Big Data Computing

Master's Degree in Computer Science

2019-2020

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SAPIENZA
UNIVERSITÀ DI ROMA

Administrivia

- Class schedule:
  - **Tuesday** from **8:00AM** to **10:00AM**
  - **Wednesday** from **3:00PM** to **6:00PM**

Room Alfa @ Via Salaria, 113

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- Office hours:
  - **Tuesday** from **2:00PM** to **4:00PM**
  - Or drop me a message to ask for a meeting

Room G39 @ Viale Regina Elena, 295 (Building G - II floor)

Administrivia

- Contacts:
  - Personal homepage: https://www.di.uniroma1.it/~tolomei
  - Email: tolomei@di.uniroma1.it

Administrivia

- Resources:
  - Course's website: https://github.com/gtolomei/big-data-computing
  - Moodle's web page: https://elearning.uniroma1.it/course/view.php?id=8460

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- Moodle will be used to send out communications via the built-in "News" forum

Please, remember to enroll using the Moodle link above!

Administrivia

- Prerequisites:
  - Familiarity with basics of Data Science and Machine Learning
  - Solid knowledge of Calculus, Linear Algebra, and Probability&Statistics
  - Programming skills (preferably in Python)

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No worries!
Many subjects will be anyway revisited during class lectures

Administrivia

- Exam:
  - Development of a software project on a typical Big Data task
  - The subject of the project must be agreed in advance with the professor
  - Available sources exist like Kaggle (https://www.kaggle.com/)
  - Can be done either **individually** or in team of **at most 2 students**
  - A brief presentation (in english) describing the project is **mandatory**
  - Other questions on all the topics covered in classes may be asked

Questions?

Outline of the Course

Big Data Phenomenon

Outline of the Course

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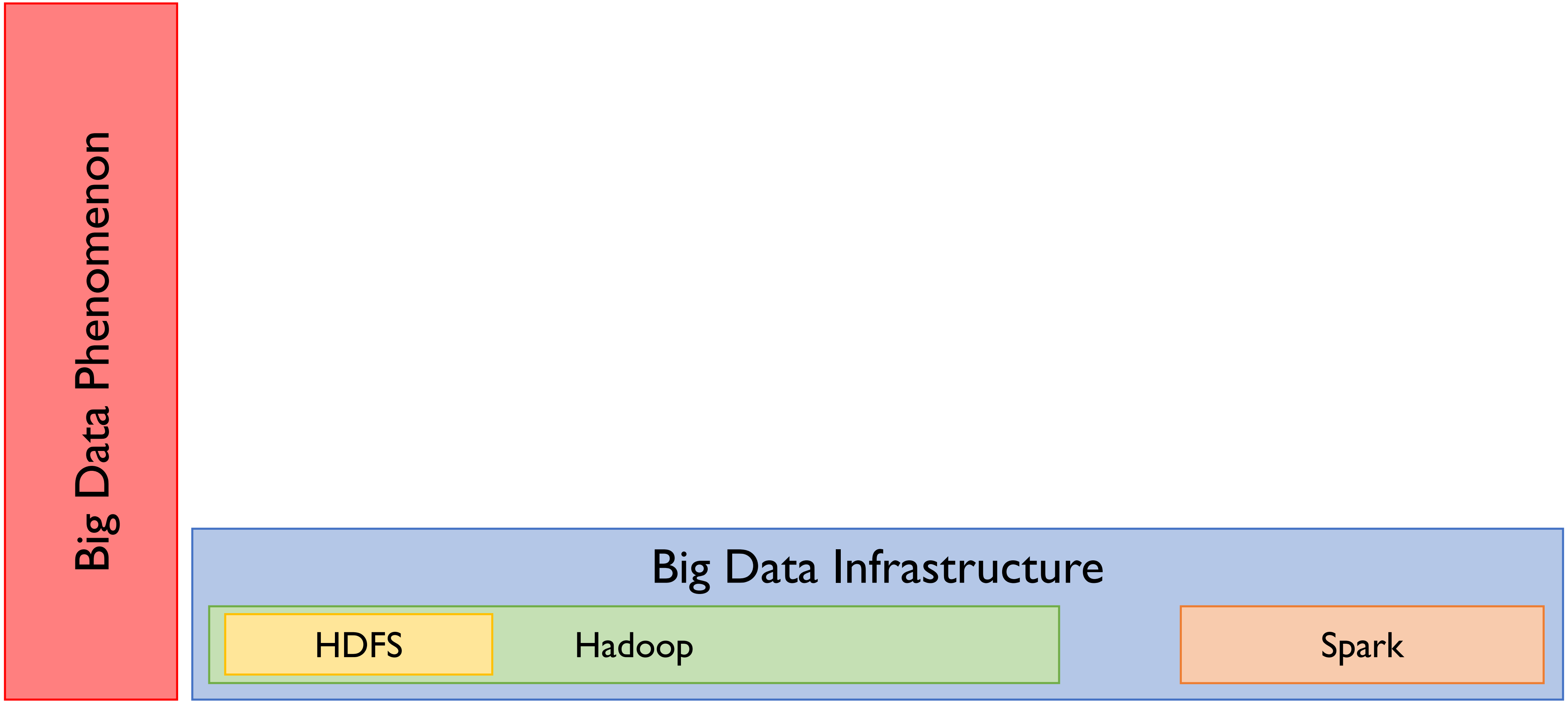
Big Data Infrastructure

Outline of the Course



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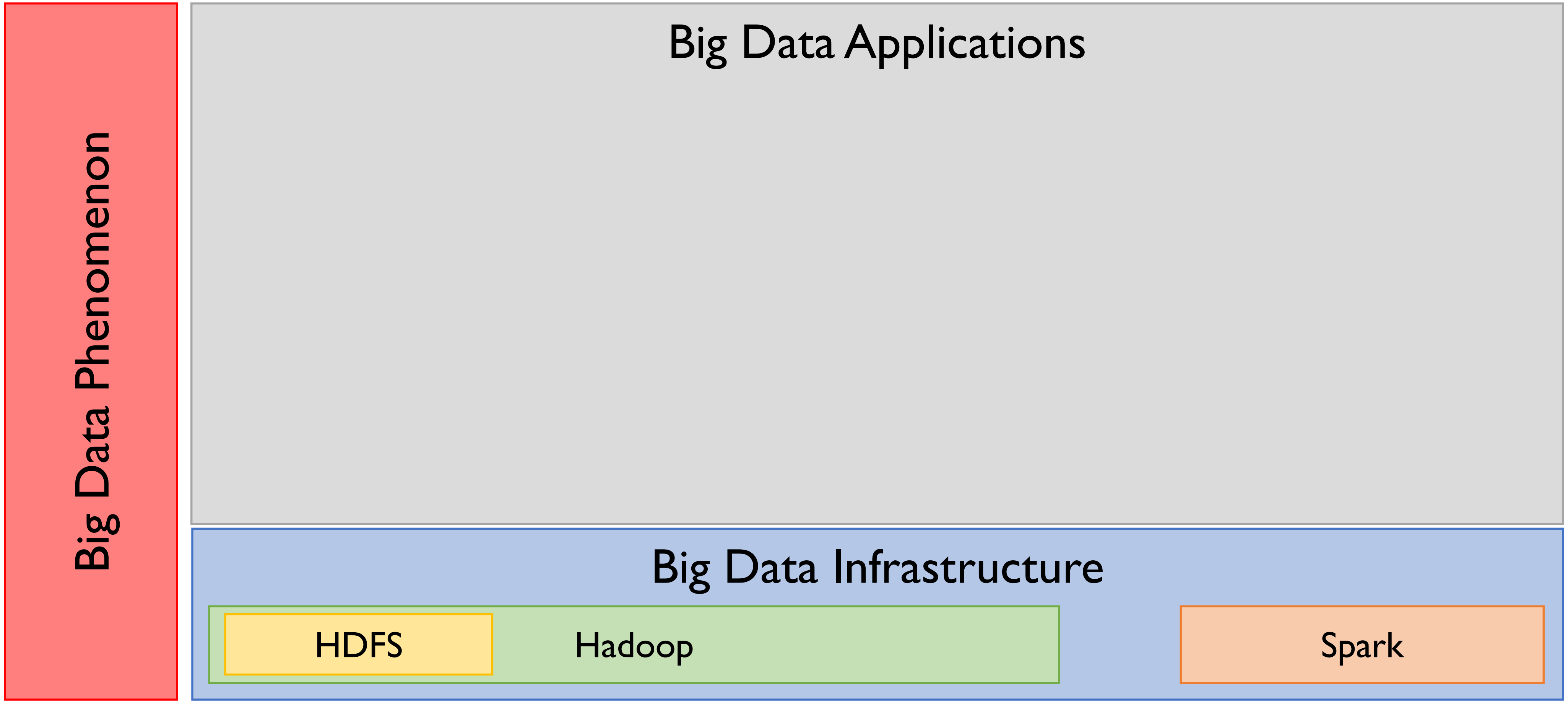

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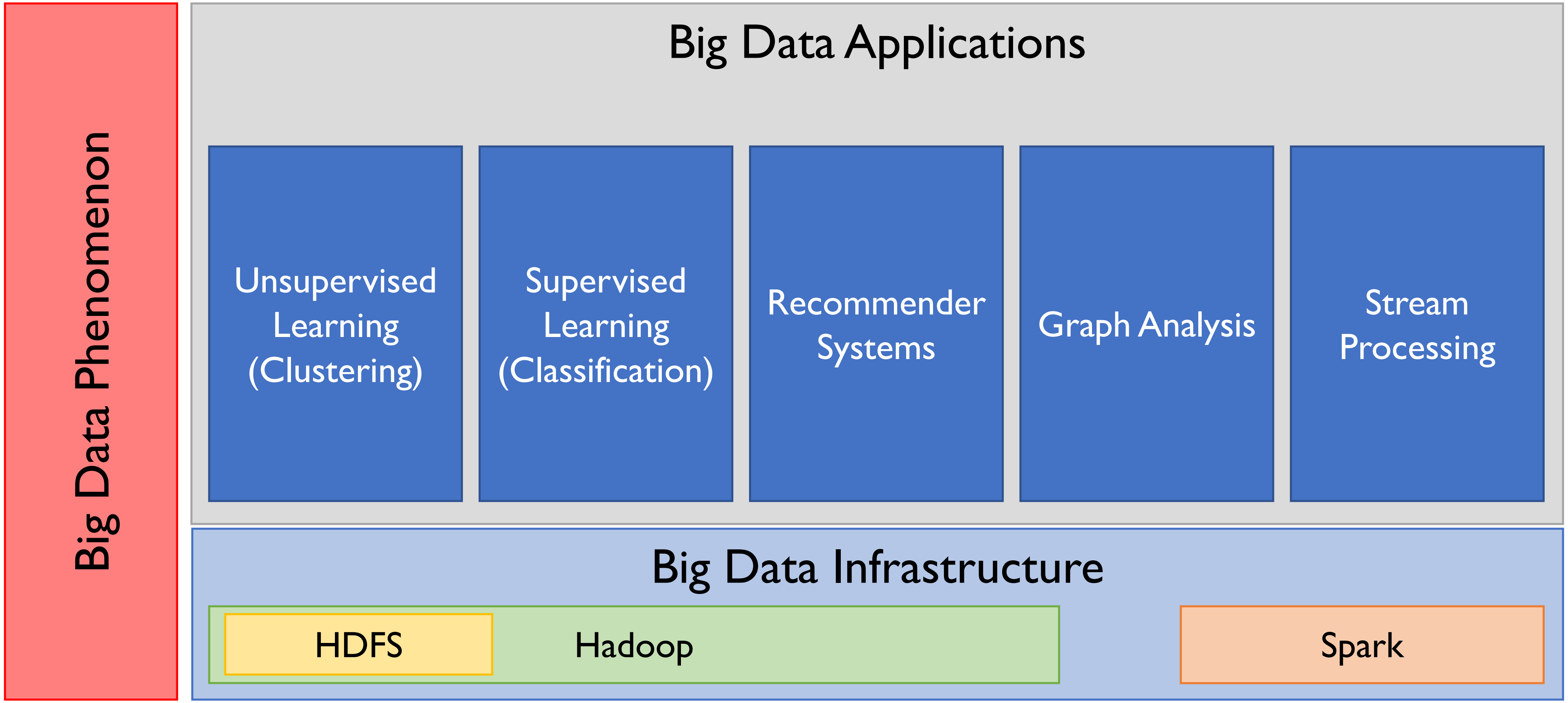
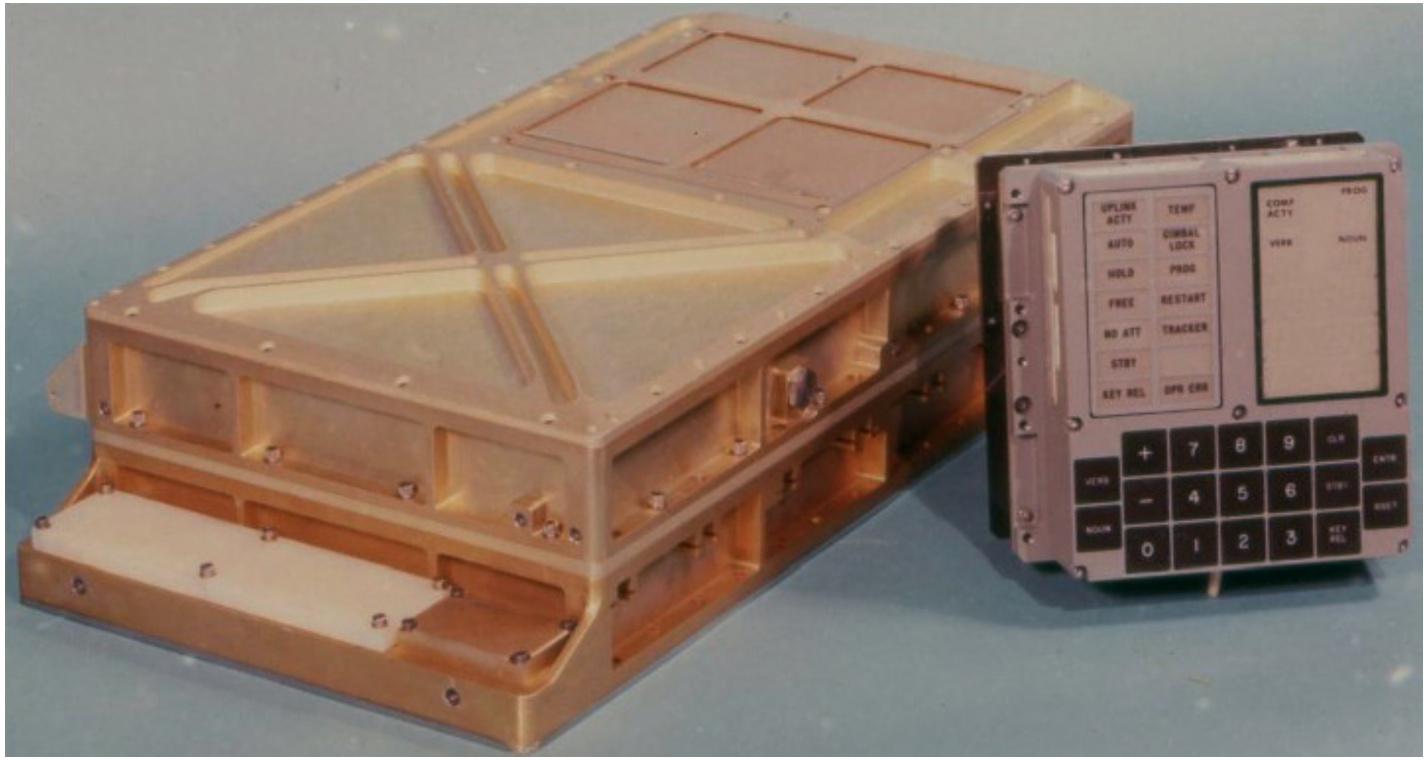


Let's Get Started!

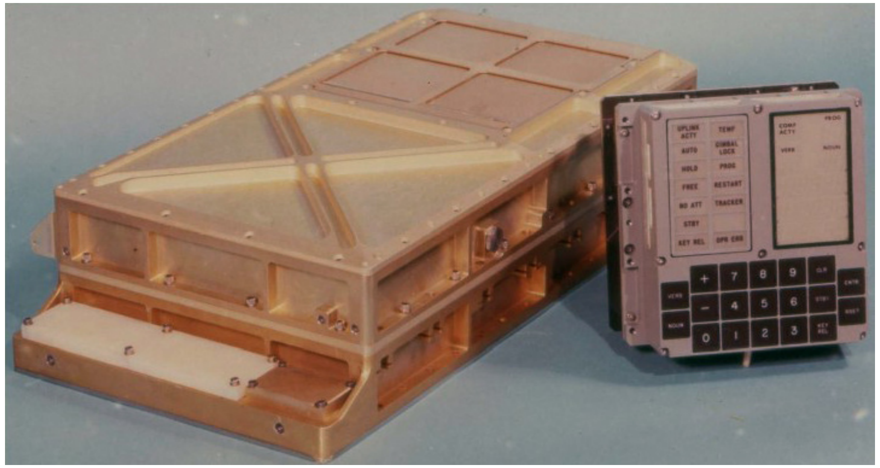
What the He…ck is That?



source: Wikipedia

The Apollo Guidance Computer (AGC)

The computer installed on each command and
lunar module of all the Apollo program's missions



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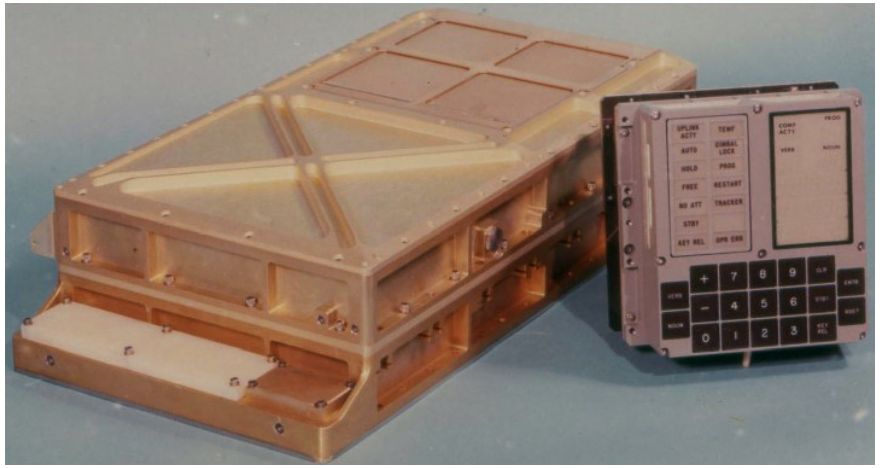
A few numbers:

- ~2 MHz CPU clock frequency
- 16 bit architecture
- 3,840 bytes of main memory (RAM)
- 69,120 bytes of non-volatile read-only memory (ROM)



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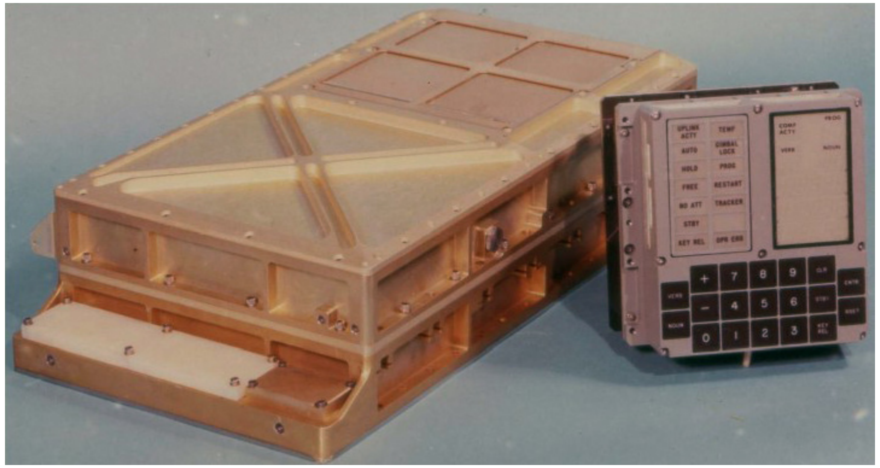

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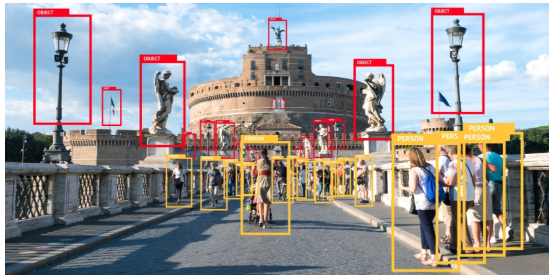
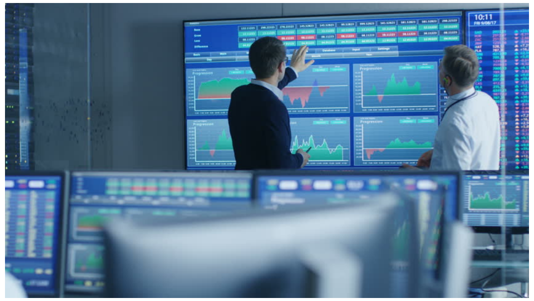
All the running software was written in AGC assembly language, now also available on [GitHub]

50 Years Have Passed…

… And The World Has Changed





AGC vs. Our Smartphone

- Most recent smartphones have
  - ~2.4 GHz CPU clock frequency
  - 4÷12 GB of RAM
  - 64÷256 GB of storage (ROM)

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~3 orders of magnitude faster (~1,000x)

~6÷7 orders of magnitude larger RAM and ROM (up to 10,000,000x)

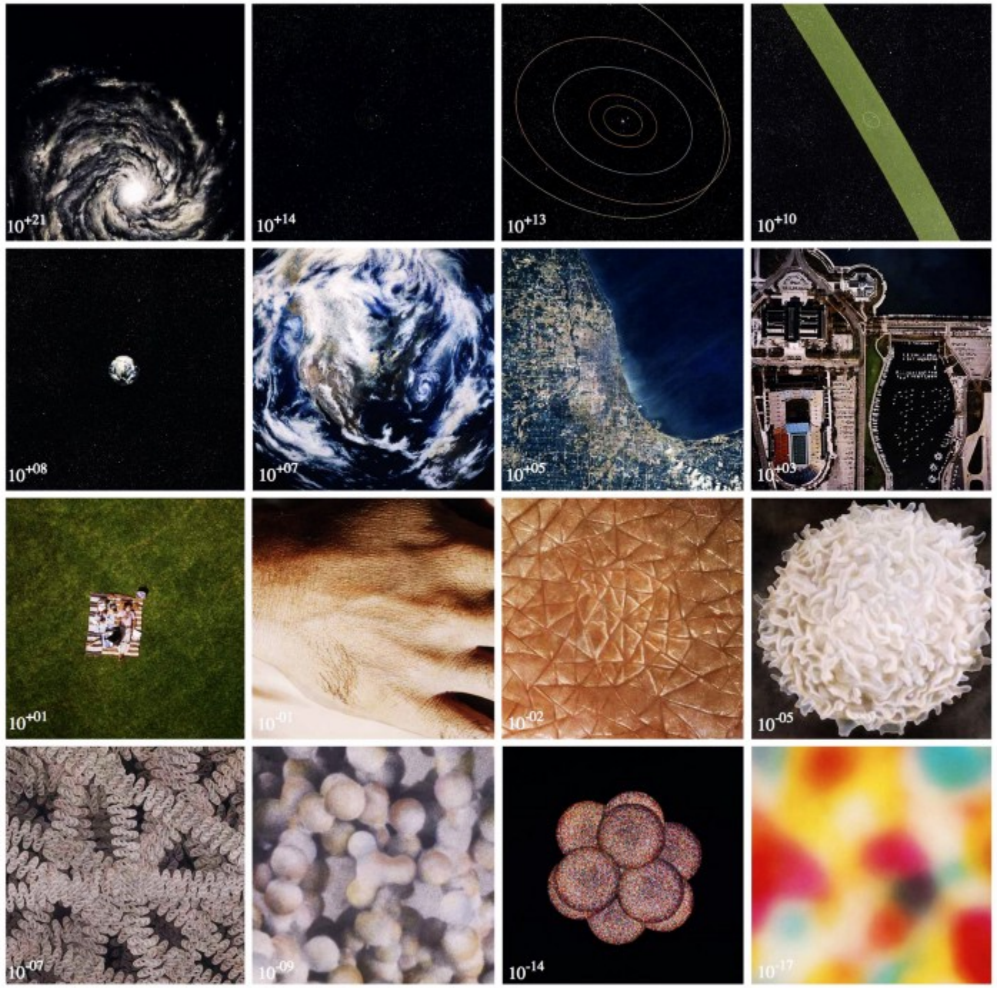
A Side Note on Units

Prefixes for multiples of bits (bit) or bytes (B)									
Decimal				**Binary**					
Value		**SI**		**Value**		**IEC**		**JEDEC**	
1000	10^3	k	kilo	1024	2^{10}	Ki	kibi	K	kilo
1000^2	10^6	M	mega	1024^2	2^{20}	Mi	mebi	M	mega
1000^3	10^9	G	giga	1024^3	2^{30}	Gi	gibi	G	giga
1000^4	10^{12}	T	tera	1024^4	2^{40}	Ti	tebi	–	
1000^5	10^{15}	P	peta	1024^5	2^{50}	Pi	pebi	–	
1000^6	10^{18}	E	exa	1024^6	2^{60}	Ei	exbi	–	
1000^7	10^{21}	Z	zetta	1024^7	2^{70}	Zi	zebi	–	
1000^8	10^{24}	Y	yotta	1024^8	2^{80}	Yi	yobi	–	

Orders of Magnitude

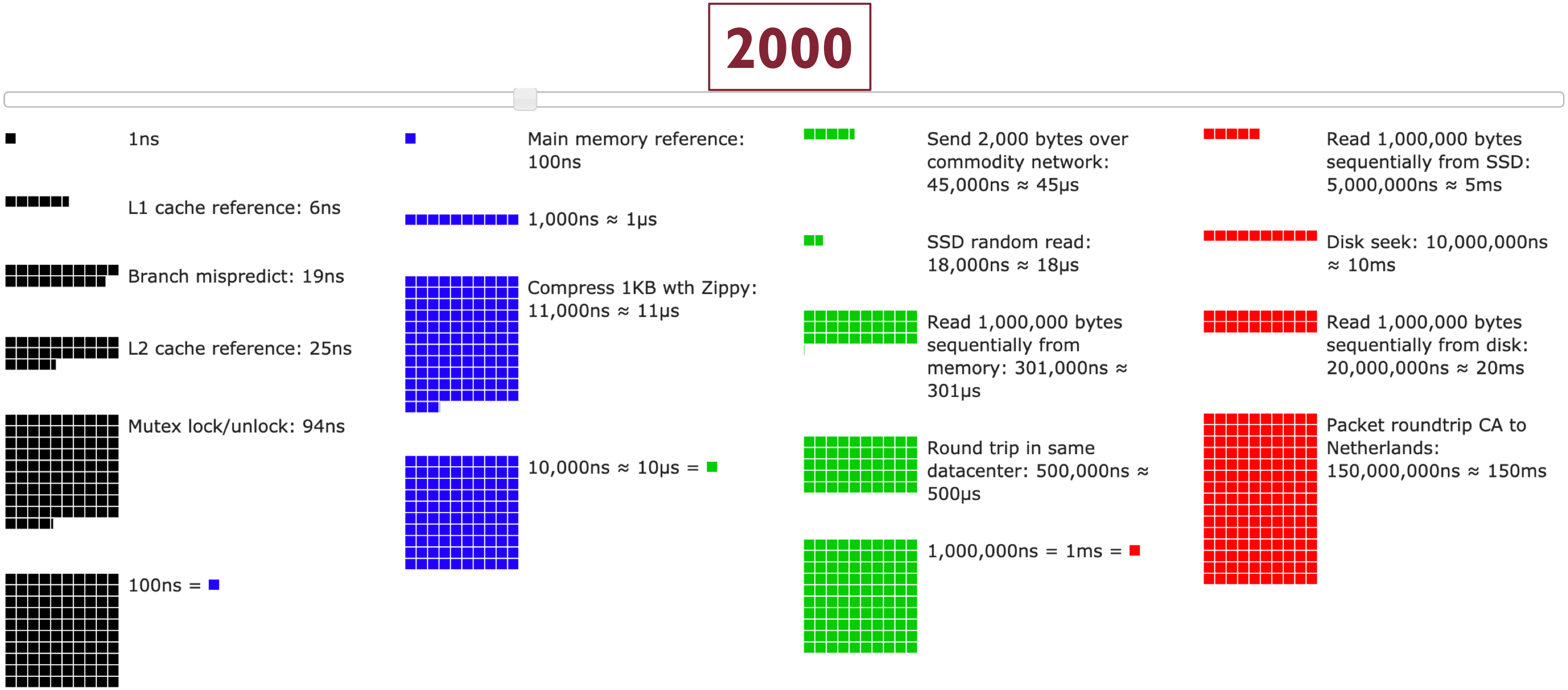
$10^0 = 1$

Orders of Magnitude



Numbers Every Computer Scientist Should Know

Colin Scott's updated and interactive version of Jeff Dean's previous one



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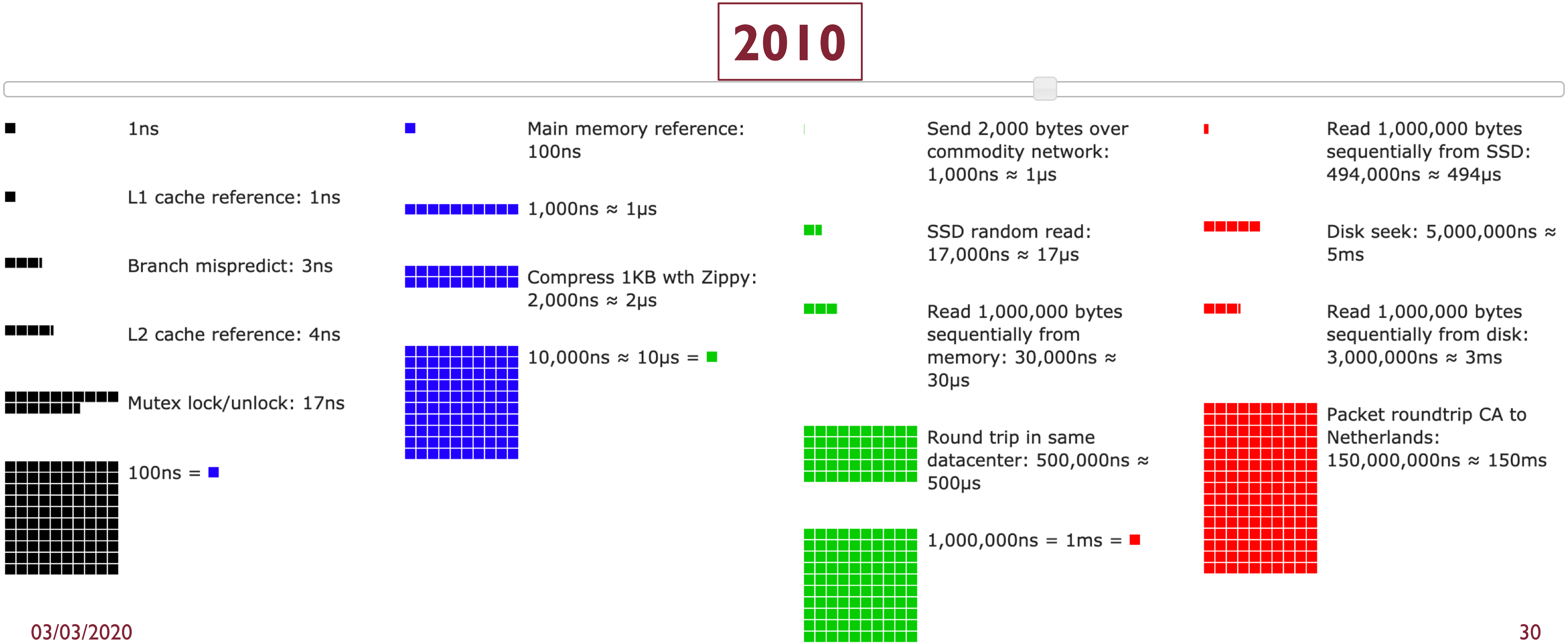

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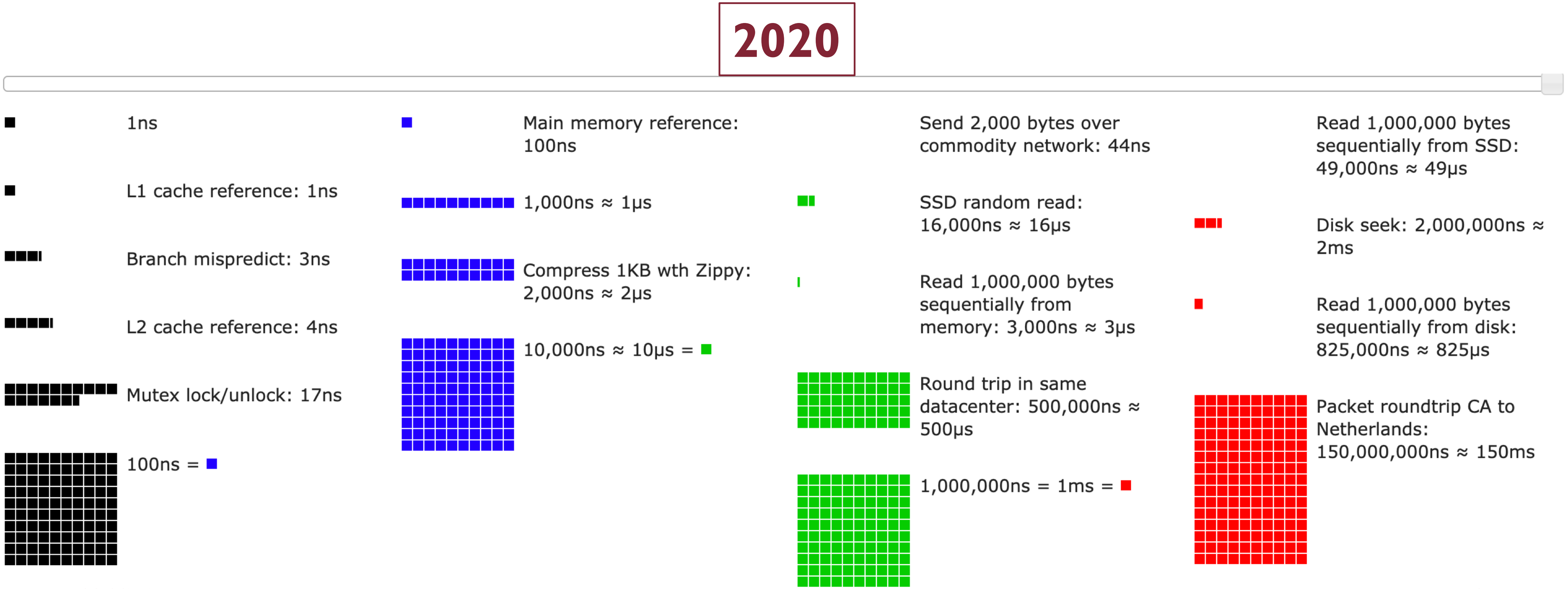
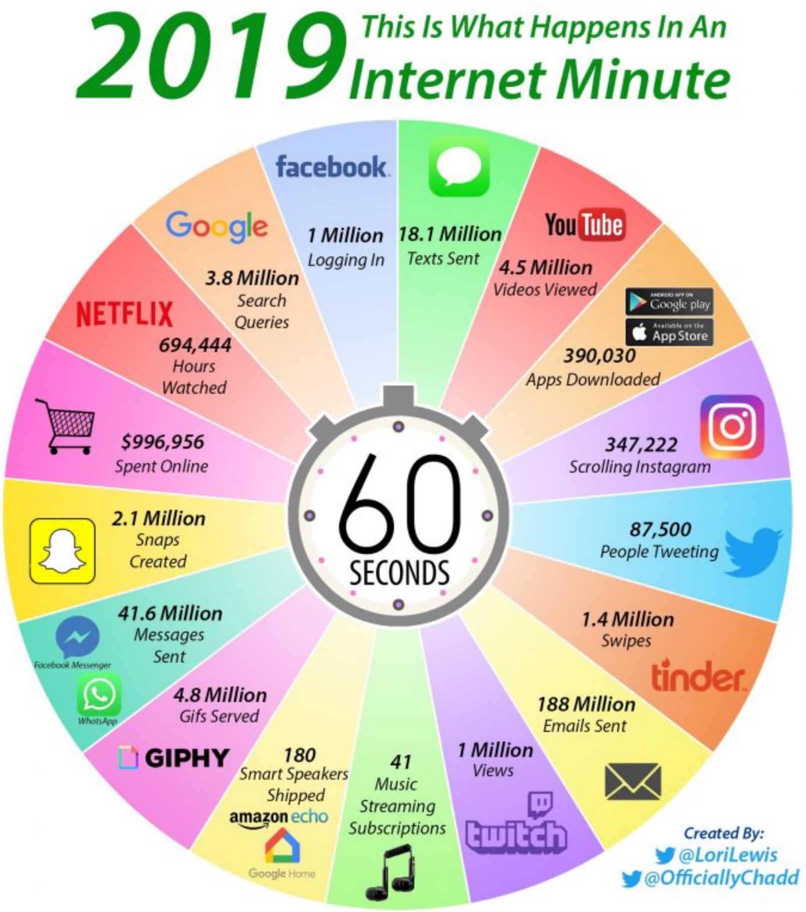


The Information Technology (IT) Revolution

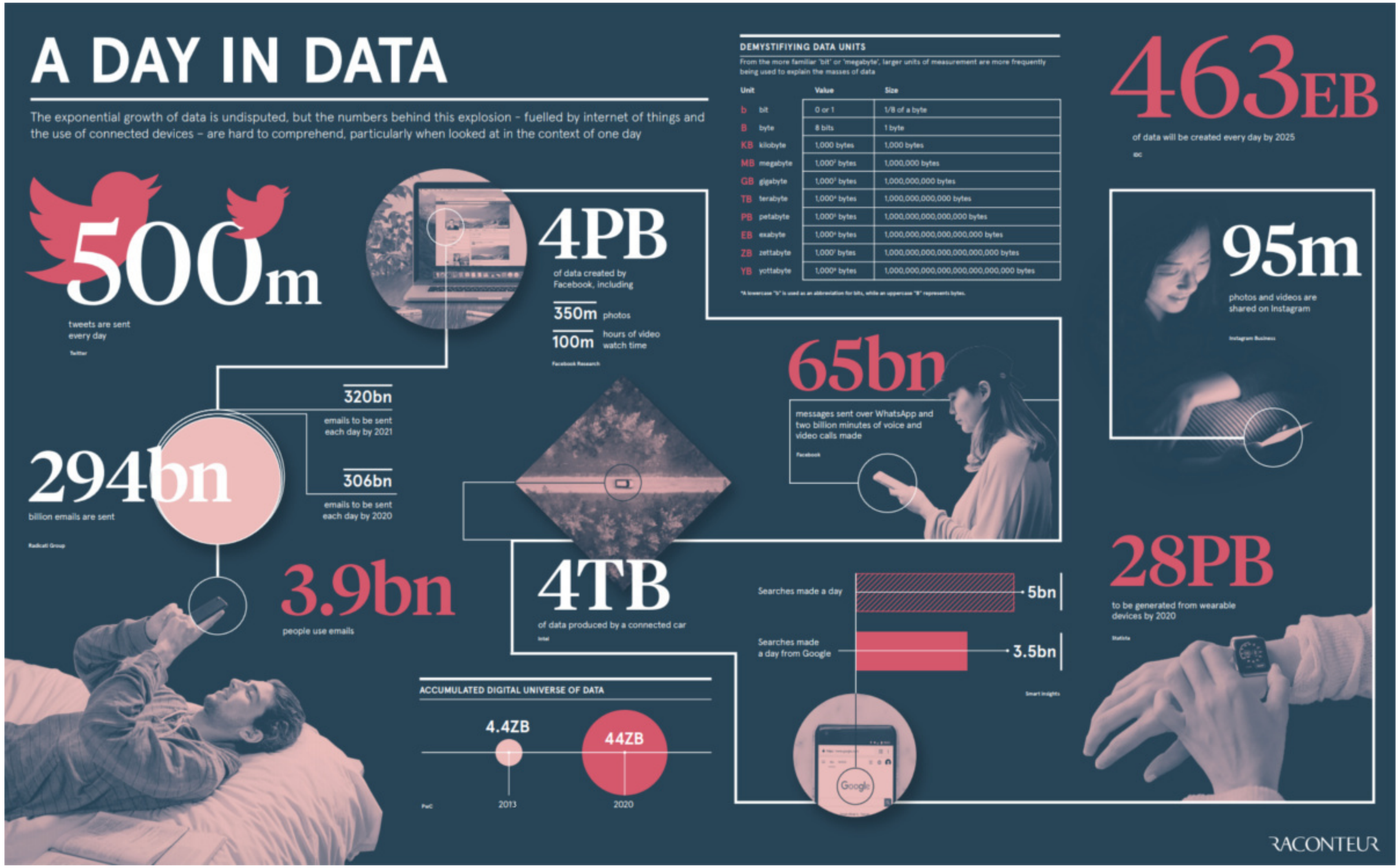
- Started almost 60 years ago and still rocketing
- Driven by:
    - Science/Engineering
    - Business
    - Society

What Happens on the Internet in 1 Minute?



https://www.dailyinfographic.com/worlds-internet-activity-for-one-minute

How Much Data is Generated Each Day?



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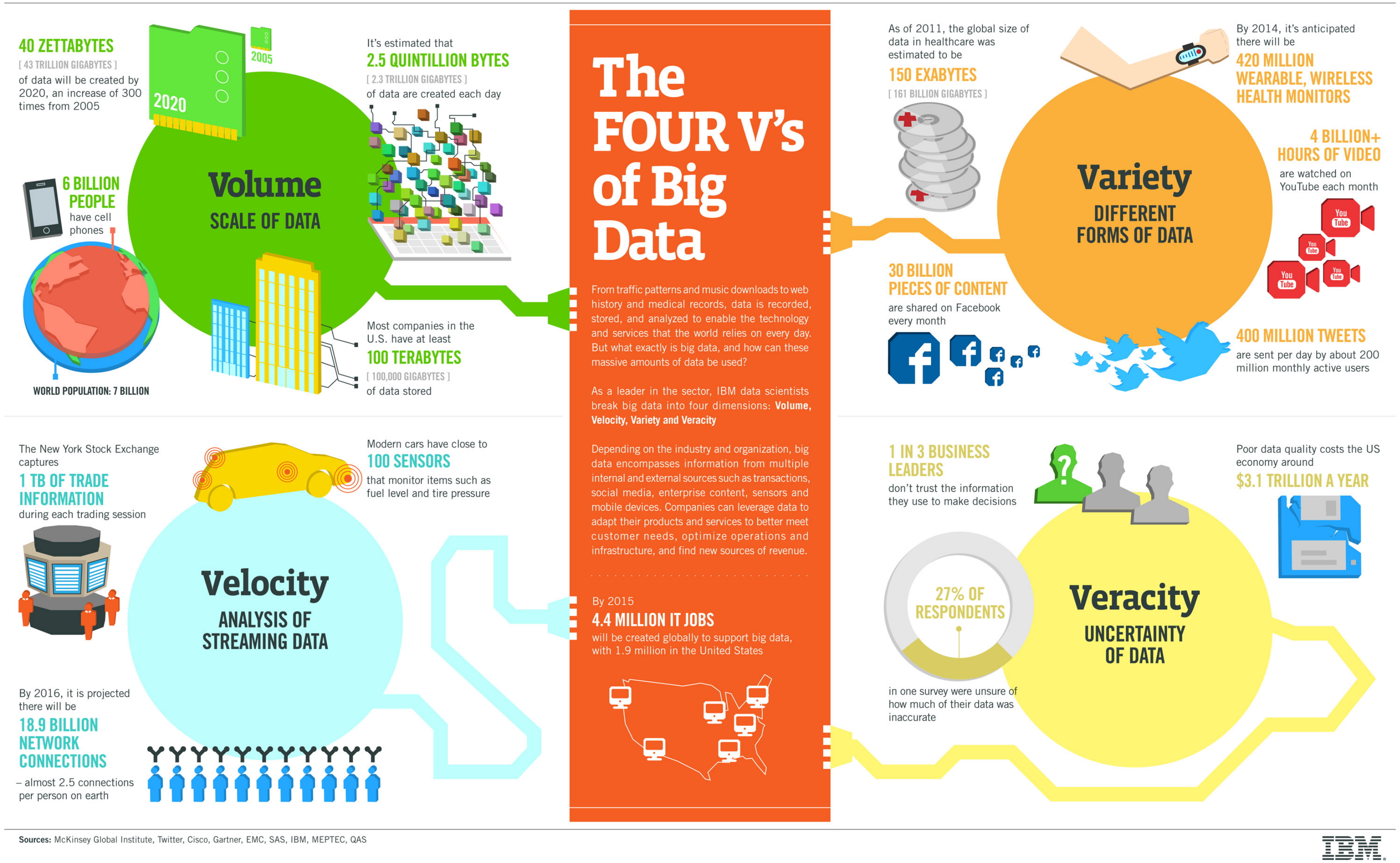
  - **Veracity** → reliability of the data used to drive decision processes

The 4 V's of Big Data



The Value of Big Data

- Extracting knowledge from data is incredibly valuable
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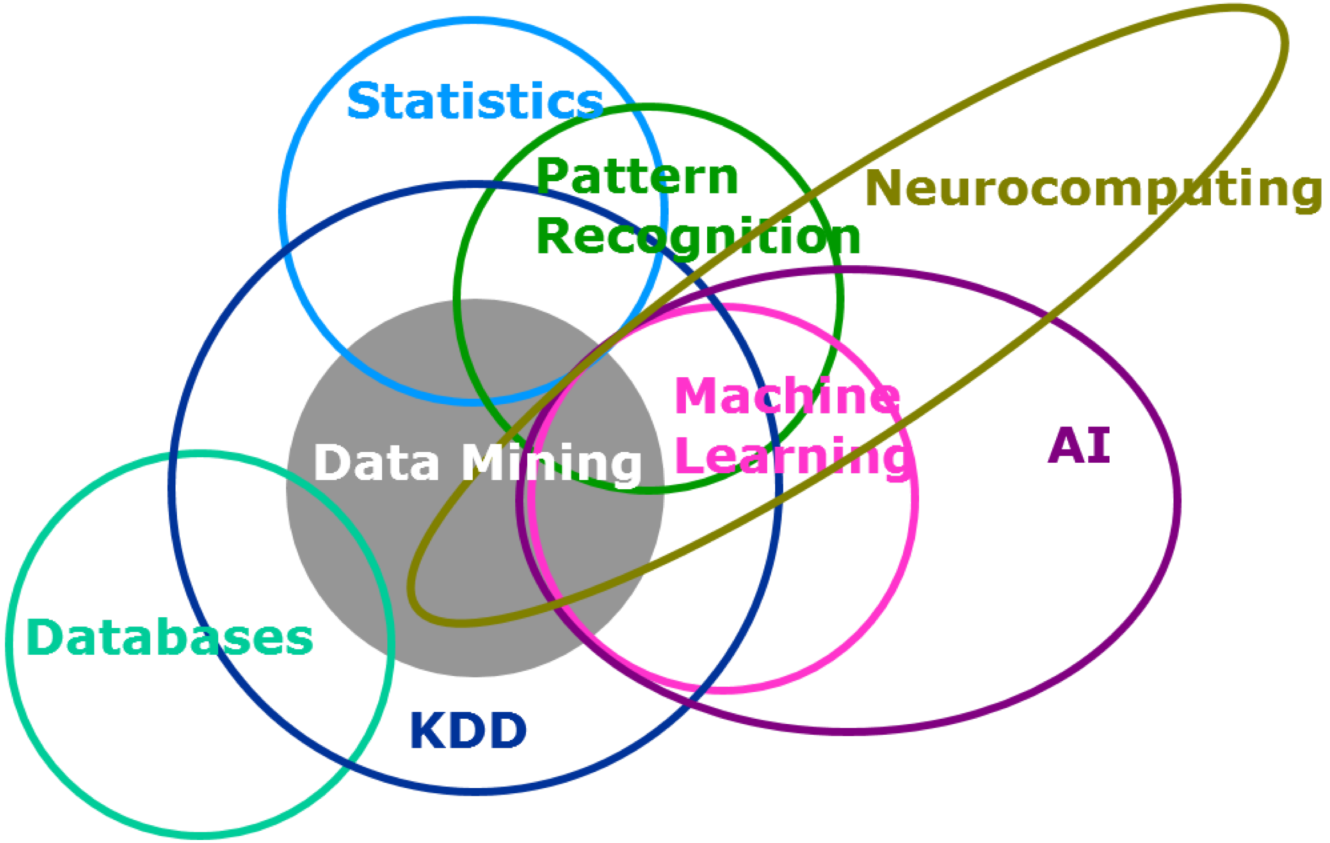
- Extracting knowledge from data is incredibly valuable
  - 5 out of 6 of the biggest companies in the world are "data companies"
- To get the most value out of it, data has to be:
  - **Stored**
  - **Managed**
  - **Analyzed**

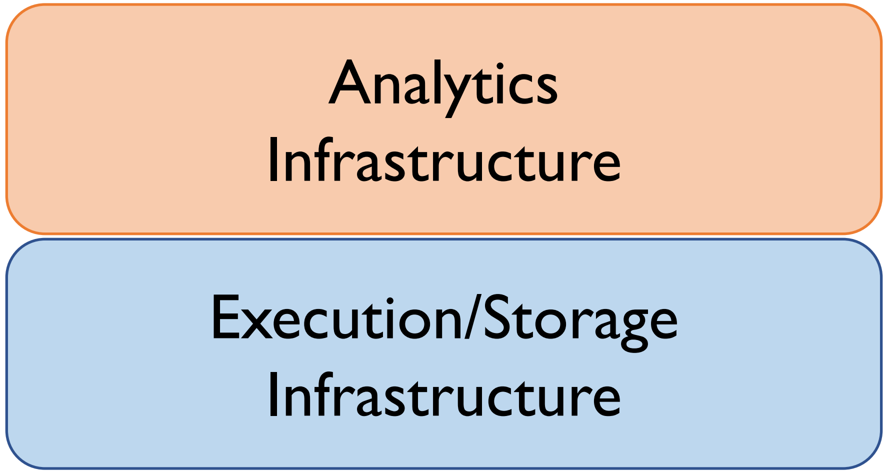
Big Data Analysis: Landscape



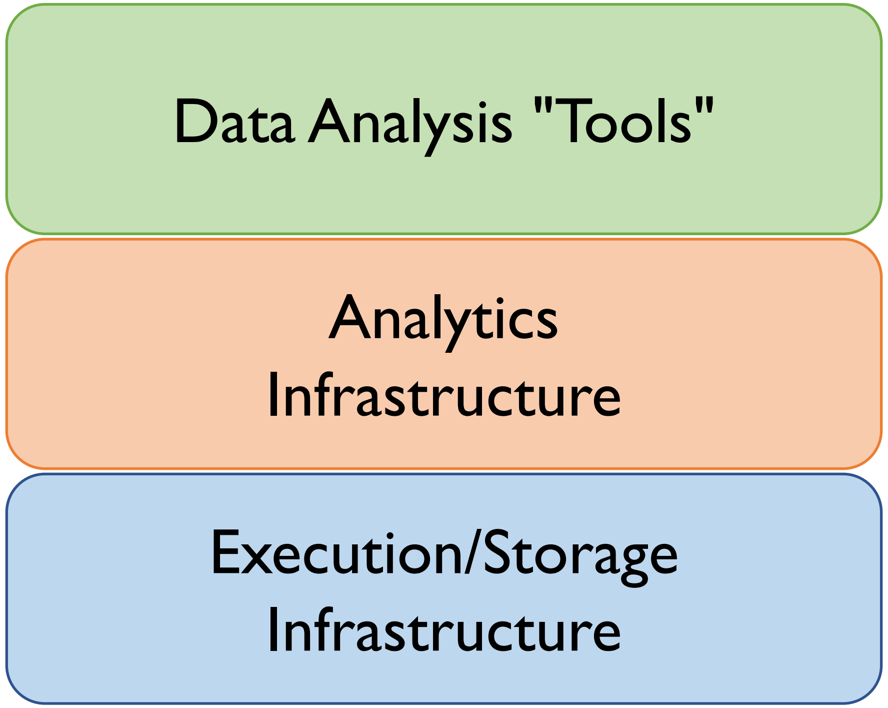
Big Data Analysis Stack

Execution/Storage
Infrastructure

Big Data Analysis Stack



Big Data Analysis Stack



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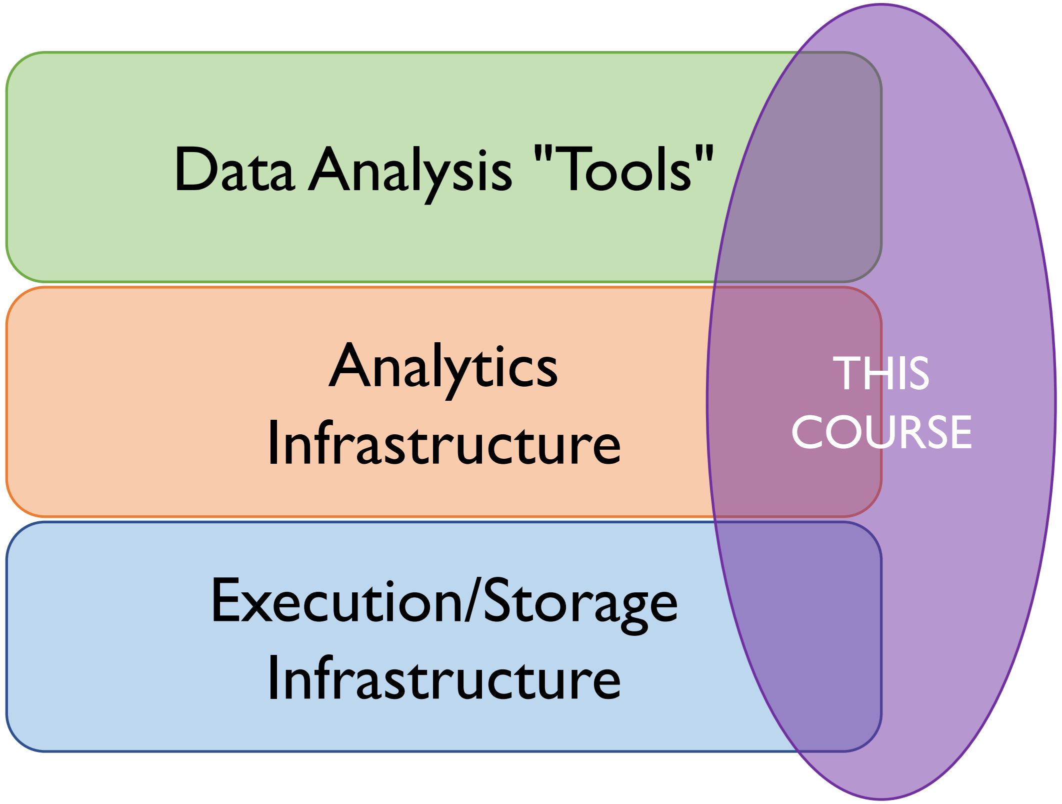


What Will We Learn?

- To extract knowledge from **different types of data**
  - High-dimensional
  - Unlabeled/Labeled
  - Graph-based
  - Infinite/never-ending streams

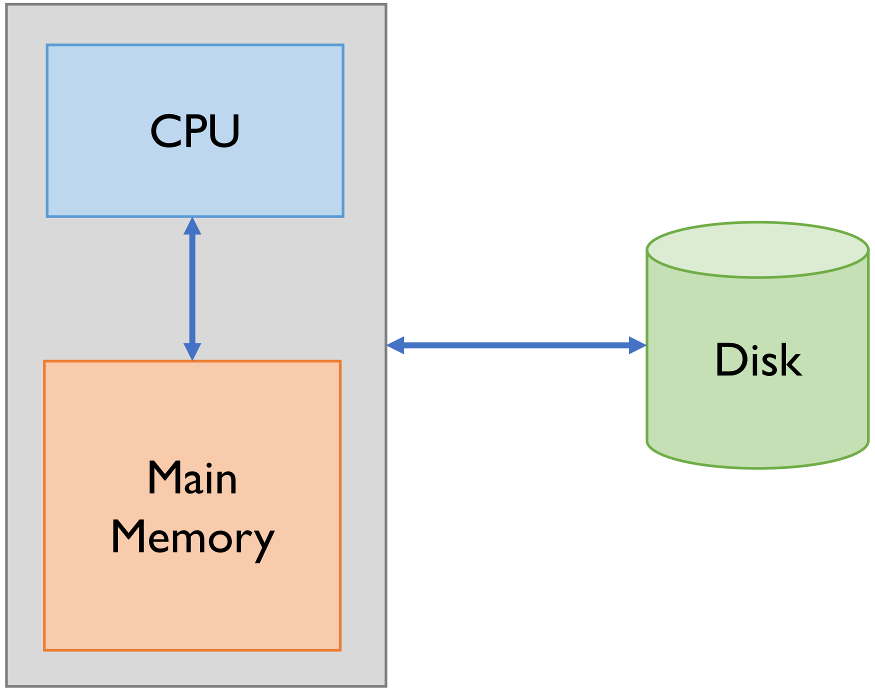
What Will We Learn?

- To use **different models of computation**
  - MapReduce
  - Streams and online algorithms
  - Single machine in-memory

What Will We Learn?

- To apply big data analysis to actually **solve real-world problems**
  - Clustering
  - Predictive Analysis
  - Recommender Systems
  - Graph Analysis
  - Stream Processing
  - …

The Single-Node Architecture



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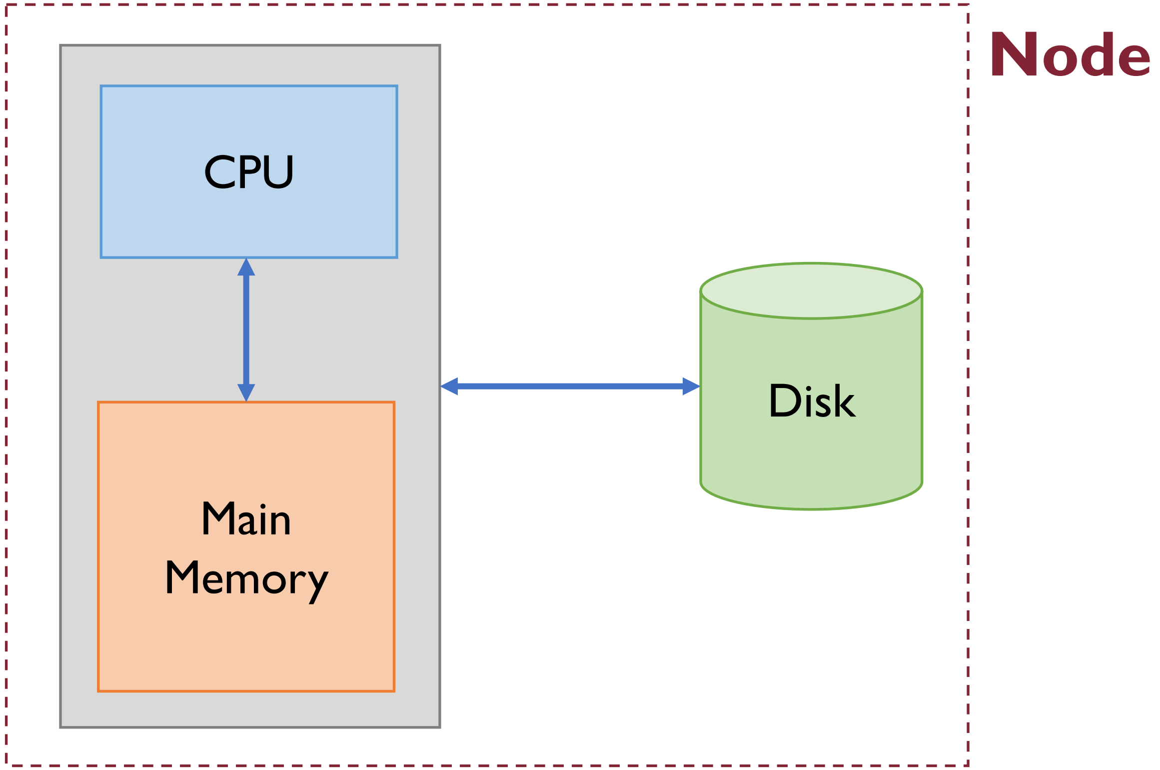
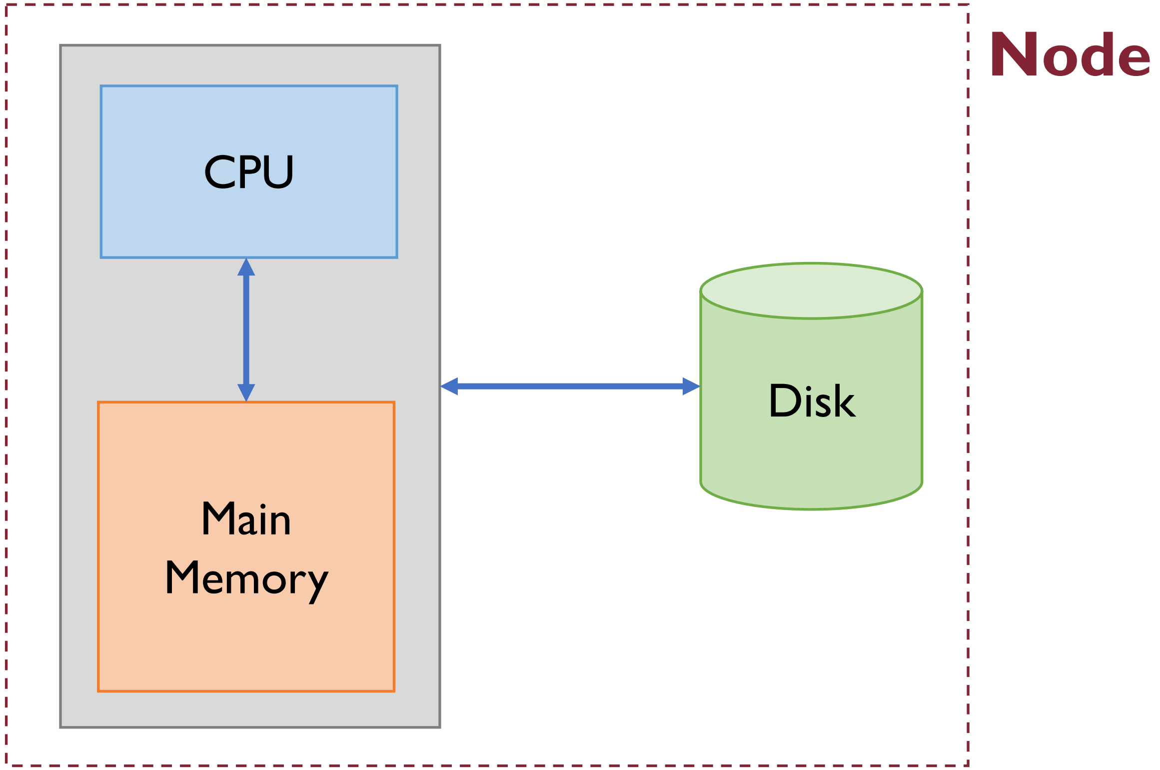


The Single-Node Architecture

Everything is ok as long as data fits entirely into main memory
(few accesses to the disk are still tolerated)



Example: Google (Toy) Index

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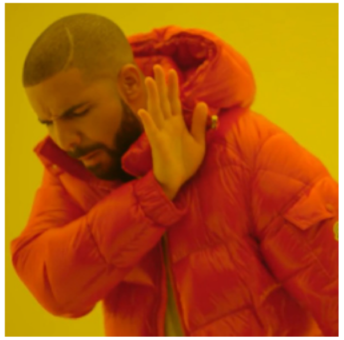

Main Memory

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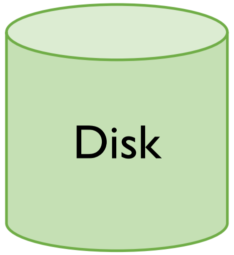

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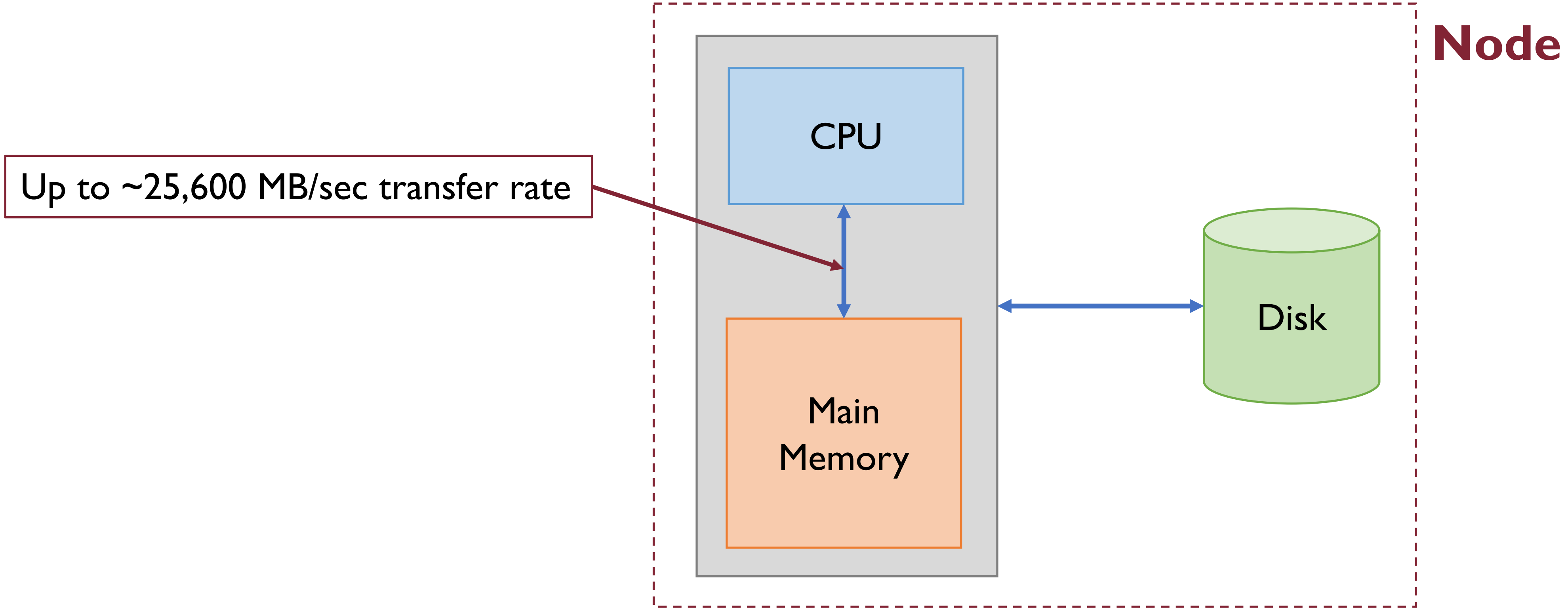

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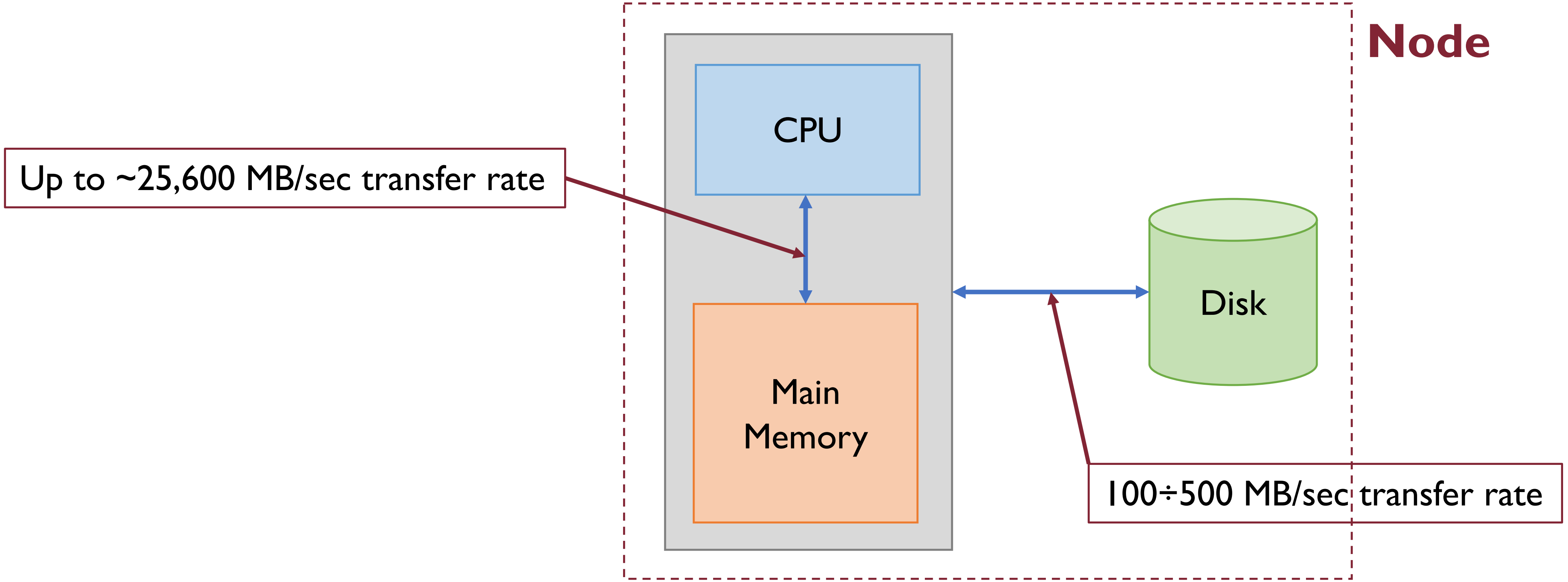

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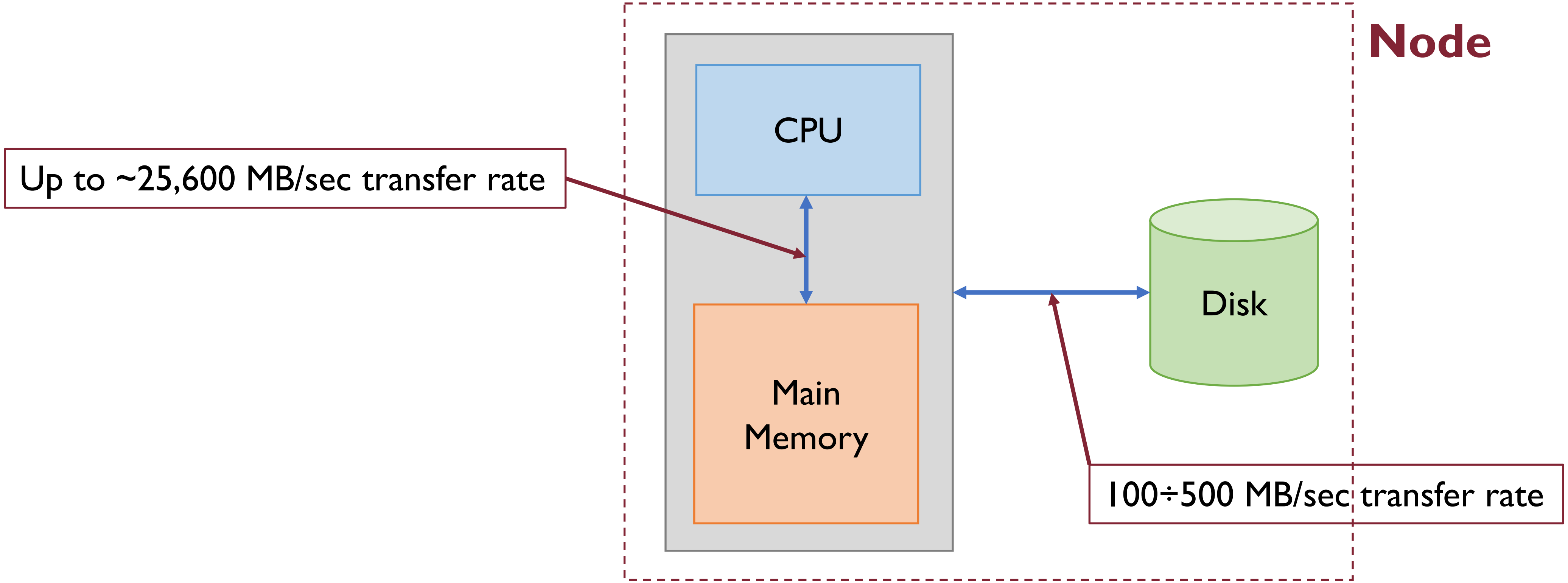

2 orders of magnitude difference between data transfer rate

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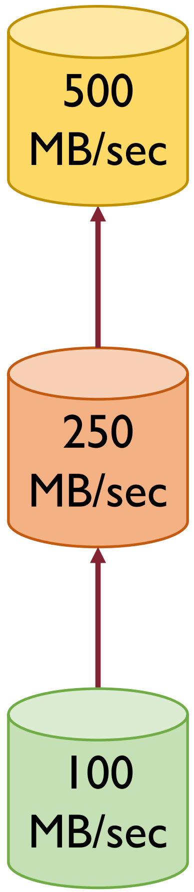
- More than half a day to just read the index, without even do any computation on it!
- Single-node architecture is clearly not enough here
  - Scaling Up vs. Scaling Out

Scaling Up/Vertical Scaling

- Buy a more performing disk (e.g., 250 or 500 MB/sec transfer rate)



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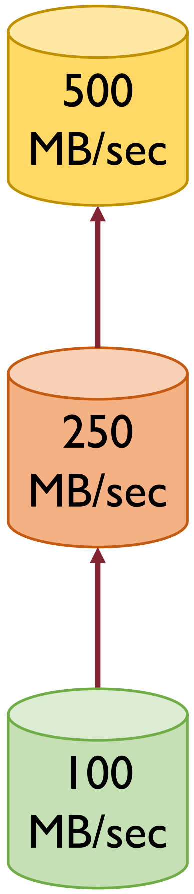
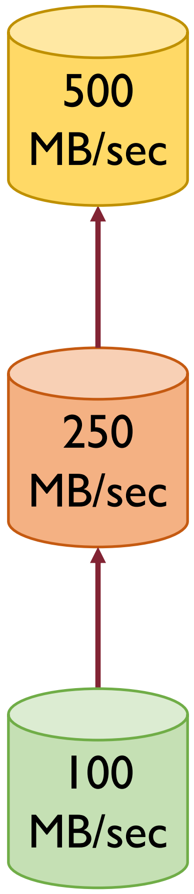


Scaling Up/Vertical Scaling

- Buy a more performing disk (e.g., 250 or 500 MB/sec transfer rate)
- **PRO**
  - Easiest solution
- **CON**
  - Improvement is physically-limited (e.g., 2.5x or 5x)
  - Expensive



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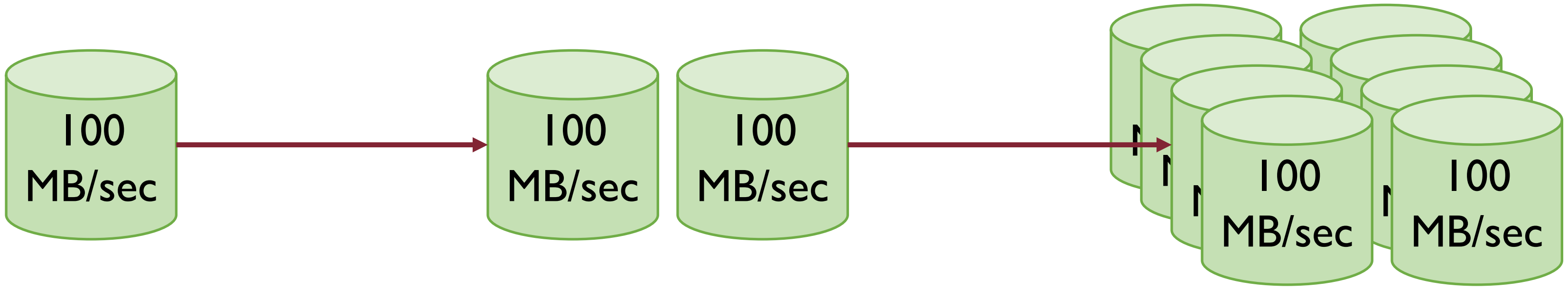

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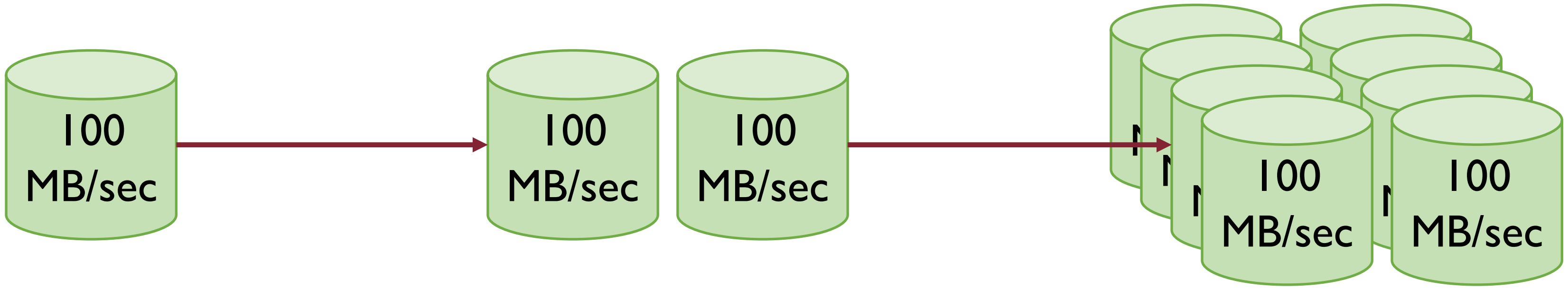

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- **PRO**
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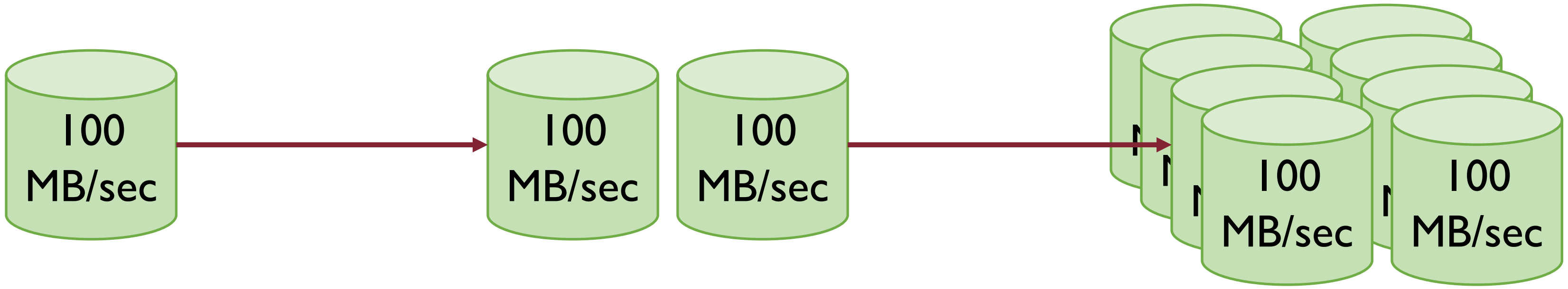
- **CON**
  - Extra overhead required to manage parallel work



Cluster Architecture

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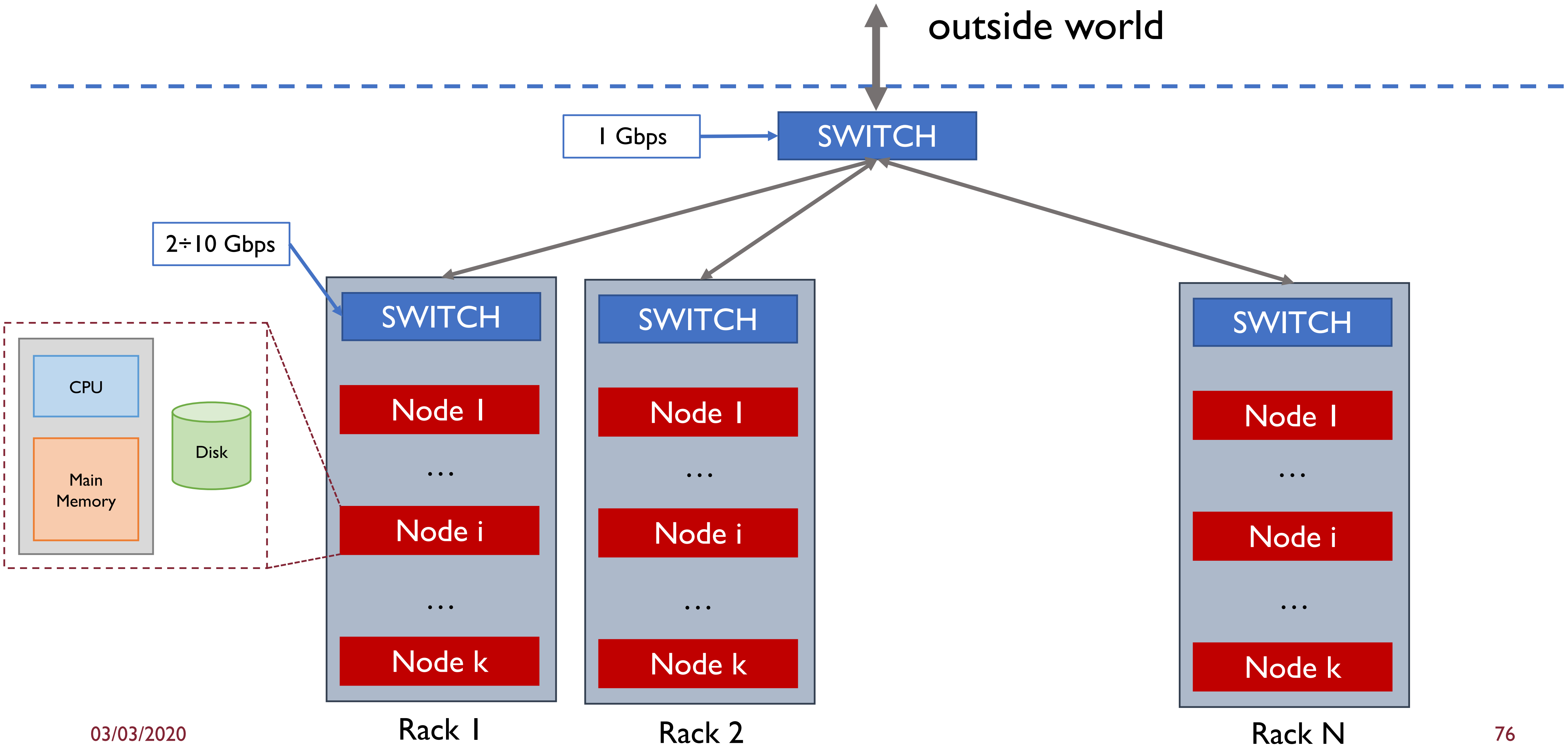
- A lot of **commodity nodes** communicating with each other
- Each group of **16÷64 nodes** is arranged in a so-called **rack**
- A **cluster** is made of multiple racks
- Network **switches** enabling node communication
  - 1 Gbps (inter-rack)
  - 2÷10 Gbps (intra-rack)

Cluster Architecture



Cluster Architecture: Challenges

- **3** major **challenges** posed by cluster architecture
  - Ensure **reliability** upon node failure
  - Minimize **network communication** bottleneck
  - Ease **distributed programming** model

Challenge: Node Failure

- Suppose we have a cluster of N nodes

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- Associate with each node a random variable $X_{i,t}$
  - $X_{i,t}$ ~ Bernoulli(p) outputs 1 (failure) with probability p = 0.001 and 0 (working) with probability (1-p) = 0.999
  - Assume for semplicity p is the same for all nodes and independent from each other

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Under the (simplified) assumption that $X_{i,t}$ are all i.i.d.

$$\boxed{T = X_{1,t} + X_{2,t} + \ldots + X_{N,t}}$$

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$$E[T] = Np$$

Challenge: Node Failure

- A single-node failure on a day may be a quite a rare event (0.1% chance)

Challenge: Node Failure

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Q1: How to make data and computation resilient to node failures?

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Q2: How to minimize data tranfers so as to reduce network communications?

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Q3: How to implement algorithms which take advantage of the distributed infrastructure without worrying about its complexities?

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- There is the need for new "tools" which allow storing, managing, and analyzing big data painlessly