Computer Organization: Data Representation

DS 5110: Big Data Systems (Spring 2023)

Lecture 2a

Yue Cheng

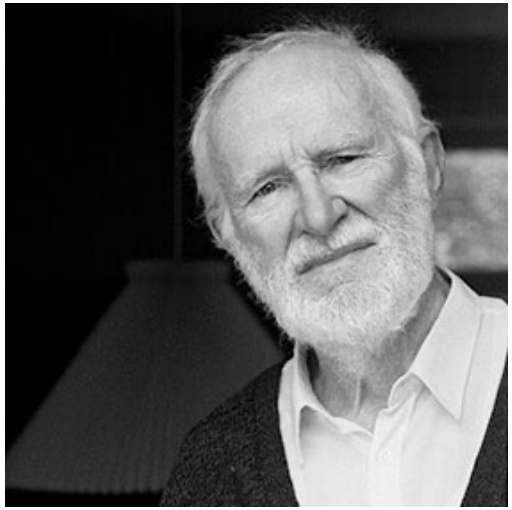
Some material taken/derived from:

- UC San Diego DSC 102 by Arun Kumar.

What is a computer?

A programmable electronic device that can store, retrieve, and process digital data

Computer science aka “Datalogy”



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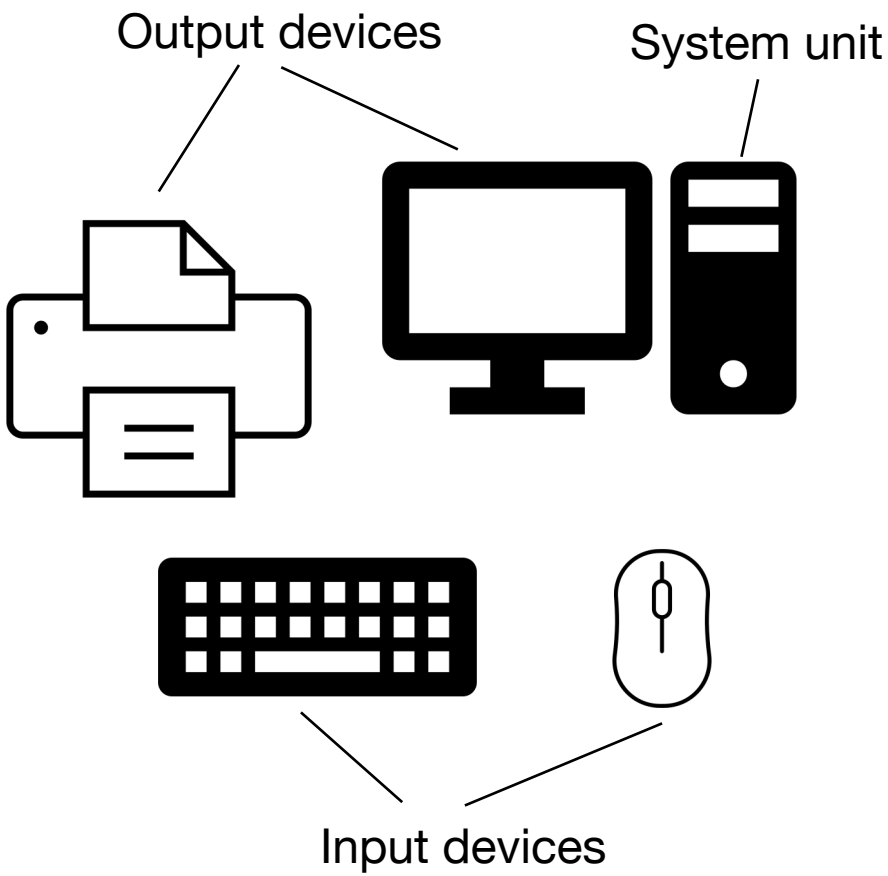

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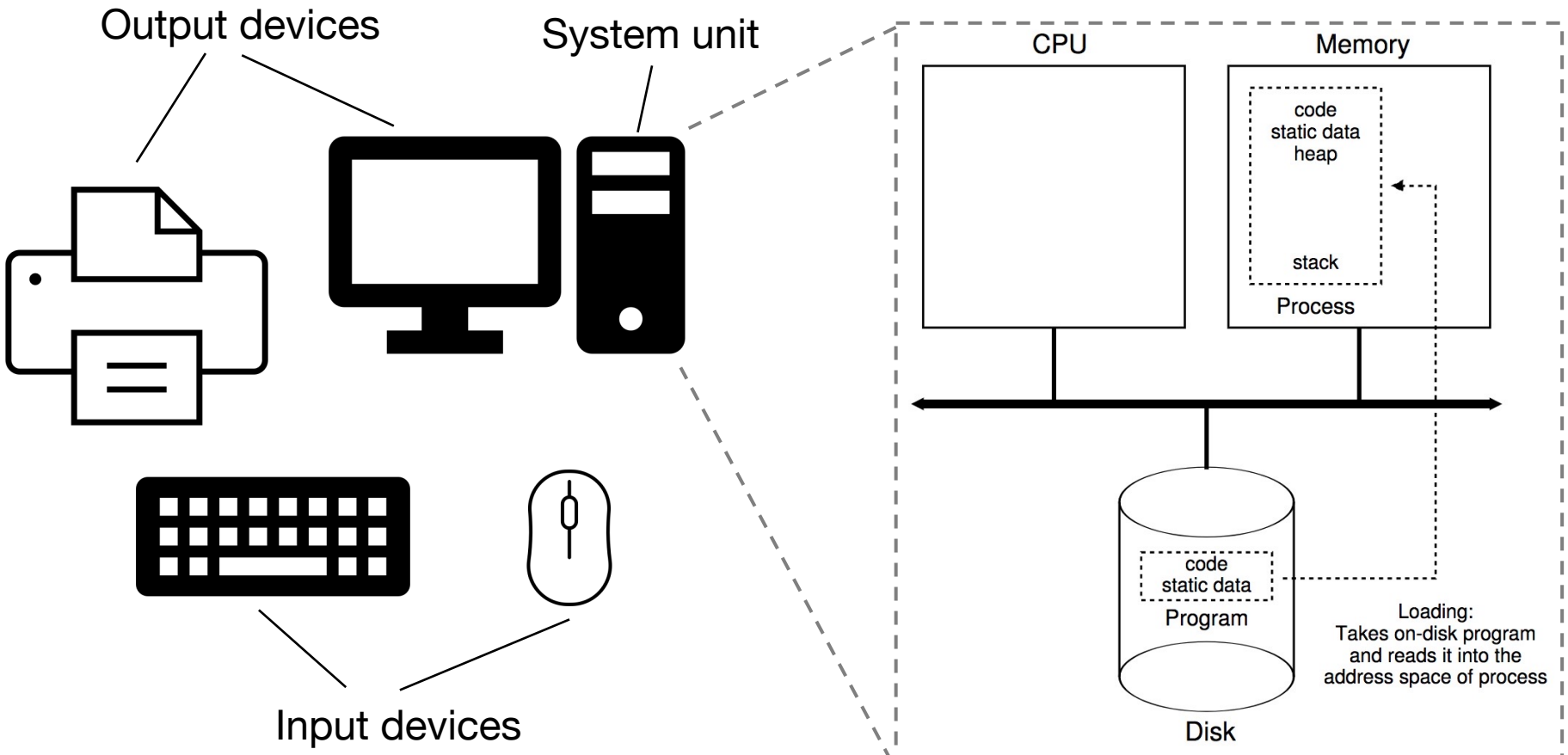
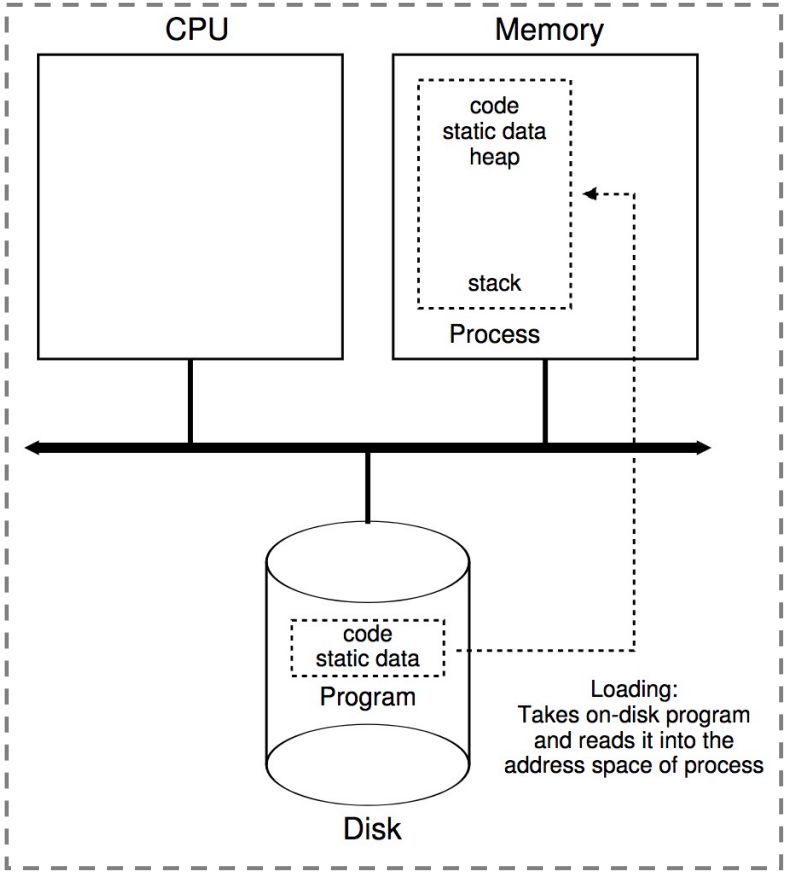


Key parts of computer hardware

- **CPU**
  - Hardware to execute instructions to manipulate data as specified by a program



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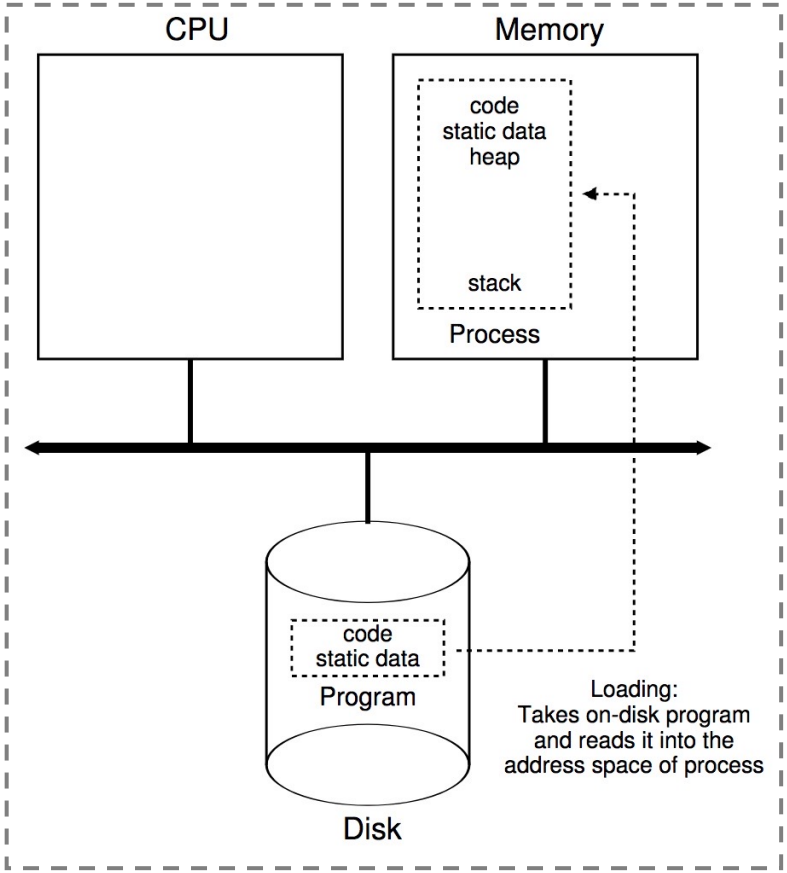

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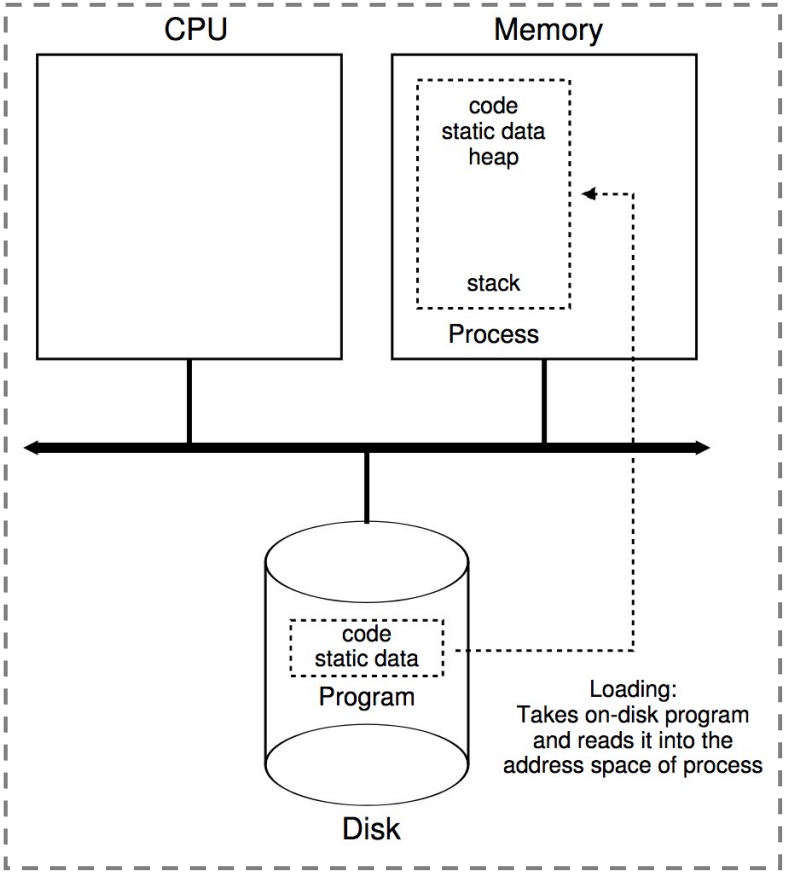
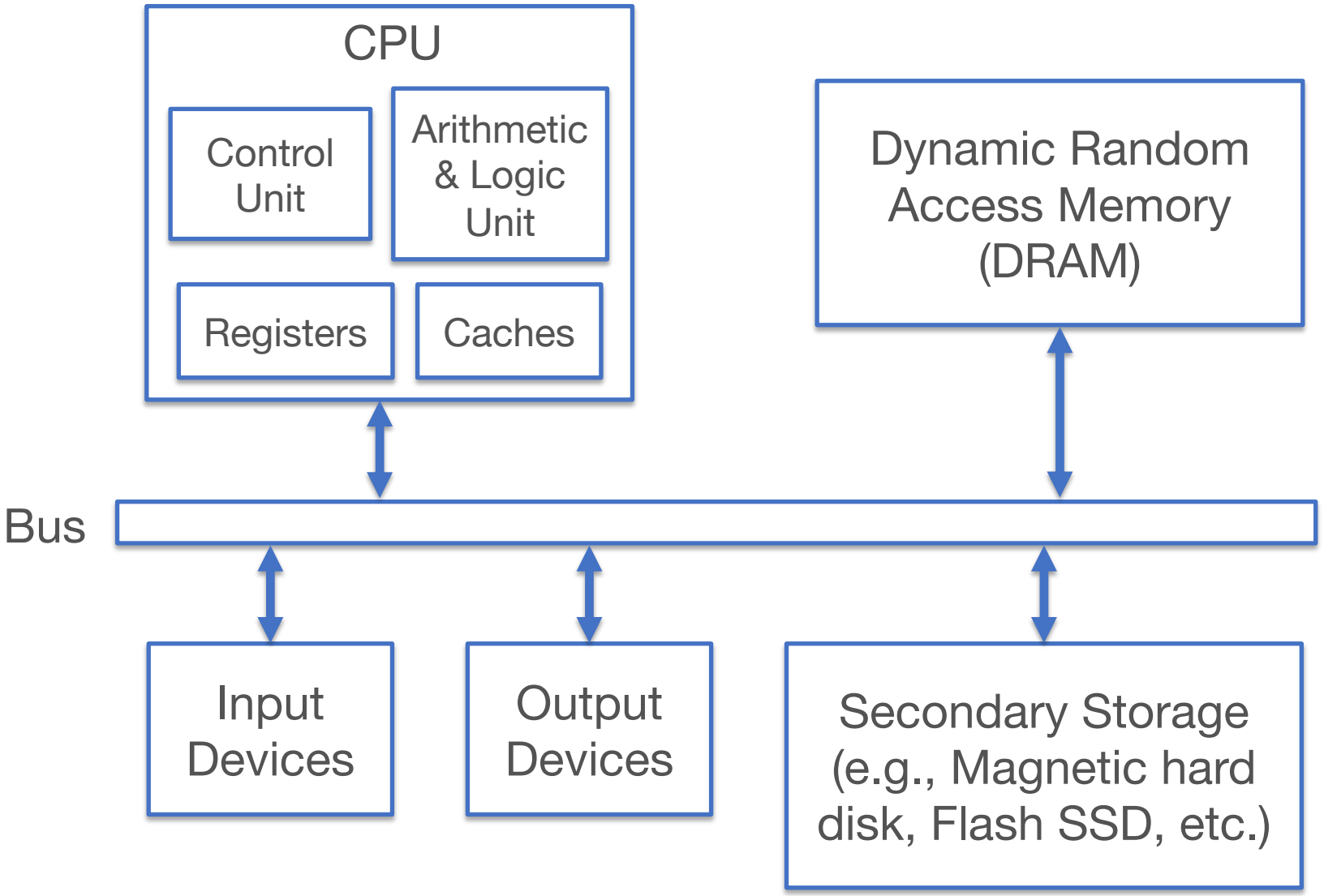
- **Disk (second storage)**
  - Persistent, slower storage with higher capacity (block addressable)



How different parts interact



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- **Data**
  - Digital representation of information that is stored, processed, displayed, retrieved, or sent by a program

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- **Application software programs**
  - A (user-space) program or a collection of (user-space) programs to perform a certain task for human use
  - Examples: Office, Chrome, Zoom

What is data?

Digital representation of data

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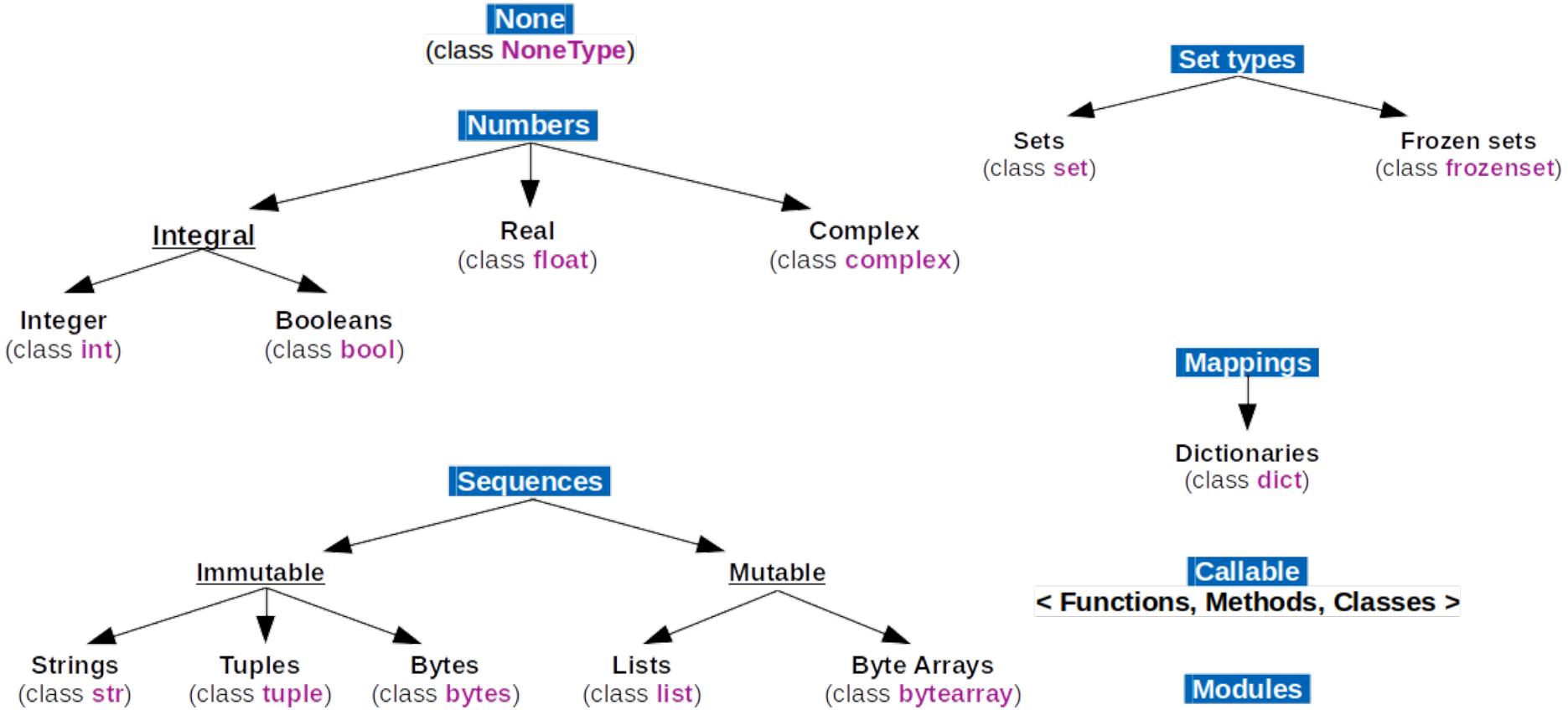
  - Example data types: Boolean, byte, integer, floating point number (float), character, string
- **Data structures:** A second layer of abstraction to organize multiple instances of same or varied data types as a more complex object with specific properties
  - Examples: Array, dictionary (hash table), tree, graph

Data types in Python 3



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- **Integer:**
  - Examples: count of something – # friends
  - Typically 4B but many variants (short, unsigned, etc.)
    - Java `int`: -2^{31} to $(2^{31}-1)$
    - C `unsigned int`: 0 to $(2^{32}-1)$
    - Python3 `int`: effectively no max limit

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- For k unique items, invert the exponent: $\log_2(k)$
- #bits should be integer, so we do $\lceil \log_2(k) \rceil$
- $\lceil \log_2(97) \rceil$: 97 → 128 = 2^7, so, 7 bits

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	7	6	5	4	3	2	1	0	Position/Exponent of 2
Decimal	128	64	32	16	8	4	2	1	Power of 2
8_{10}									
26_{10}									
163_{10}									

Hexadecimal examples

- Hexadecimal representation is a common stand-in for binary representation; more succinct and readable
  - Base 16 instead of base 2 cuts display length by 4x
  - Digits are 0, 1, …, 9, A (10_{10}), B, …, F (15_{10})
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Alternative notations

0xA3 or $A3_H$

Float

- Float
  - Examples: salary, model weights
  - IEEE-754 single-precision format is 4B long; double-precision format is 8B long
  - Java and C float is single; Python float is double

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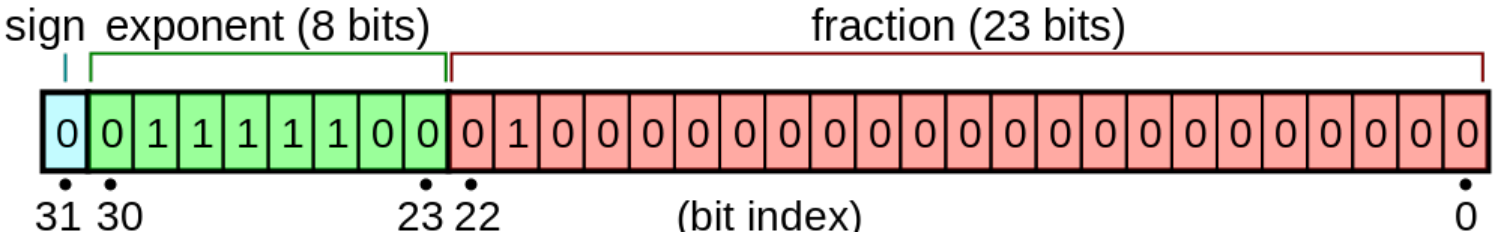

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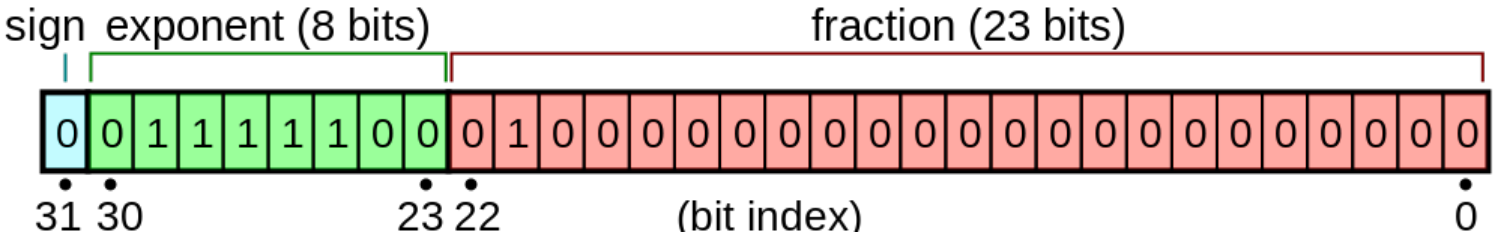

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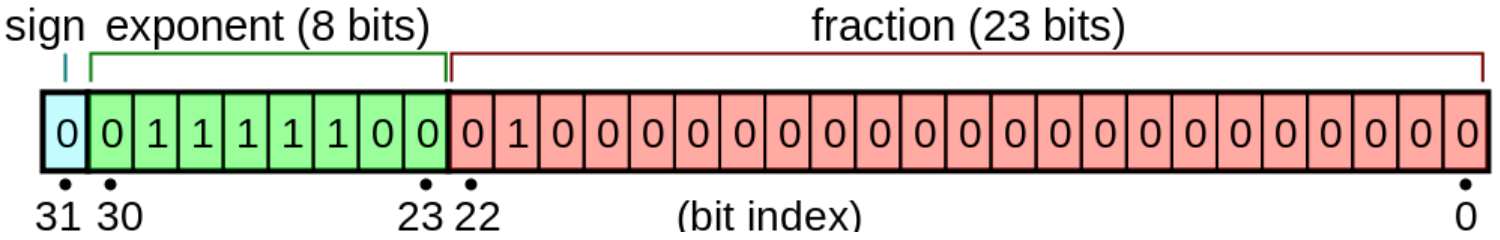

$$(-1)^{sign} \times 2^{exponent-127} \times (1 + \sum_{i=1}^{23} b_{23-i} 2^{-i})$$

$$(-1)^0 \times 2^{124-127} \times (1 + 1 \cdot 2^{-2}) = (1/8) \times (1 + (1/4)) = 0.15625$$

Float

- Due to representation imprecision issues, floating point arithmetic (addition, multiplication) is **not** associative

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Yue ds5110-spring23 $ python3
Python 3.9.6 (default, Oct 18 2022, 12:41:40)
[Clang 14.0.0 (clang-1400.0.29.202)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
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0.4
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- In binary32, special encodings recognized:
  - Exponent 0xFF and fraction 0 is +/- “infinity”
  - Exponent 0xFF and fraction <> 0 is “NaN”
  - Max is 2^{127} x $(2-2^{-23})$, i.e., ~3.4 x 10^{38}

More on float standards

- Double-precision (float64, 8B) and half-precision (float16, 2B)
  - Different #bits for exponent, fraction
- float16 is now common for deep learning parameters

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    - Examples: ‘D’ is 68, ‘d’ is 100, ‘!’ is 33, ‘?’ is 63

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  - Unicode UTF-8 subsumes ASCII
    - 4B for ~1.1 million “code points” including many other language scripts, math symbols, emojis, etc.
    - 😄 👍🏻 : https://unicode.org/emoji/charts/full-emoji-list.html

Data structures

- Data structures: A second layer of abstraction to organize multiple instances of same or varied data types as a more complex object with specific properties
  - ML feature vectors: array of floats
  - Neural network weights: set of multi-dimensional arrays (matrices or tensors) of floats
  - Trees: binary trees, N-ary trees
  - Graphs: sets of vertices (integers) and sets of edges (pair of integers) that connect vertices
  - And a lot more…