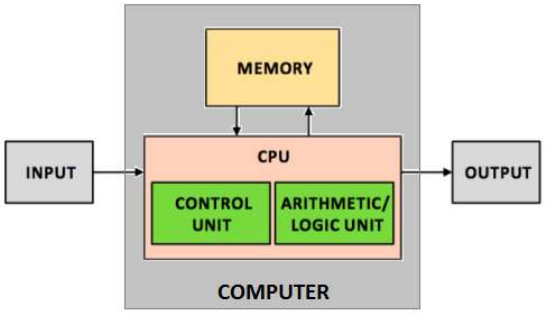
Computer Structure and Language

Hamid Sarbazi-Azad
Department of Computer Engineering
Sharif University of Technology (SUT)
Tehran, Iran

Von Neumann Stored-program Structure

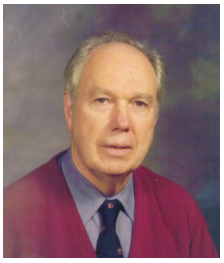


Stored-program model or Von Neumann model is the base structure.

To improve its performance, other structures are used ☺

Flynn's Taxonomy for Computer Structure

Flynn introduced his taxonomy in 1966 based on the concept of data and instruction streams.



Michael J. Flynn (1934-)

Instruction Stream:

The sequence of instructions fetched and executed by the processor

Data Stream:

The sequence of data accessed and processed by an Instruction Stream

Flynn's Taxonomy (Cont.)

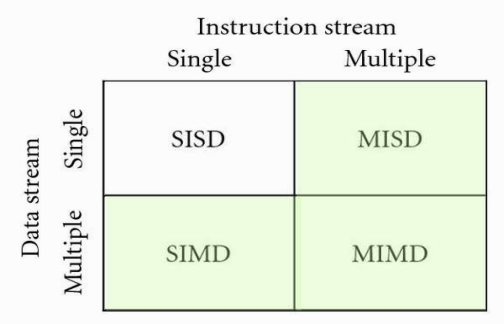
A stream-based 4-category classification of computer structures:

SISD: Single Instruction Stream, Single Data Stream

SIMD: Single Instruction Stream, Multiple Data Streams

MISD: Multiple Instruction Streams, Single Data Stream

MIMD: Muliple Instruction Streams, Mulitple Data Streams

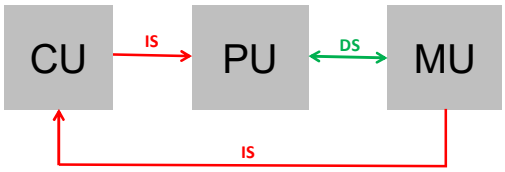


ADVANCED STRUCTURES

Flynn's Taxonomy (Cont.)

SISD: Single Instruction Stream, Single Data Stream

It is just the basic Van Neumann computer structure.



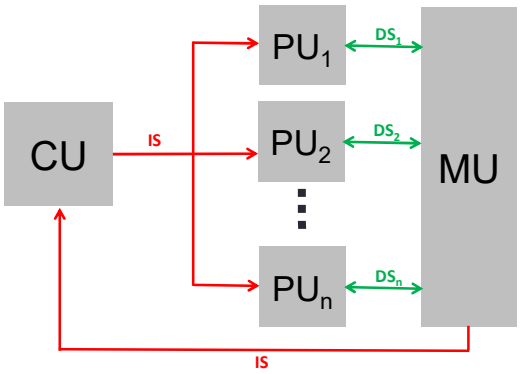
CU: control unit PU: processing unit MU: memory unit

DS: data stream IS: instruction stream

Flynn's Taxonomy (Cont.)

SIMD: Single Instruction Stream, Multiple Data Streams

Most early supercomputers employed this structure.

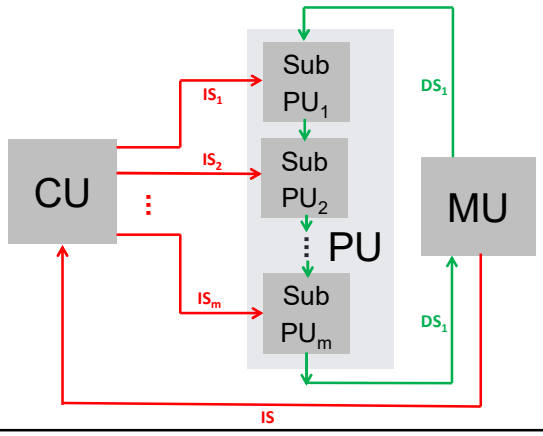


Flynn's Taxonomy (Cont.)

MISD: Multiple Instruction Streams, Single Data Stream

Some computer architects believe there is no MISD machine; but some others believe Pipelined computers & Systolic arrays are MISD structures.

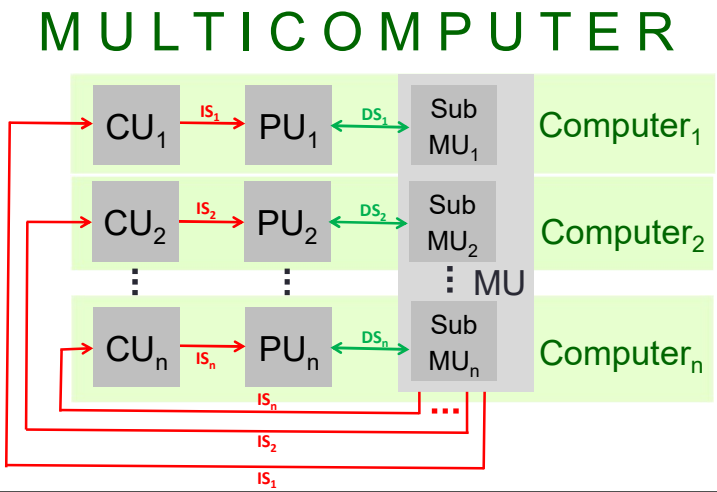
Pipelined structures are the most cost-effective ones.



Flynn's Taxonomy (Cont.)

MIMD: Multiple Instruction Streams, Multiple Data Streams

Almost all current supercomputers use this structure.



Supercomputers

Use of different **Advanced Computer Structures in SIMD, MISD and MIMD categories** and **Advances in integrated circuits technology (i.e. Moore's law)** have fuelled the thirst for building powerful computers (supercomputers) during the last 6 decades.

Supercomputers are evaluated every 6 months and listed in www.top500.org based on computing power in FLOPS (Floating-point Operations Per Second).

Remember IEEE 754 Floating-point format! Adding/multiplying two IEEE 754 floating-point numbers is considered a FLOP.

Supercomputers (some successful systems…)

Cray 1

SIMD machine

- Year 1975
- 160 MFLOPS
- Vector machine
- 8 MB main memory

Supercomputers (some successful systems…)

Cray T3E (<=3 Teraflops)
MIMD Machine

Delivered 1995

Processing Element

Microprocessor	21164A (EV5.6), 4-way superscalar RISC, 2 floating-point operations/cycle, 32- and 64-bit IEEE FP format
Local memory	256 or 512MB
Peak performance	1350 MFLOPS per PE
Packaging	8 PEs per module, liquid cooled
PEs per system	40 to 2048 in increments of 8 PEs
Technology	64MB 50 nanosecond DRAM
Architecture	Cache coherent, physically distributed, globally addressable
Total memory	10GB to 1TB

InterconnectionNetwork

Topology	3D bi-directional torus

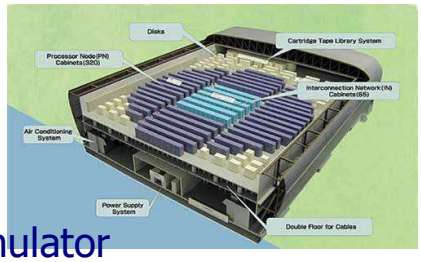
Supercomputers (some successful systems…)

The Earth Simulator
Multi-SIMD machine

Operational in late 2002
Result of 5-year design and implementation effort
Equivalent power to top 15 US supercomputers @ 2002

- 640 nodes
- 8 vector processors per node, 5120 total
- 8 GFLOPS per processor, 40 TFLOPS (40×10^{12} FLOPS) total
- 16 GB memory per node, 10 TB total
- 2800 km of cables
- 320 cabinets (2 nodes each)
- Cost: US$350 M

Supercomputers (some successful systems…)



The Earth Simulator

Supercomputers (some successful systems…)

IBM BlueGene

MIMD machine

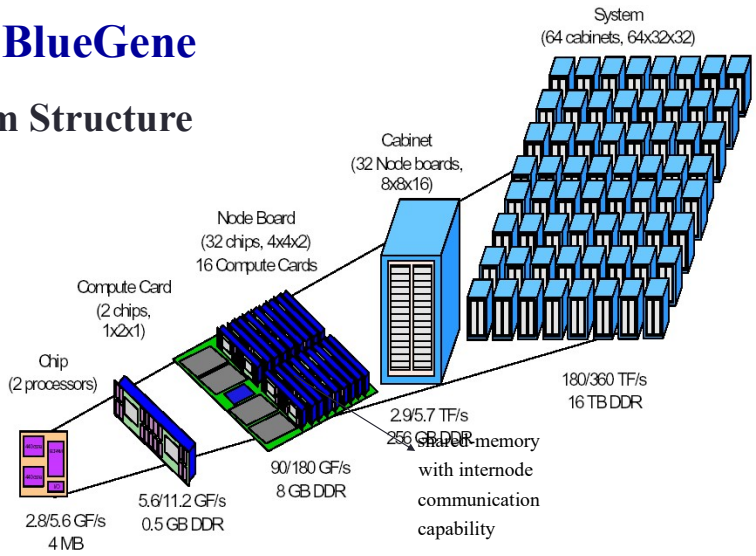
Delivered: 2004-2007

Peak performance: 360 TFLOPS
Topology: 3D Torus
Number of nodes: 65536
Node: 2 processors each having a double floating-point unit
Cost: US$130 M

Supercomputers (some successful systems…)

IBM BlueGene

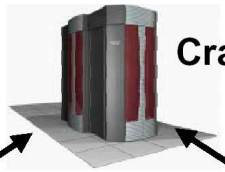
System Structure



Supercomputers (some successful systems…)

Cray X1 (not completed)

Massive SIMD-MIMD



Cray X1

Cray PVP

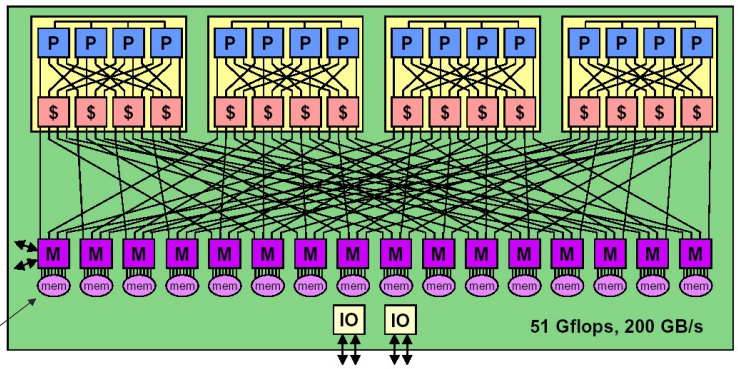
- Powerful single processors
- Very high memory bandwidth
- Non-unit stride computation
- Special ISA features
- Modernized the ISA and microarchitecture

Cray T3E

- Distributed shared memory
- High BW scalable network
- Optimized communication and synchronization features
- Improved via custom processors

Supercomputers (some successful systems…)

Cray X1 Node



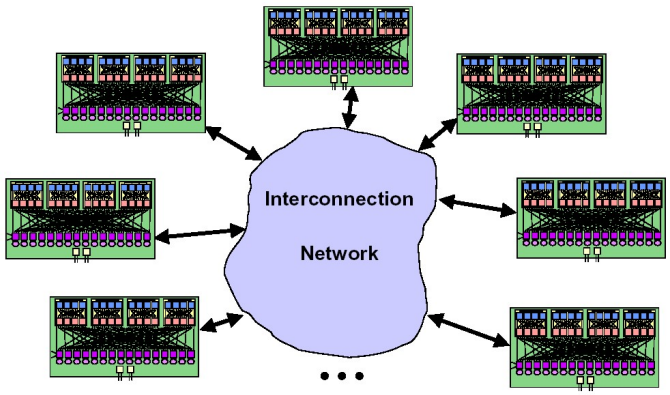
shared-memory cluster

- Four multistream processors (MSPs), each 12.8 Gflops
- High bandwidth local shared memory (128 Direct Rambus channels)
- 32 network links and four I/O links per node

Supercomputers (some successful systems…)

Cray X1

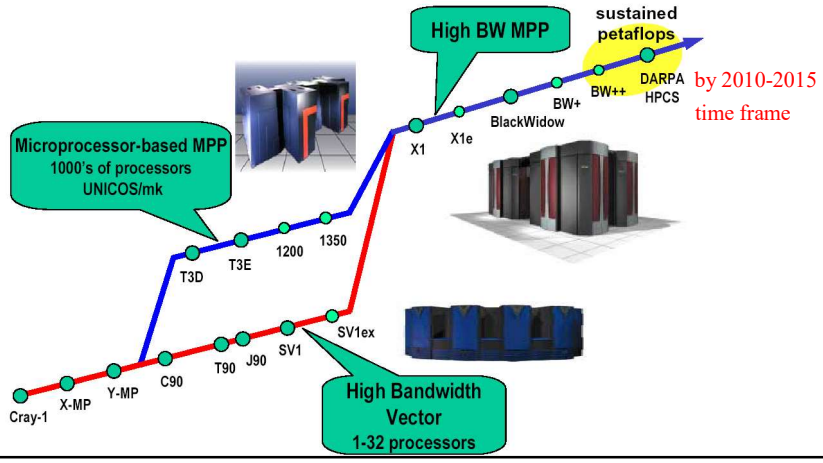
NUMA Scalable up to 1024 Nodes



Supercomputers (some successful systems…)

Cray X1

Cray Supercomputer Evolution and Roadmap



Supercomputers (some successful systems…)

IBM Roadrunner

Massive MIMD

IBM's recent supercomputer that has changed the known rules of supercomputing.

Project started in 2006 (delivered 2008) at Los Alamos National Lab to deliver world's first PFLOPS supercomputer.

Used to ensure safety & reliability of US nuclear weapons stockpile. Also used for research in astronomy, energy, human genome science, climate change, and military applications.

Supercomputers (some successful systems…)

IBM Roadrunner

It uses Cell (multi-core) processors designed by Sony, Toshiba and IBM, and introduced the new line of Low-Cost Supercomputing.

Total cost: US$133 M
Uses: 12960 Cell processors (each a 9-core processor)
Peak performance: 1.33 PFLOPS (1.33×10^{15} FLOPS)
Sustained performance: 1 PFLOPS
Power: 3.9 MW
Area: 296 Racks, 511 m^2.
Weight: 227 Tons

Supercomputers (current top 10 machines), June 2023

Rank	System	#Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,699,904	1,194.00	1,679.82	22,703
2	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,630,848	442.01	537.21	29,899
3	**LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE EuroHPC/CSC Finland	2,220,288	309.10	428.70	6,016
4	**Leonardo** - BullSequana XH2000, Xeon Platinum 8358 32C 2.6GHz, NVIDIA A100 SXM4 64 GB, Quad-rail NVIDIA HDR100 Infiniband, Atos EuroHPC/CINECA Italy	1,824,768	238.70	304.47	7,404
5	**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	148.60	200.79	10,096
6	**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	94.64	125.71	7,438
7	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China	10,649,600	93.01	125.44	15,371
8	**Perlmutter** - HPE Cray EX235n, AMD EPYC 7763 64C 2.45GHz, NVIDIA A100 SXM4 40 GB, Slingshot-10, HPE DOE/SC/LBNL/NERSC United States	761,856	70.87	93.75	2,589
9	**Selene** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia NVIDIA Corporation United States	555,520	63.46	79.22	2,646
10	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000, NUDT National Super Computer Center in Guangzhou China	4,981,760	61.44	100.68	18,482

Supercomputers (some successful systems…)

Frontier
Massive MIMD

Total cost: ~ US$ 600M
Core#: ~ 9 M cores
Peak performance: ~ 1.7 exaFLOPS (~69 GFLOPS/Watt)
Memory: ~ 5 Peta Bytes
Power: 21 MW
Years built: 2021-2022

Frontier v.s. human brain?

In 2014, Japanese researchers used 10-PFLOPS K-Computer (2011-2019), 4th fastest supercomputer in the world at the time, to crunch the calculations for a single second of part of brain activity in 40 minutes! (see https://www.scienceabc.com/humans/the-human-brain-vs-supercomputers-which-one-wins.html)

European Union has started Human Brain Project in 2013, to fully simulate human brain (see https://www.humanbrainproject.eu/en/).

Frontier		**Human Brain**
~ 1.7 PFLOPS	Computing Capability	1.2 PFLOPS[1]
~ 1400 m^3	Volume	1400 cm^3 (~0.001m^3)
~ 21 MW	Power Consumption	20 W
~ US$ 600 M	Price (value)	?

Compare to US$ 446M for A380 airplane

CSL Course Outline:

Goal: We learn different functional parts of a computer and their interactions to run a program written in machine language.

We also learn assembly programming, and the steps a high-level program sees to finally run on a given machine.

Topics covered:

1. Computer structure/language and assembly programming (25%)
2. The IBM360/370 structure and assembly language (20%)
3. The Intel 8086/88 structure and assembly programming (25%)
4. The RISC-V structure and assembly language (10%)
5. The GPU structure and assembly programming (15%)

References

1. A. S. Tanenbaum, **Structured computer organization,** Prentice-Hall.
2. W. Rudd, **Assembly language programming and the IBM360/370 computers**, Prentice-Hall.
3. Y.-C. Liu, G. Gibson, **Microcomputer systems: the 8086/8088 family: architecture, programming, and design**, Prentice-Hall.
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7. Nvidia, **CUDA-binary-utilities,** Release 12.2. https://docs.nvidia.com/cuda/pdf/CUDA_Binary_Utilities.pdf
8. Nvidia, **PTX ISA,** Release 8.2. https://docs.nvidia.com/cuda/archive/12.2.1/pdf/ptx_isa_8.2.pdf

Marking policy:

Midterm 1 Exam	20%	10:00AM, Thursday 11th Aban 1402
Midterm 2 Exam	15%	10:00AM, Thursday 16th Azar 1402
Midterm 3 Exam	15%	10:00AM, Thursday 7th Dey 1402
Final Exam	15%	9:00AM, Sunday 1st Bahman 1401
Project	20%	Wednesday, 11th Bahman 1402
Homework	15%	Weekend (Friday night) for homework given in Sunday/Tuesday.

CSL course team

Lecturer: Hamid Sarbazi-Azad
Email: azad@sharif.edu / azad@ipm.ir
Phone: 66166622
Room: 621

Head TA: Negar Akbarzadeh
Email: n.akbarzadeh93@gmail.com
Phone: 66166672
Room: HPCAN Lab. (703)

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