# CSC 411

## Computer Organization (Fall 2024)
## Lecture 9: Computer systems

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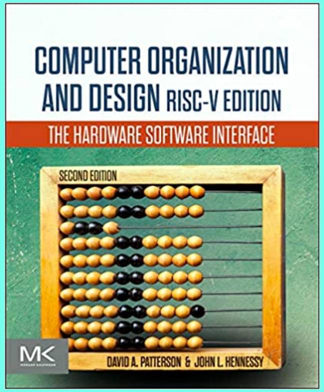
# Disclaimer

Some figures and slides are adapted from:

- Computer Organization and Design (Patterson and Hennessy)
  - The Hardware/Software Interface




# Units of measure

# SI prefixes

| Factor | Name | Symbol | Factor | Name | Symbol |
|---|---|---|---|---|---|
| $10^{1}$ | deca | da | $10^{-1}$ | deci | d |
| $10^{2}$ | hecto | h | $10^{-2}$ | centi | c |
| $10^{3}$ | kilo | k | $10^{-3}$ | milli | m |
| $10^{6}$ | mega | M | $10^{-6}$ | micro | µ |
| $10^{9}$ | giga | G | $10^{-9}$ | nano | n |
| $10^{12}$ | tera | T | $10^{-12}$ | pico | p |
| $10^{15}$ | peta | P | $10^{-15}$ | femto | f |
| $10^{18}$ | exa | E | $10^{-18}$ | atto | a |
| $10^{21}$ | zetta | Z | $10^{-21}$ | zepto | z |
| $10^{24}$ | yotta | Y | $10^{-24}$ | yocto | y |
| $10^{27}$ | ronna | R | $10^{-27}$ | ronto | r |
| $10^{30}$ | quetta | Q | $10^{-30}$ | quecto | q |

SI prefixes are a set of 24 prefixes used in the International System of Units (SI) to indicate multiples and submultiples of SI units. They are based on powers of 10, and each prefix has a unique symbol.

# Binary prefixes

The SI prefixes refer strictly to powers of 10. They should not be used to indicate powers of 2 (for example, one kilobit represents 1000 bits and not 1024 bits). The names and symbols for prefixes to be used with powers of 2 are recommended as follows:

| | | |
|---|---|---|
| kibi | Ki | $2^{10}$ |
| mebi | Mi | $2^{20}$ |
| gibi | Gi | $2^{30}$ |
| tebi | Ti | $2^{40}$ |
| pebi | Pi | $2^{50}$ |
| exbi | Ei | $2^{60}$ |
| zebi | Zi | $2^{70}$ |
| yobi | Yi | $2^{80}$ |

| Decimal term | Abbreviation | Value | Binary term | Abbreviation | Value | % Larger |
|---|---|---|---|---|---|---|
| kilobyte | KB | $10^3$ | kibibyte | KiB | $2^{10}$ | 2% |
| megabyte | MB | $10^6$ | mebibyte | MiB | $2^{20}$ | 5% |
| gigabyte | GB | $10^9$ | gibibyte | GiB | $2^{30}$ | 7% |
| terabyte | TB | $10^{12}$ | tebibyte | TiB | $2^{40}$ | 10% |
| petabyte | PB | $10^{15}$ | pebibyte | PiB | $2^{50}$ | 13% |
| exabyte | EB | $10^{18}$ | exbibyte | EiB | $2^{60}$ | 15% |
| zettabyte | ZB | $10^{21}$ | zebibyte | ZiB | $2^{70}$ | 18% |
| yottabyte | YB | $10^{24}$ | yobibyte | YiB | $2^{80}$ | 21% |
| ronnabyte | RB | $10^{27}$ | robibyte | RiB | $2^{90}$ | 24% |
| queccabyte | QB | $10^{30}$ | quebibyte | QiB | $2^{100}$ | 27% |

# Computer systems

# The computer revolution

- Progress in computer technology
  - underpinned by domain-specific accelerators
- Novel applications (not long ago considered fiction):
  - generative AI, automotive computers, smartphones, human genome project, web, search engines
- Although common hardware technologies …
  - different design requirements

`Computers in all forms are now pervasive`

## Classes of computers

- Personal computers (desktops/laptops)
  - low cost, general purpose, variety of software
  - subject to cost/performance tradeoff
- Server computers
  - network based, large workloads
  - high capacity, performance, reliability
  - range from small servers to building sized supercomputers (high-end scientific and engineering calculations)
- Embedded computers
  - largest class by volume
  - hidden as components of systems (Internet of Things)
  - power/performance/cost constraints

## The post PC era

- Personal Mobile Device (PMD) — overtaking PCs
  - battery operated, internet-connected
  - smart phones, tablets, electronic glasses
- Cloud computing — overtaking traditional servers
  - Warehouse Scale Computers (WSC) — e.g. Amazon AWS
  - Software as a Service (SaaS)
    - portion of software run on a PMD and a portion run in the Cloud

## Accelerators and heterogeneous computing

- Multiple cores in one chip
- System-on-a-Chip (SoC) design
- Graphics processing units (GPUs)
  - throughput-oriented multicore processors
  - great for gaming and machine learning
- Focus on performance and energy efficiency
  - critical in all classes of computers

# High performance computing

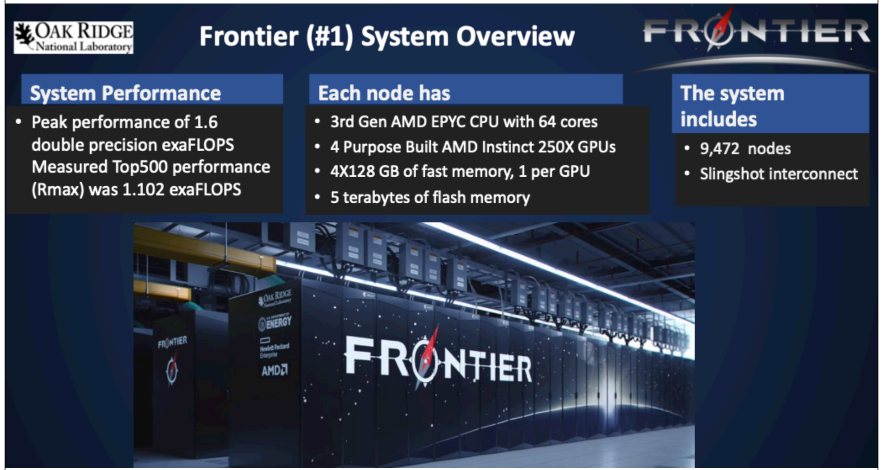
# Top 500 project

- 500 most powerful computers in the world
  - exascale applications
- Updated twice a year
  - ISC'xy in June, Germany and SC'xy in November, U.S.

| | TOP500 NOVEMBER 2023 | Manufacturer | Computer | Country | Cores | Rmax [Pflops] | Power [MW] |
|---|---|---|---|---|---|---|---|
| 1 | Oak Ridge National Laboratory | HPE | Frontier<br>HPE Cray EX235a,<br>AMD EPYC 64C 2.0GHz, Instinct MI250X, Slingshot-11 | USA | 8,730,112 | 1,102 | 21.1 |
| 2 | Argonne National Laboratory | HPE | Aurora*<br>HPE Cray EX<br>Xeon CPU Max 9470 52C 2.4GHz, Intel Data Center GPU Max, Slingshot-11 | USA | 4,742,808 | 585.3 | 24.6 |
| 3 | Microsoft Azure | Microsoft | Eagle<br>Microsoft NDv5<br>Xeon Platinum 8480C 48C 2GHz, NVIDIA H100, NVIDIA Infiniband NDR | USA | 1,123,200 | 561.2 | |
| 4 | RIKEN Center for Computational Science | Fujitsu | Fugaku<br>Supercomputer Fugaku,<br>A64FX 48C 2.2GHz, Tofu interconnect D | Japan | 7,630,848 | 442.0 | 29.9 |
| 5 | EuroHPC / CSC | HPE | LUMI<br>HPE Cray EX235a,<br>AMD EPYC 64C 2.0GHz, Instinct MI250X, Slingshot-11 | Finland | 2,069,760 | 309.1 | 6.0 |

credit: Berkeley's CS267 lectures

# Top computer in the world

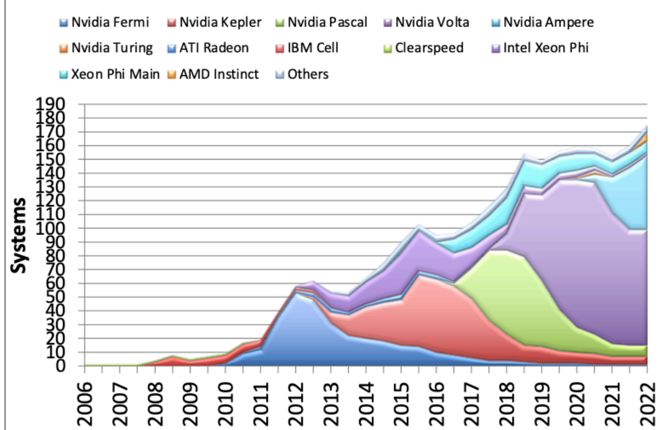



credit: Berkeley's CS267 lectures

# Exascale applications at LBNL


credit: Berkeley's CS267 lectures

# Heterogenous devices




2022: Over 1/3rd of all systems have **accelerators or co-processors**

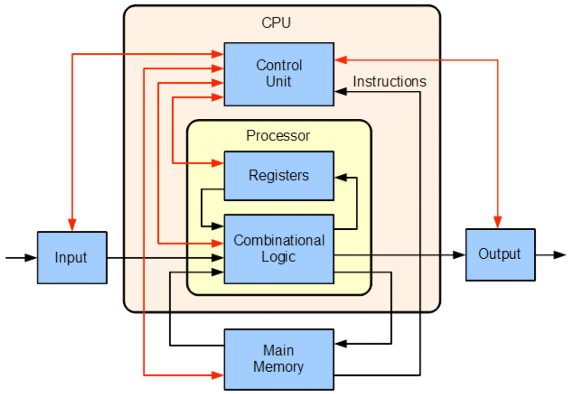
The actual "performance share" is higher

credit: Berkeley's CS267 lectures

# Abstractions

# The Von-Neumann model

- High-level organization of computer hardware



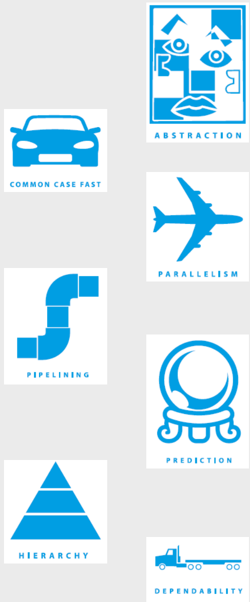

```
Same model for
all kinds of
computers:
desktop,
server, embedded

Input/output
includes:
display,
keyboard, mouse,
hard disk, CD/
DVD, network
adapters, …
```

https://en.wikipedia.org/wiki/Computer_architecture

# Seven great ideas

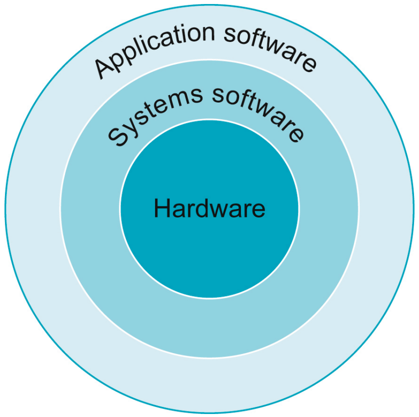
- Use **abstraction** to simplify design
- Make the **common case fast**
- Performance via **parallelism**
- Performance via **pipelining**
- Performance via **prediction**
- **Hierarchy** of memories
- **Dependability** via redundancy




# Abstraction layers (computing system)

| | |
|---|---|
| | Problem |
| | Algorithm |
| | Program / Language |
| | System Software (OS, VM) |
| ISA (Instruction Set Architecture) | SW / HW Interface |
| Implementation of the ISA | Microarchitecture |
| Building blocks (gates) | Logic |
| | Devices |
| | Electrons |

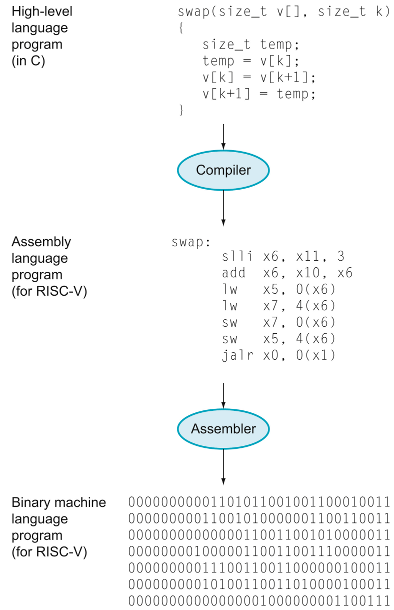
# Below your program

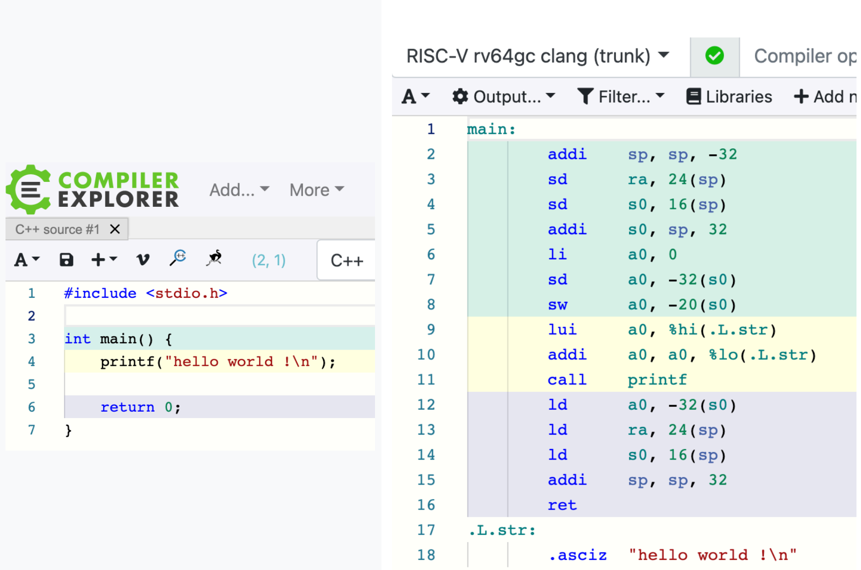



- Application software
  - written in high-level language
- System software
  - compiler: translates HLL code to machine code
  - operating system: service code
    - handling input/output
    - managing memory and storage
    - scheduling tasks & sharing resources
- Hardware
  - processor, memory, I/O controllers

# Levels of program code

- High-level language
  - level of abstraction closer to problem domain
  - provides for productivity and portability
- Assembly language
  - textual representation of instructions
- Hardware representation
  - binary digits (bits)
  - encoded instructions and data




https://godbolt.org/

# Looking into an executable

```c
#include <stdio.h>

int main() {
    printf("hello world !\n");

    return 0;
}
```

```
$ objdump -d
```

# Instruction set architecture

"the words of a computer's language are called *instructions*, and its vocabulary is called an *instruction set*" [Computer Organization and Design, P&H]

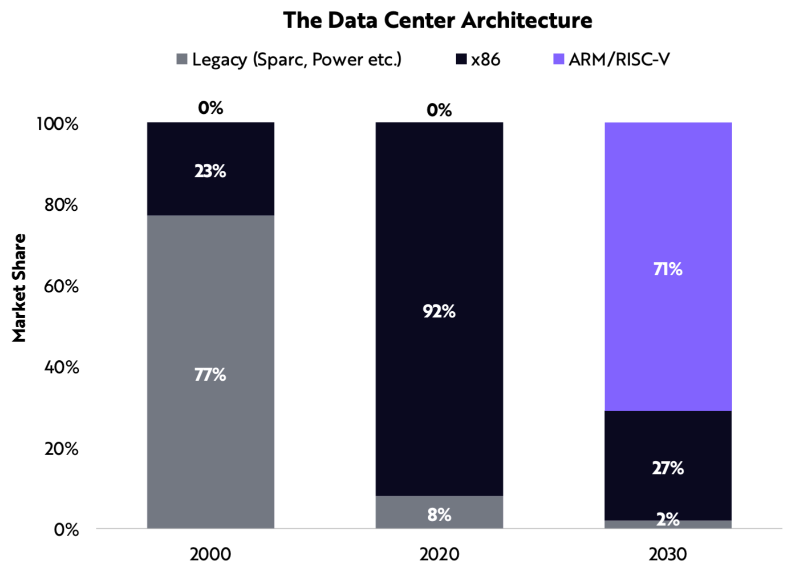
`the basic job of a CPU is to execute instructions`

# Definitions

- Instruction set
  - the **repertoire** of instructions of a computer
  - different computers have different instruction sets
    - … with many aspects in common
- Instruction set architecture (ISA)
  - a **contract** between hardware and software
  - defines instruction format, syntax, and semantics
- Microarchitecture
  - implementation of the architecture, i.e., how the processor physically executes the instructions
  - e.g., cache sizes, core frequency, pipelining, branch prediction
  - different microarchitectures for the same ISA (e.g., Intel vs AMD for x86)

# Major ISAs

- Major ISAs
  - X86 (Intel and AMD)
    - desktop computers, laptops, servers
  - ARM
    - widely used on embedded, phones, recently on laptops, servers
  - RISC-V
    - fast-growing, used in embedded systems, servers, personal computers
- Even more microarchitectures
  - Apple/Samsung/Qualcomm have their own microarchitecture (implementation) of ARM
  - Intel/AMD have different microarchitectures for x86




Big Ideas 2021, ARK Investment Management LLC

# CISC vs RISC

- Complex Instruction Set Computer (CISC)
  - more complex instructions, can directly manipulate memory
  - X86, X86_64 (Intel and AMD, desktop/laptop/server)
    - X86* internally are still RISC
- Reduced Instruction Set Computer (RISC)
  - simpler instructions, load-store architecture
  - ARM (smartphone/pad)
  - **RISC-V** (free ISA, closer to MIPS than other ISAs)
  - Others: Power ISA, SPARC, etc

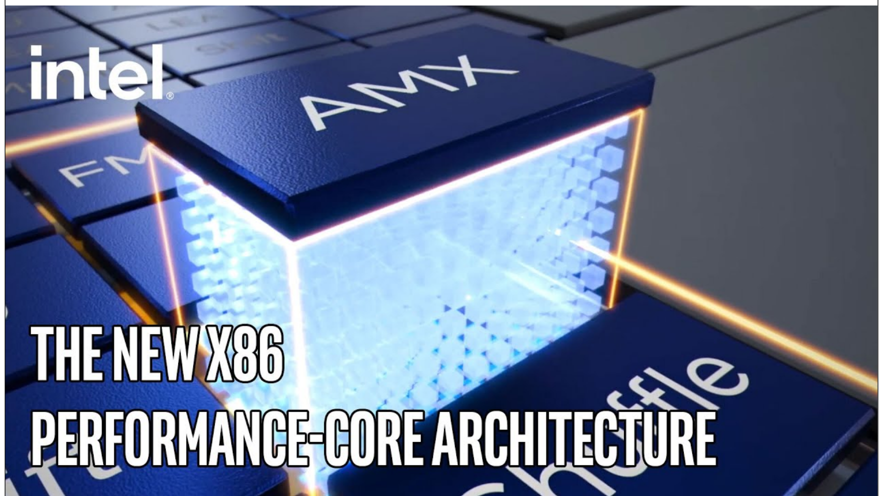
# CISC vs RISC

- CISC
  - early trend was to add more and more instructions
  - VAX architecture had an instruction to multiply polynomials!
  - operations may directly manipulate memory
- RISC philosophy
  - keep the instruction set **small and simple**
  - makes it easier to build fast hardware.
  - let software do complicated operations by composing simpler ones

ACM has named **John L. Hennessy**, former President of Stanford University, and **David A. Patterson**, retired Professor of the University of California, Berkeley, recipients of the **2017 ACM A.M. Turing Award** for pioneering a systematic, quantitative approach to the design and evaluation of computer architectures with enduring impact on the microprocessor industry.

https://www.youtube.com/watch?v=3LVeEjsn8Ts

# Intel's x86 core




https://www.youtube.com/watch?v=ijTRvIQV7bE

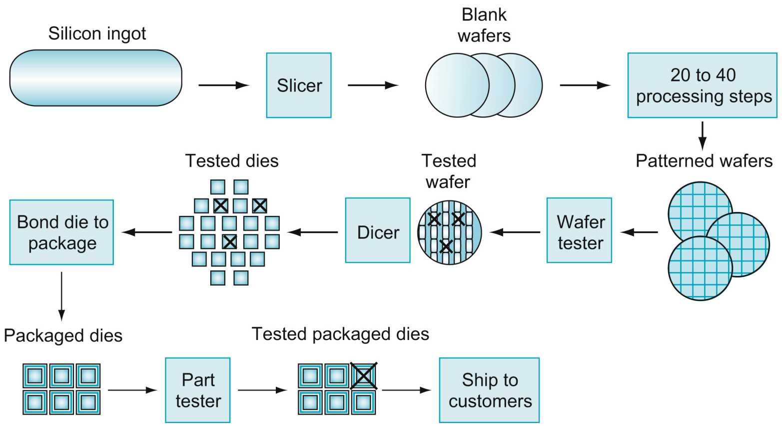
# Chip Manufacturing

## Semiconductor technology

- Conductors
  - materials that easily conduct
- Insulators
  - materials that do not conduc

- Semiconductors
  - materials with conductivity between conductors and insulators
  - those properties can be controlled by doping (adding/ removing electrons)
  - Silicon (base material for computer technology)

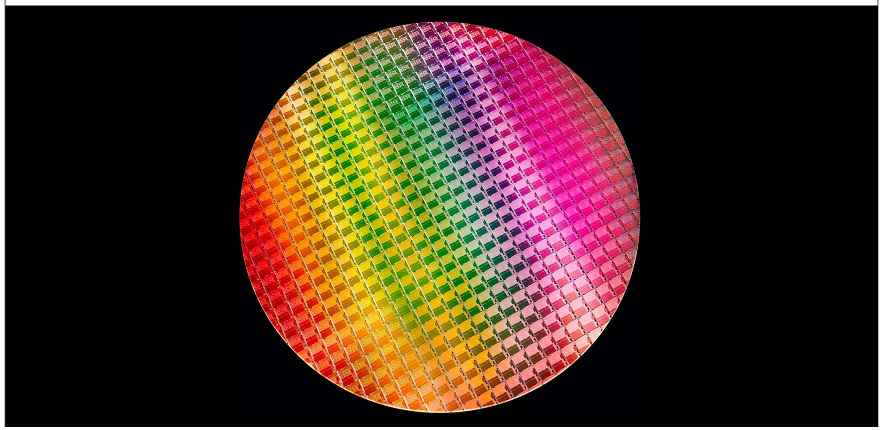
## Manufacturing integrated circuits



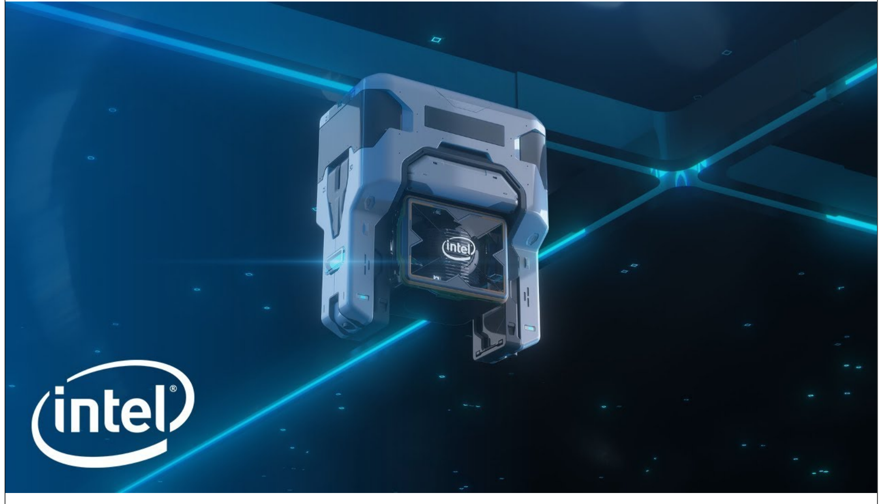

Yield: proportion of working dies per wafer

## Intel® Core 10th Gen

- 300mm wafer (almost 1 foot), 506 chips, 10nm technology
- Each chip is 11.4 x 10.7 mm (a bit less than .5 in)



# From sand to silicon




https://www.youtube.com/watch?v=_VMYPLXnd7E