multimedia Systems
  - Handheld Systems

Real-Time Operating Systems (Chap19)

- Well-defined fixed-time constraints
  - "Real-time" doesn't mean speed, but *keeping **deadlines***
- Guaranteed response and reaction times
- Often used as a control device in a dedicated application:
  - Scientific experiments, medical imaging systems, industrial control systems, weapon systems, etc
- Real-time requirement: hard or soft

Soft vs. Hard Real-Time

- Soft real-time requirements:
  - Missing the deadline is unwanted, but is not immediately critical
  - A critical real-time task gets priority over other tasks, and retains that priority until it completes
  - Examples: multimedia streaming
- Hard real-time requirements:
  - Missing the deadline results in *a fundamental failure*
  - Secondary storage limited or absent, data stored in short term memory, or read-only memory (ROM)
  - Examples: nuclear power plant controller

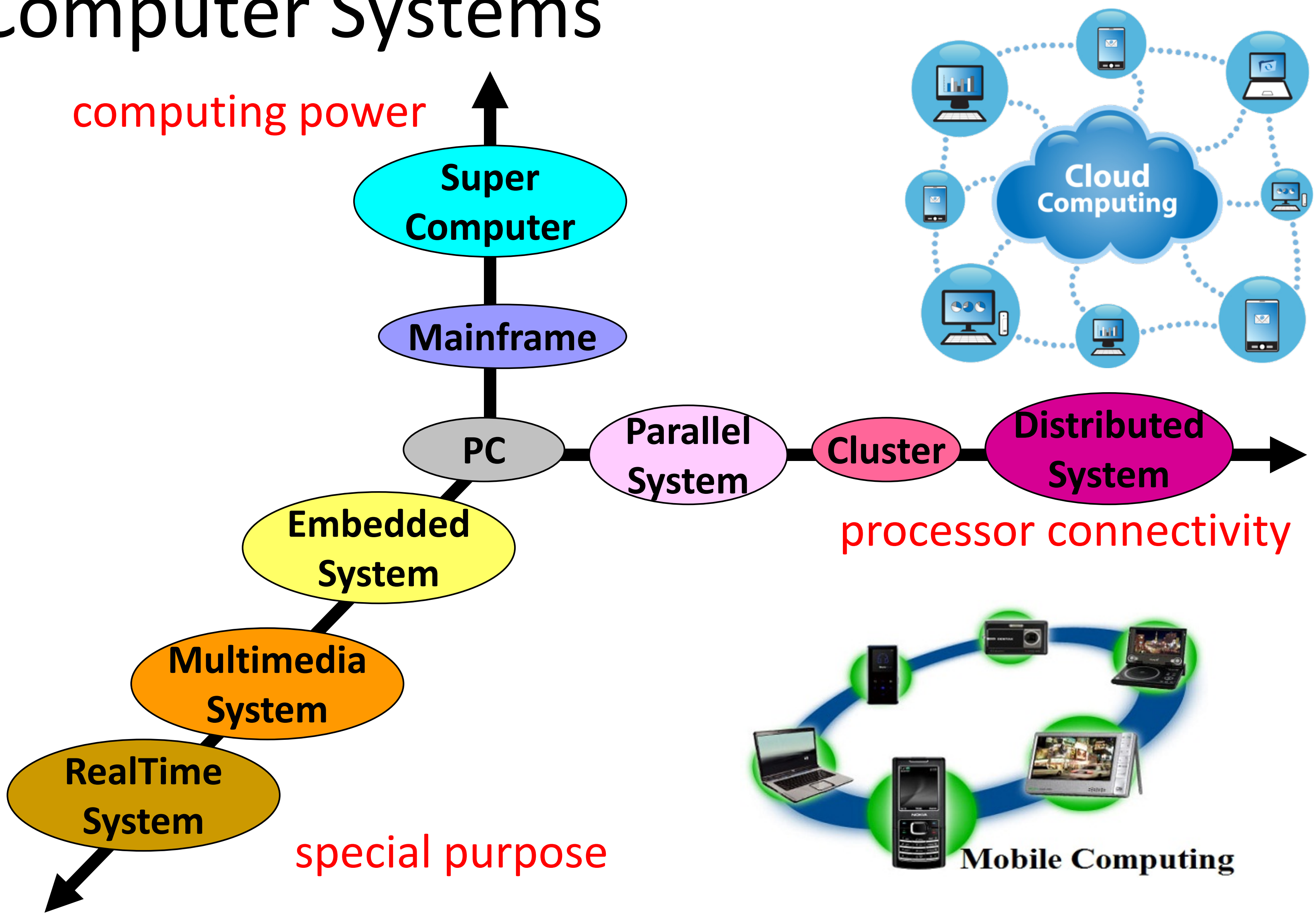
Multimedia Systems (Chap20)

- A wide range of applications including audio and video files (e.g. ppstream, online TV)
- Issues:
  - Timing constraints: 24~30 frames per second
  - On-demand/live streaming: media file is only played but not stored
  - Compression: due to the size and rate of multimedia systems

Handheld/Embedded Systems

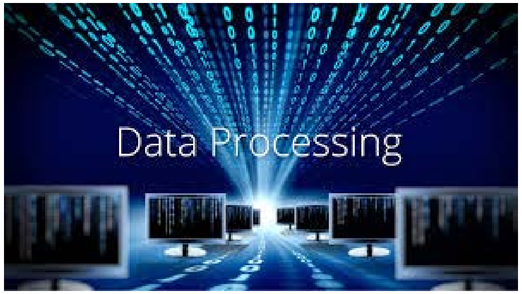
- Personal Digital Assistants (PDAs)
- Cellular telephones
- HW specialized OS
- Issues
  - Limited memory
  - Slow processors
  - Battery consumption
  - Small display screens

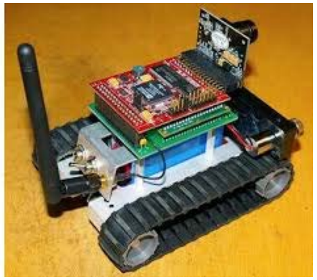
Computer Systems

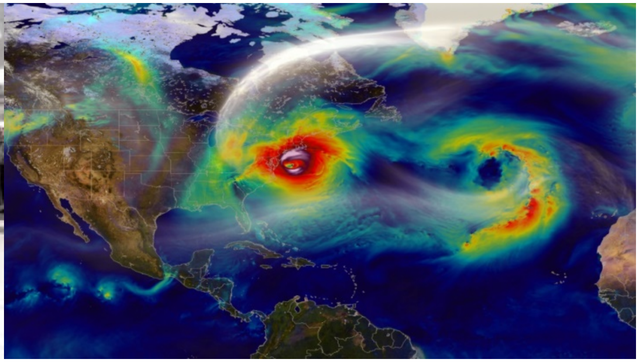


Computer Systems

- Which system to use? How to use it?
- They have many things in common, but also with different design decisions for their OS.







Review Slides

- Mainframe system
  - Batch, **Multi-programming** and **Time-sharing**
- Comparison
  - Tightly coupled system vs. Loosely coupled system
  - Client-server vs. P2P
  - Memory architecture: NUMA vs. UMA
  - Real-time system: Soft vs. Hard real-time
- Computer systems
  - Multi-core processor
  - Supercomputer
  - Distributed / Cluster system
  - Heterogeneous computing system