Big Data Computing

Master's Degree in Computer Science

2022-2023

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Sapienza Università di Roma

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SAPIENZA
UNIVERSITÀ DI ROMA

Who Am I?

Who Am I?

UniPI
(1999-2005)

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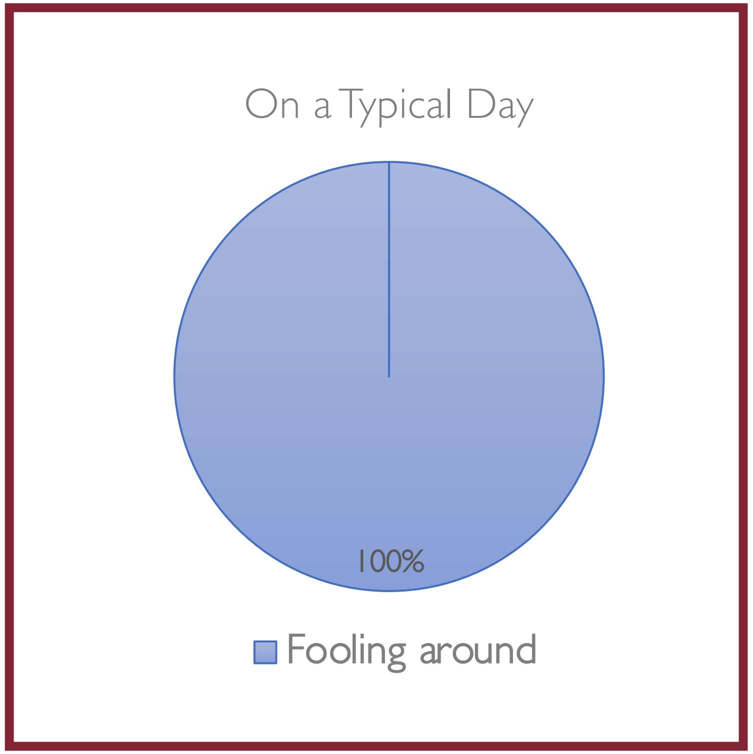

Expectation

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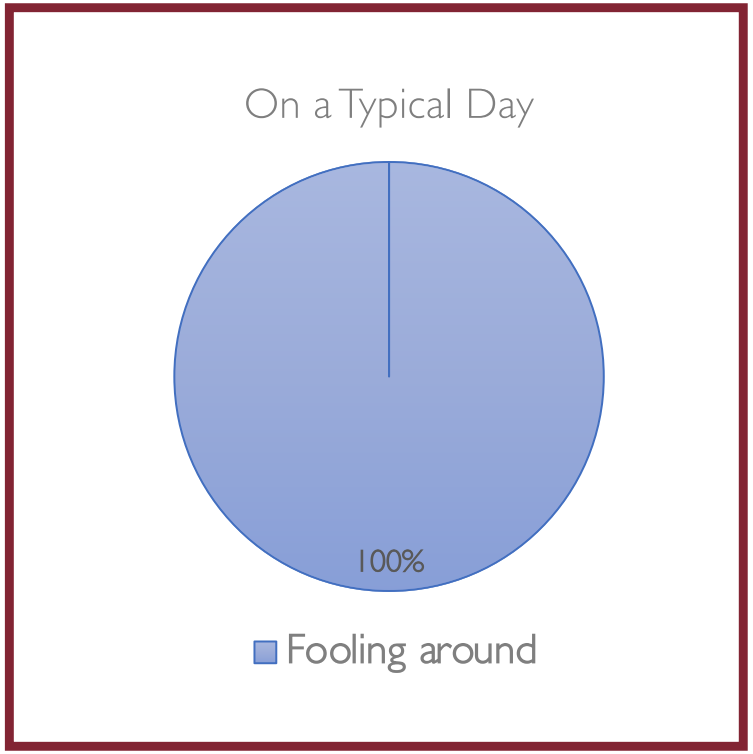
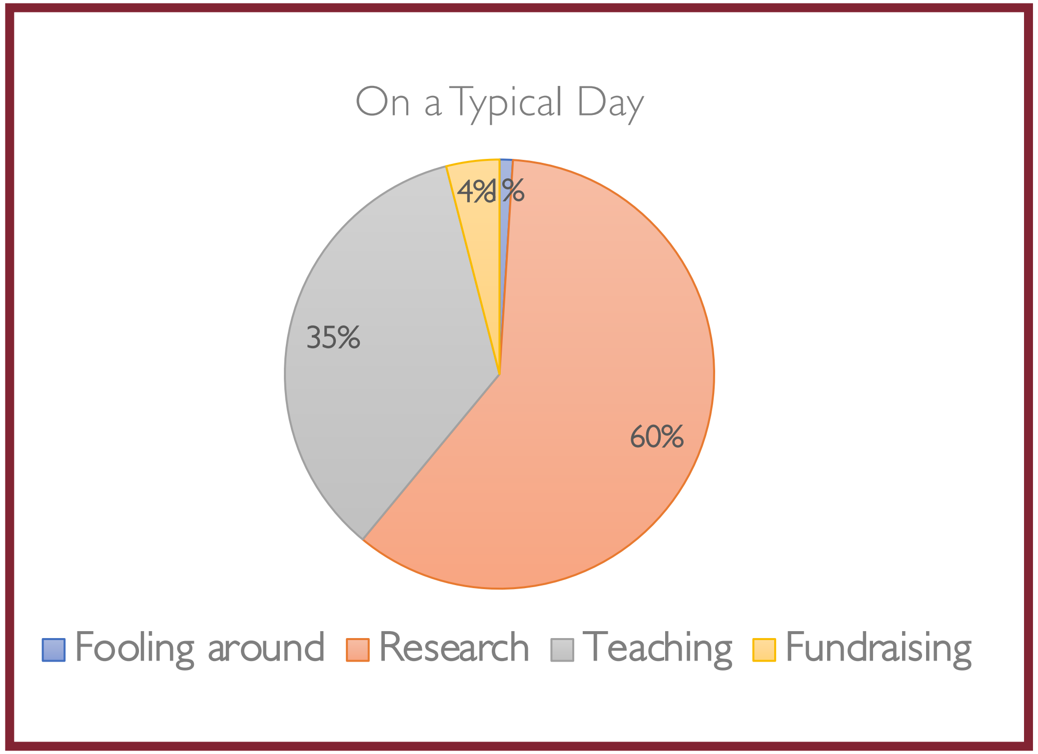


Expectation

vs.



Reality

Research On What?

HERCOLE Lab

Research On What?

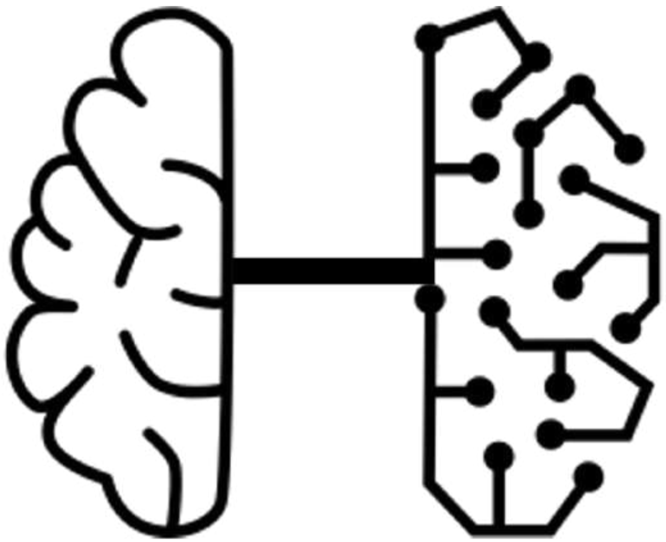
Human-Explainable

HERCOLE Lab

Research On What?

Robust

Human-Explainable



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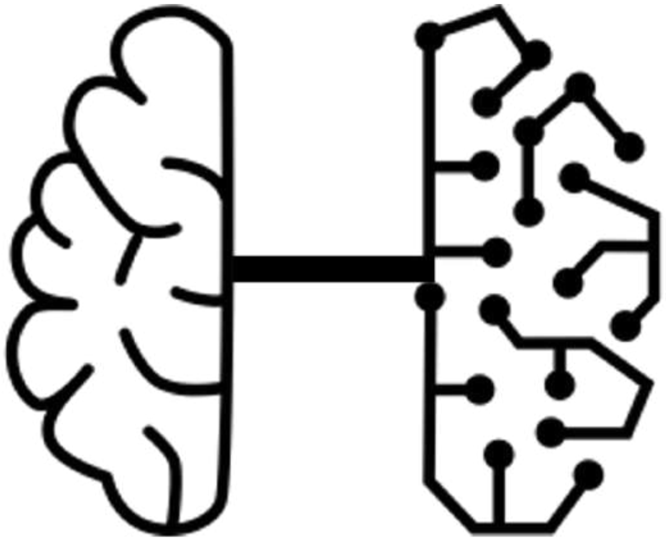

COllaborative

HERCOLE Lab

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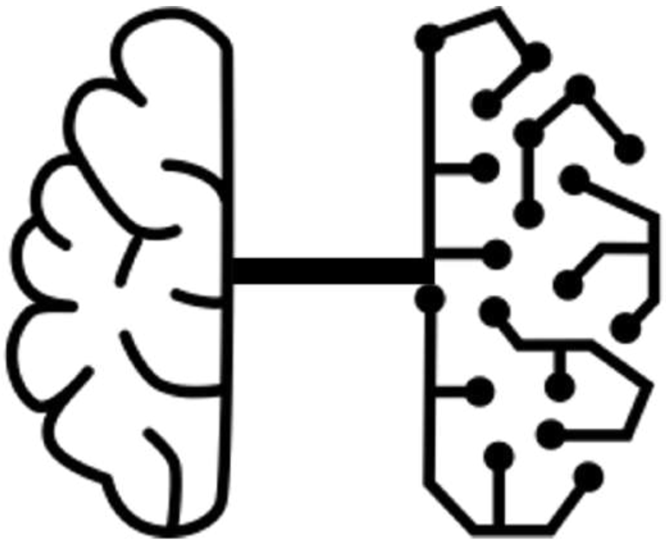

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LEarning

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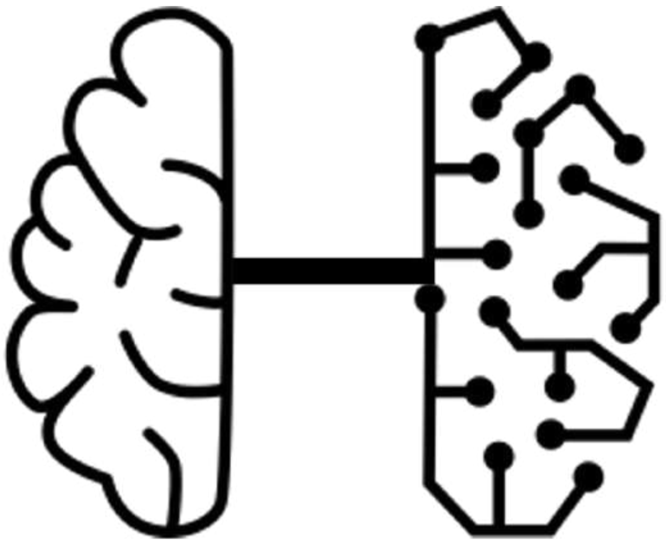

HERCOLE Lab

Check out the lab's [home page](#)

(still under construction, sic!)

Research On What?

Sounds cool?

HERCOLE Lab

Meanwhile you can follow us on Twitter @HercoleLab

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- Class schedule:
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- Office hours:
  - Drop me a message to ask for a meeting online (Google Meet or Zoom) or in-person at my office (Room 106 @ Viale Regina Elena, 295 – 1st Floor, Building E)

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=16079

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  - Along with other resources (e.g., suggested readings/books) if needed
- Moodle will be used mainly to communicate via the "News" forum
  - And for project submission (more on this later…)

Please, remember to enroll using the Moodle link above!

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- <u>Prerequisites</u>:
  - 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

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  - Other questions on all the topics covered in classes may be asked

Questions?

Outline of the Course

Big Data Phenomenon

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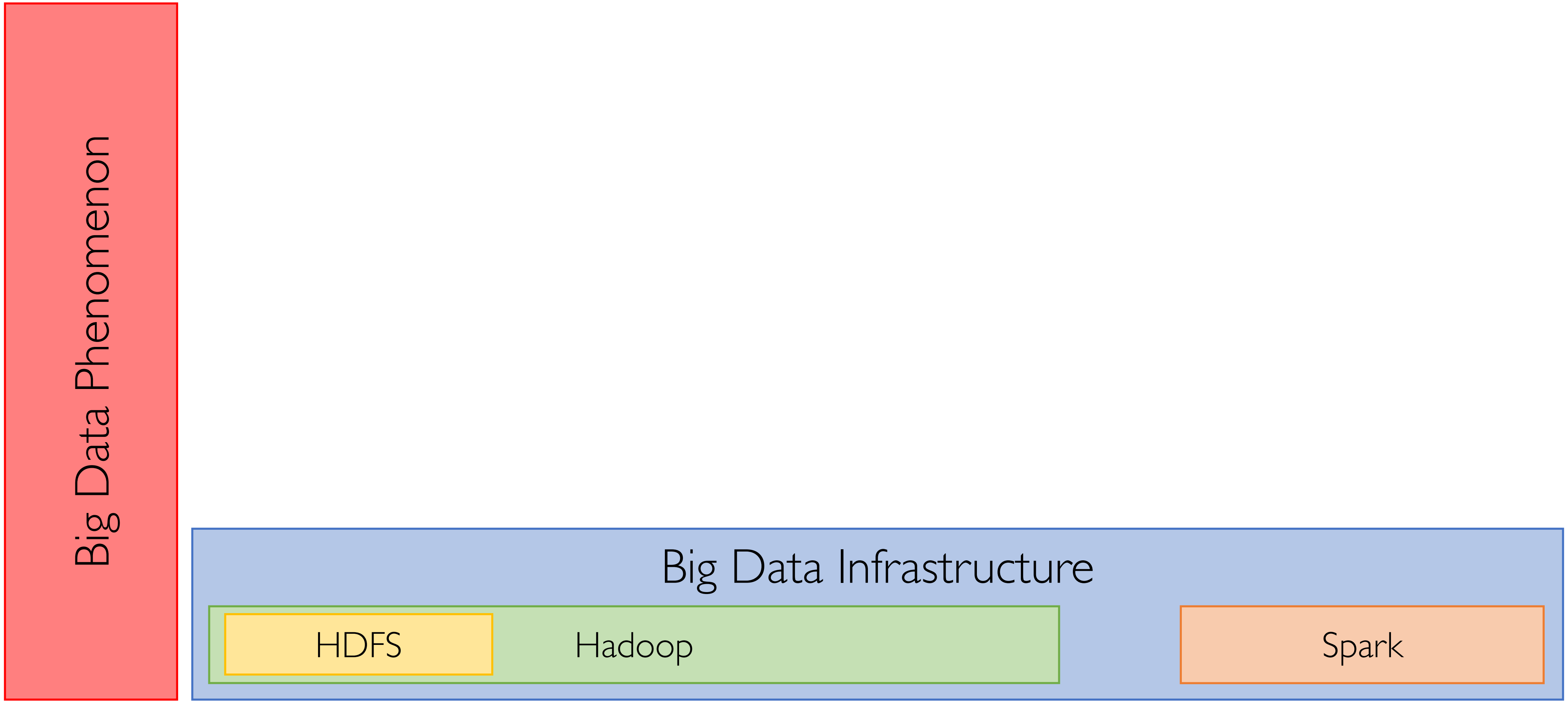
Big Data Infrastructure

Outline of the Course



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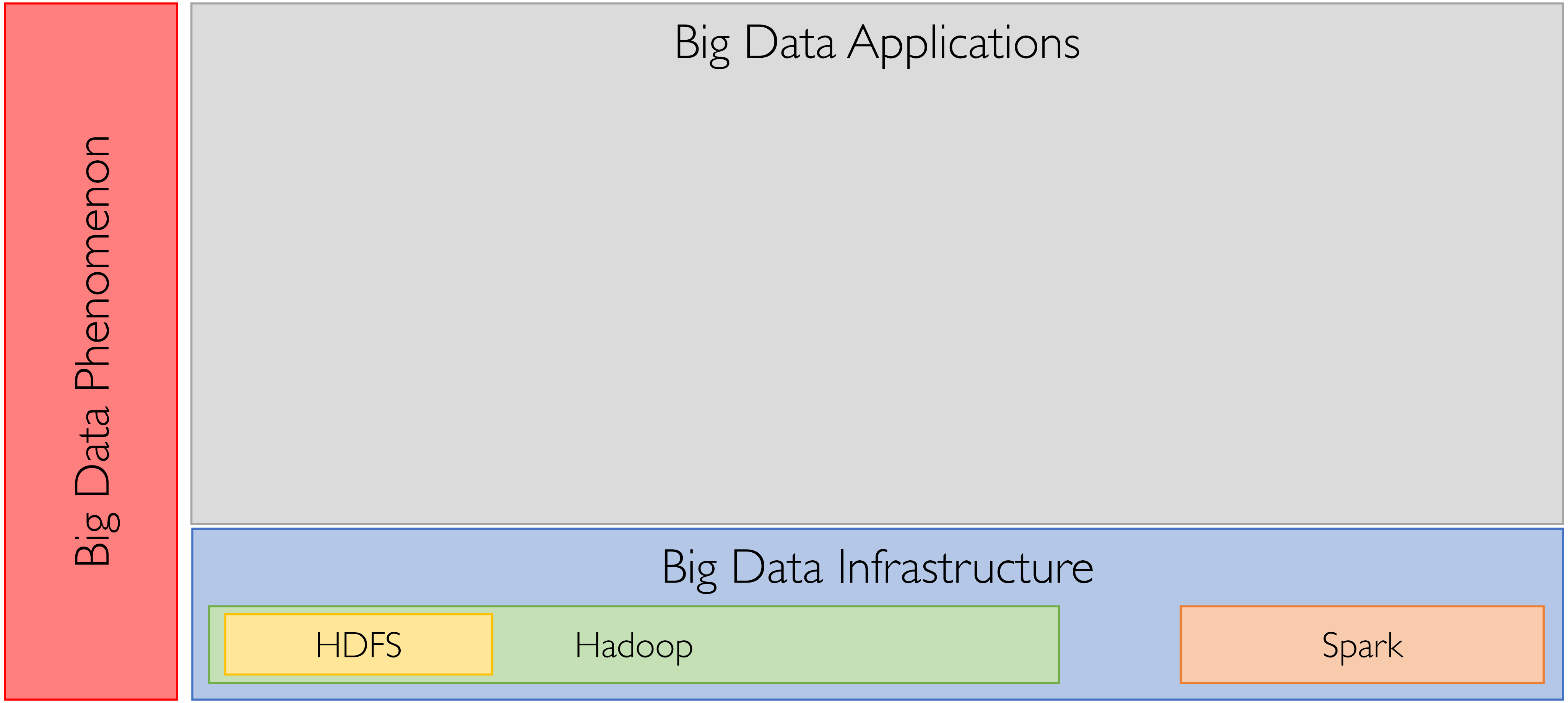

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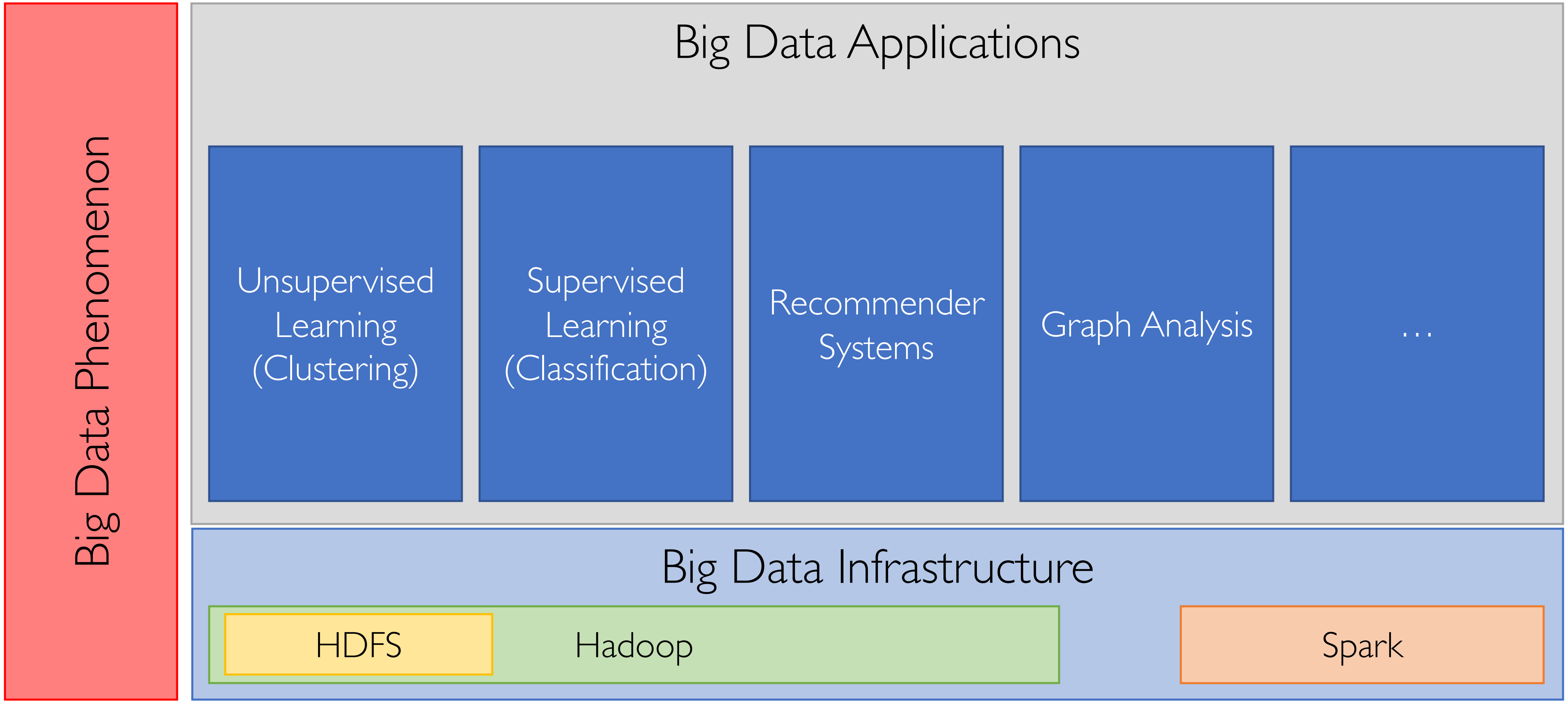

Let's Get Started!

What the He…ck is That?

source: Wikipedia

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

Almost 55 Years Have Passed…

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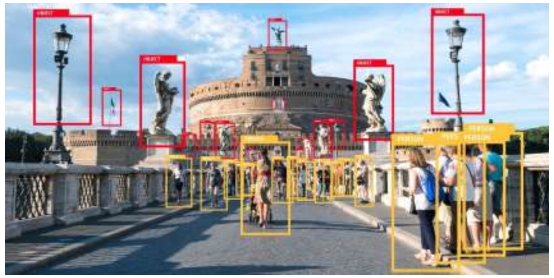






AGC vs. Our Smartphone

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

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

A Side Note on Units

Prefixes for multiples of bits (bit) or bytes (B)

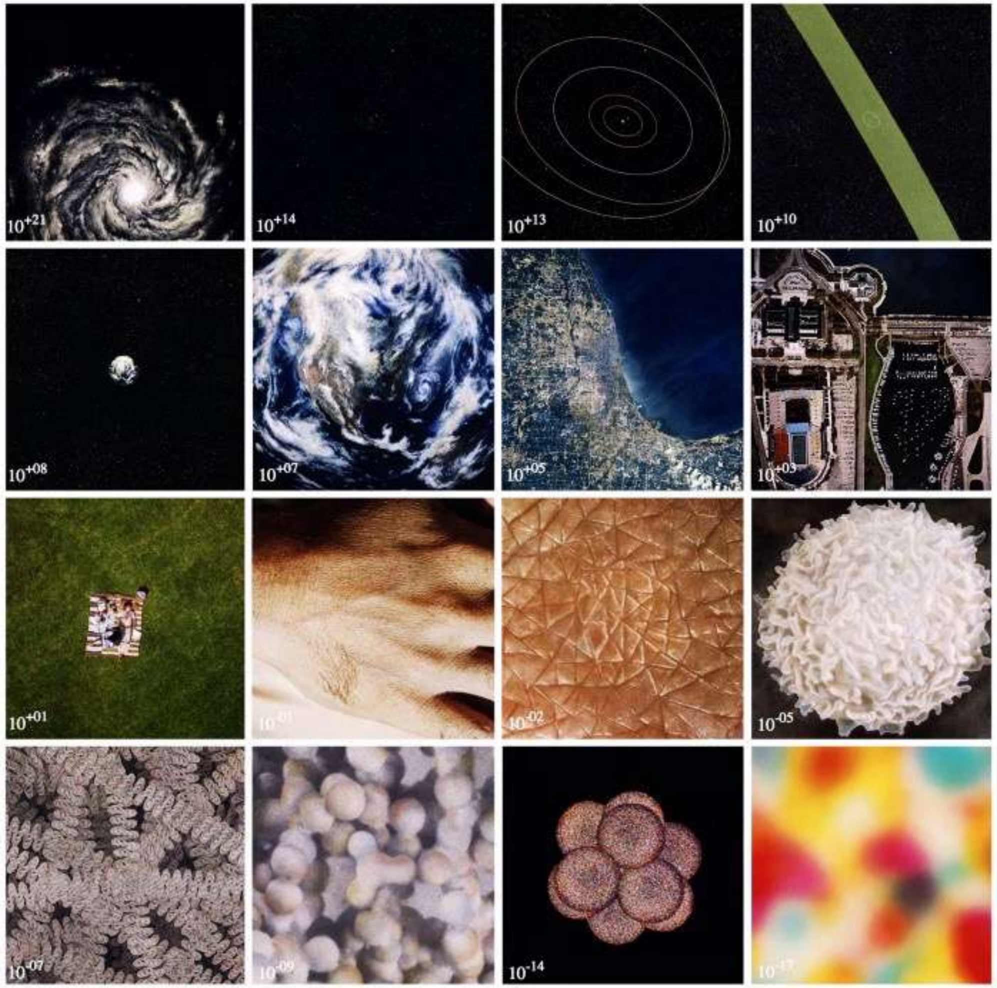
Decimal				Binary					
Value		SI		Value		IEC		JEDEC	
1000	10^3	k	kilo	1024	2^{10}	Ki	kibi	K	kilo
1000^2	10^6	M	mega	1024^2	2^{20}	Mi	mebi	M	mega
1000^3	10^9	G	giga	1024^3	2^{30}	Gi	gibi	G	giga
1000^4	10^{12}	T	tera	1024^4	2^{40}	Ti	tebi	–	
1000^5	10^{15}	P	peta	1024^5	2^{50}	Pi	pebi	–	
1000^6	10^{18}	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

$10^0 = 1$

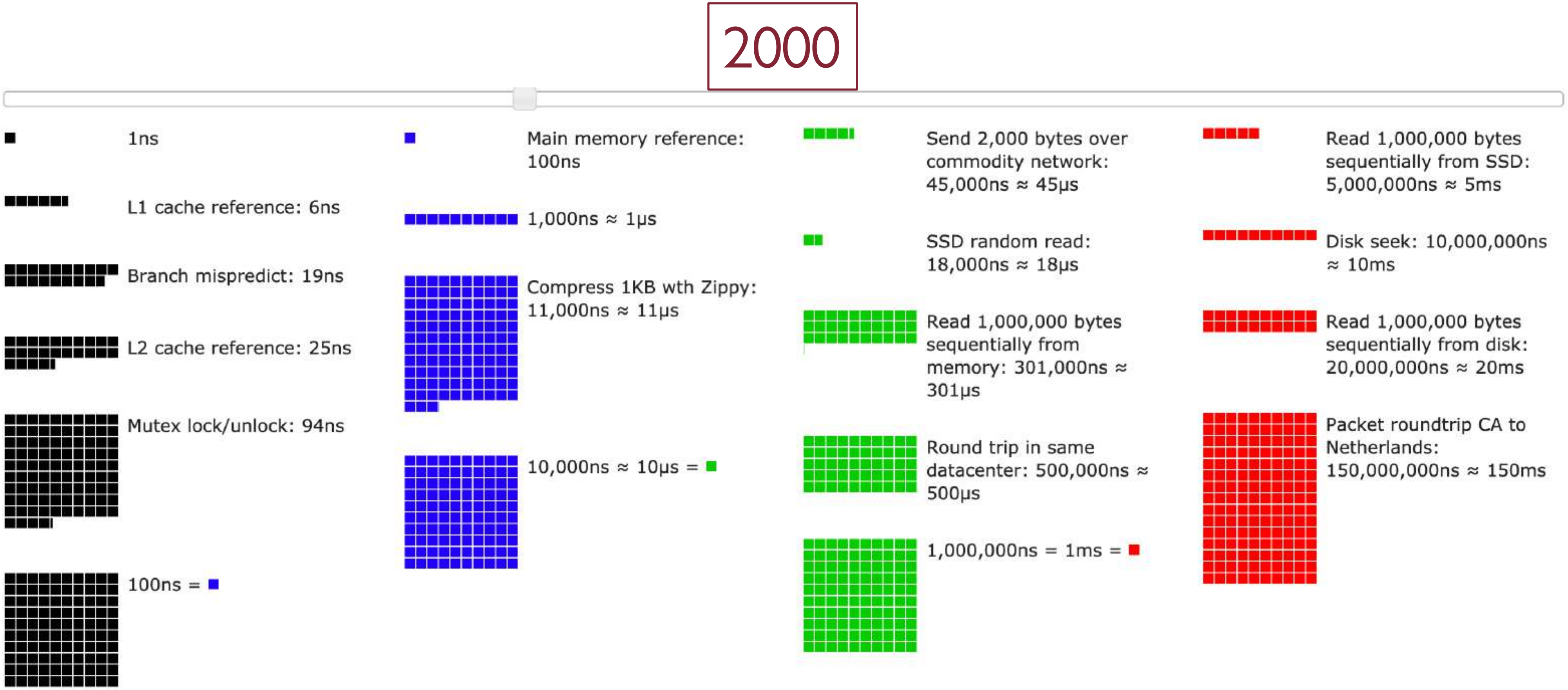
source: https://www.youtube.com/watch?v=Ww4gYNrOkkg

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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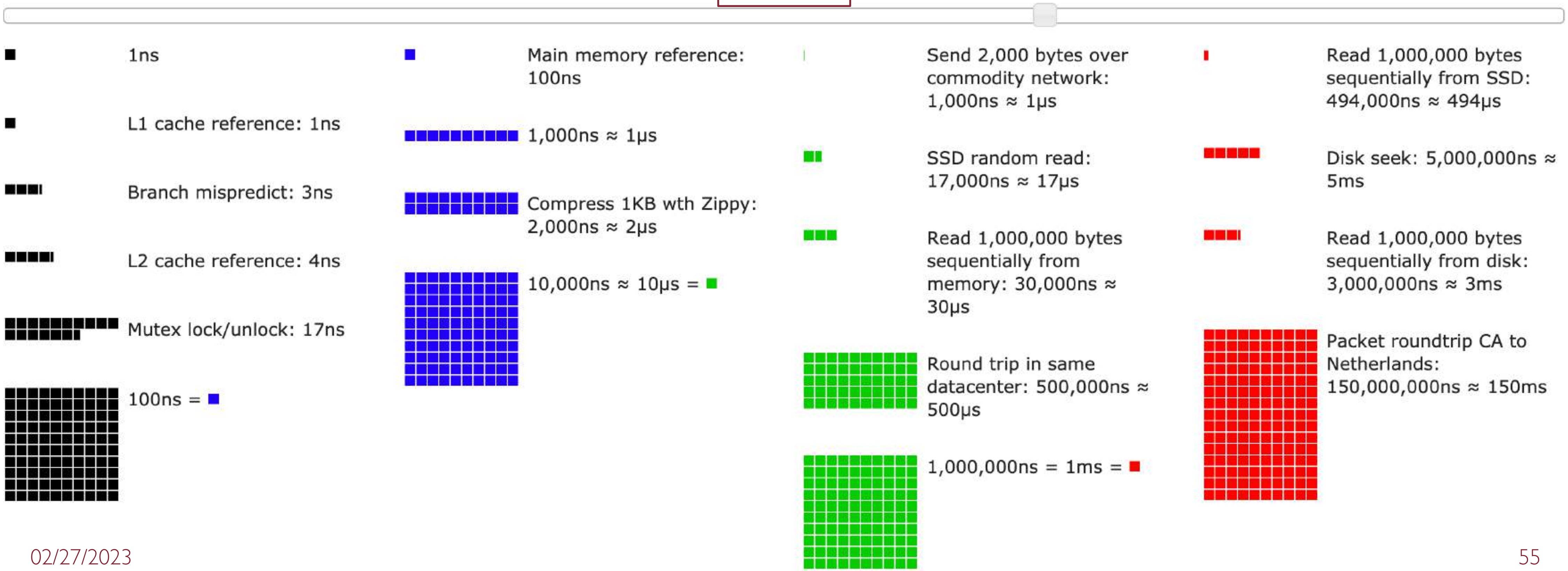
2010



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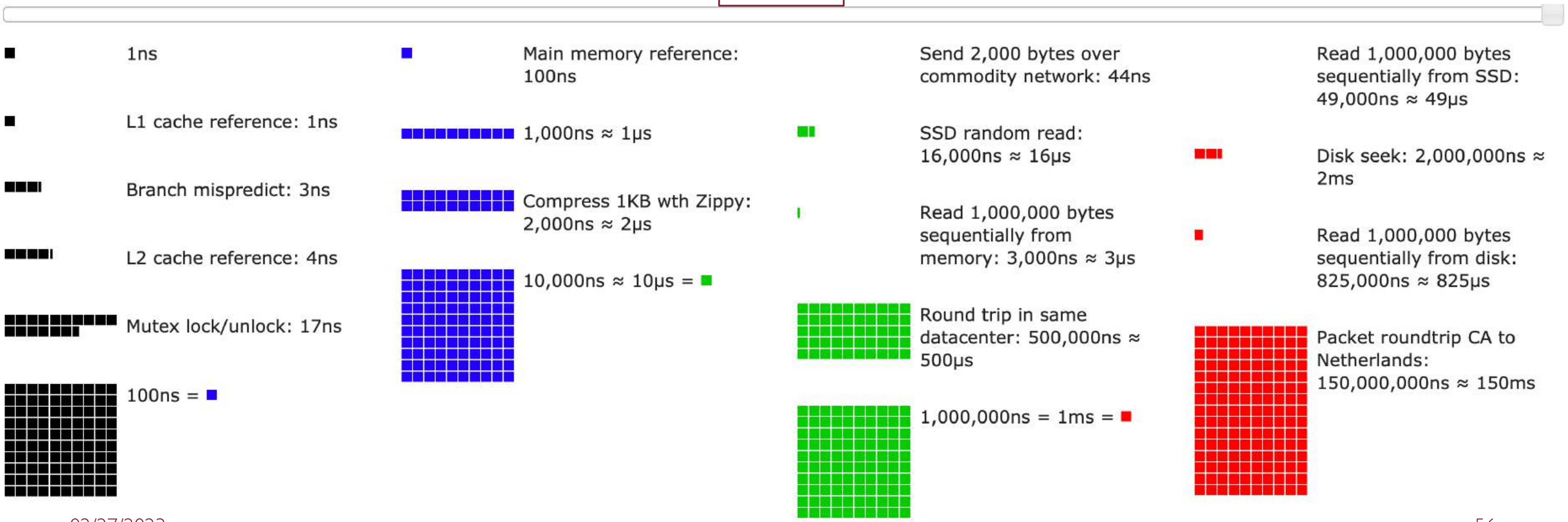
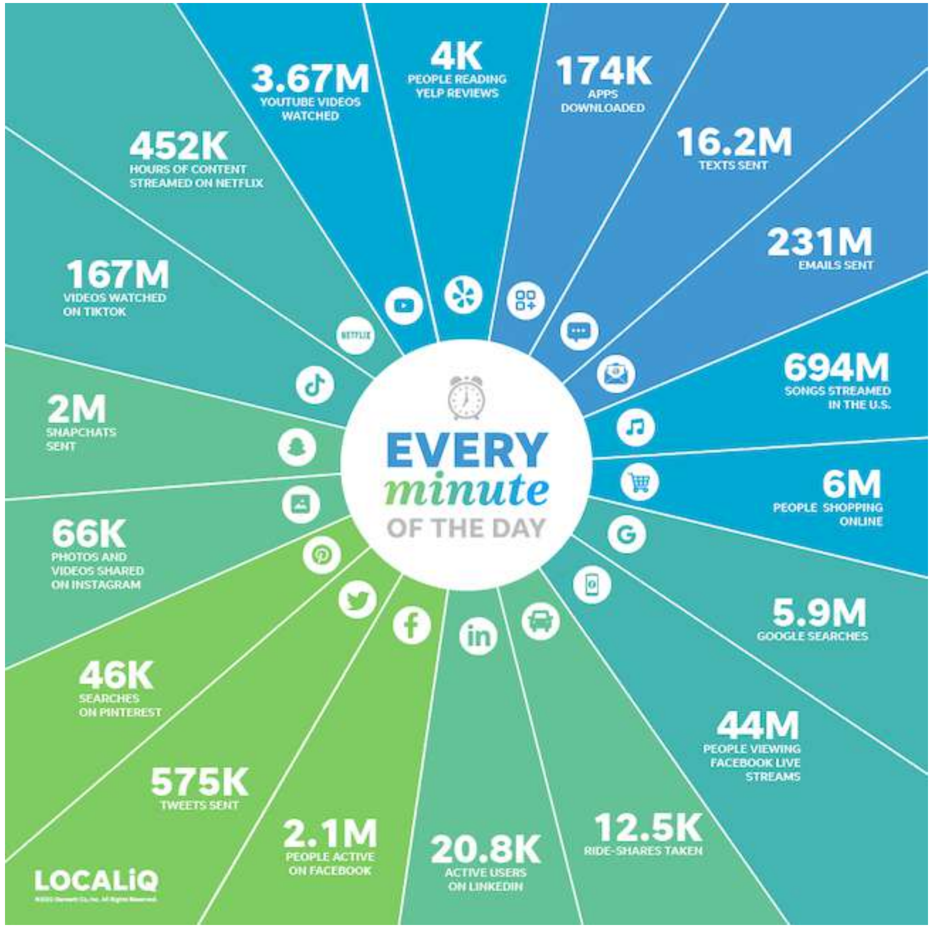
2020



The Information Technology (IT) Revolution

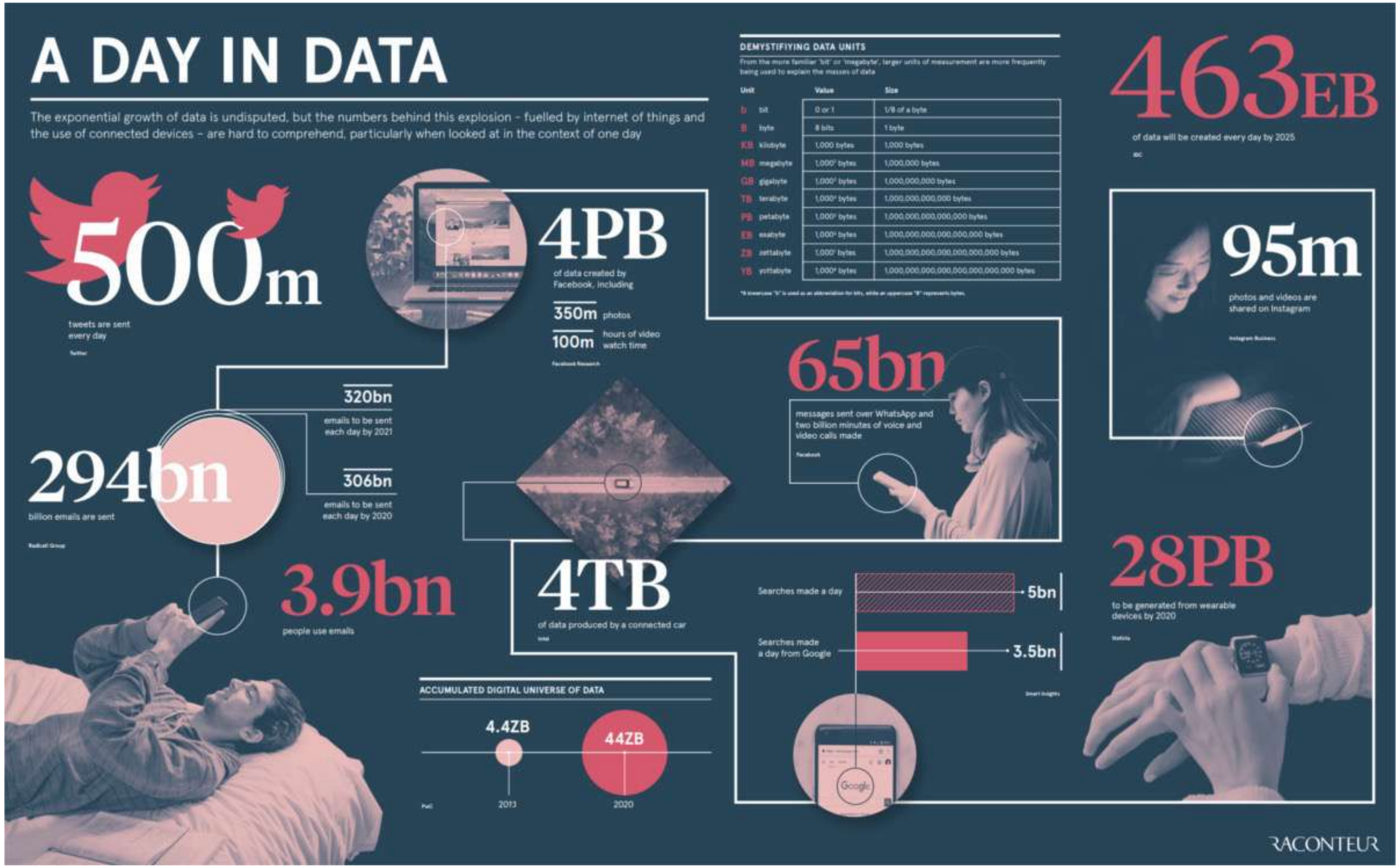
- Started almost 60 years ago and still rocketing
- Driven by:
  - Science/Engineering
  - Business
  - Society

What Happens on the Internet in 1 Minute?



source: [LocaliQ]

How Much Data is Generated Each Day?



source: [VisualCapitalist]

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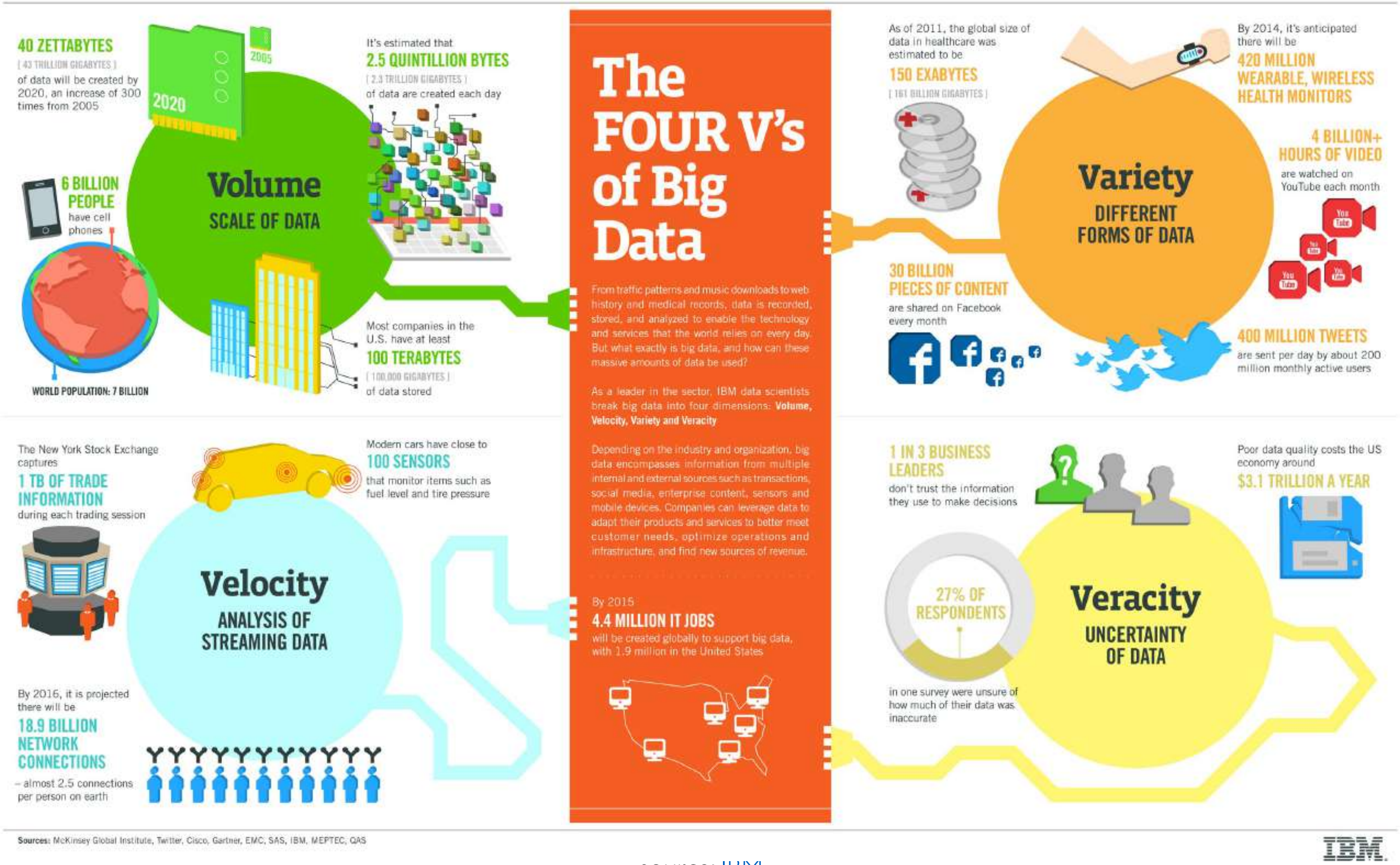
  - Veracity → reliability of the data used to drive decision processes

The 4 V's of Big Data



source: [IBM]

The Value of Big Data

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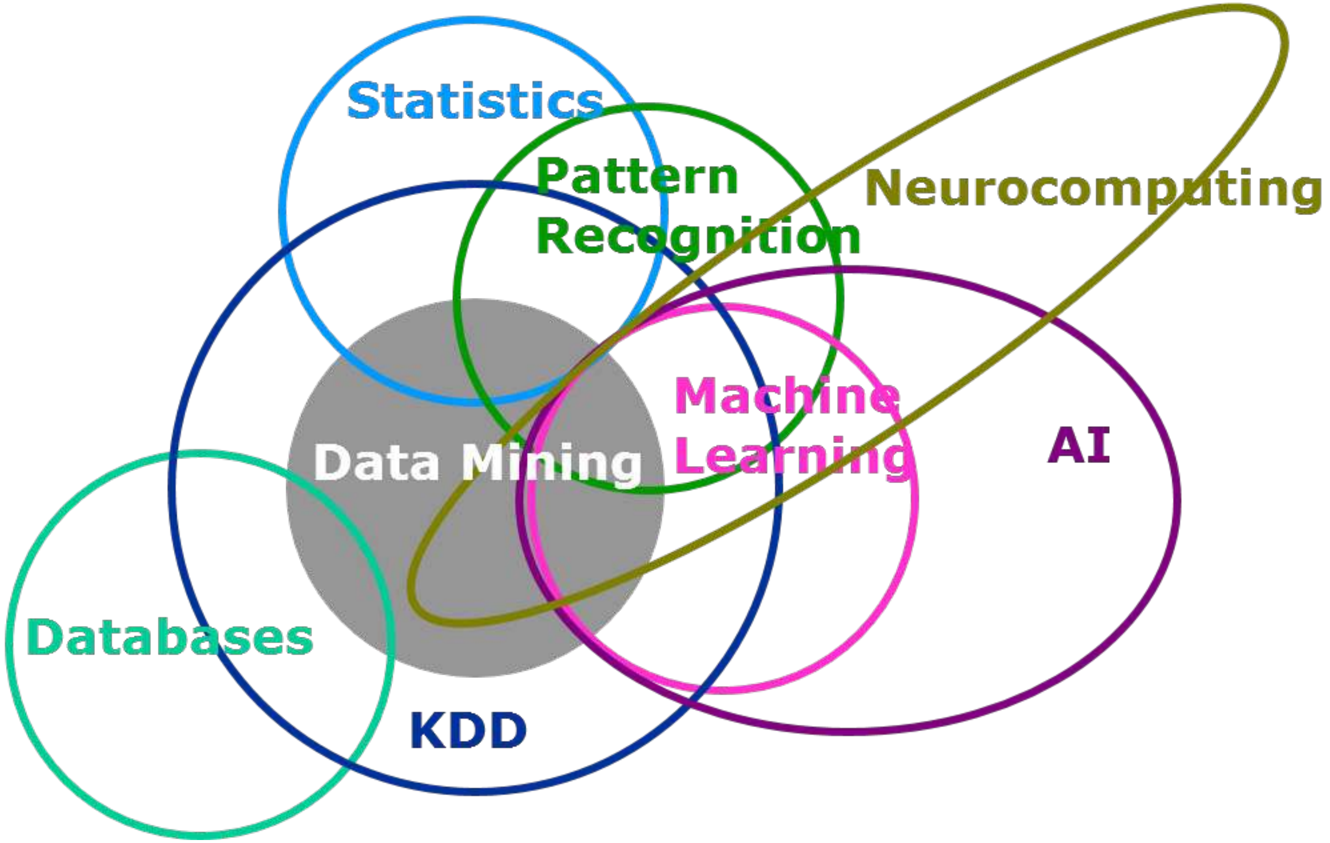
  - 5 out of 6 of the biggest companies in the world are "data companies"
- To get the most value out of it, data has to be:
  - Stored
  - Managed
  - Analyzed

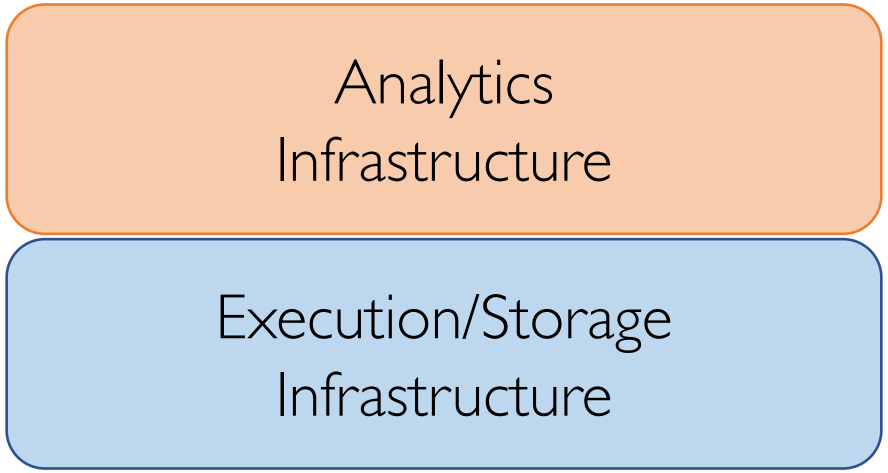
Big Data Analysis: Landscape



Big Data Analysis Stack

Execution/Storage
Infrastructure

Big Data Analysis Stack



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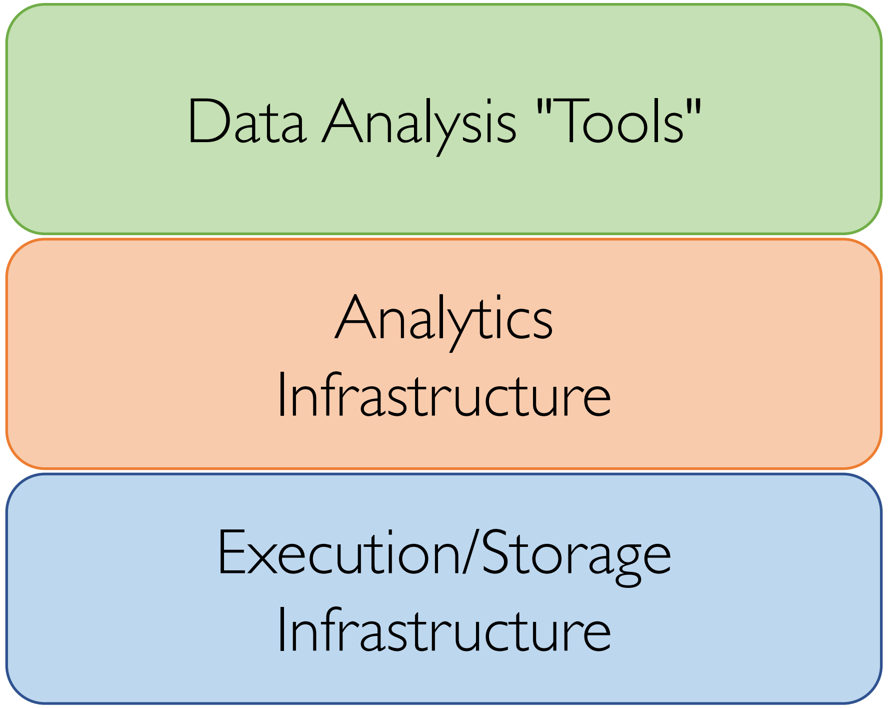

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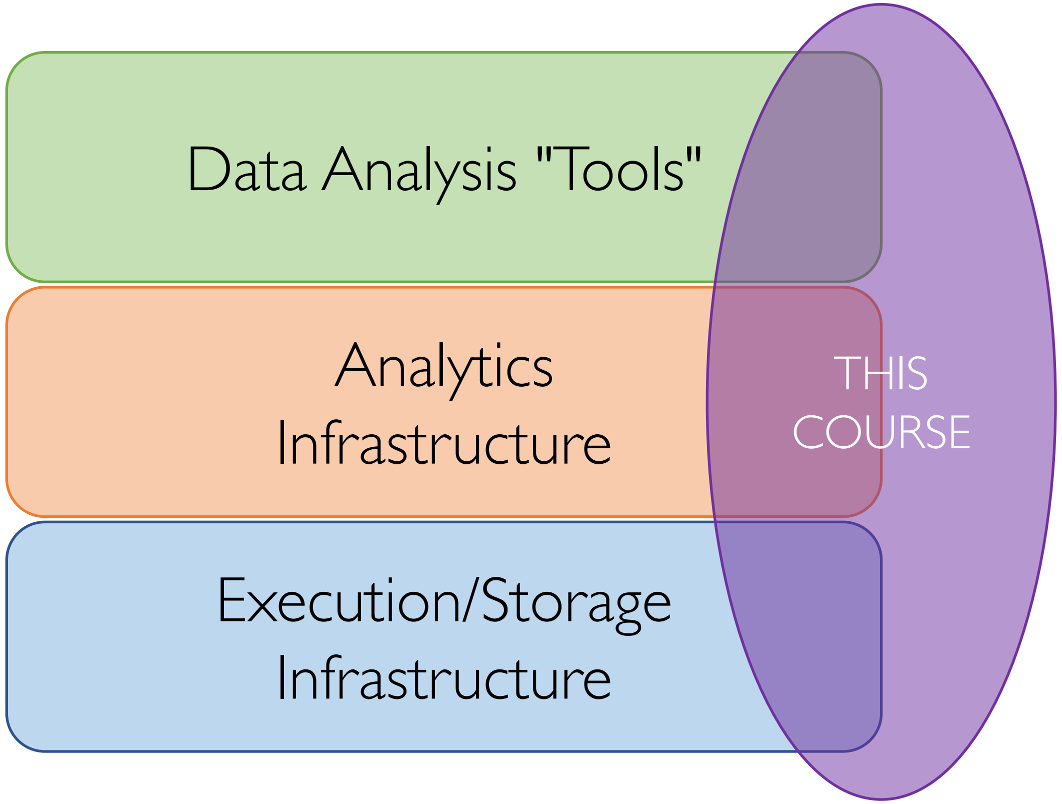


What Will We Learn?

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

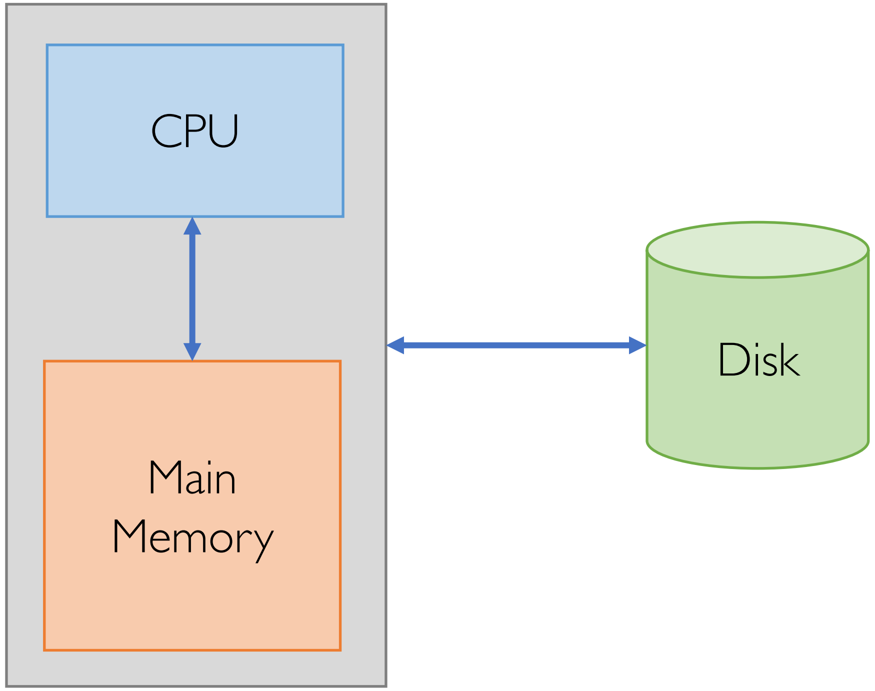
What Will We Learn?

- 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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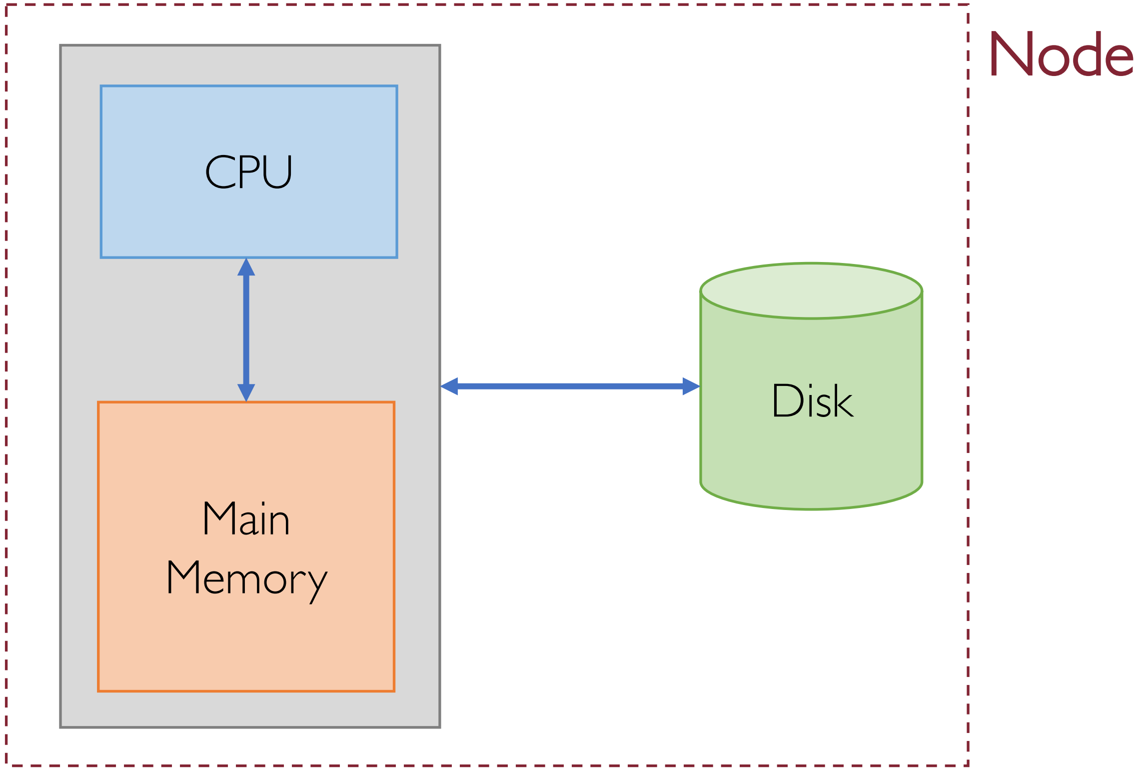
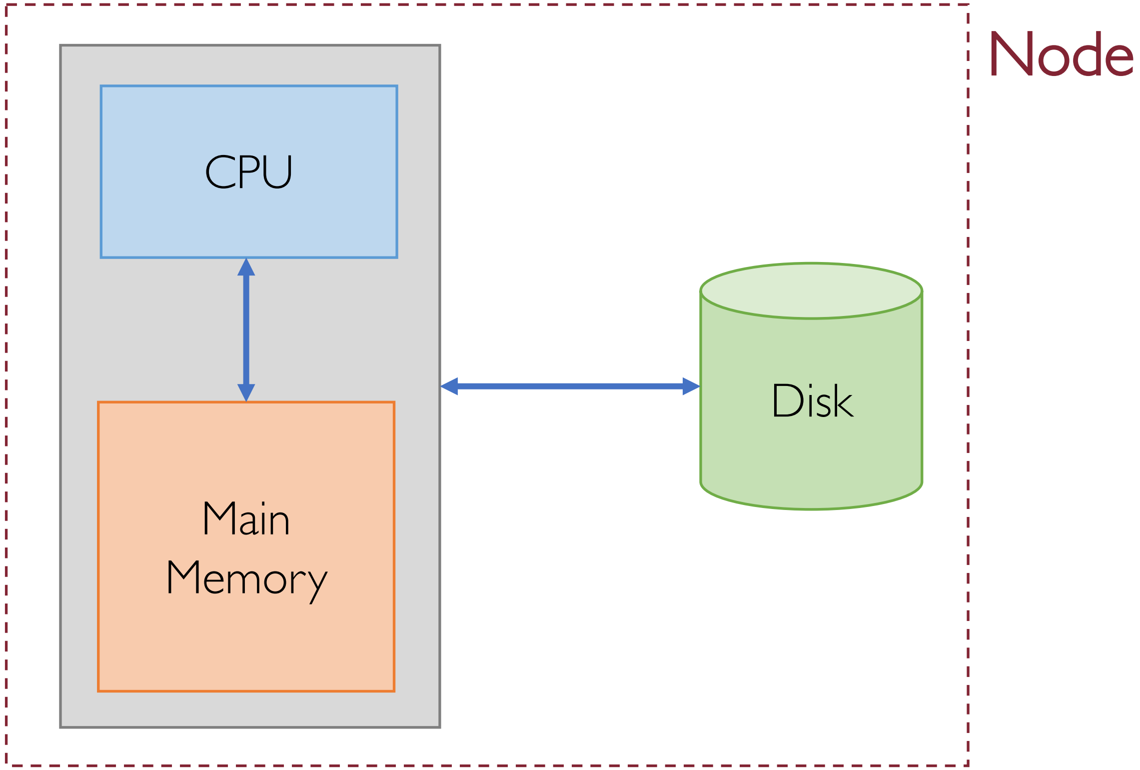


The Single-Node Architecture

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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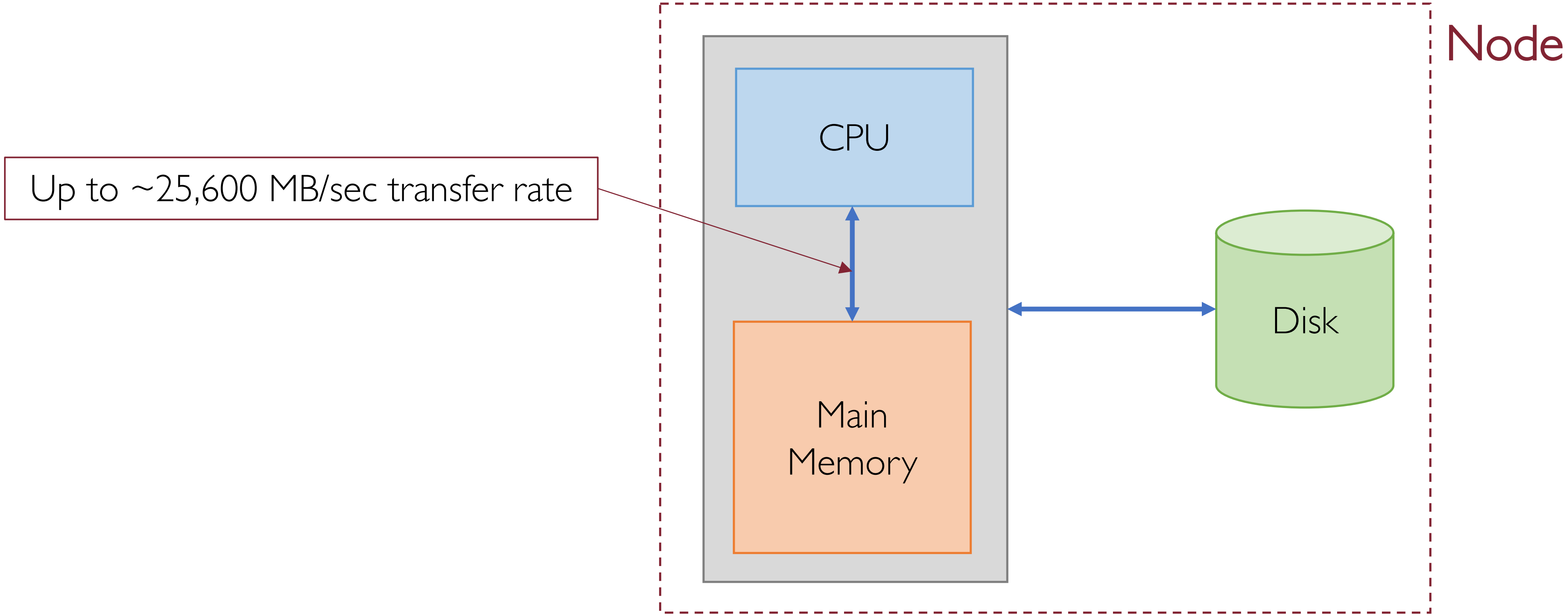

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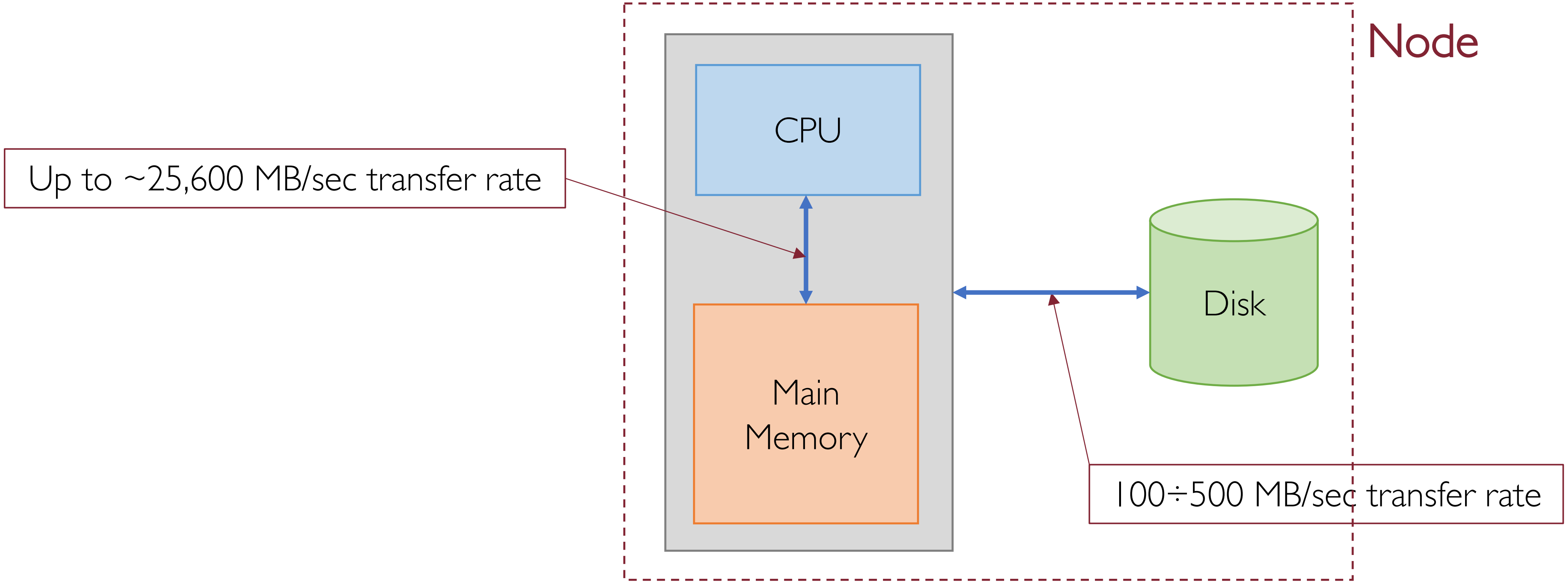

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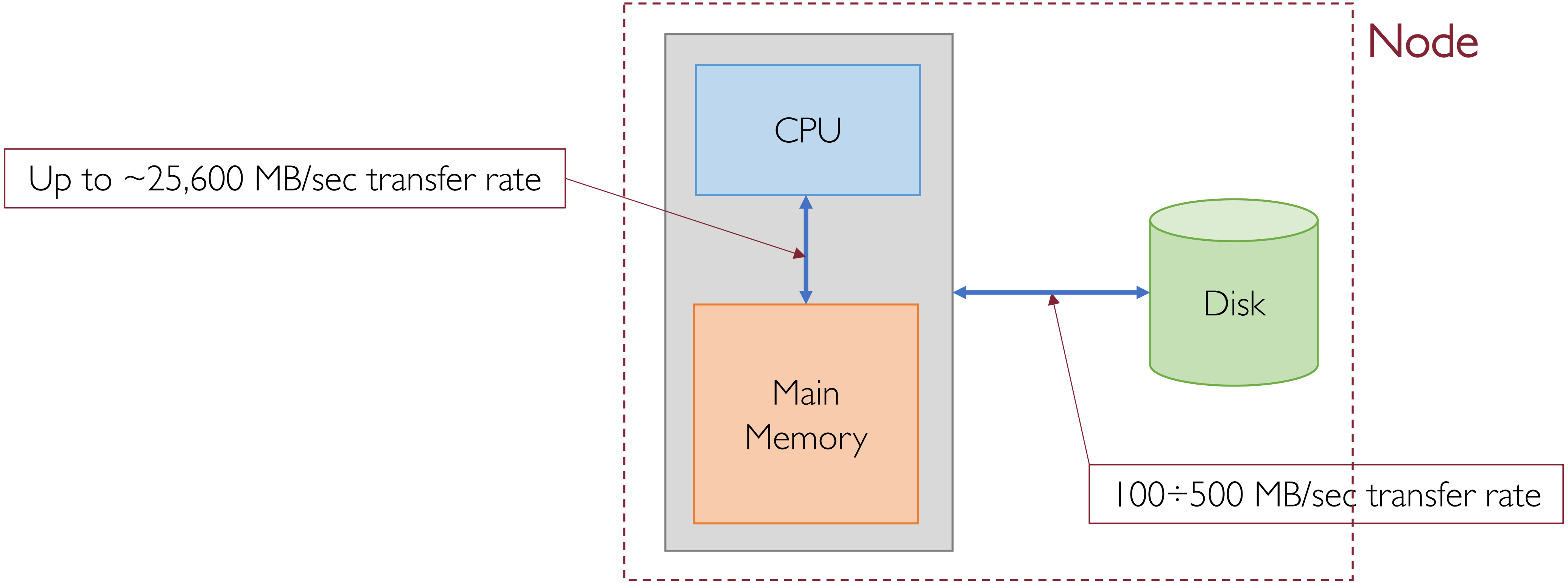

2 orders of magnitude difference between data transfer rate

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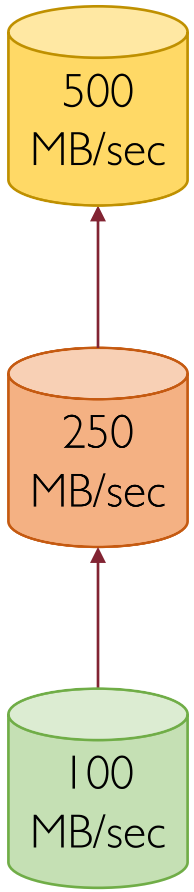
- Single-node architecture is clearly not enough here
  - Scaling Up vs. Scaling Out

Scaling Up/Vertical Scaling

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



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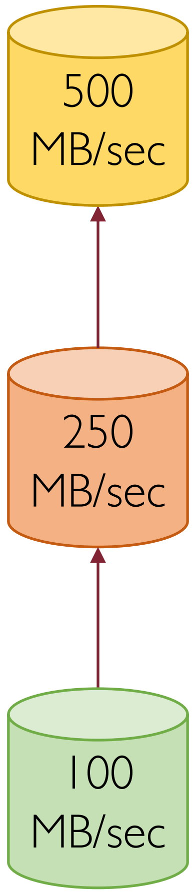

Scaling Up/Vertical Scaling

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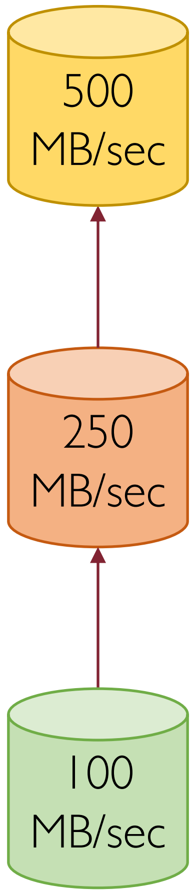
- CON
  - Improvement is physically-limited (e.g., 2.5x or 5x)
  - Expensive



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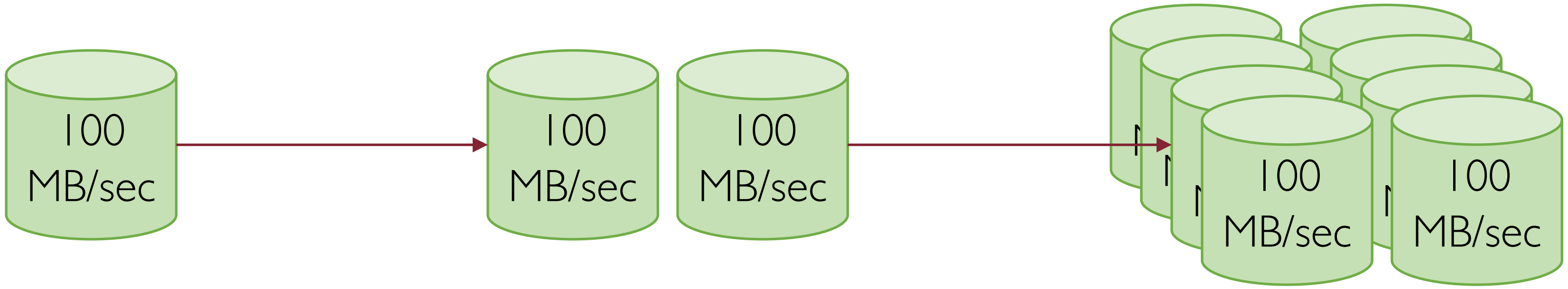

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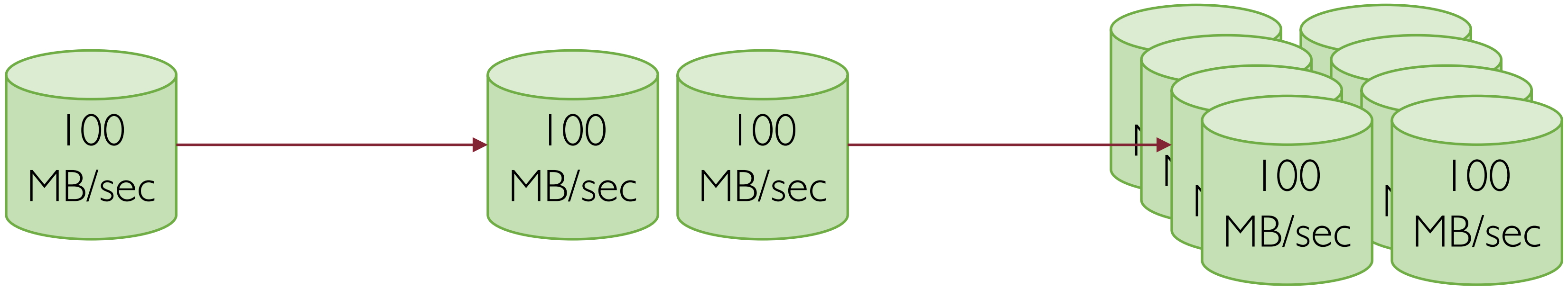

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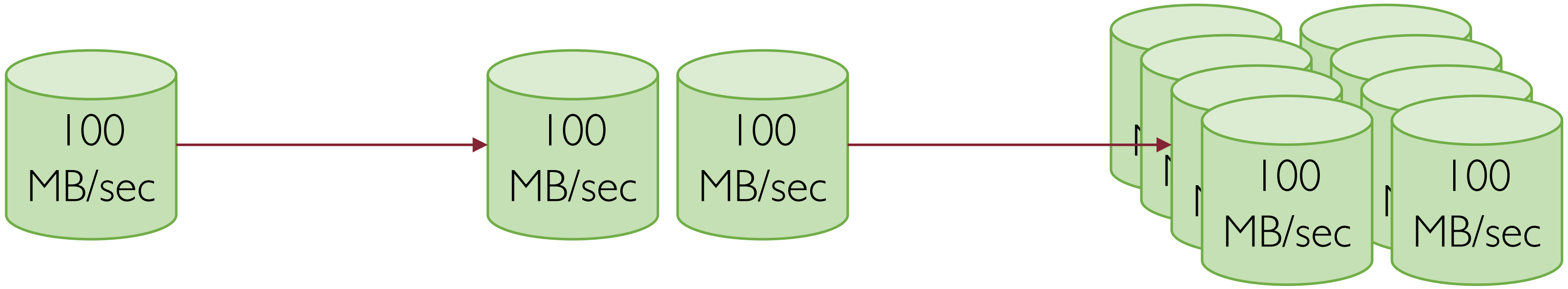
  - Extra overhead required to manage parallel work



Cluster Architecture

- Computing architecture based on the scaling out principle

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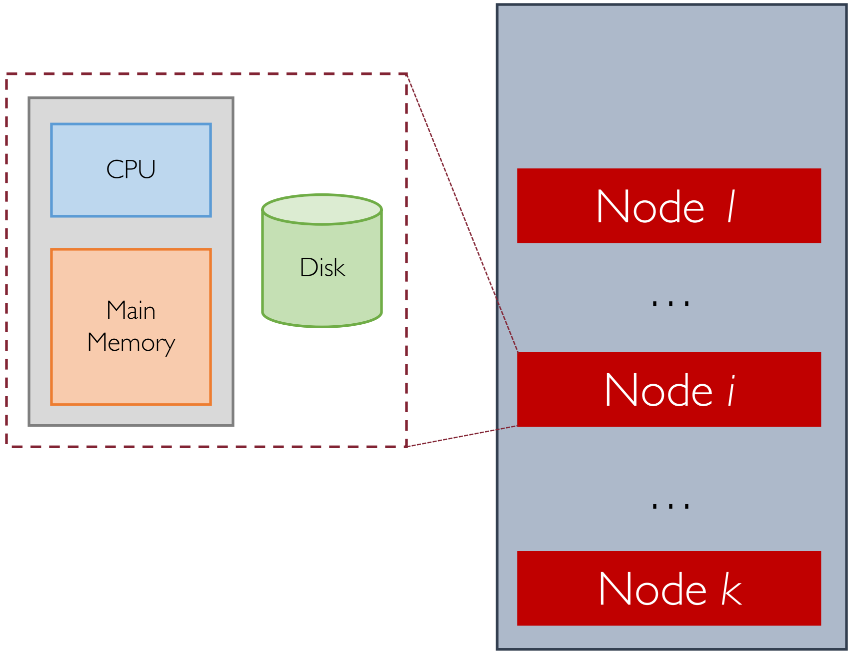
- A cluster is made of multiple racks
- Network switches enabling node communication
  - 1 Gbps (inter-rack)
  - 2÷10 Gbps (intra-rack)

Cluster Architecture



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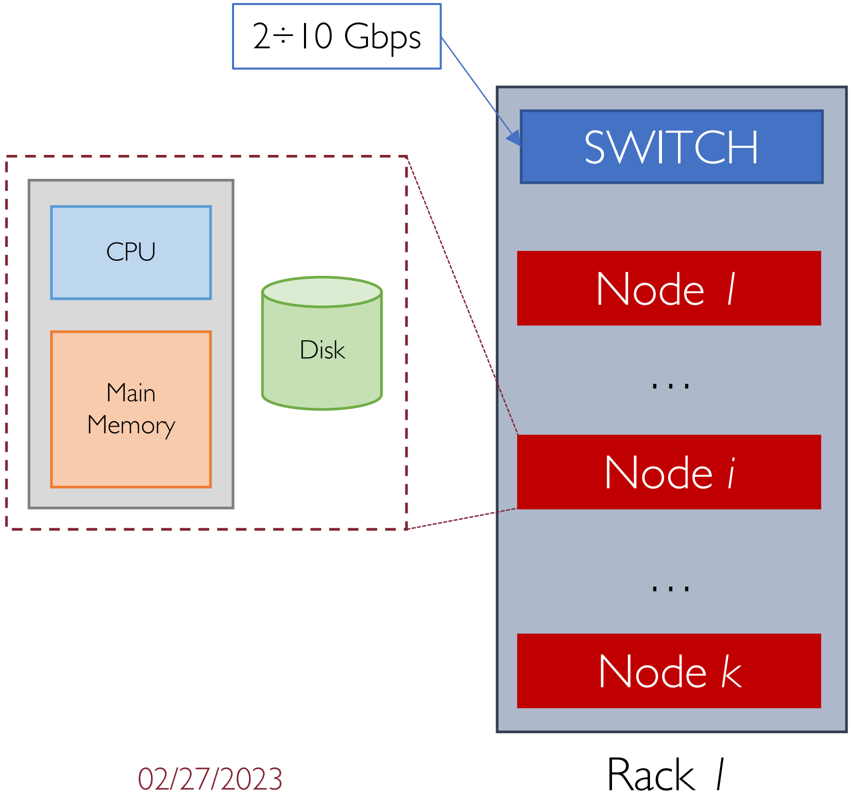

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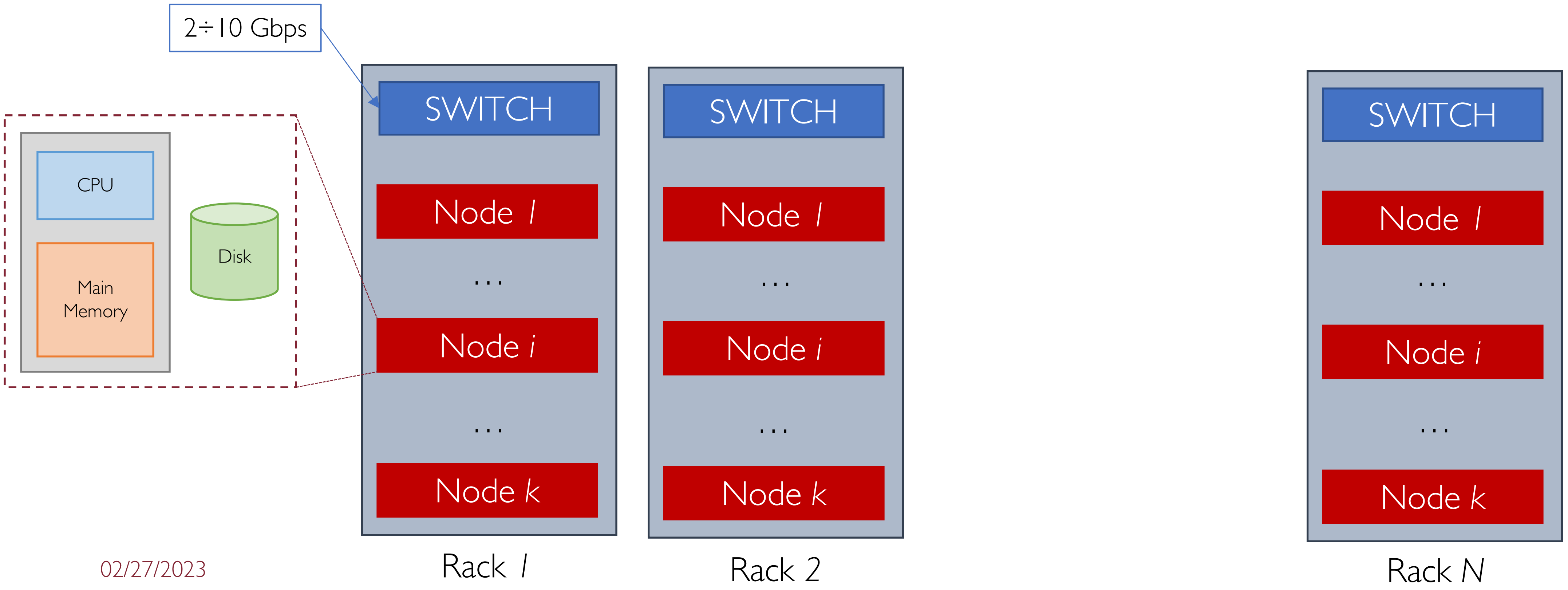

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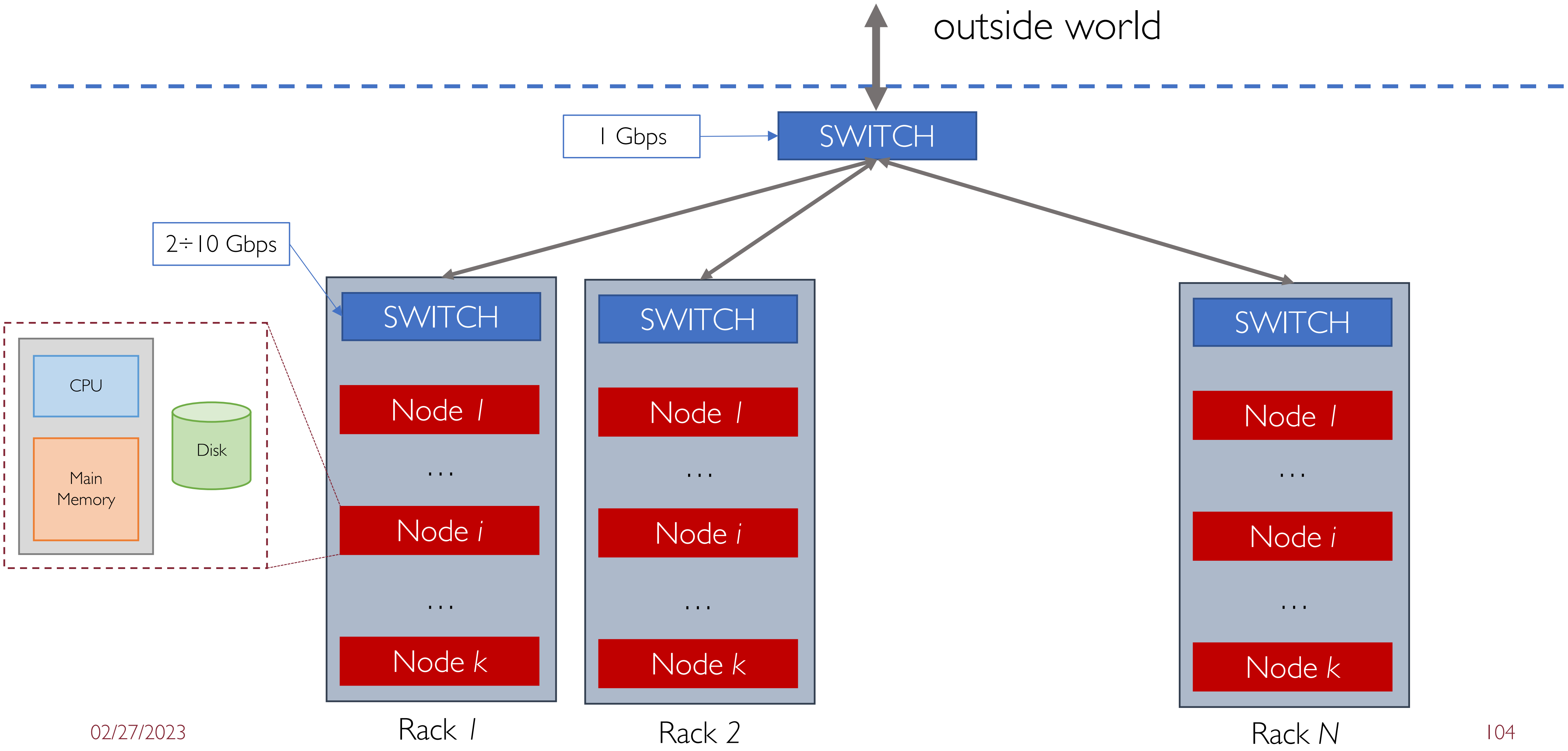

Cluster Architecture: Challenges

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  - Assume for semplicity p is the same for all nodes and independent from each other

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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