Parallel Architectures

(CS 3006)

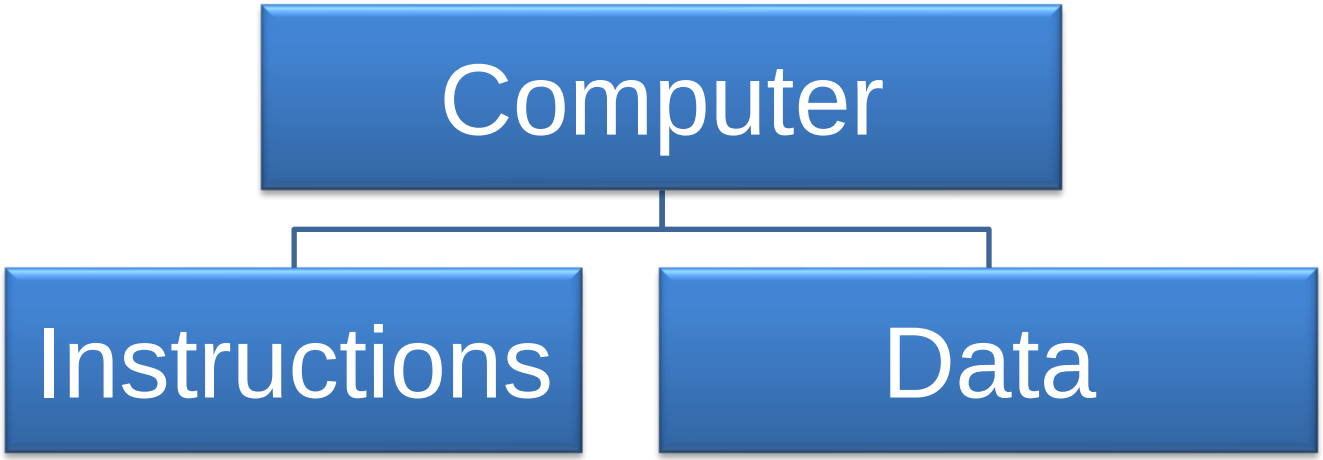
Dr. Shujaat Hussain

Department of Computer Science,
National University of Computer & Emerging Sciences,
Islamabad Campus

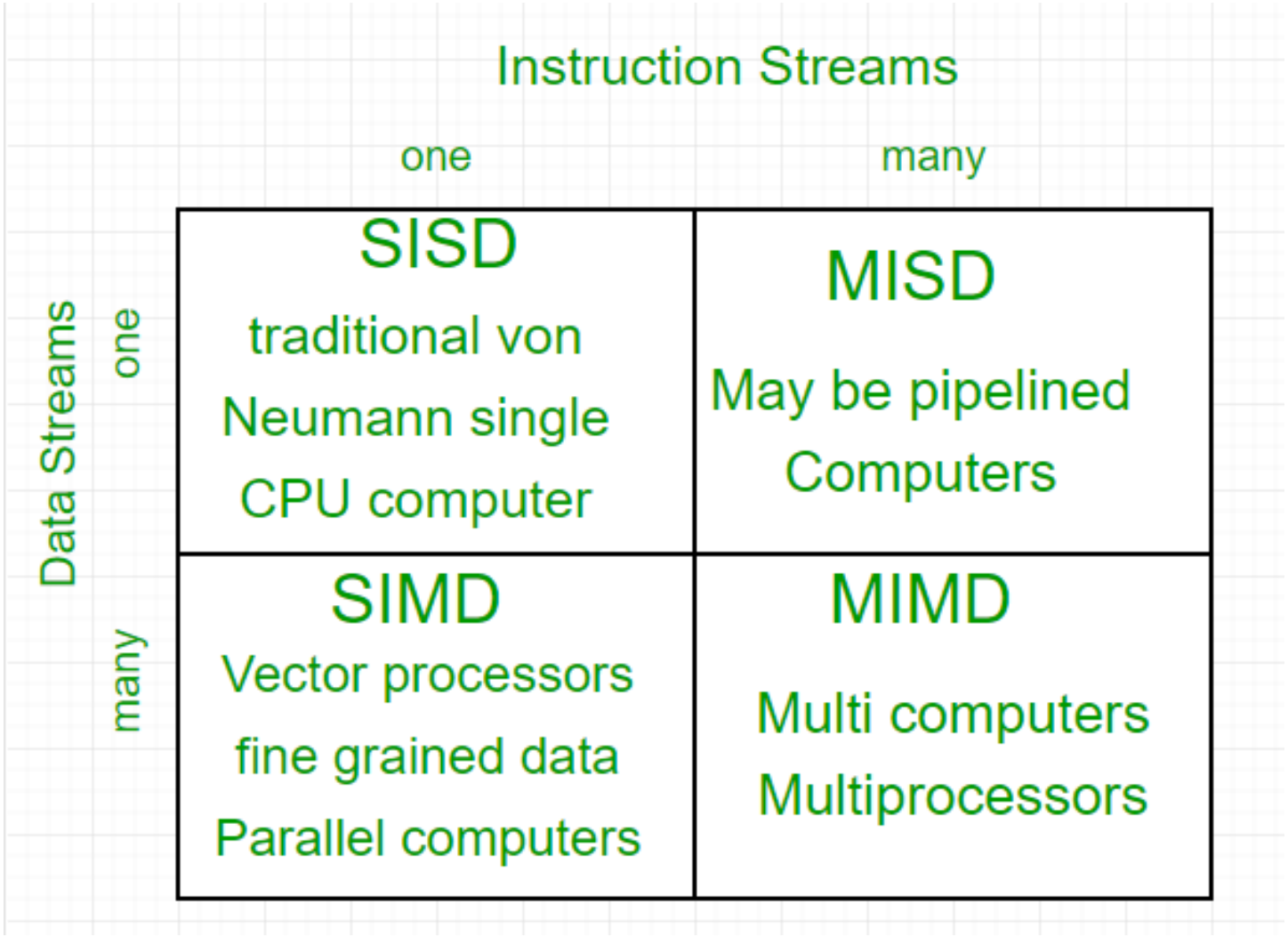
Flynn's Taxonomy

- Specific **classification** of **parallel architecture**

- By **Michael Flynn** (from Stanford, in 1966)
  - Made a **classification** of **computer systems** known as **Flynn's Taxonomy**

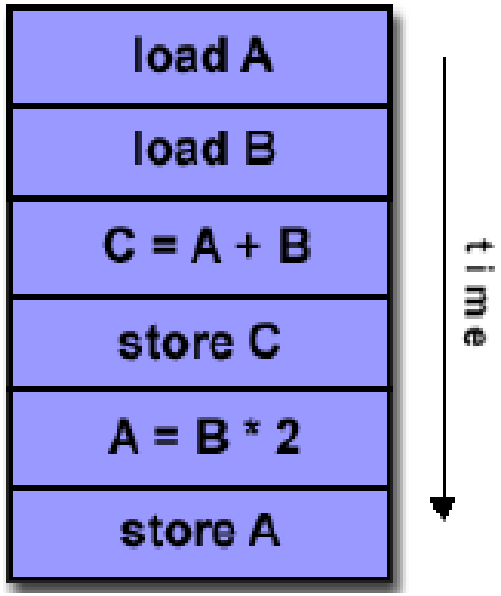


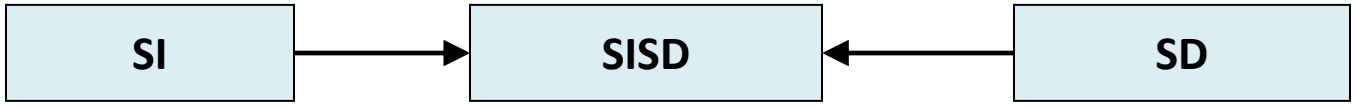
Flynn's Taxonomy



1. Single Instruction, Single Data Stream – *SISD*

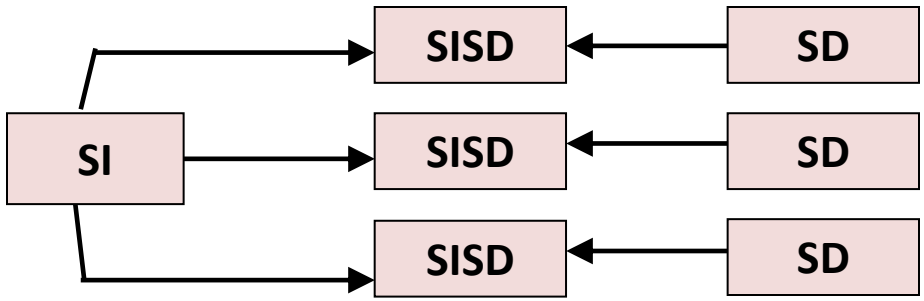
- Single processor
- Single instruction stream
- Data stored in single memory
- Deterministic execution





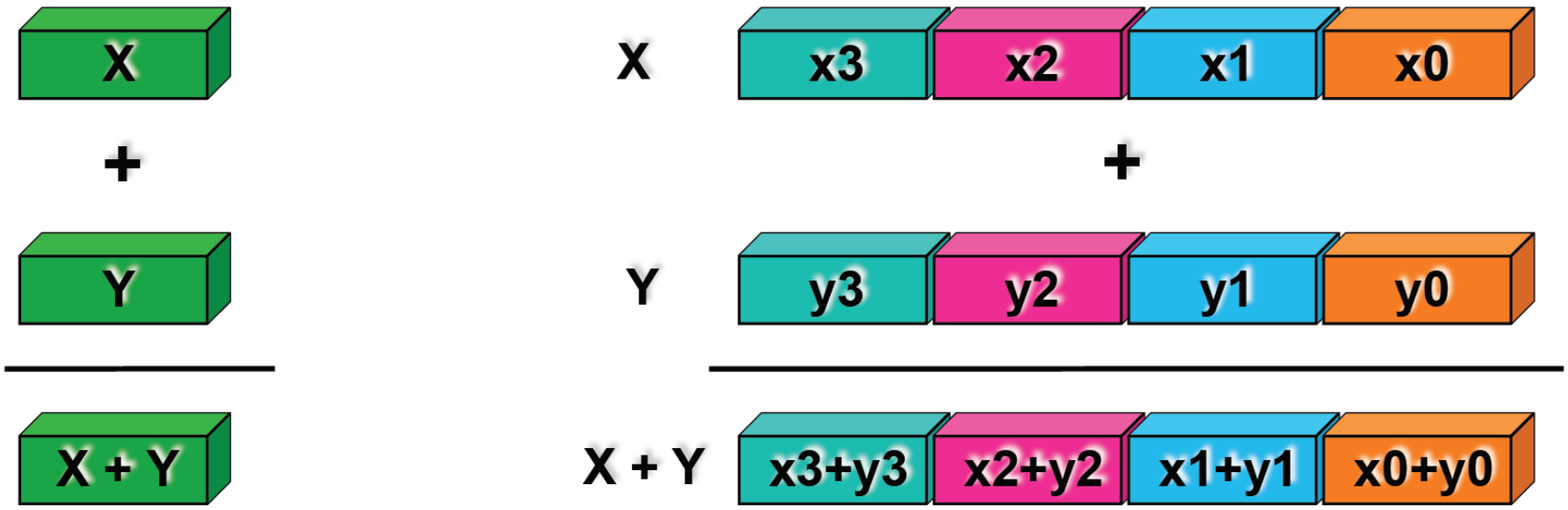
2. Single Instruction, Multiple Data Stream - *SIMD*

- A **parallel processor**
- **Single instruction**: all **processing units** **execute same instruction** at **any given clock cycle**
- **Multiple data**: Each **processing unit** can **operate on** a **different data element**
- **Large number** of **processing elements** **(with local memory)**
- **Examples**: **GPUs, etc.**



2. Single Instruction, Multiple Data Stream - *SIMD*

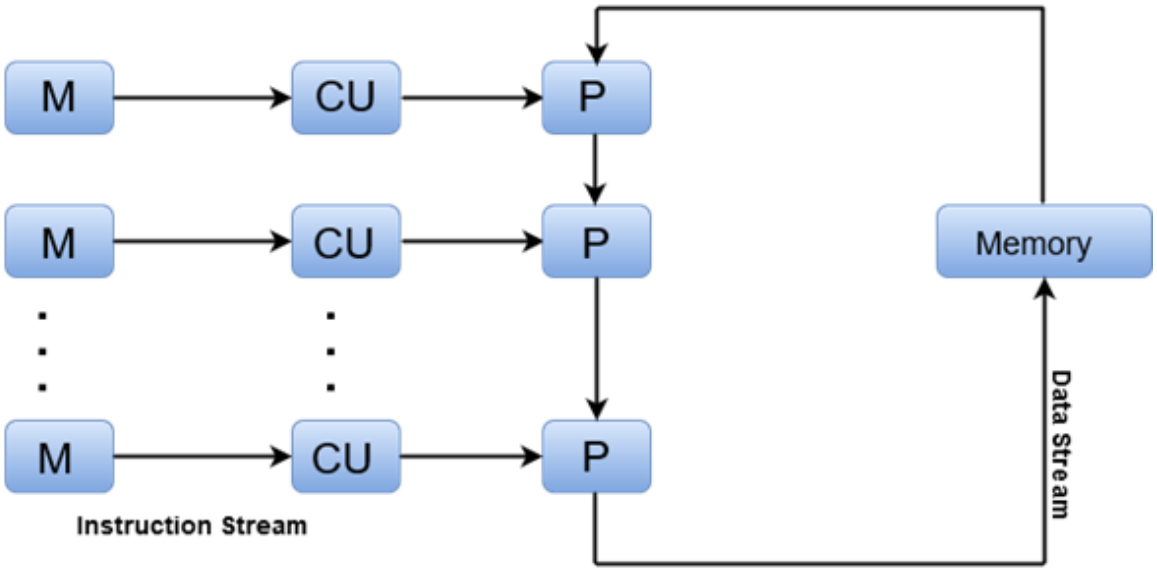
- **Scalar processing**
  - —one operation produces one result
- **SIMD vector units**
  - —one operation produces multiple results



Slide Credit: Alex Klimovitski & Dean Macri, Intel Corporation

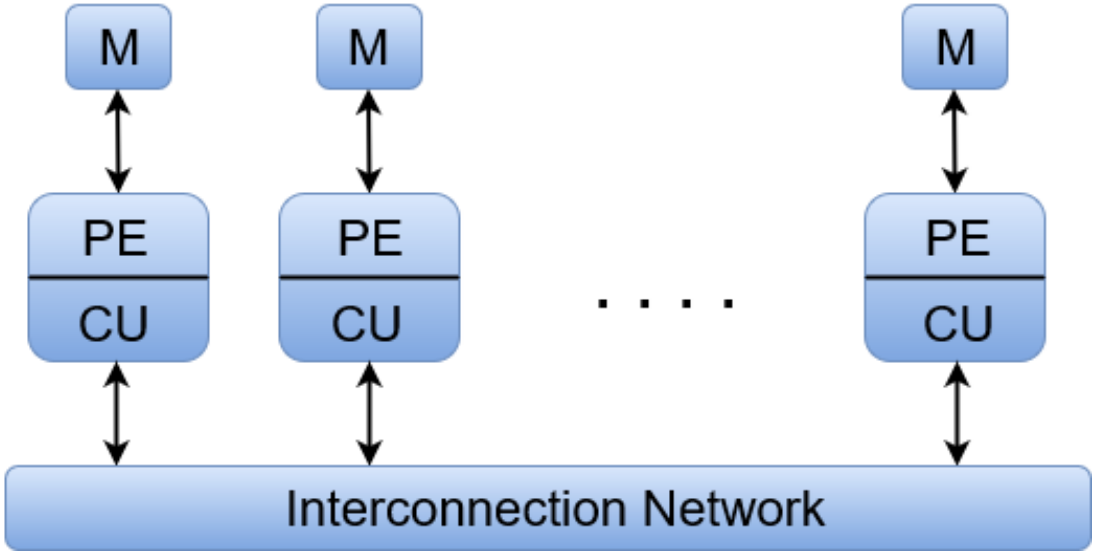
3. Multiple Instruction, Single Data Stream - *MISD*

- **Sequence** of **data**
- Transmitted to **set of processors**
- **Each processor executes different instruction** sequence, using **same Data**
- Examples: *Pipelined Vector Processors, etc.*



4. Multiple Instruction, Multiple Data Stream- *MIMD*

- **Most common parallel processor architecture**
- **Simultaneously execute different instructions**
- Using **different** sets of **data**
- Examples: ***Multi-cores***, ***SMPs***, ***Clusters, Grid, Cloud***

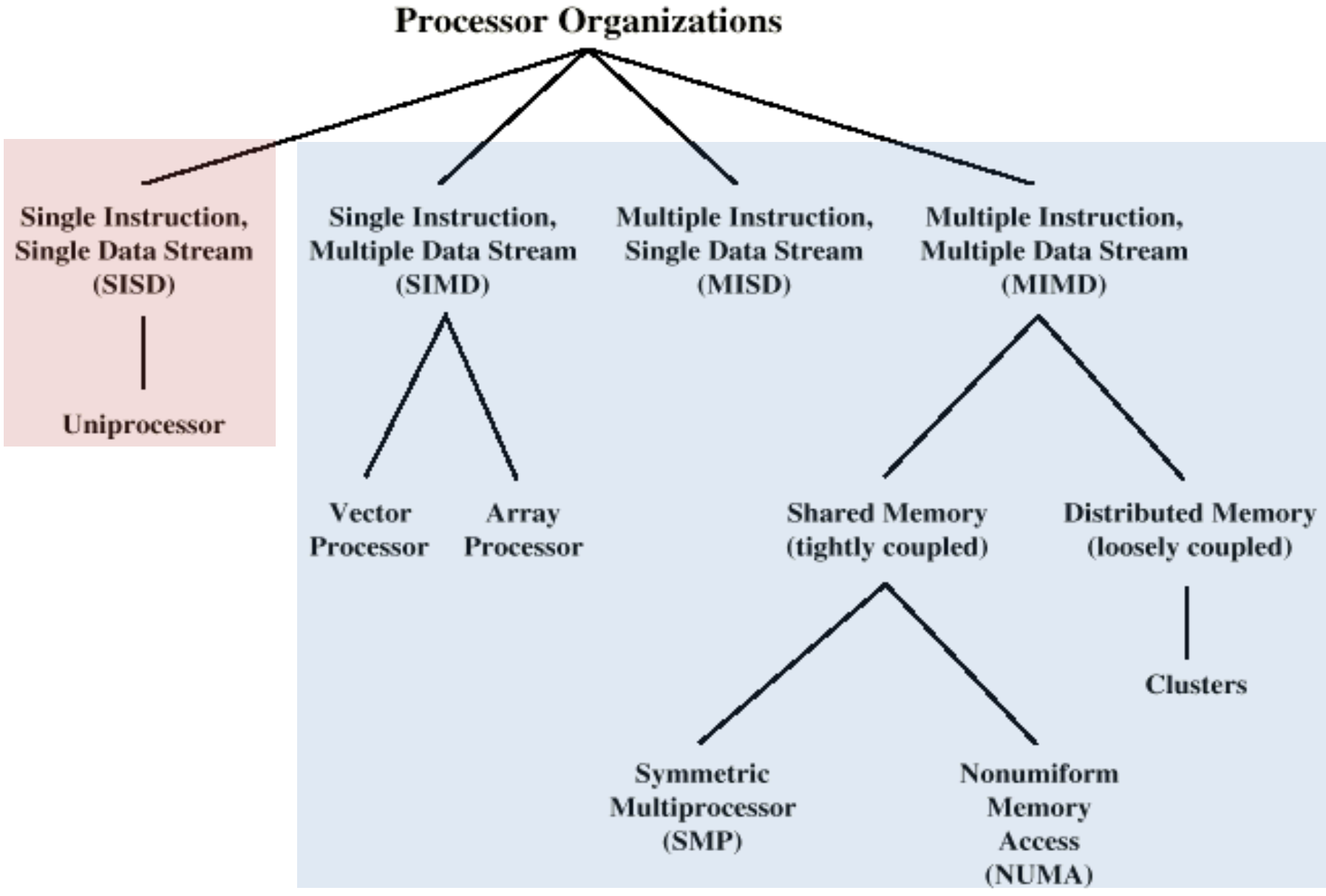


MIMD - Overview

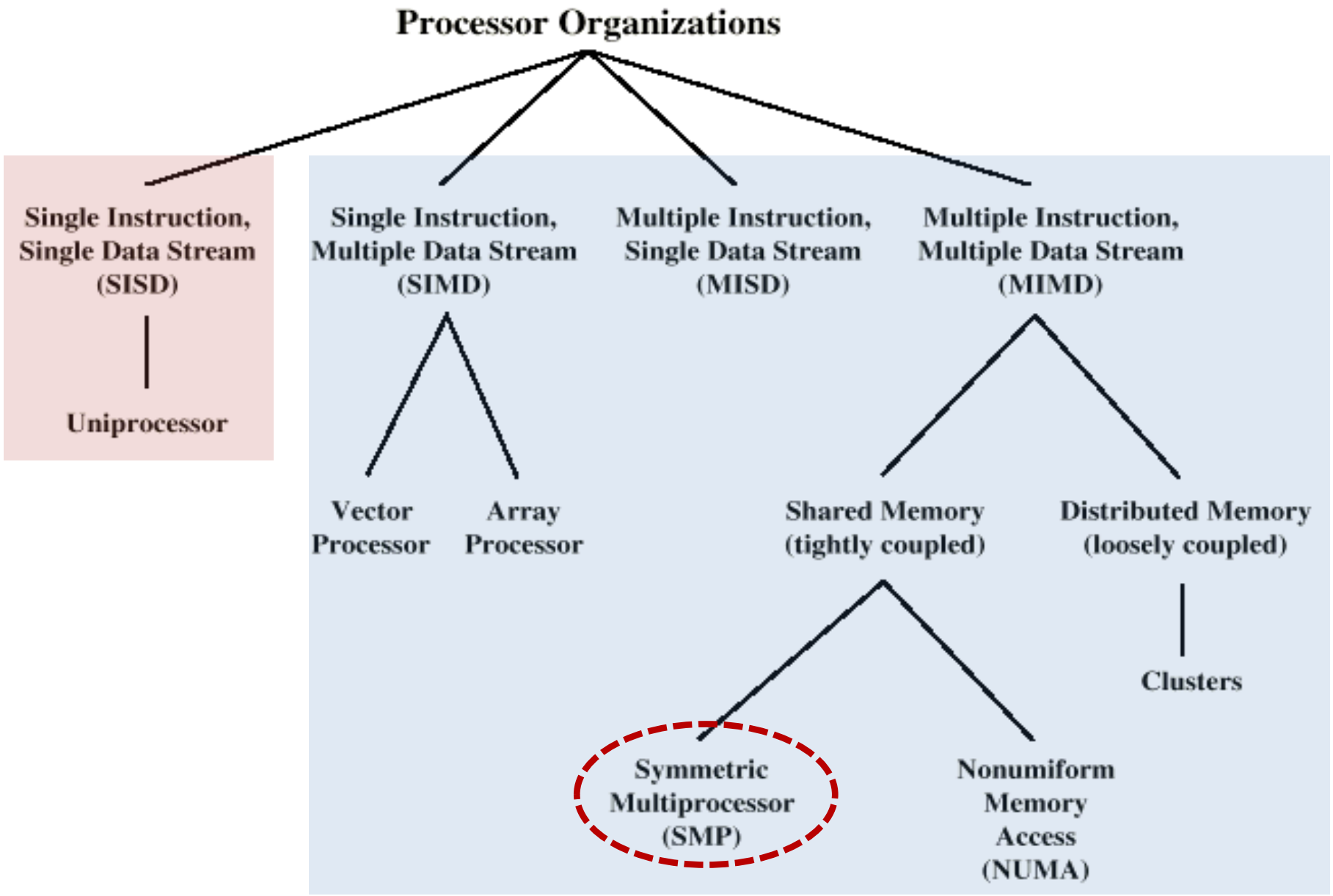
- **General purpose processors**
- **Each** can **process** all **instructions** necessary
- Further ***classified by method of processor communication:***

    1. **Shared Memory**
    2. **Distributed Memory**

Taxonomy of Processor Architectures



Taxonomy of Processor Architectures



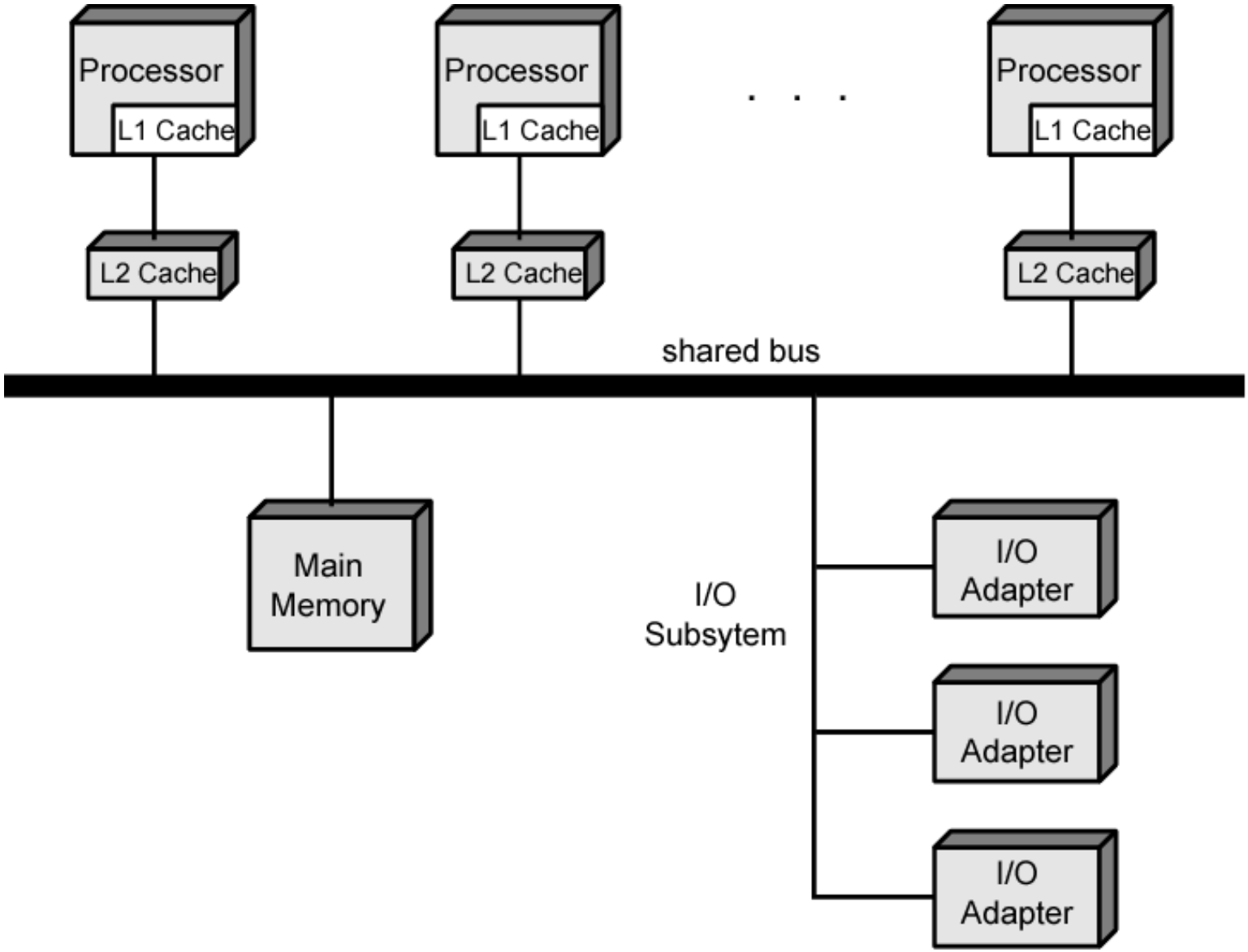
Symmetric Multiprocessor (SMP)

- **Processors share memory (tightly coupled)**
- **Communicate via shared memory (single bus)**
- **Same memory access time** (any memory region, from any processor)
- **Processors share I/O address space too**

SMP Advantages

- **Performance**
  - **work** can be **done** in **parallel**
- **Availability**
  - **Failure** of a **single processor** **does not halt system**
- **Incremental growth**
  - **Adding** additional **processors** **enhances performance**
- **Scaling**
  - **Range of products** based on **number of processors**

Symmetric Multiprocessor Organization

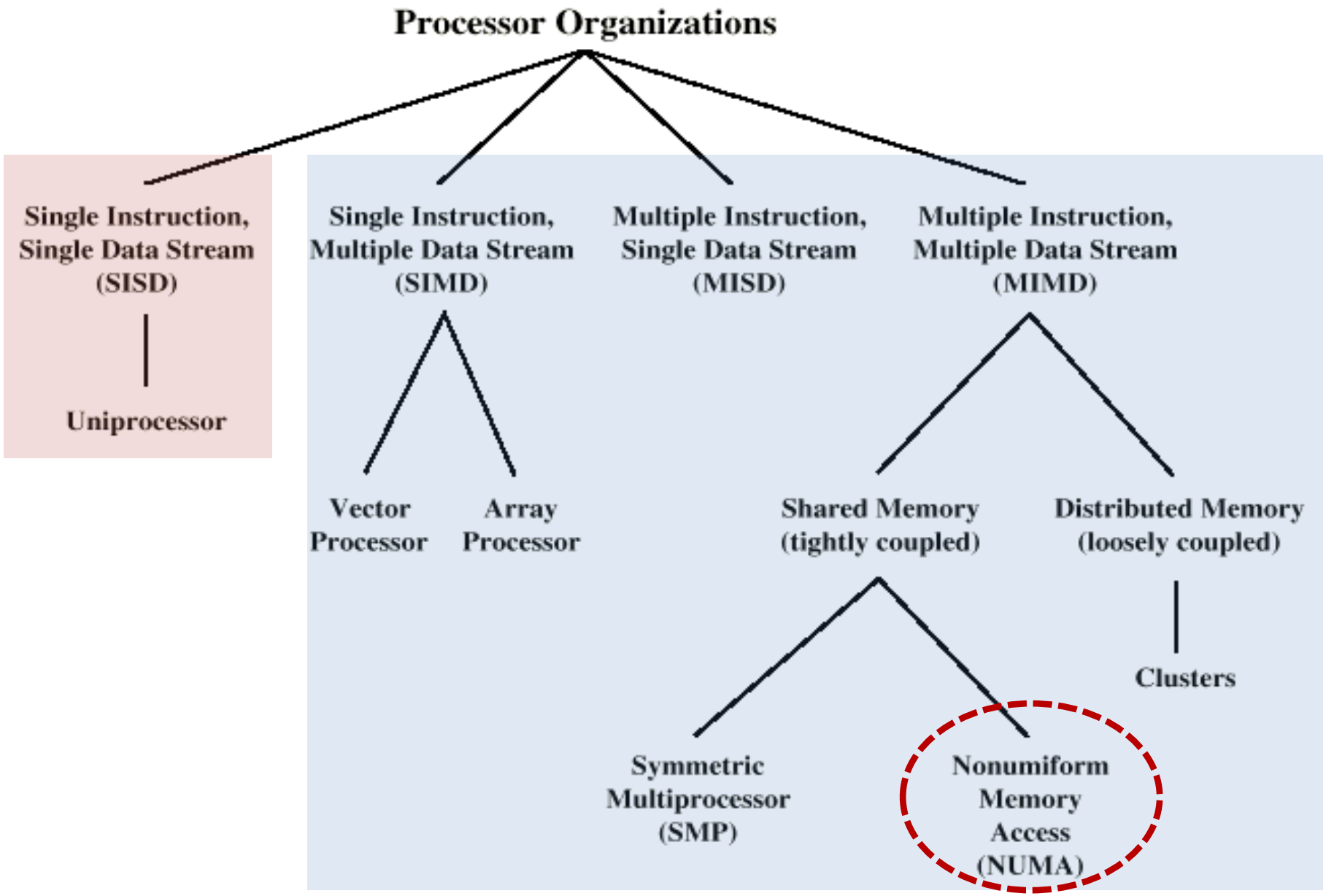


Multithreading and Chip Multiprocessors

- **Instruction stream** divided into **smaller streams called "threads"**

- **Executed** in **parallel**

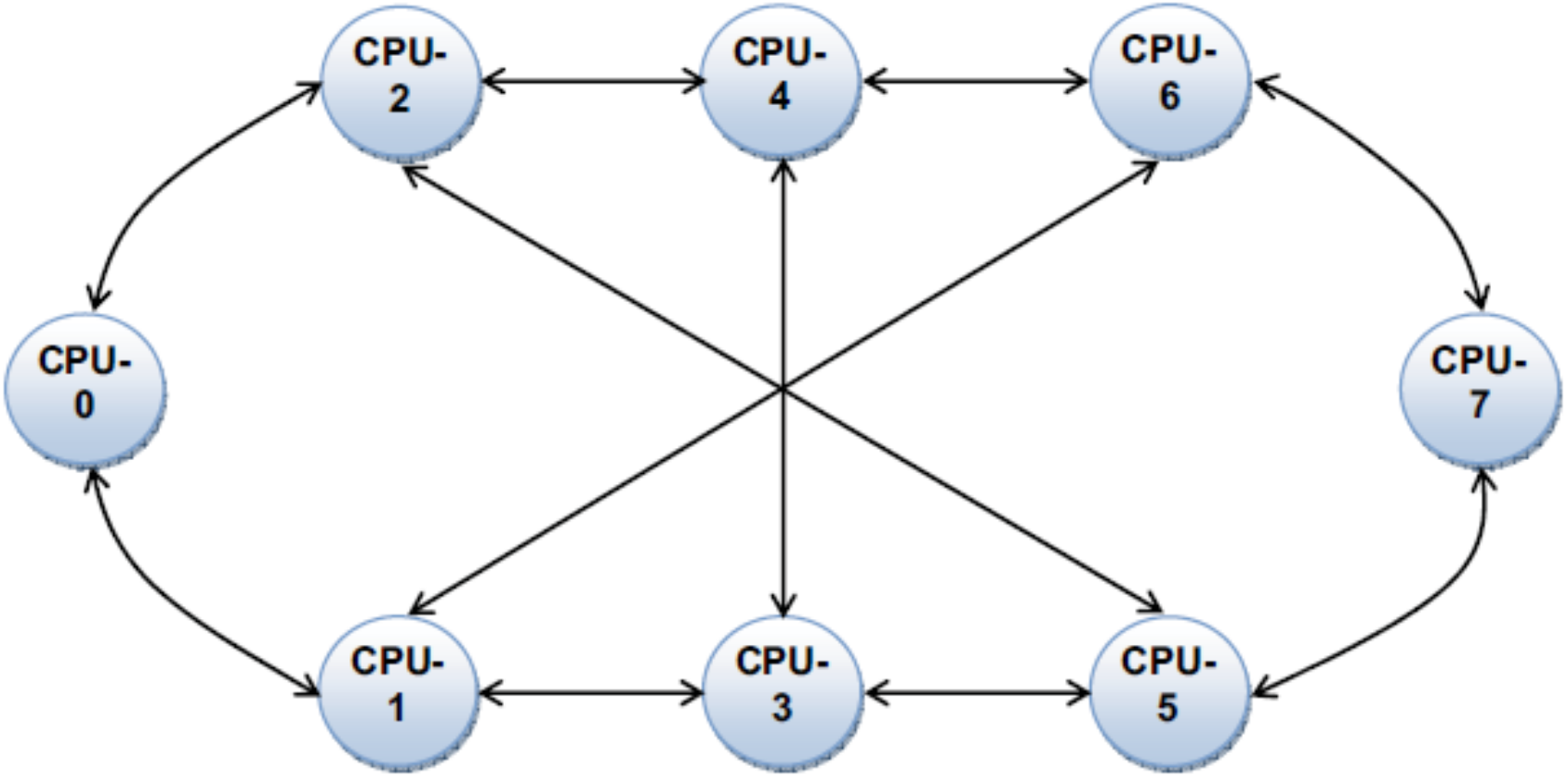
Taxonomy of Processor Architectures



Tightly Coupled - NUMA

- **Non-Uniform Memory Access (NUMA)**
  - Access times to different regions of memory **differs**

SunFire X4600M2 NUMA machine



Non-uniform Memory Access (NUMA)

- **Non-uniform memory access**
  - All **processors** have **access** to **all parts of memory**
  - **Access time** of processor **differs** depending on **memory region**
  - **Different processors** access **different regions** of memory at **different speeds**

- **Cache-coherent NUMA (cc-NUMA)**
  - **Cache coherence** is **maintained** among the **caches** of the **various processors**

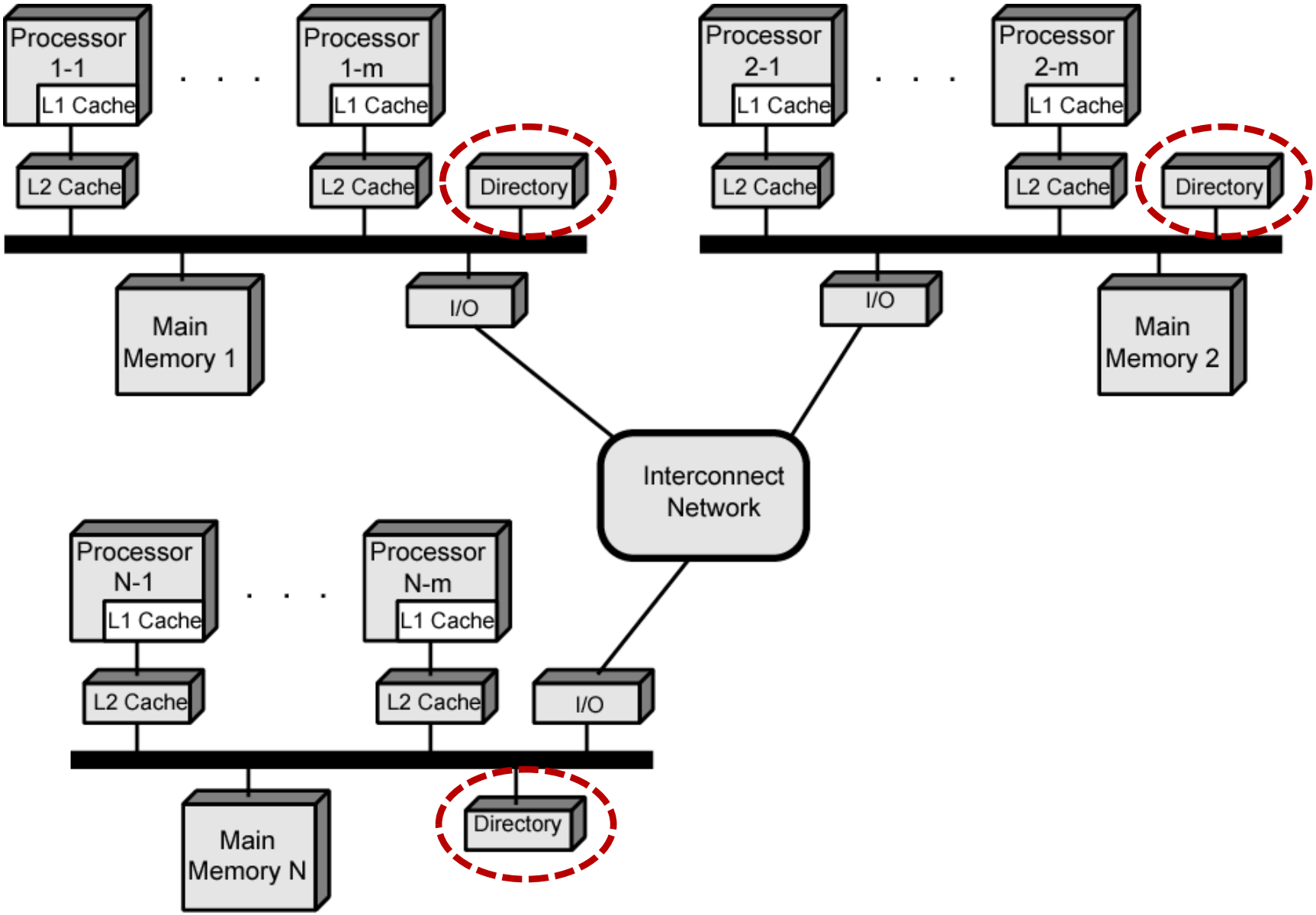
Motivation (Why NUMA)

- **SMP** has **practical limit** to **number** of **processors**
  - Bus traffic limits to between 16 and 64 processors

- In **clusters** each **node** has **own memory**:
  - **Apps do not see large global memory**
  - **Coherence maintained by software not hardware**

- **NUMA retains SMP flavour** while giving **large scale multiprocessing**

CC-NUMA Organization



CC-NUMA Operation

- **Each processor** has own **L1** and **L2** cache
- Each **node** has **own main memory**
- **Nodes connected** by some **networking facility**
- Each **processor** sees **single addressable memory**
- **Hardware support** for **read/write** to **non-local memories**, ***cache coherency***

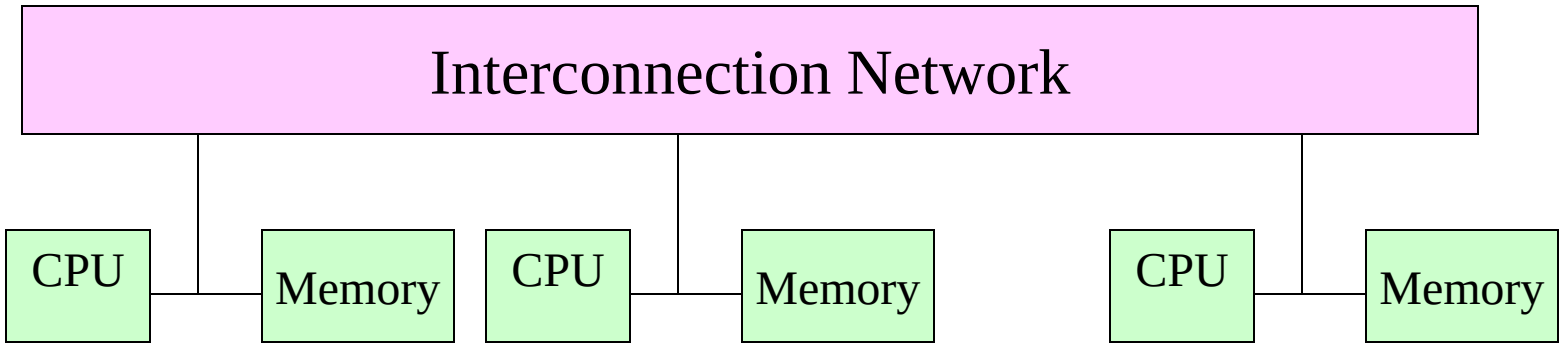
- **Memory request order:**
  1. **L1 cache → L2 cache** (**local** to **processor**)
  2. Main memory (**local** to **node**)
  3. Remote memory

NUMA Pros & Cons

- Effective performance at higher levels of parallelism than SMP
- No major software changes
- Performance can breakdown if too much access to remote memory

Distributed Memory / Message Passing

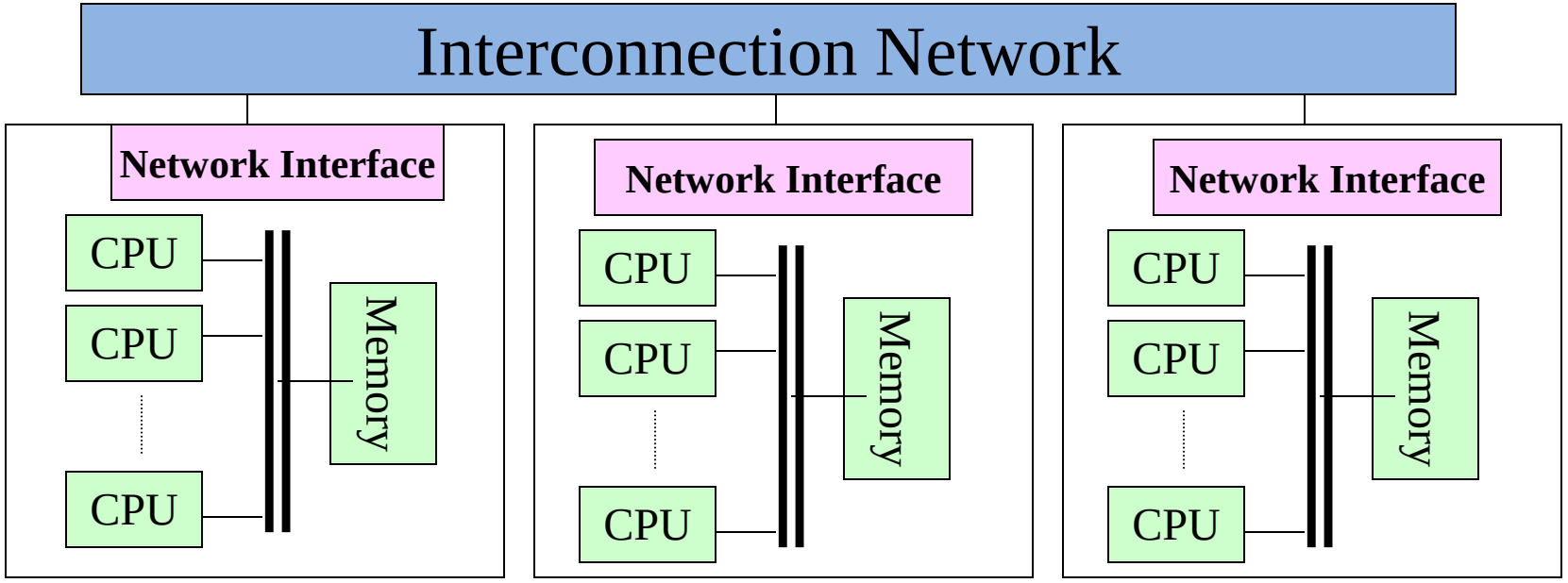
- Each **processor** has **access** to its **own memory only**
- **Data transfer** between **processors** is **explicit** (via message passing functions): **E.g., MPI library**
- User has **complete control/responsibility** for **data placement** and **management**



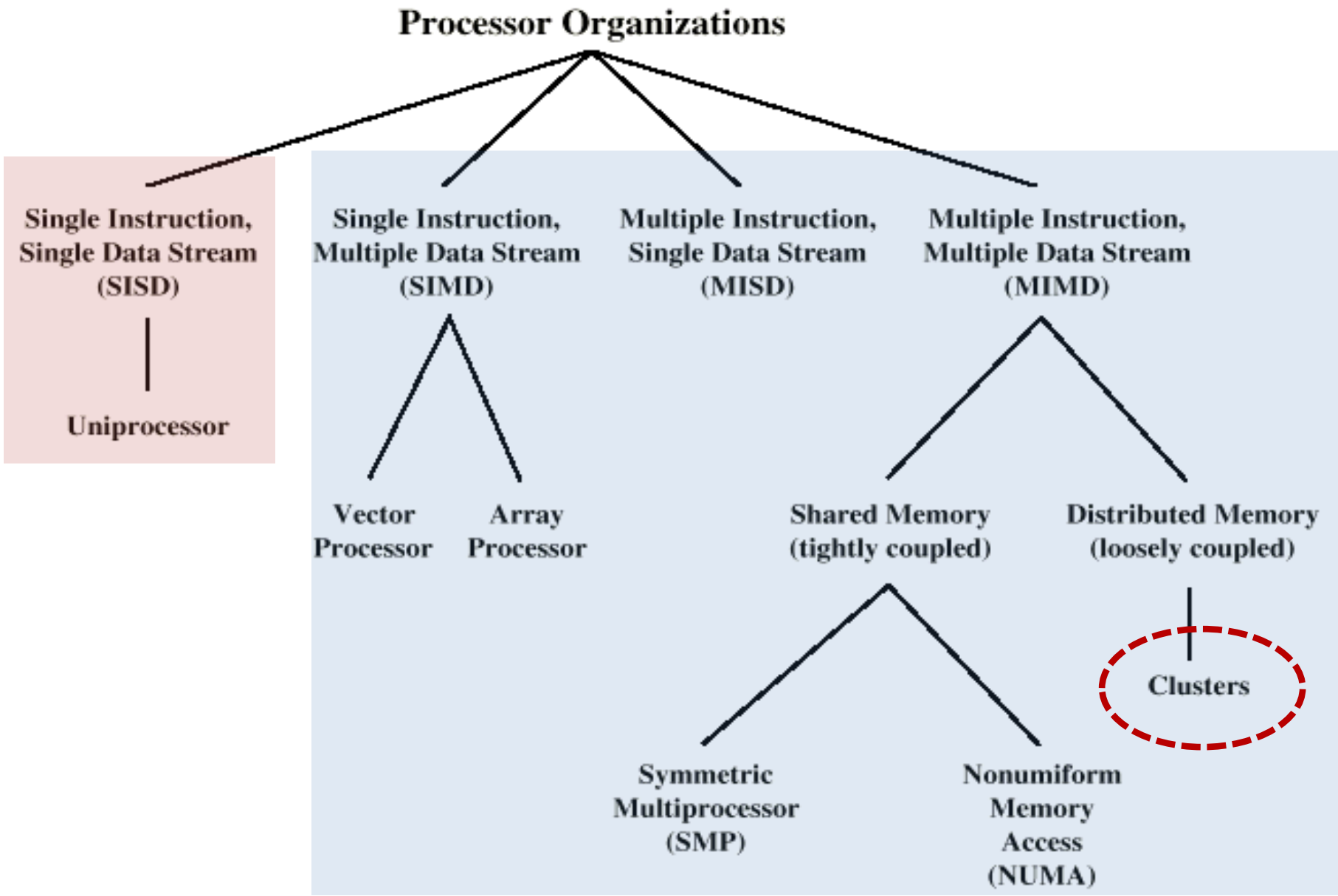
Hybrid Systems

- **Distributed memory system** with **multiprocessor shared memory nodes**

- **Most common parallel architecture**



Taxonomy of Processor Architectures



Distributed Computing

- Using **distributed systems** to **solve large problems**

- **Paradigms:**
  - **Cluster** computing
  - **Grid** computing
  - **Cloud** computing

Cluster Computing

Clusters - Loosely Coupled

- **Collection** of **independent** **uni-processor** **systems** or **SMPs**
- **Interconnected** to form a **cluster**
- **Communication via** fixed path or **network** connections
- **Not a single shared memory**

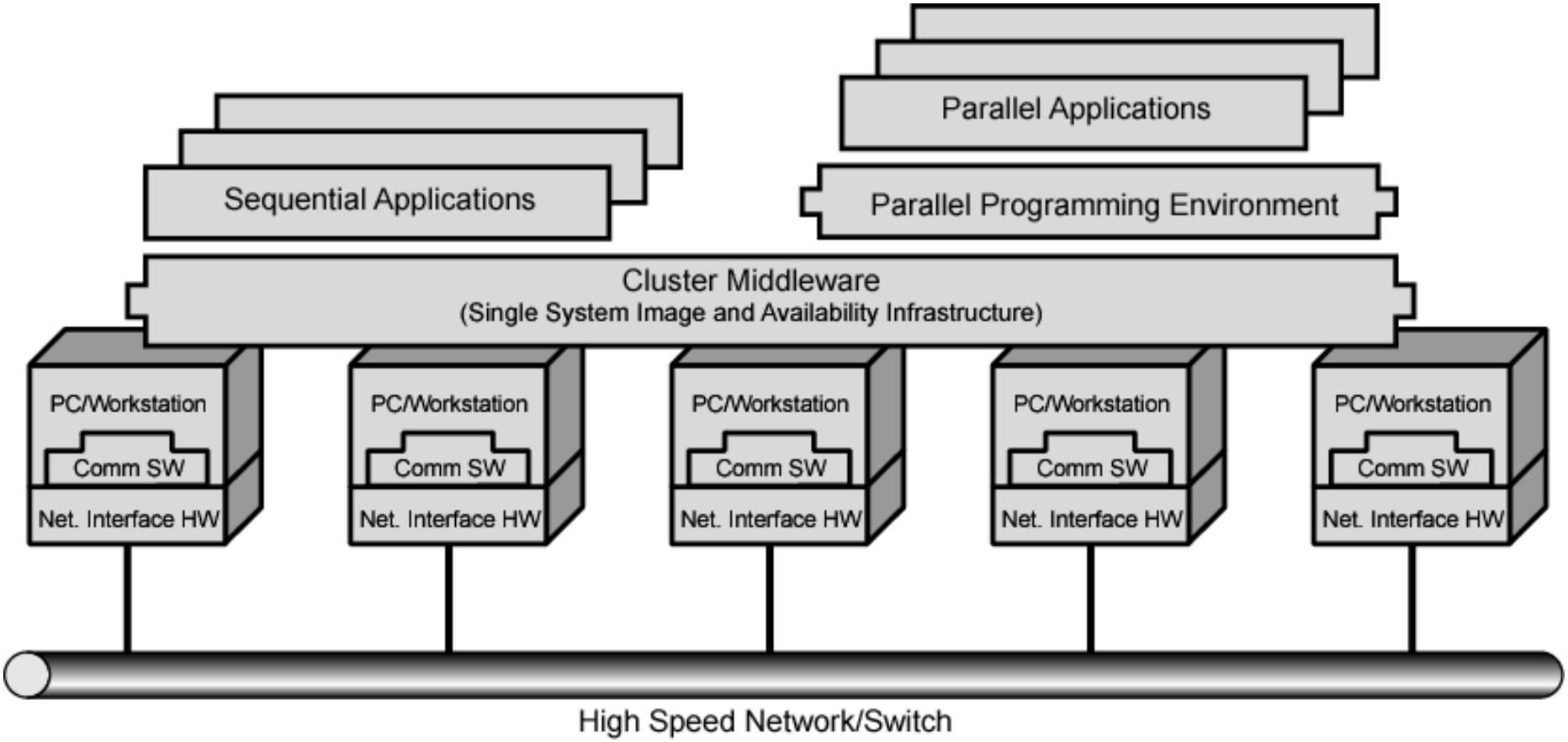
Introduction to Clusters

- **Alternative** to **SMP**
- **High performance**
- **High availability**
- A **group** of **interconnected** whole **computers**
- **Working together** as **unified resource**
- **Illusion** of being **one big machine**
- Each **computer called** a **node**

Cluster Benefits

- Scalability
- Superior price/performance ratio

Cluster System Architecture



Cluster Middleware

- **Unified image to user**
  - Single system image
- **Single point of entry**
- **Single file hierarchy**
- **Single job management system**
- **Single user interface**
- **Single I/O space**

Cluster vs. SMP

- **Both provide multiprocessor support**

- **SMPs:**
  - **Easier** to **manage** and **control**
  - **Closer** to **single processor systems**:
    - Scheduling is main difference
    - Less physical space required
    - Lower power consumption

Cluster vs. SMP

- **Clustering:**
  - **Superior incremental scalability**
  - **Superior availability**
    - **Redundancy**

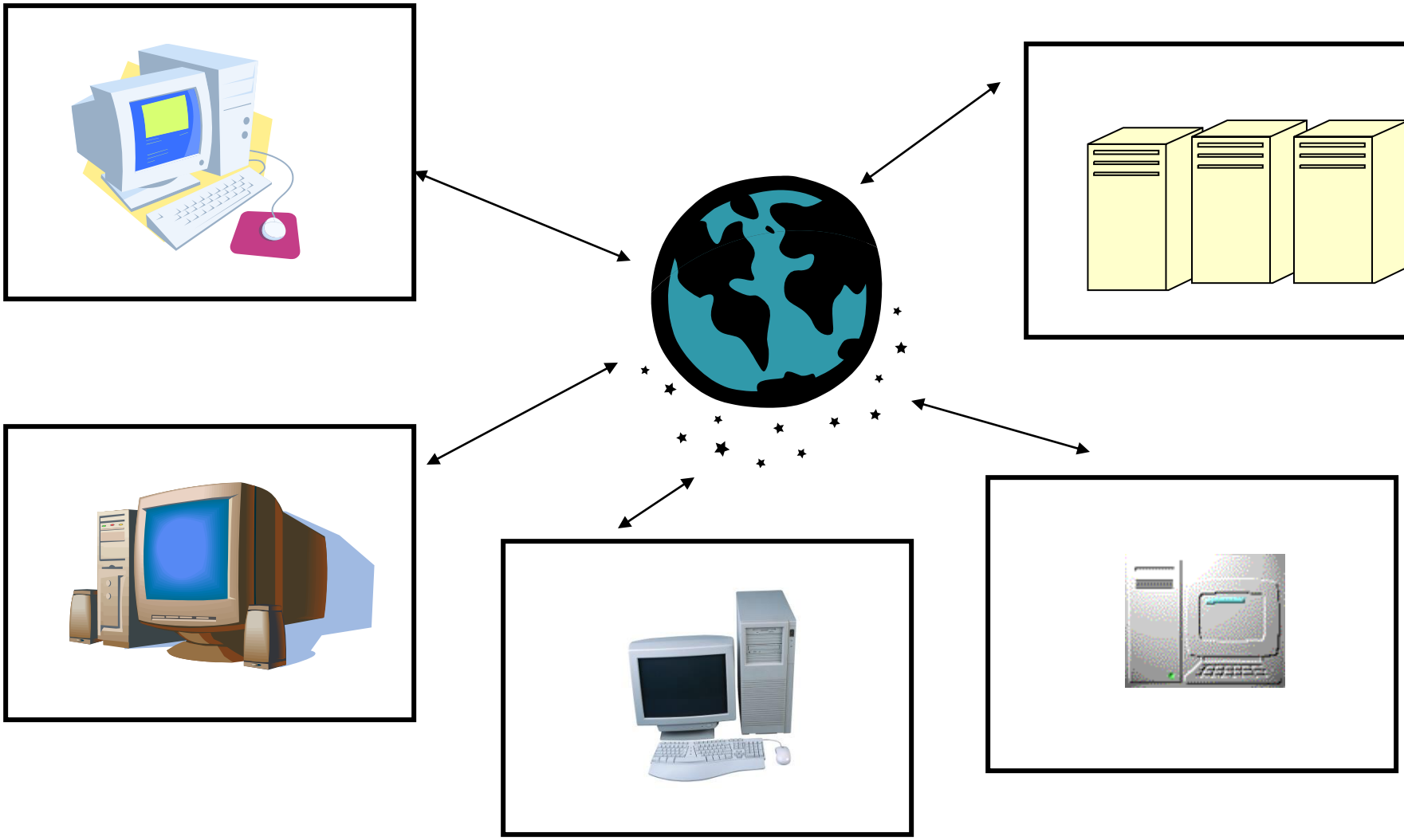
Grid Computing

Grid Computing

- **Heterogeneous computers** over the whole world providing **CPU power** and **data storage capacity**
- **Applications** can be **executed** at **several locations**
- **Geographically distributed services**
- **Coordinates/Access of resources**; **as contract to centralized control**
- Uses **standard**, **open**, **general-purpose protocols** and **interfaces**

Credits: Grid Computing by Camiel Plevier

Grid Architecture

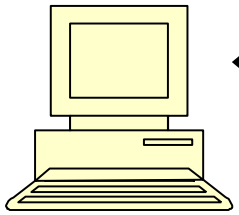


Autonomous, globally distributed computers/clusters

A typical view of Grid environment

Grid Information Service

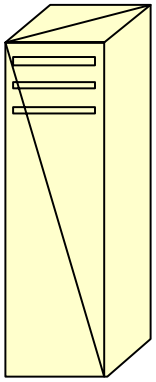
Grid Information Service system **collects** the **details** of the **available Grid resources**. **Passes information to resource broker.**



Details of Grid resources

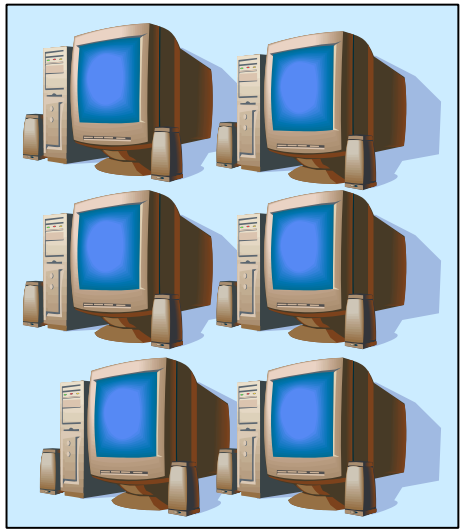
Grid application

Computation result



Computational jobs

Processed jobs



User

A **User** **submit computation** or data **intensive application** to Grids.

Resource Broker

A **Resource Broker** **distribute** the **jobs** in an **application** to the **Grid resources** based on user's **QoS requirements** and **available Grid resources.**

Grid Resources

Grid Resources (**Cluster**, **PC**, **Supercomputer**, **database**, **instruments**, etc.)

Cloud Computing

What is Cloud Computing?

- **Cloud Computing** is a **network-based computing** that takes place **over the Internet**:
  - a **collection/group** of **integrated** and **networked hardware**, **software,** and **Internet infrastructure** (called a **platform**).

- **Hides the complexity and details of the underlying infrastructure**

What is Cloud Computing?

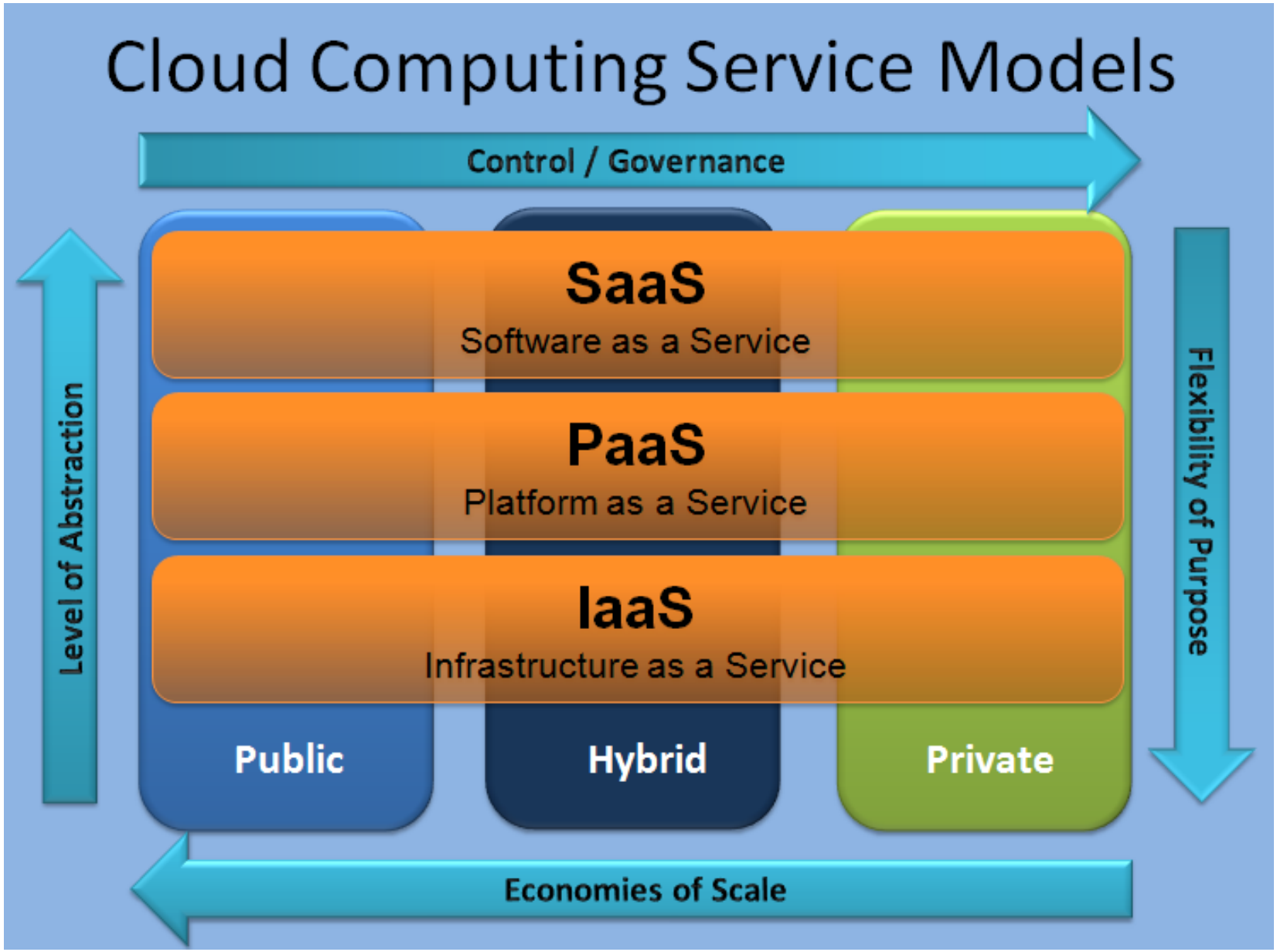
- **On demand services**, that are **always ON**, **Anywhere**, **Anytime** and **Any place**

- **Pay for use** and as **needed**

- **Elastic:** **scale up** and **down (capacity** and **functionalities)**

- **Shared pool** of **configurable computing resources**

Service Models



Cloud Service Models

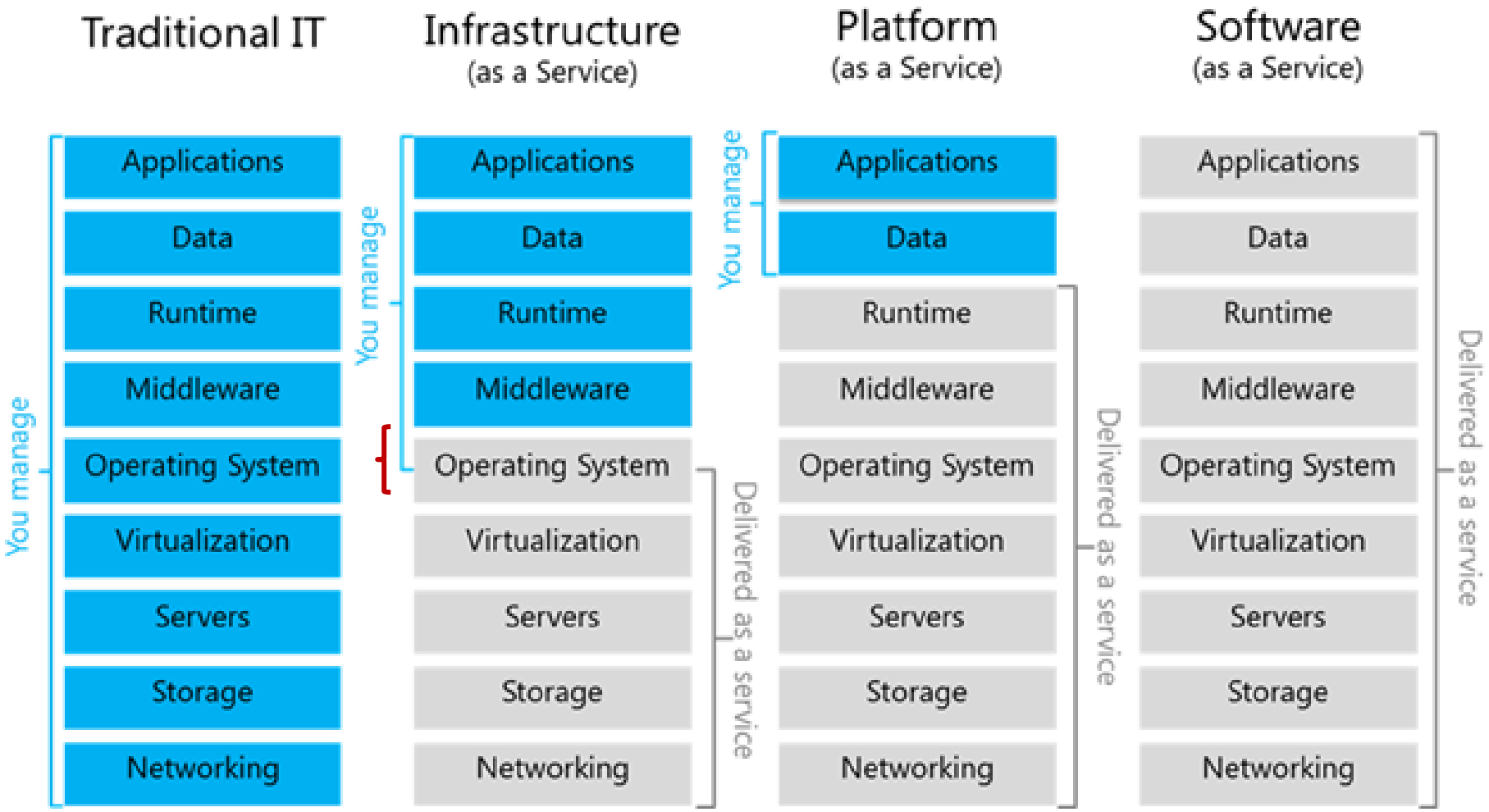
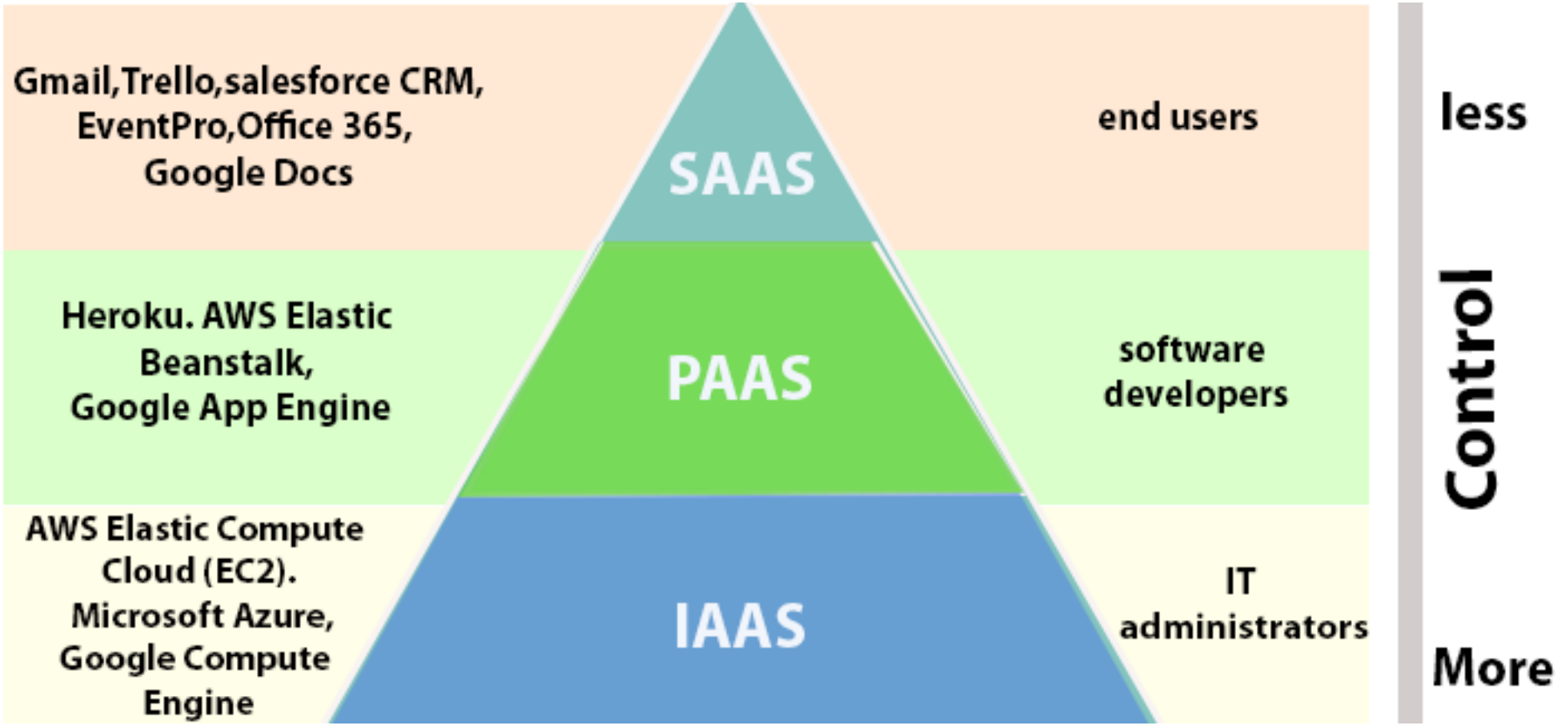


Figure source: https://dachou.github.io/assets/20110326-cloudmodels.png

Cloud Providers



SuperComputers

What is Cloud Computing?

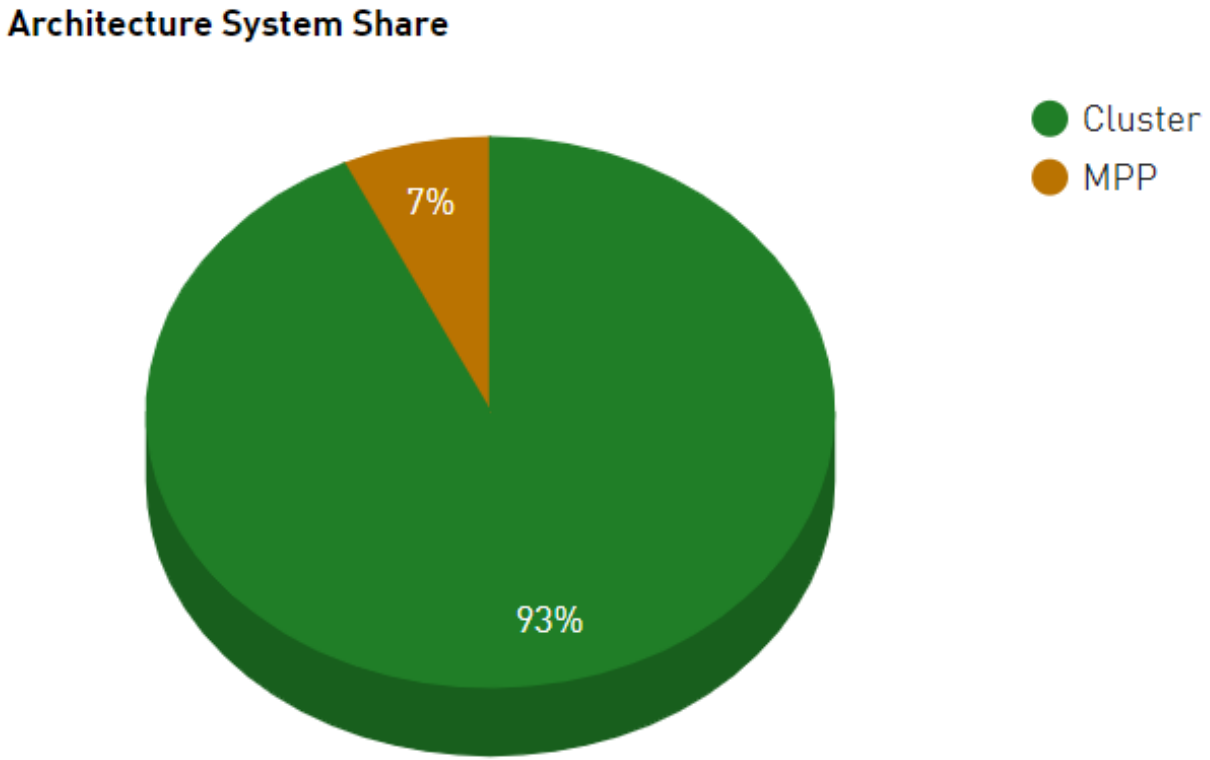
- **Typical definition***: A **computer** that **leads** the world in **terms of processing capacity**, **speed** of **calculation**, at the time of its introduction
  - **Computer speed** is **measured** in **FLoating Point Operations Per Second (FLOPs)**
  - Currently the **LINPACK Benchmark** is **officially** used to **determine** a **computers speed**. **http://www.netlib.org/benchmark/hpl**
  - **Top 500 SuperComputers**
  - A **ranked list** of **general purpose systems** that are in **common use** for **high-end applications**

*https://home.chpc.utah.edu/~thorne/computing/L13_Supercomputing_Part1.pdf

Top 5 of the list (Nov. 2020)

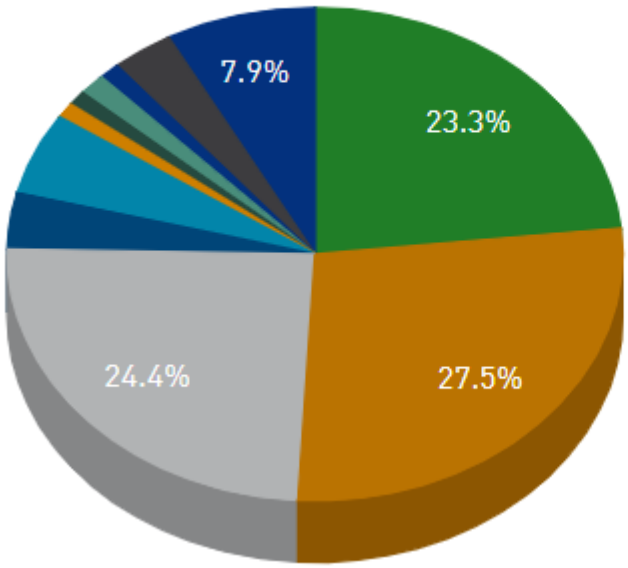
Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,630,848	442,010.0	537,212.0	29,899
2	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148,600.0	200,794.9	10,096
3	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
4	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
5	**Selene** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia NVIDIA Corporation United States	555,520	63,460.0	79,215.0	2,646

Top 500 SuperComputers - Nov. 2020



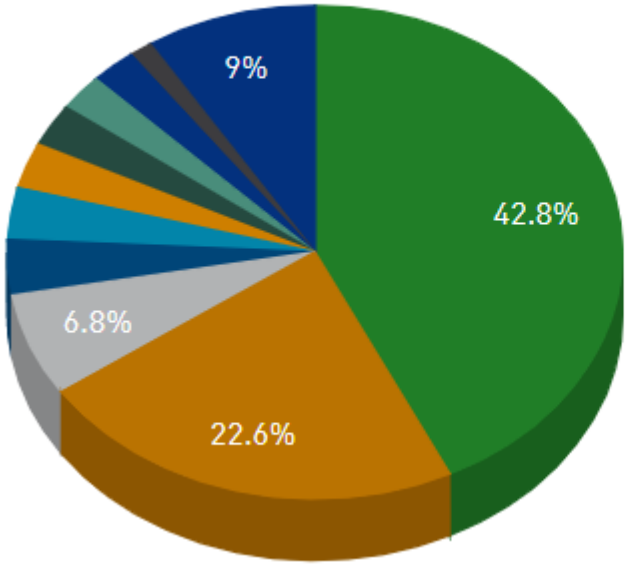
Top 500 SuperComputers - Nov. 2020

Countries Performance Share



China
United States
Japan
France
Germany
Netherlands
Ireland
United Kingdom
Canada
Italy
Others

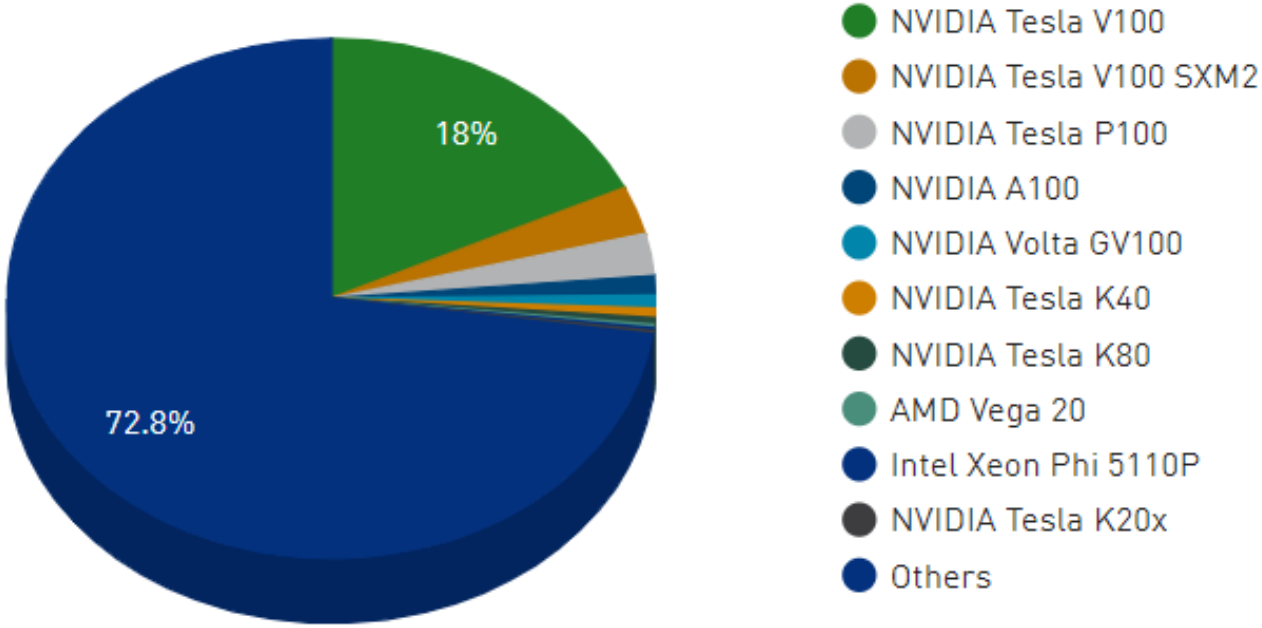
Countries System Share



China
United States
Japan
France
Germany
Netherlands
Ireland
United Kingdom
Canada
Italy
Others

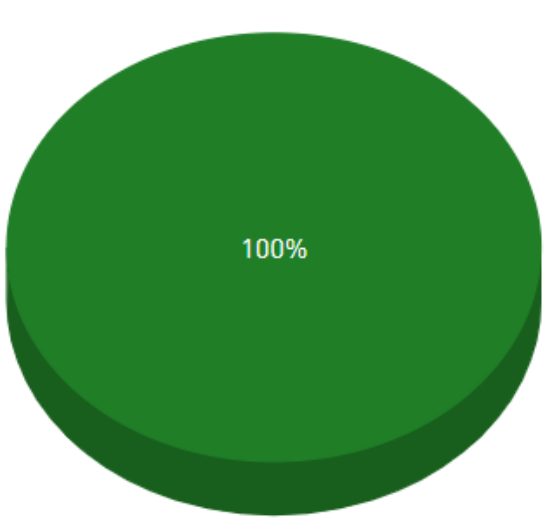
Top 500 SuperComputers - Nov. 2020

Accelerator/Co-Processor System Share

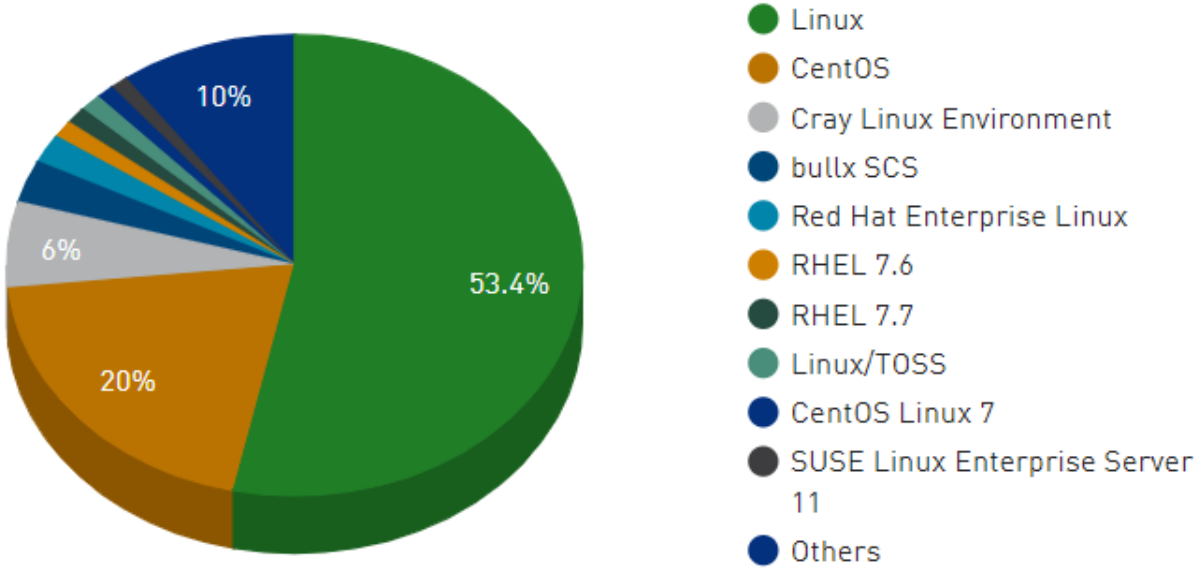


Top 500 SuperComputers - Nov. 2020

Operating system Family System Share



Operating System System Share



Any Questions?