Introduction to Scientific Computing I

Lecture 4

Amir Farbin

Von Neumann Architecture

- ***Memory array:*** (MEM) holds all the "commands" (instructions) and "numbers" (data).

- ***Control Unit:***

    - ***Program counter***: select which instruction to execute from MEM. It normally just increases by 1 in each step.

- ***Arithmetic block:*** multiplexers connecting to different binary different operations (+, -, …), with input / output

    - Generate inputs to our arithmetic block from MEM.

- [***Registers:*** hold input/output of arithmetic block]

- Instructions

    - Two types: data instructions and control instructions.

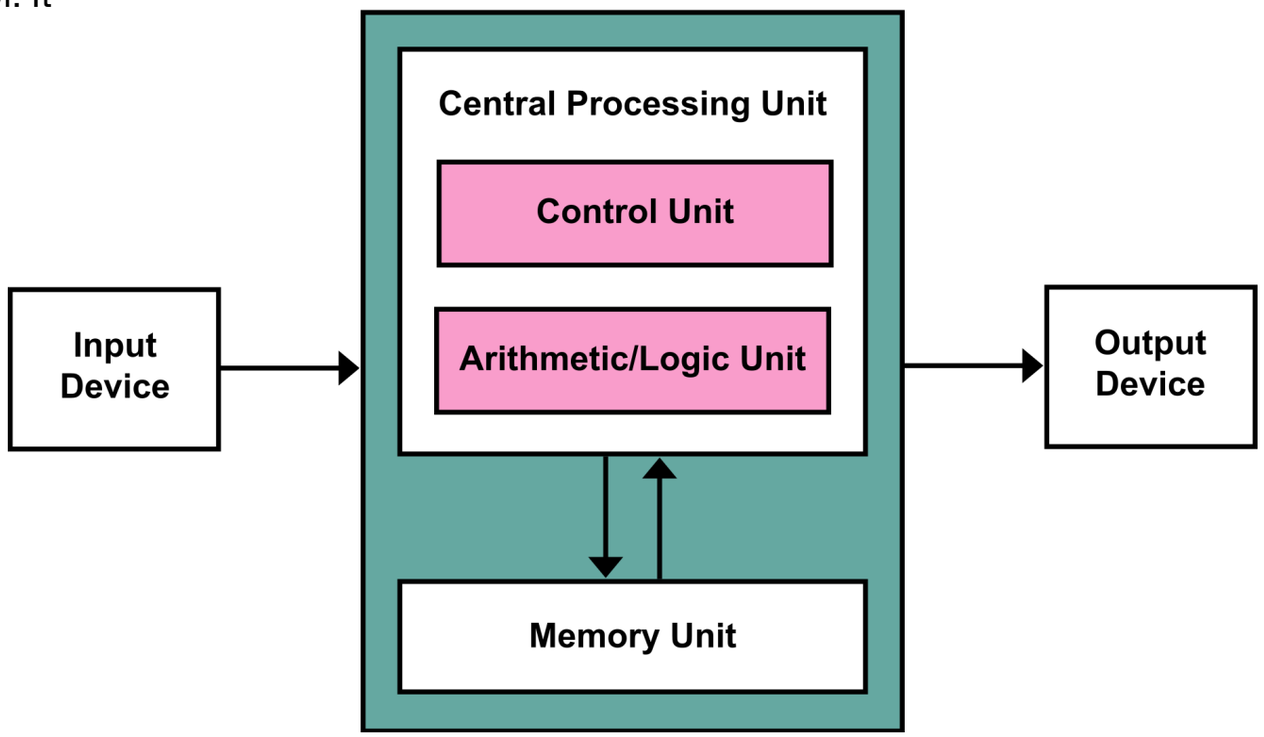
    - Each data instruction contains four things:

        - two addresses specifying which two numbers to pick from MEM

        - one command saying what operation to perform

        - and another location saying where to put the result back.

    - The control instructions put another address back into the "program counter."



Programming

- Each CPUs understands its own instruction sets.
- Low level operations:
  - Copy in/out data from memory into registers.
  - Perform operations on registers.
  - Conditional (if/then) and Control flow (jump)
  - Manage a stack (where small sets of data can be shared between different blocks of code)
- Each instruction are each assigned a specific binary value and are not human readable…
- Assembly is a human-read language that most closely mirrors Machine Language.

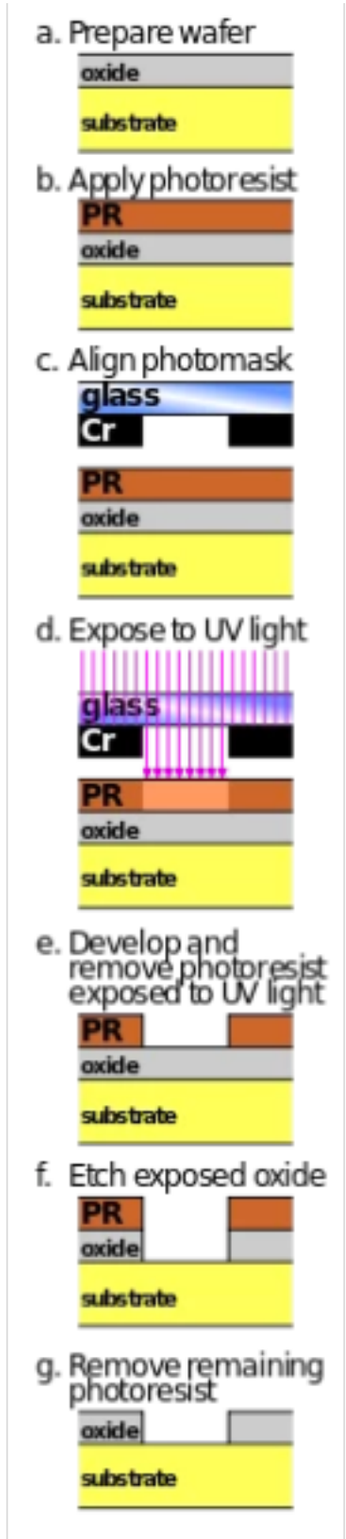
```
x3000 LD R1, x006          ; load data pointer
x3001 LDR R2, R1, #0       ; load data value
x3002 BRz x005             ; branch to end if zero
      ;
      ; repeating statements go here
      ;
x3003 ADD R1, R1, #1       ; increment data pointer
x3004 BRnzp x001           ; branch back to top
x3005 HALT
      ;
      ; data section
      ;
x3006 x4000 ; address of data

; The translation into LC-2 Machine Code
      0011 0000 0000 0000      ; load at x3000
X3000 0010 001 0 0000 0110     ; LD R1, x006
x3001 0110 010 001 000000      ; LDR R2, R1, #0
x3002 0000 010 0 0000 0101     ; BRz x005
      ;
      ; repeating statements go here
      ;
x3003 0001 001 001 1 00001     ; ADD R1, R1, #1
x3004 0000 111 0 0000 0001     ; BRnzp x001
x3005 1111 0000 0010 0101      ; HALT
      ;
      ; data section
      ;
x3006 0100 0000 0000 0000      ; x4000
```

from: http://www.eecs.umich.edu/courses/eecs284/example1.htm

Scilicon Electronics

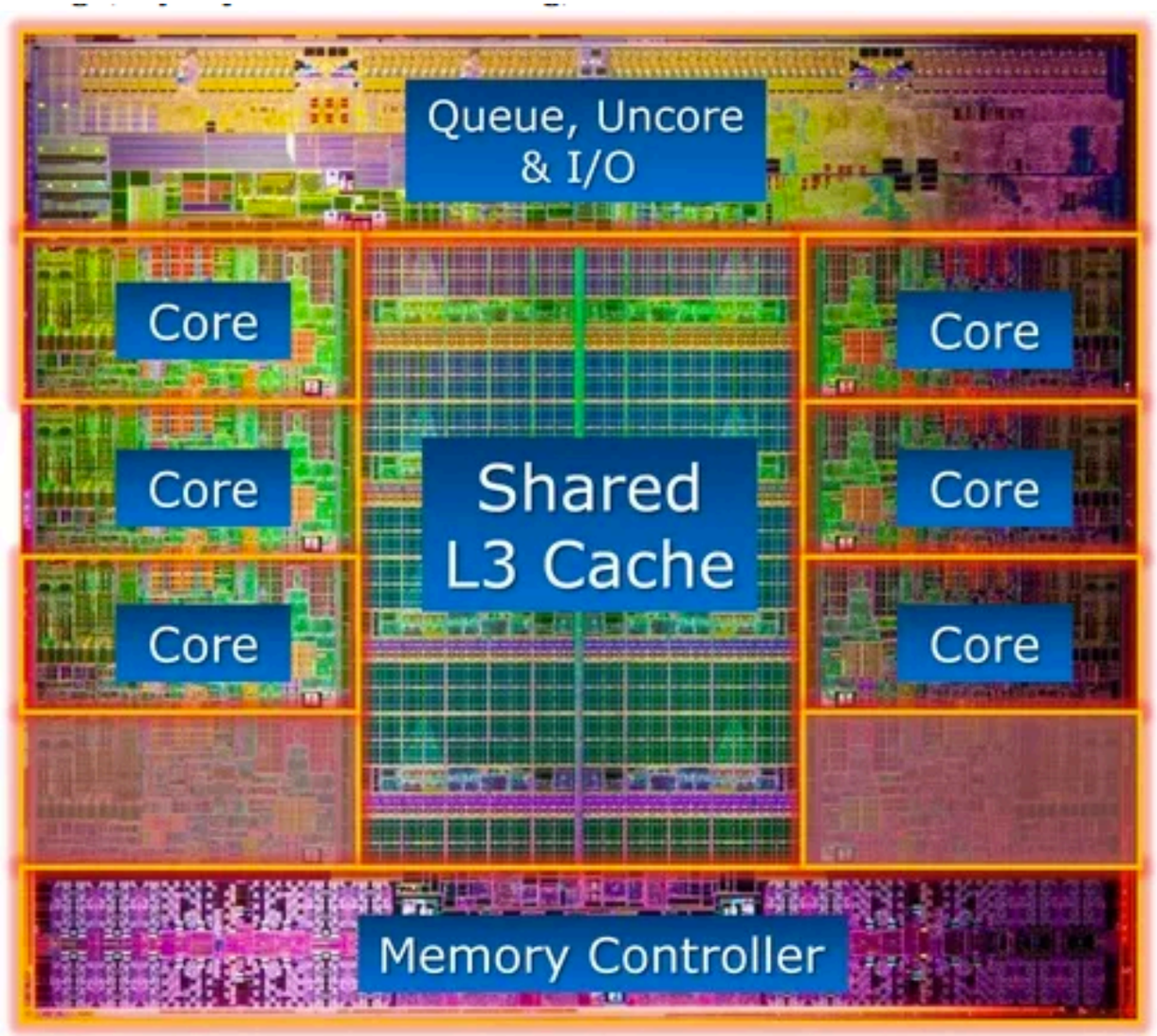
- Modern processors have billions of transistors in precisely arranged and connected.

- Photolithography: pattern is an image that is focused on silicon covered with layers photo-sensitive material, that can be subsequently etched away or have metal deposited on, leaving a pattern.

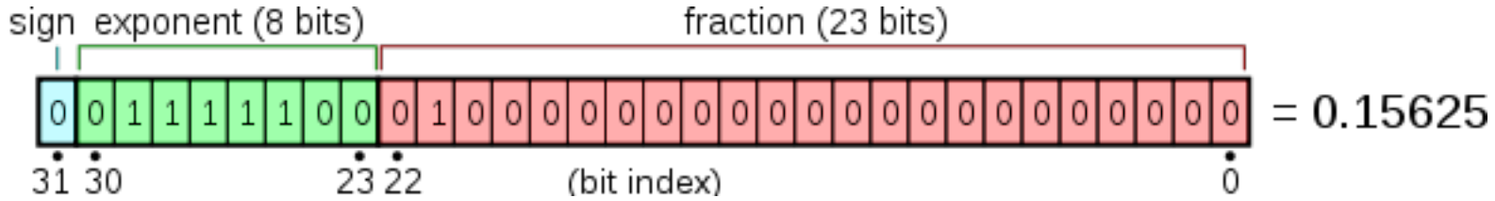


Modern Processors

- Variable clock rates (in GHz).
- Biggest constraints: energy consumption and heat dissipation.
- Large amounts of memory (GBs), not on processor.
- Cache: small part of memory, mirrored inside/ closer to processor to accelerate memory access.
    - Multi-level: Exchange size vs proximity/ speed
- Out-of-order processing
- Many cores



Floating Point



Floating Point Operation per Second (FLOPS) =

cores

x

cycles/second

x

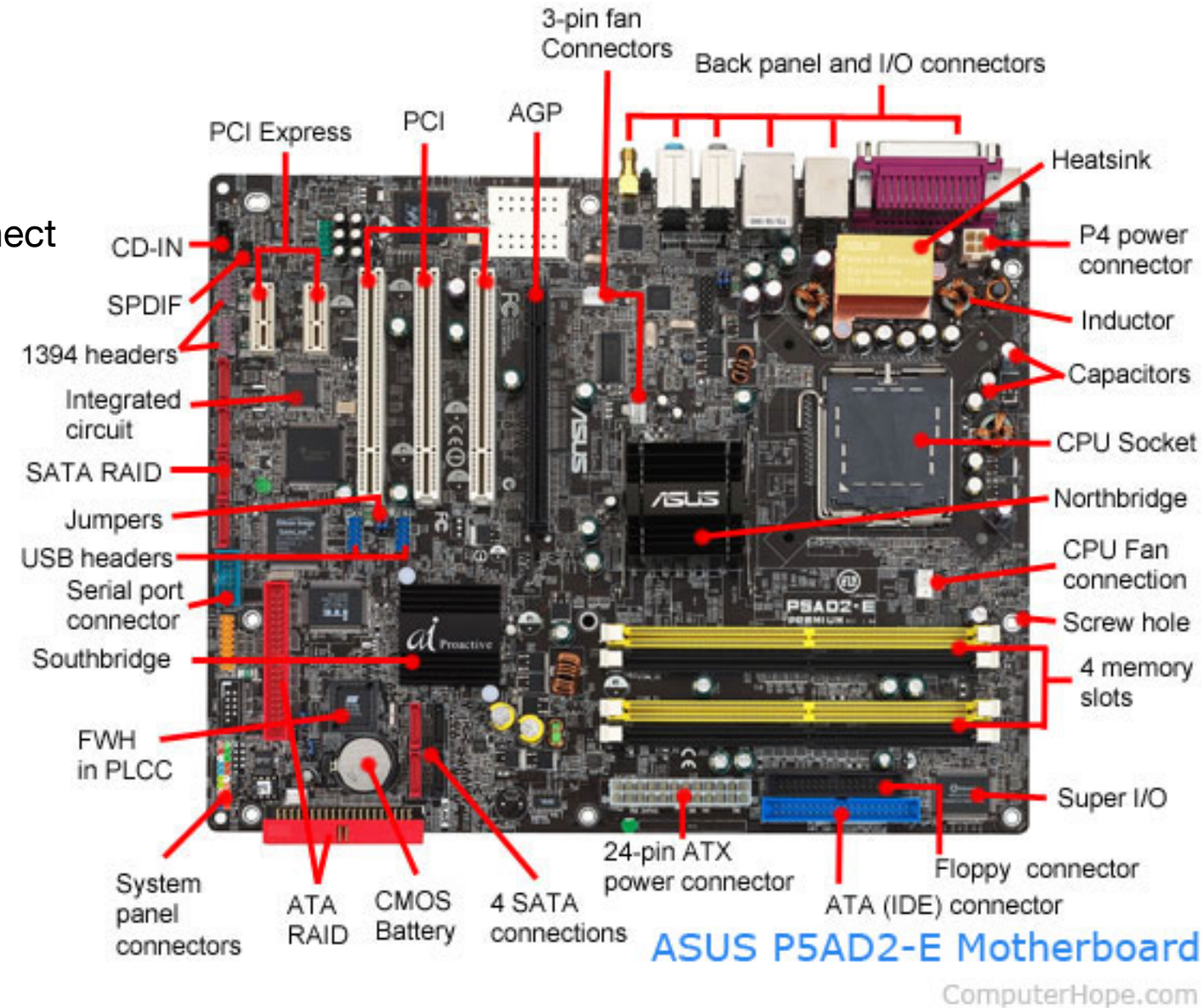
FLOP/cycle

FLOPs per cycle for various processors [edit]

Microarchitecture	ISA	FP64	FP32	FP16
Intel Atom (Bonnell, Saltwell, Silvermont and Goldmont)	SSE3 (64-bit)	2	4	0
Intel Core (Merom, Penryn) Intel Nehalem[6] (Nehalem, Westmere)	SSE4 (128-bit)	4	8	0
Intel Sandy Bridge (Sandy Bridge, Ivy Bridge)	AVX (256-bit)	8	16	0
Intel Haswell[6] (Haswell, Devil's Canyon, Broadwell) Intel Skylake (Skylake, Kaby Lake, Coffee Lake, Whiskey lake, Amber lake)	AVX2 & FMA (256-bit)	16	32	0
Intel Xeon Phi (Knights Corner)	SSE & FMA (256-bit)	16	32	0
Intel Skylake-X Intel Xeon Phi (Knights Landing, Knights Mill)	AVX-512 & FMA (512-bit)	32	64	0
AMD Bobcat	AMD64 (64-bit)	2	4	0
AMD Jaguar AMD Puma	AVX (128-bit)	4	8	0
AMD K10	SSE4/4a (128-bit)	4	8	0
AMD Bulldozer[6] (Piledriver, Steamroller, Excavator)	AVX (128-bit) Bulldozer-Steamroller AVX2 (128-bit) Excavator FMA3 (Bulldozer)[7] FMA3/4 (Piledriver-Excavator)	4	8	0
AMD Zen (Ryzen 1000 series, Threadripper 1000 series, Epyc Naples) AMD Zen+[6][8][9][10] (Ryzen 2000 series, Threadripper 2000 series)	AVX2 & FMA (128-bit, 256-bit decoding)[11]	8	16	0
AMD Zen 2[12] (Ryzen 3000 series, Threadripper 3000 series, Epyc Rome)	AVX2 & FMA (256-bit)	16	32	0
ARM Cortex-A7, A9, A15	ARMv7	1	8	0
ARM Cortex-A32, A35, A53, A55, A72, A73, A75	ARMv8	2	8	0
ARM Cortex-A57[6]	ARMv8	4	8	0
ARM Cortex-A76, A77	ARMv8	8	16	0
Qualcomm Krait	ARMv8	1	8	0
Qualcomm Kryo (1xx - 3xx)	ARMv8	2	8	0
Qualcomm Kryo (4xx)	ARMv8	8	16	0
Samsung Exynos M1 and M2	ARMv8	2	8	0
Samsung Exynos M3 and M4	ARMv8	3	12	0
IBM PowerPC A2 (Blue Gene/Q)	?	8	8 (as FP64)	0
Hitachi SH-4[13][14]	SH-4	1	7	0
Nvidia Fermi (only GeForce GTX 465-480, 560 Ti, 570-590)	PTX	1/4 (locked by driver, 1 in hardware)	2	0
Nvidia Fermi (only Quadro 600-2000)	PTX	1/8	2	0
Nvidia Fermi (only Quadro 4000-7000, Tesla)	PTX	1	2	0
Nvidia Kepler (GeForce (except Titan and Titan Black), Quadro (except K6000), Tesla K10)	PTX	1/12 (for GK110: locked by driver, 2/3 in hardware)	2	0
Nvidia Kepler (GeForce GTX Titan and Titan Black, Quadro K6000, Tesla (except K10))	PTX	2/3	2	0
Nvidia Maxwell Nvidia Pascal (all except Quadro GP100 and Tesla P100)	PTX	1/16	2	1/32

Motherboard

- Central Processing Unit
- Random Access Memory
- Firmware
- Off processor Cache
- Expansion Bus: Peripheral Component Interconnect (PCI)
- Chipset: control data flow in/out of CPU
    - Northbridge: CPU / memory
    - Southbridge: CPU / IO
- IO Controllers:
    - Disk: ATA, SATA, RAID
    - Peripherals: USB, …
    - Network: Ethernet, WiFi
- CPU Clock

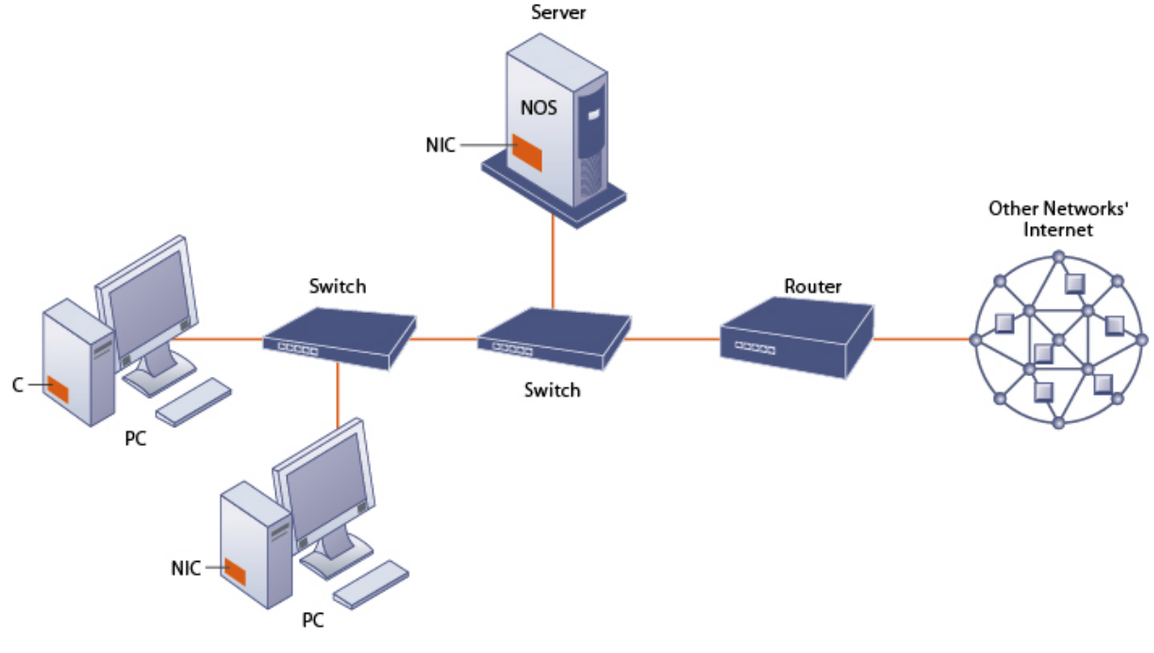


Computer

- Case
- Power supply
- Fan
- Motherboard
    - CPU
        - Heat sink / Fan
    - RAM
    - Graphics Processing Unit (GPU)
    - USB, Ethernet, etc connectors
- Storage: Hard Drive or Silicon Disk Drive

Network

- Local Area Network (LAN) / Wide Area Networks (WAN)
- Signals sent via coaxial cable, twister pair, fiber optics, …
- Components: adapter, switch (connects computers), router (connects networks), wireless…
- Open Systems Interconnection model Layers
    - Physical: bits. Rates now approaching 100 Gb.
    - Ethernet:
        - Every component has a unique address (48-bit MAC address)
        - Data broken into frames, with source/destination address and error checking data.
    - Network: for example Internet Protocol (IP)
        - Packets sent via IP address
        - Addresses kept in Domain Name System (DNS): Match name → address.
    - Transport:
        - How data is exchanged, broken up, transmitted, routed, …
        - Transmission Control Protocol (TCP): Services listen / communicate on ports.



OSI model				
Layer			Protocol data unit (PDU)	Function[6]
Host layers	7	Application	Data	High-level APIs, including resource sharing, remote file access
	6	Presentation		Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption
	5	Session		Managing communication sessions, i.e., continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4	Transport	Segment, Datagram	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing
Media layers	3	Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control
	2	Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
	1	Physical	Symbol	Transmission and reception of raw bit streams over a physical medium

TOP 10 Sites for November 2019

For more information about the sites and systems in the list, click on the links or view the complete list.

1-100 | 101-200 | 201-300 | 301-400 | 401-500

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**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
2	**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
3	**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
4	**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	61,444.5	100,678.7	18,482
5	**Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR , Dell EMC Texas Advanced Computing Center/Univ. of Texas United States	448,448	23,516.4	38,745.9	
6	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray/HPE Swiss National Supercomputing Centre (CSCS) Switzerland	387,872	21,230.0	27,154.3	2,384
7	**Trinity** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray/HPE DOE/NNSA/LANL/SNL United States	979,072	20,158.7	41,461.2	7,578
8	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	32,576.6	1,649
9	**SuperMUC-NG** - ThinkSystem SD650, Xeon Platinum 8174 24C 3.1GHz, Intel Omni-Path , Lenovo Leibniz Rechenzentrum Germany	305,856	19,476.6	26,873.9	
10	**Lassen** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, Dual-rail Mellanox EDR Infiniband, NVIDIA Tesla V100 , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	288,288	18,200.0	23,047.2	

1. Storage, Filesystem
2. Firmware → Operating System → Apps
3. Machine Language → Python

Storage

- Storage devices provide an interface to read / write data into specific locations of some in non-violative media.
    - On traditional ***Hard Drive***, the data is written magnetically on a spinning metal disk.
        - The disk is divided up into sectors, the minimum storage unit.
        - Each sector has an address, which corresponds its physical location on the disk.
        - ***Solid State Drives*** store data on silicon… originally presented same interface as HDs, but new interfaces such as non-volatile memory express (NVMe) are designed for SSDs.
        - In Unix these are referred to as: /dev/hda, /dev/hdb, … /dev/sda, /dev/sdb
- ***Partition***: The disk sectors are partitioned into groups of sectors, each where a different file system can be created.
    - Partition table: keeps track of the locations of the partitions.
    - /dev/hda1, /dev/sdb2
    - Partitions can be further divided into logical partitions.

File system

- File system is a scheme for controlling how data is stored and retrieved from a partition.
    - File system organizes the sectors into blocks.
    - Organization:
        - Data is grouped into files.
            - Files have meta-data: e.g. when created, access permissions, …
        - Files are organized into directories.
    - FS holds a map Files names → Blocks.
        - Different file systems have different restrictions file names (e.g. allowed characters or case sensitivity).
        - General convention, “FOO.BAR”, FOO is filename, BAR is the extension which helps indicate the format of the file contents.
- FS enforce Access Control or Permissions… who can read what file.
- Different File system types:
    - Windows: FAT (FAT16, FAT32), exFAT NTFS, …
    - Mac: HFS, HFS+, APFS
    - Unix: ext2, ext3, ext4, ZFS, …
- SWAP: In some Operating Systems, the system can use storage as RAM when out of memory.