Python Numeric Types

DS 5110: Big Data Systems

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Lecture 5

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Some material taken/derived from:
- Wisconsin CS 544 by Tyler Caraza-Harter.

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(Data Systems for Data Science)

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Is 0.1 + 0.2 = 0.3 in Python?

zsu — python3 — python3 — Python — 70×9

```
➜  ~ python3
Python 3.12.3 (main, Apr  9 2024, 16:03:47) [Clang 14.0.0 (clang-1400.
0.29.202)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> print(0.1 + 0.2 == 0.3)
False
>>> print(0.1 + 0.2)
0.30000000000000004
>>> 
```

Learning objectives

- Know how machine stores numeric types, especially **floating points**
- Compare different numeric types in terms of **memory space cost**, **range**, and **precision**

Python numeric types (built in)

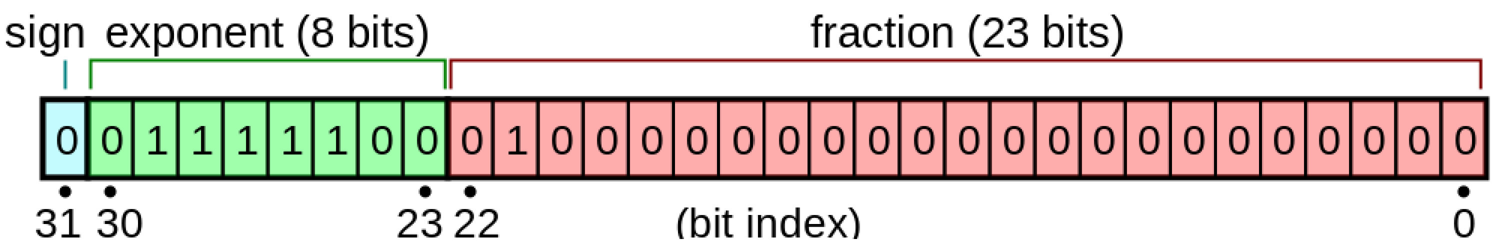
Official lib: https://docs.python.org/3/library/stdtypes.html#numeric-types-int-float-complex

Python numeric types

- int
  - No max/min size (Python is unusual in this way)
  - Bigger values -> more bits necessary
- float
  - Defaults 64 bits (double precision)
    - You can also use float32 given a certain framework (e.g., PyTorch, numpy, etc.)
  - Most pre-trained ML models use float32 for parameters

float32

- Standard IEEE format (float32)



$$p = (-1)^s \times 2^{e-127} \times (1.m_1 m_2 \ldots m_{23})_2$$

$$= (-1)^s \times 2^{e-127} \times \left(1 + \sum_{i=1}^{23} m_i \times 2^{-i}\right)$$

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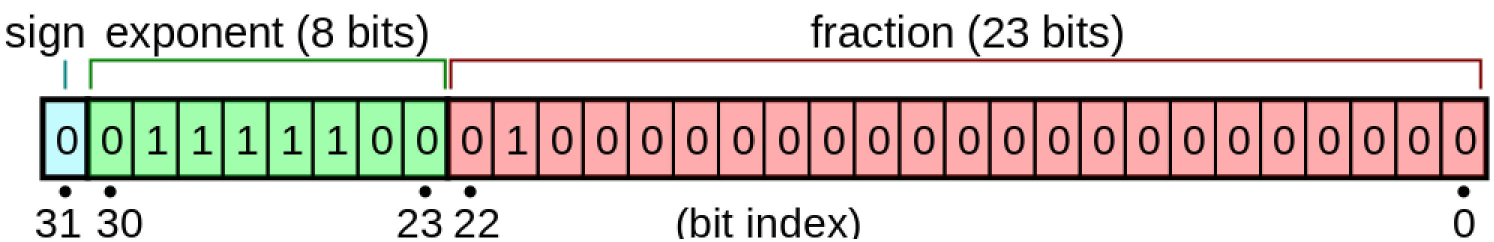

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$$(-1)^0 \times 2^{124-127} \times (1 + 1 \cdot 2^{-2}) = (1/8) \times (1 + (1/4)) = 0.15625$$

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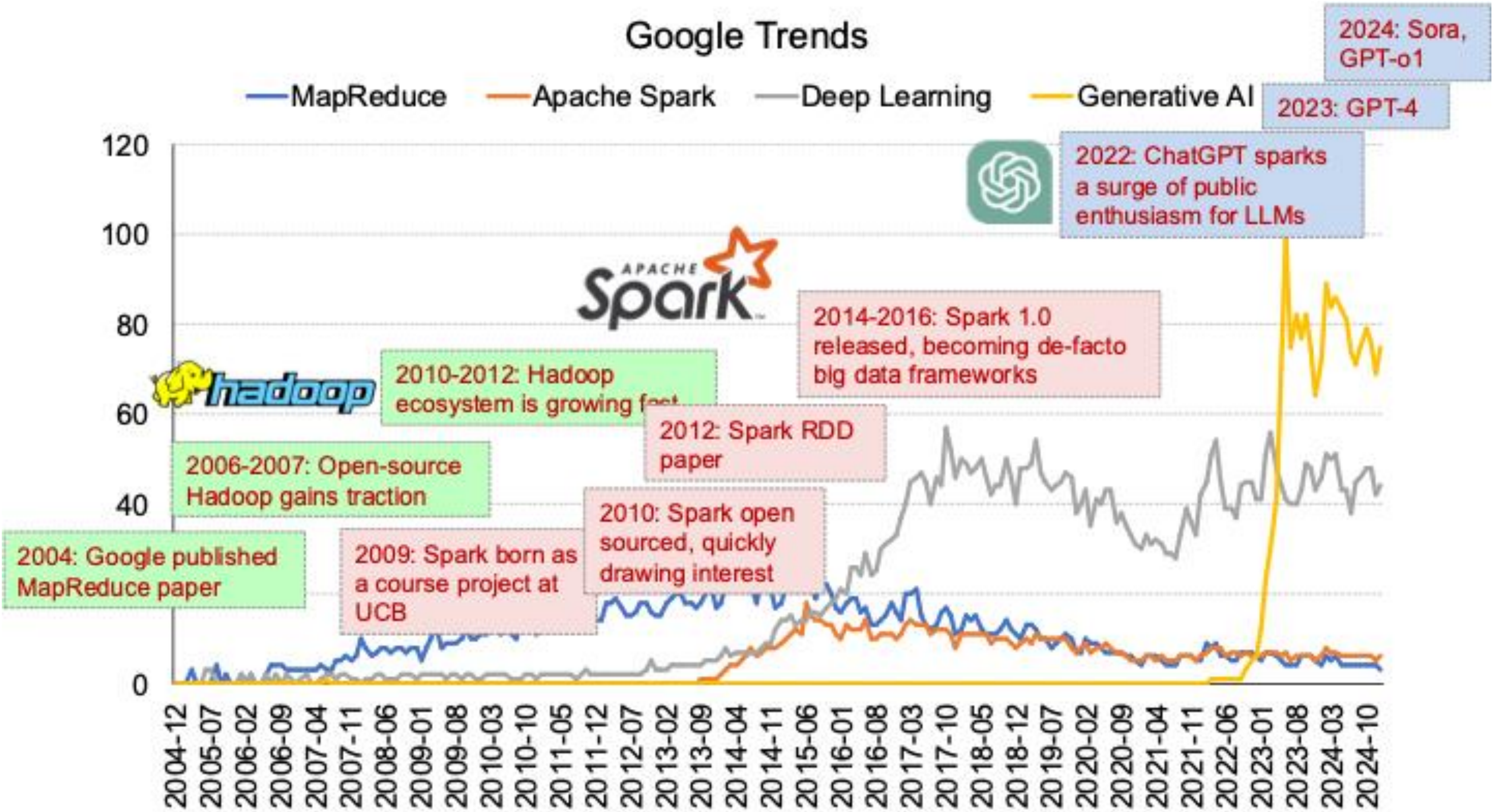
- complex,
  - e.g. complex('-1.23+4.5j')

Other (commonly used) numeric types

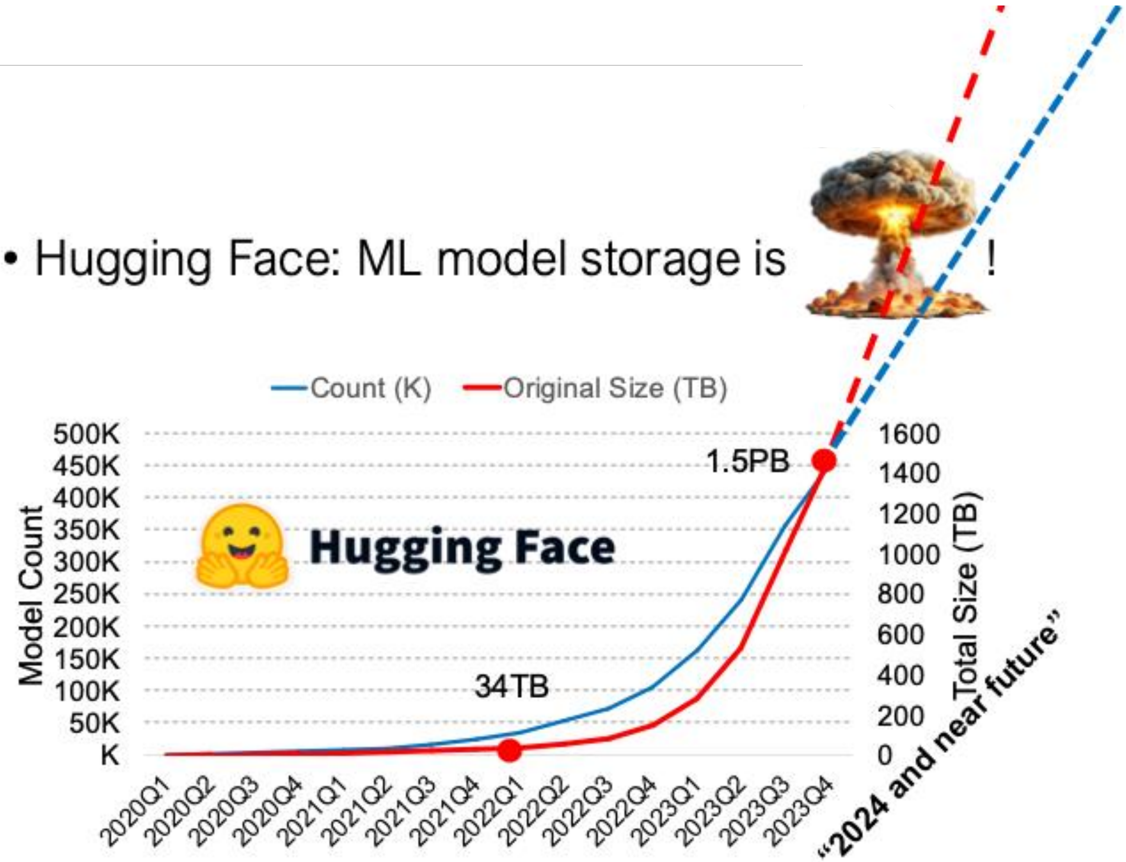
- Common numeric types that (a) CPU can directly manipulate and (b) popular Python frameworks (e.g., PyTorch) support
  - ints: uint8, int8, int16, int32, int64
  - floats: float16, float32, float64
  - dtype (data type)

A brief history about Big Data



Data explosion in the GenAI era

• Hugging Face: ML model storage is !



HuggingFace's AI/ML models are growing exponentially!

Floating points in Large Language Models

- Modern deep learning (DL) relies on floating point computations.
- Large-scale models (e.g., GPT, LLaMA) require **memory-efficient** representations.
- Lower **precision** formats (FP16, BF16, FP8) improve **speed** & **efficiency**.
- Trade-off: **Accuracy** VS. **Speed** VS. **Memory**.

Floating points in Large Language Models

- FP32 (32-bit)- standard precision in LLMs
  - 8-bit exponent, 23-bit mantissa. High precision but high memory cost. Used in early ML models.
- FP16 - Faster Computation, Less Memory
  - 5-bit exponent, 10-bit mantissa. Less precise but faster on GPUs. Efficiently used in NVIDIA Tensor Cores.
- BF16 - Balancing Range & Precision
  - 8-bit exponent, 7-bit mantissa. Same exponent as FP32 but a lower mantissa. Used in Google TPUs.
- FP8 - The Future of Efficient Inference
  - Emerging format (E5M2, E4M3). Reduces model size 4x of FP32. Lower precision but good enough for inference.

Floating points in Large Language Models

Format	Bits	Exponent	Mantissa	Memory	Use Case
FP32	32	8 bits	23 bits	4 bytes	Standard training
FP16	16	5 bits	10 bits	2 bytes	Faster training
BF16	16	8 bits	7 bits	2 bytes	Training stability
FP8	8	E5M2 or E4M3	2-3 bits	1 byte	Efficient inference

Demos …