Big Data Computing

Master's Degree in Computer Science

2020-2021

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SAPIENZA
UNIVERSITÀ DI ROMA

Administrivia

- Class schedule:
  - Tuesday from 5:00PM to 7:00PM
  - Wednesday from 4:00PM to 7:00PM

Room G50 @Viale Regina Elena, 295
Building G

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- Office hours:
  - Drop me a message to ask for a meeting online (Google Meet or Zoom)

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=12771

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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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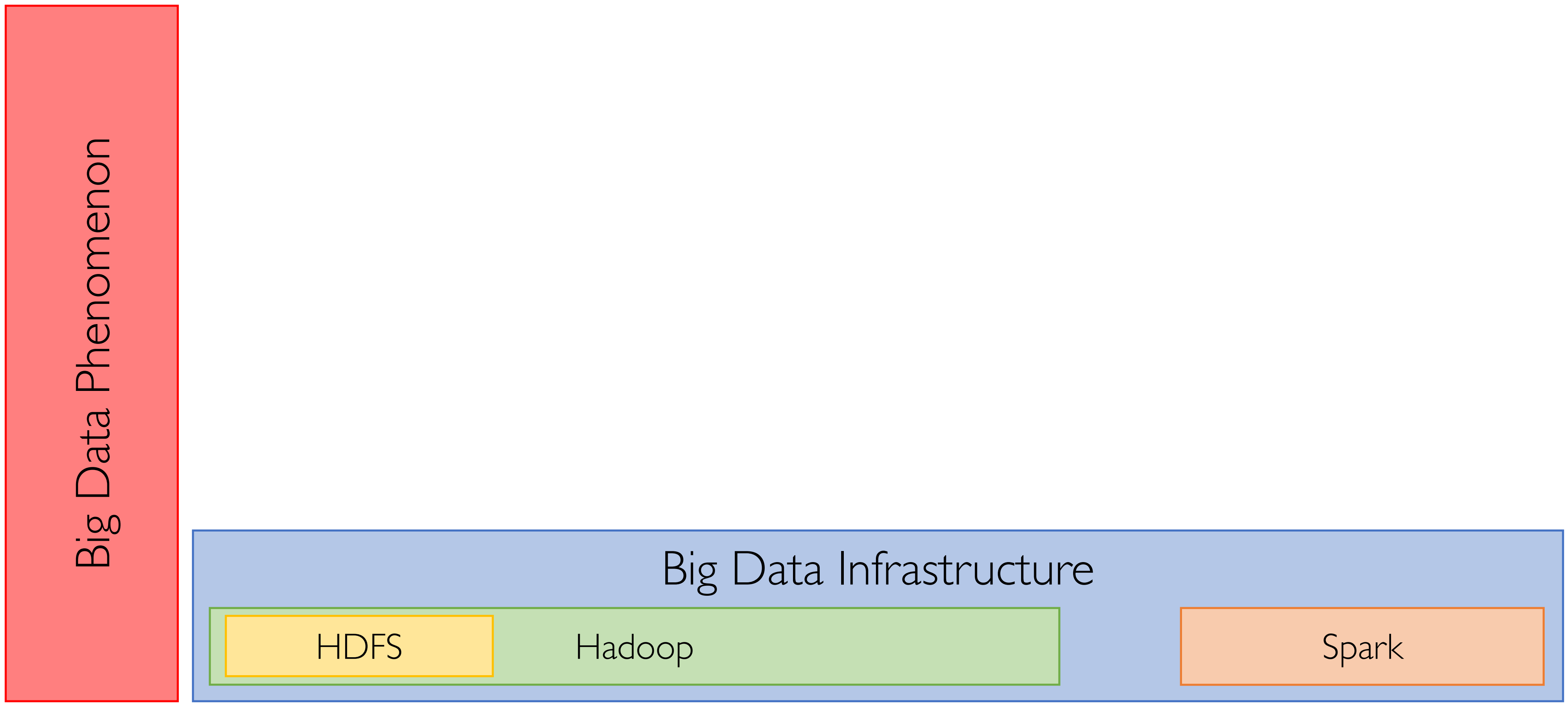

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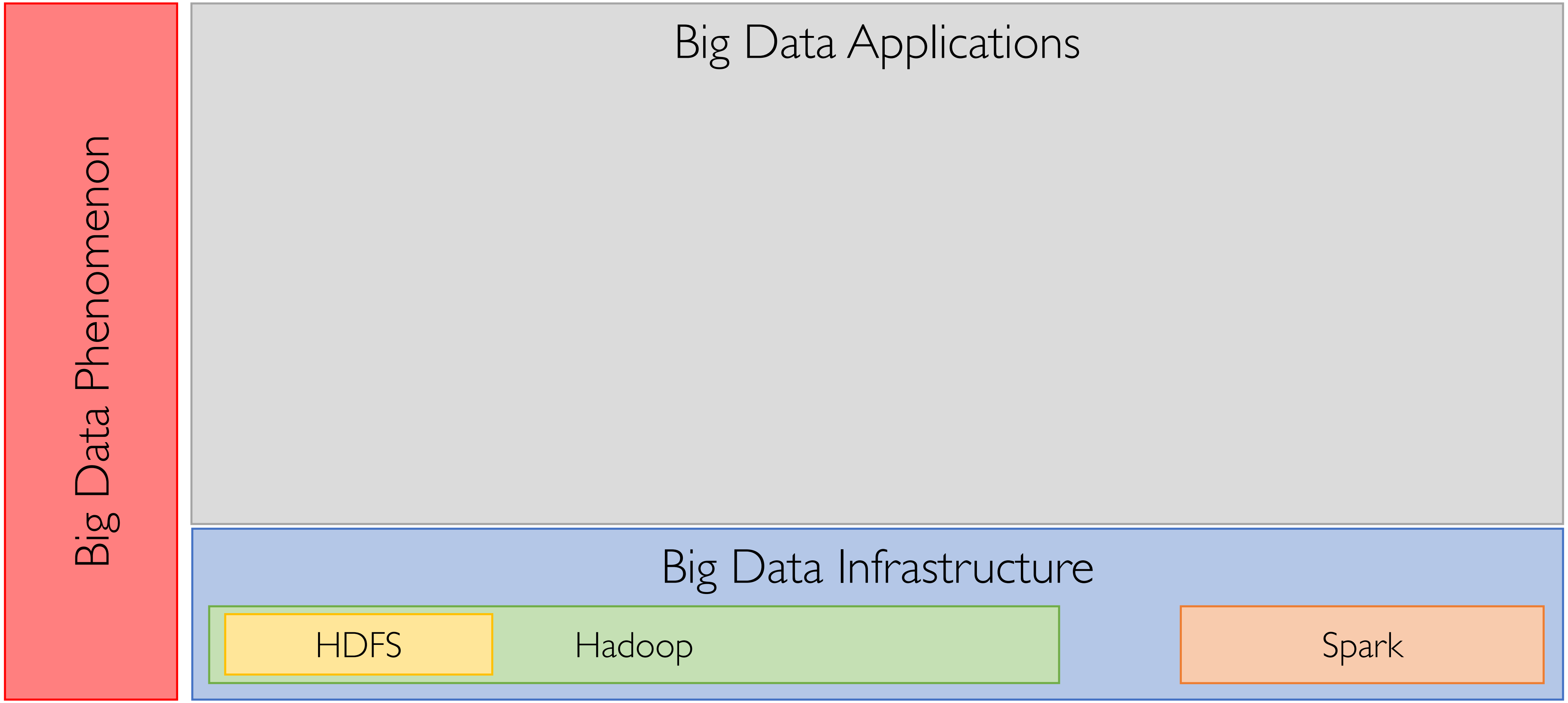

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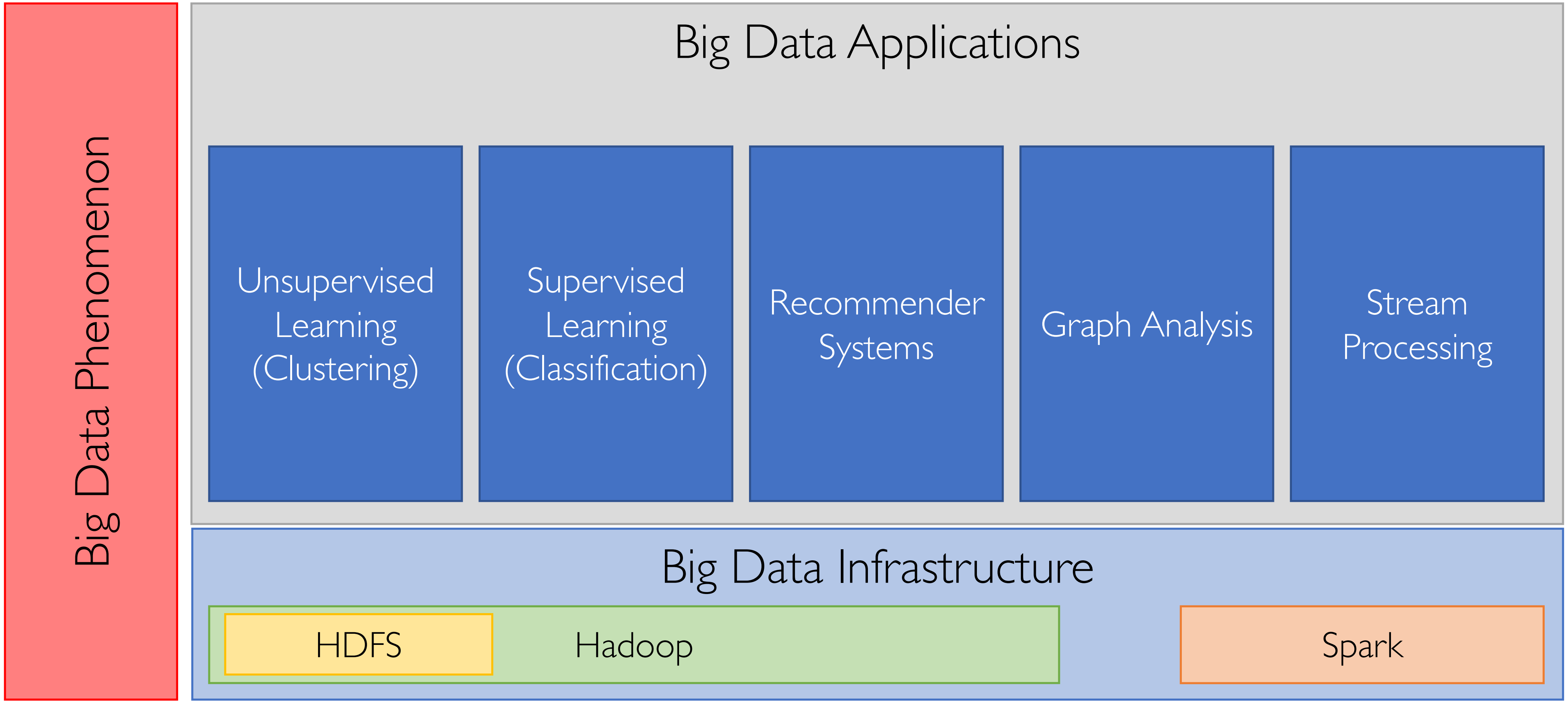

Let's Get Started!

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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A few numbers:
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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

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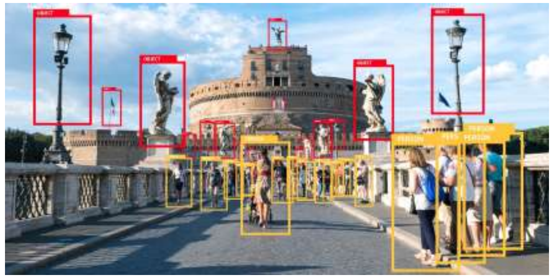

AGC vs. Our Smartphone

- Most recent smartphones have
  - ~2.4 GHz CPU clock frequency
  - 4÷12 GB of RAM
  - 64÷256 GB of internal storage (**don't** call it ROM!)

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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)

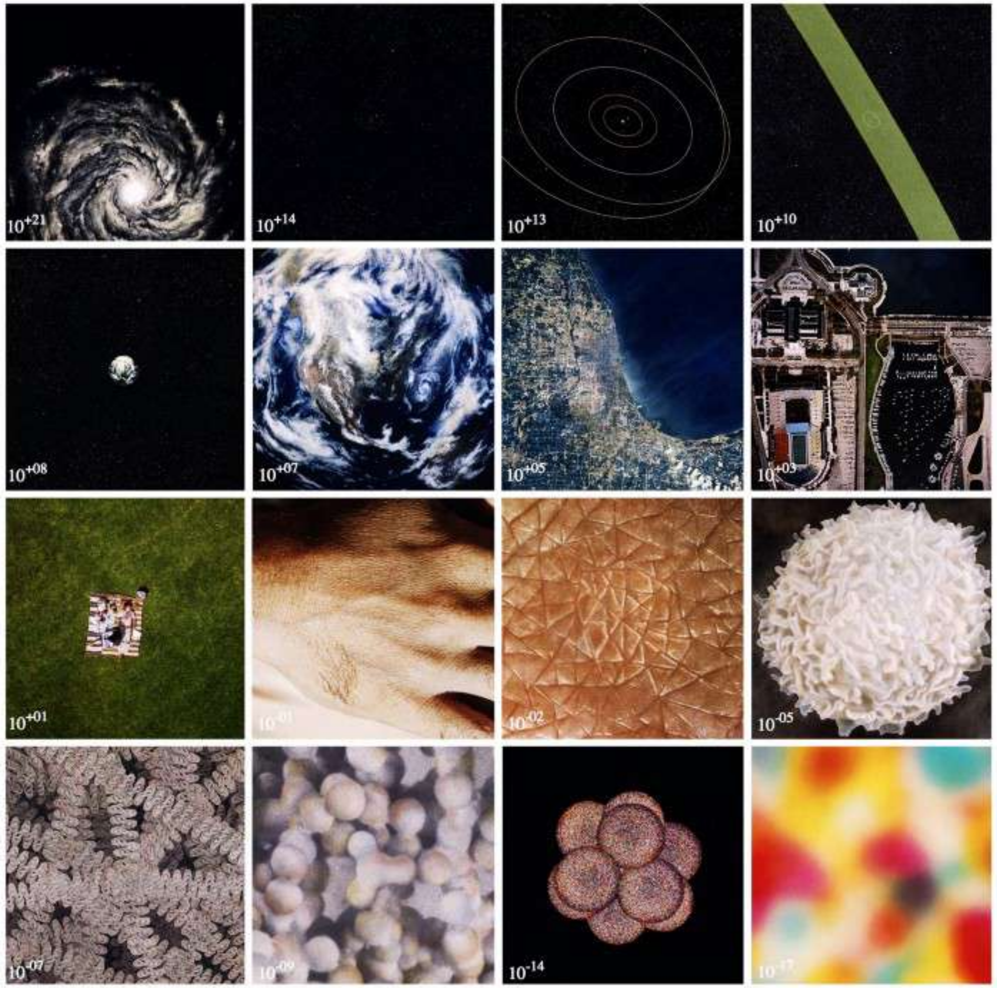
A Side Note on Units

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

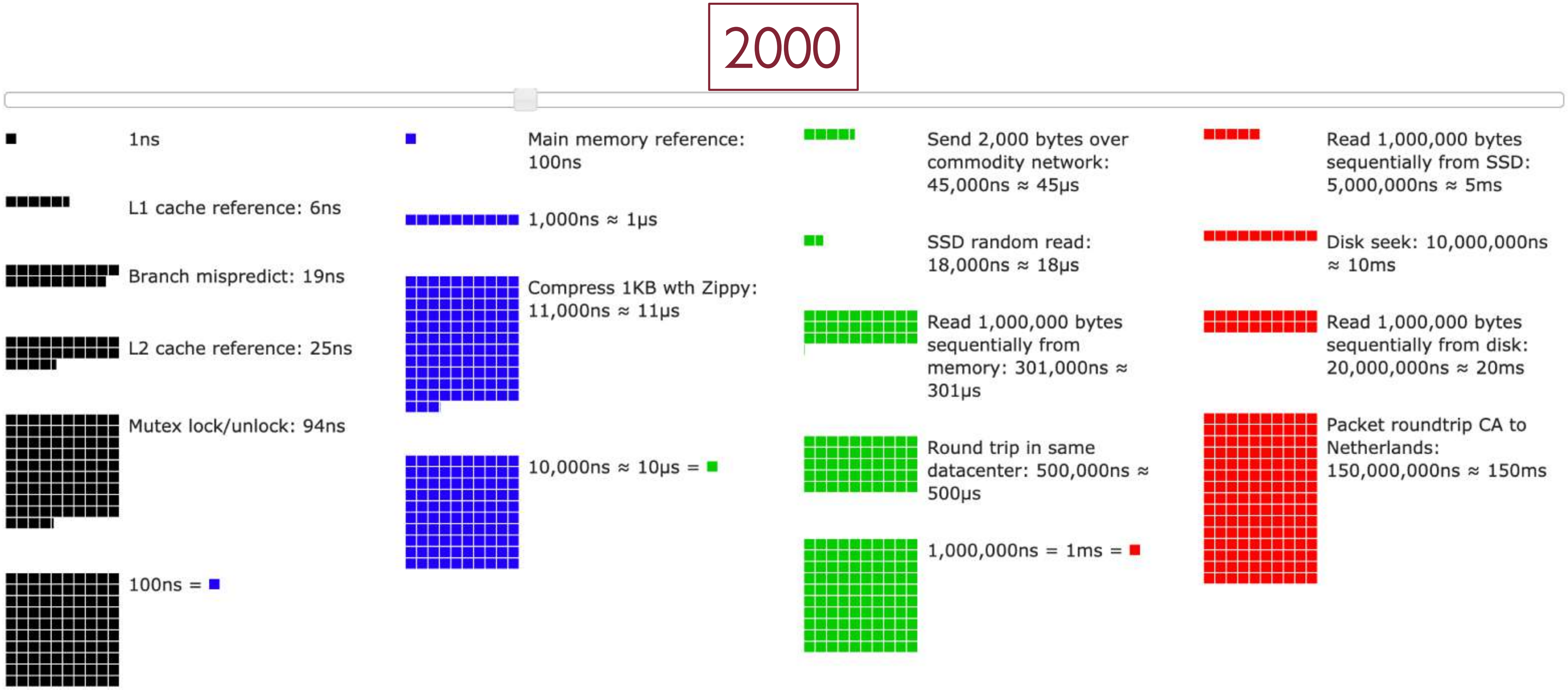
$10^0 = 1$

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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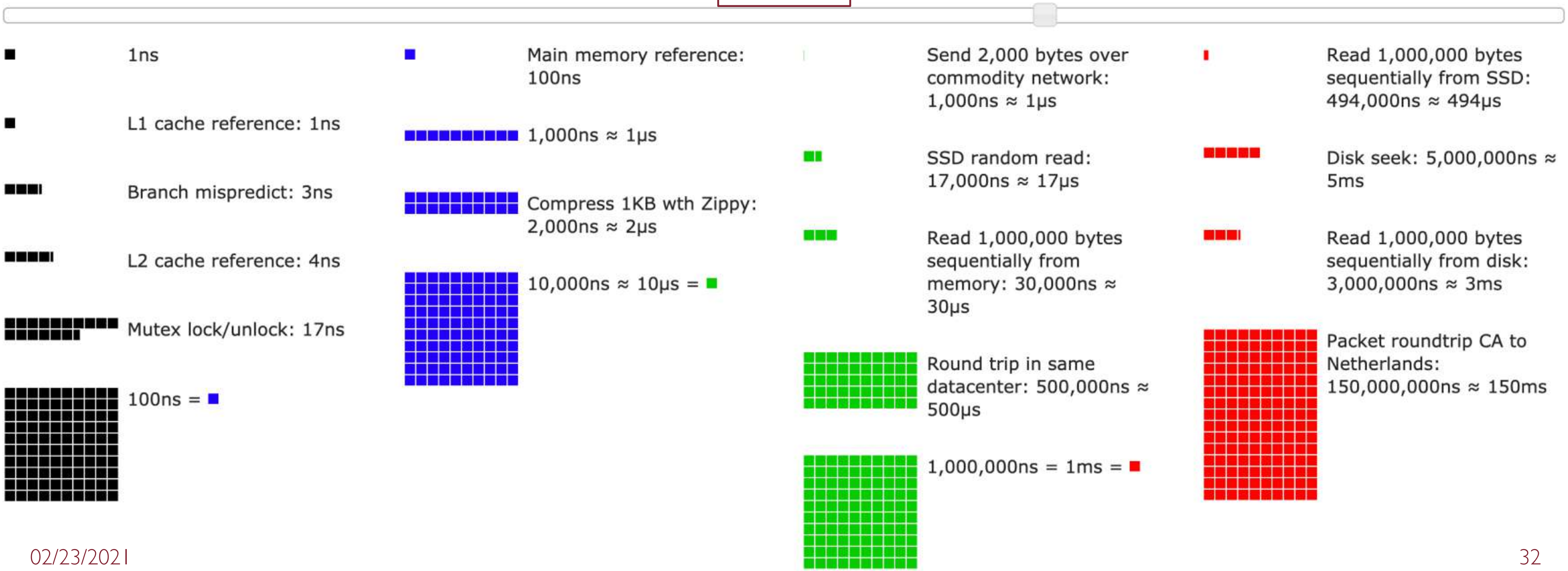
2010



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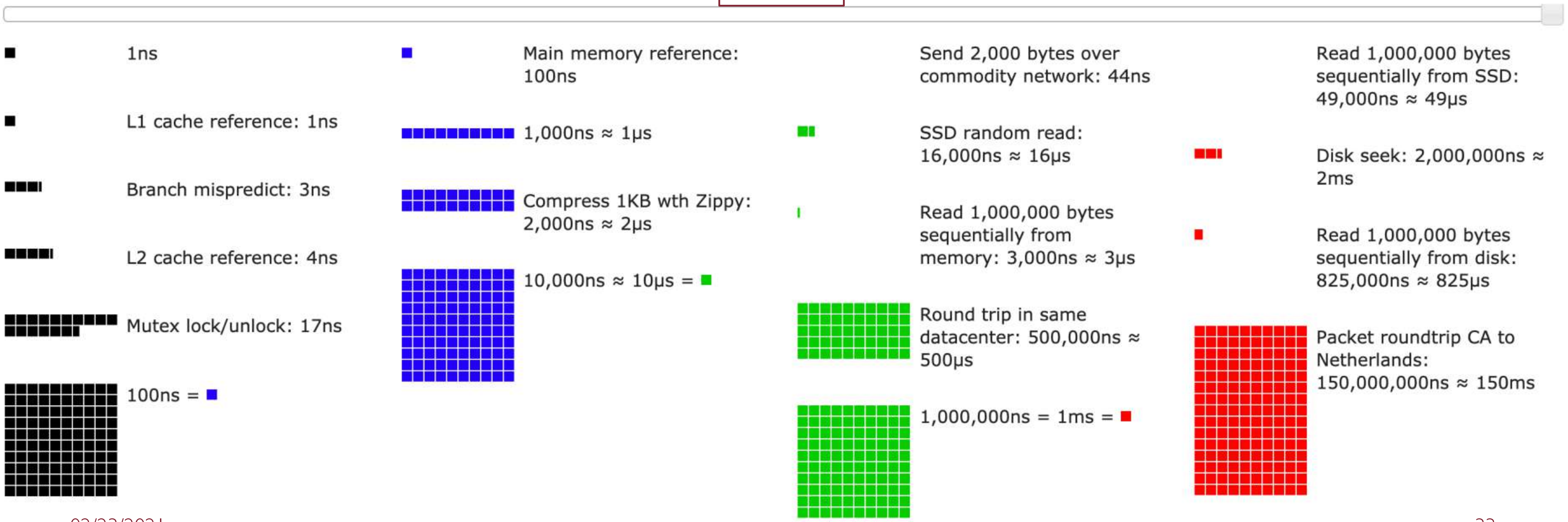
2020



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?

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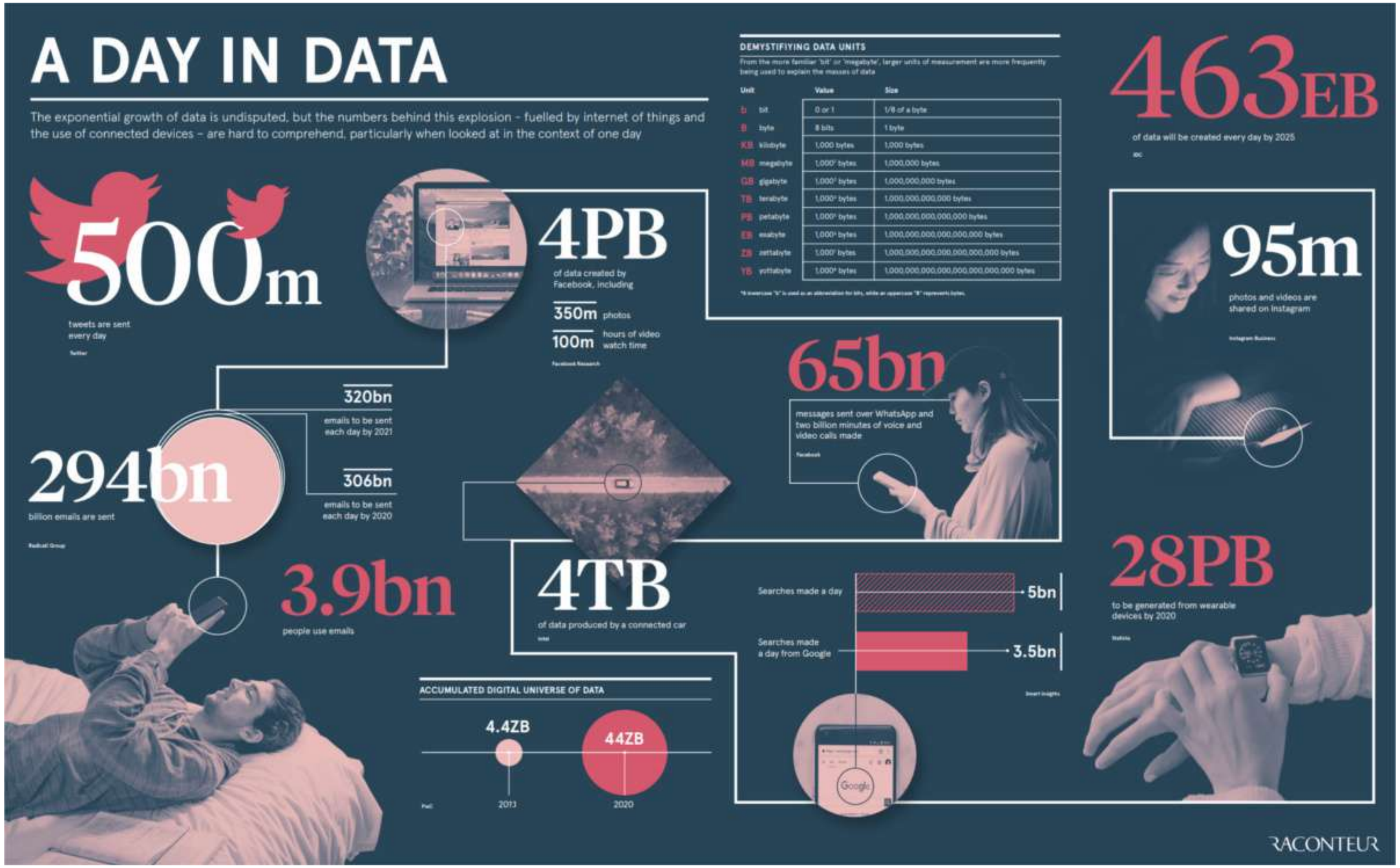
How Much Data is Generated Each Day?



https://www.visualcapitalist.com/how-much-data-is-generated-each-day/

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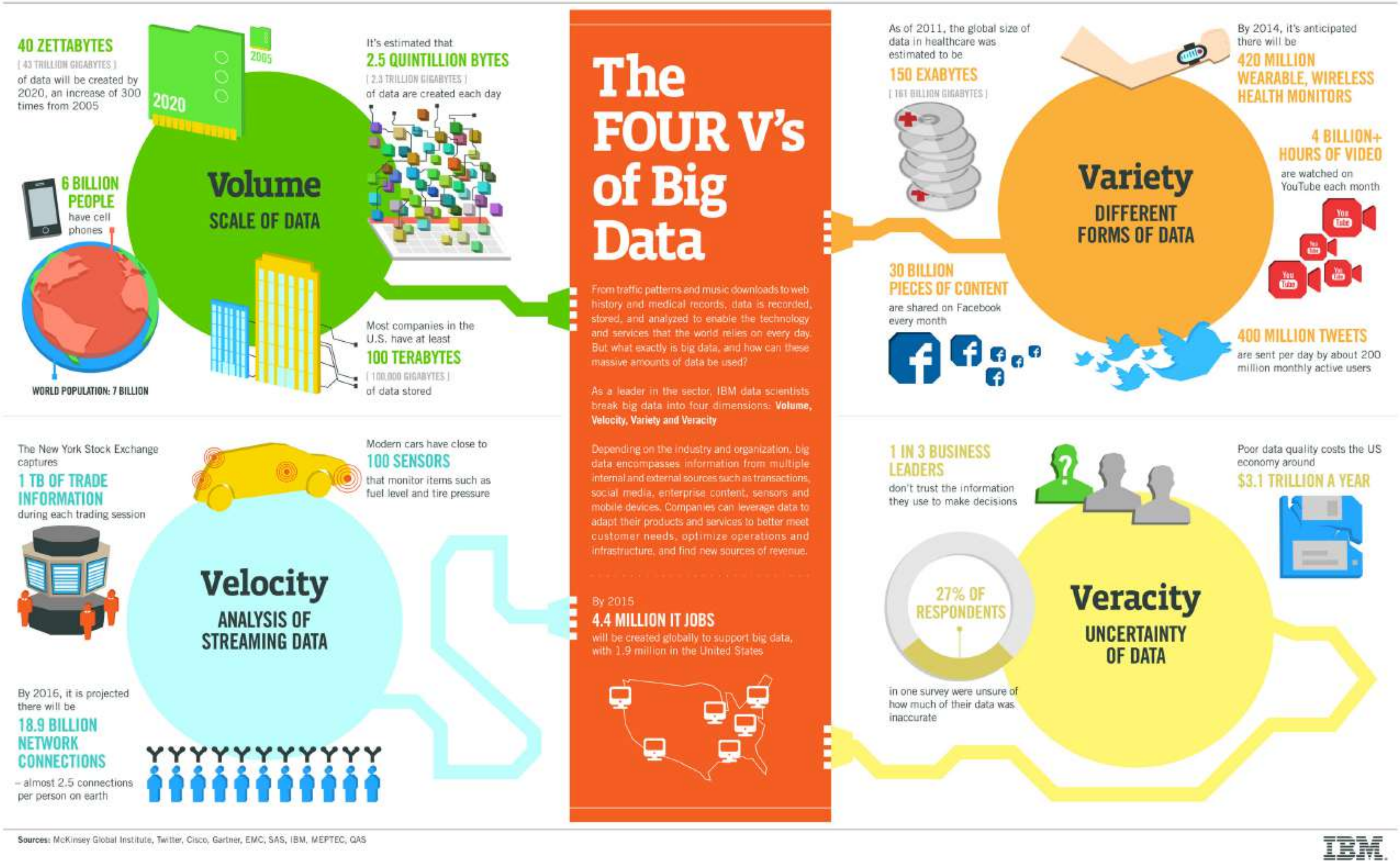
  - Velocity → insane speed at which data is generated (e.g., Twitter stream)
  - Veracity → reliability of the data used to drive decision processes

The 4 V's of Big Data



https://www.ibmbigdatahub.com/infographic/four-vs-big-data

The Value of Big Data

- Extracting knowledge from data is incredibly valuable
  - 5 out of 6 of the biggest companies in the world are "data companies"

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- Extracting knowledge from data is incredibly valuable
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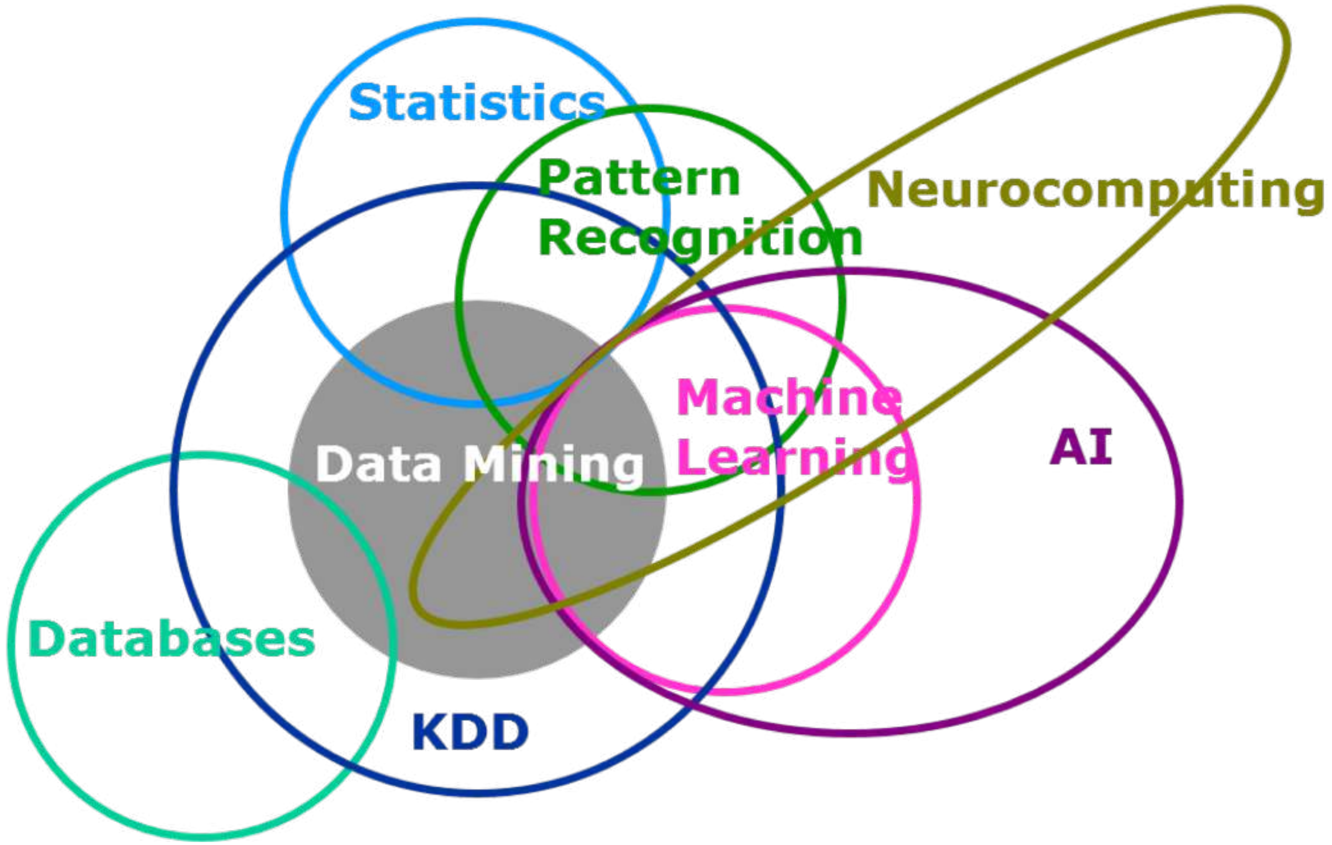
- To get the most value out of it, data has to be:
  - Stored
  - Managed
  - Analyzed

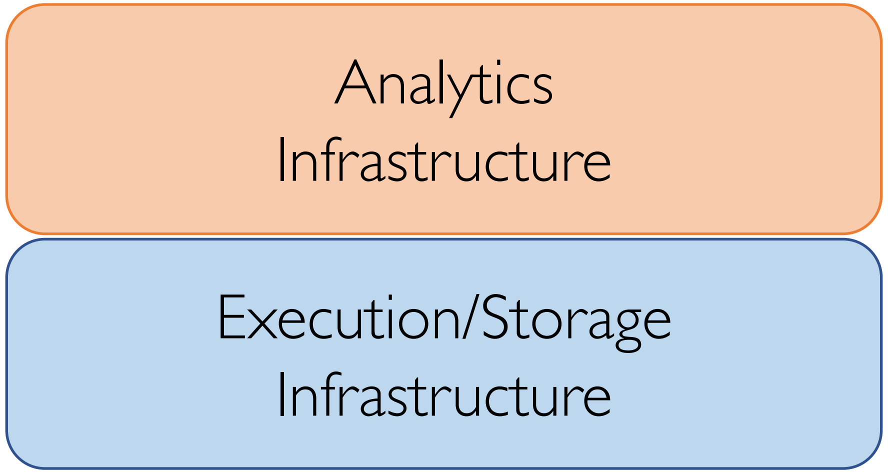
Big Data Analysis: Landscape



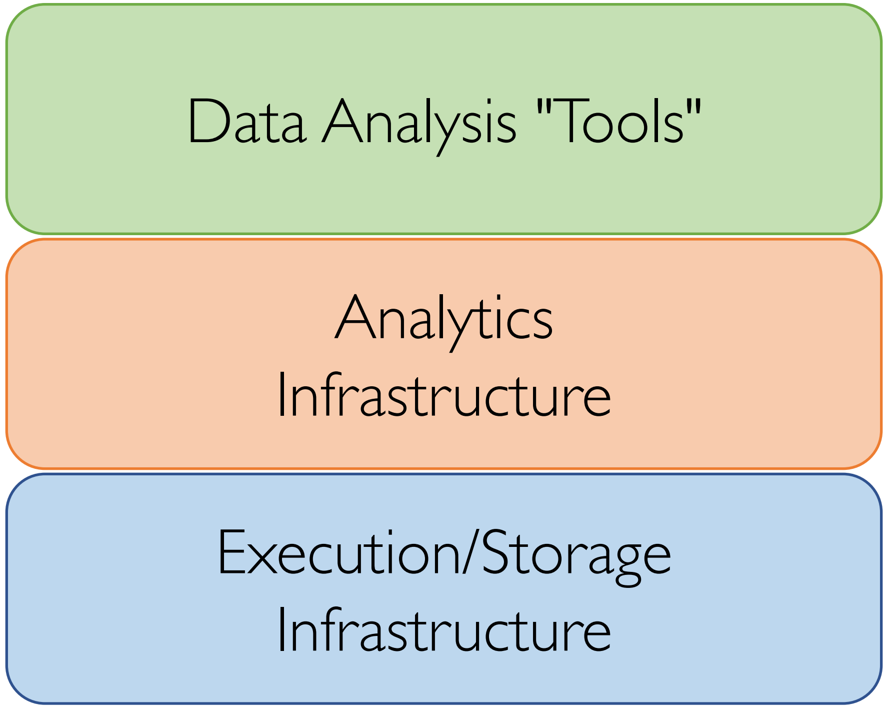
Big Data Analysis Stack

Execution/Storage
Infrastructure

Big Data Analysis Stack



Big Data Analysis Stack



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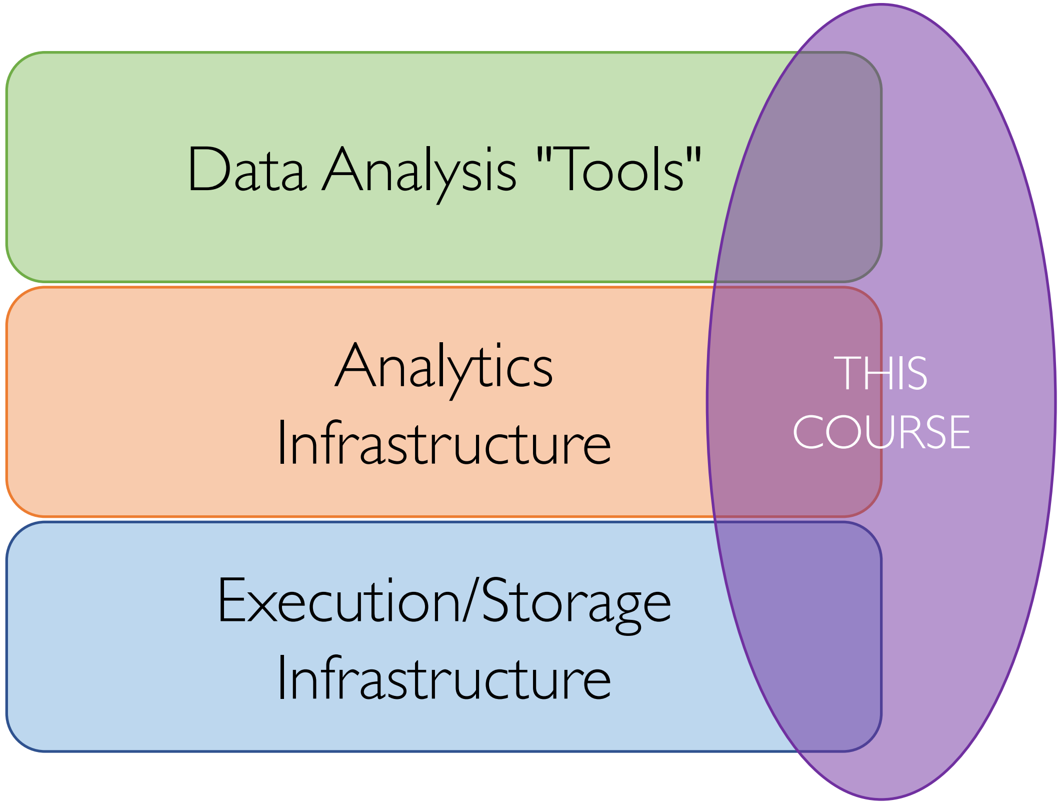


What Will We Learn?

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

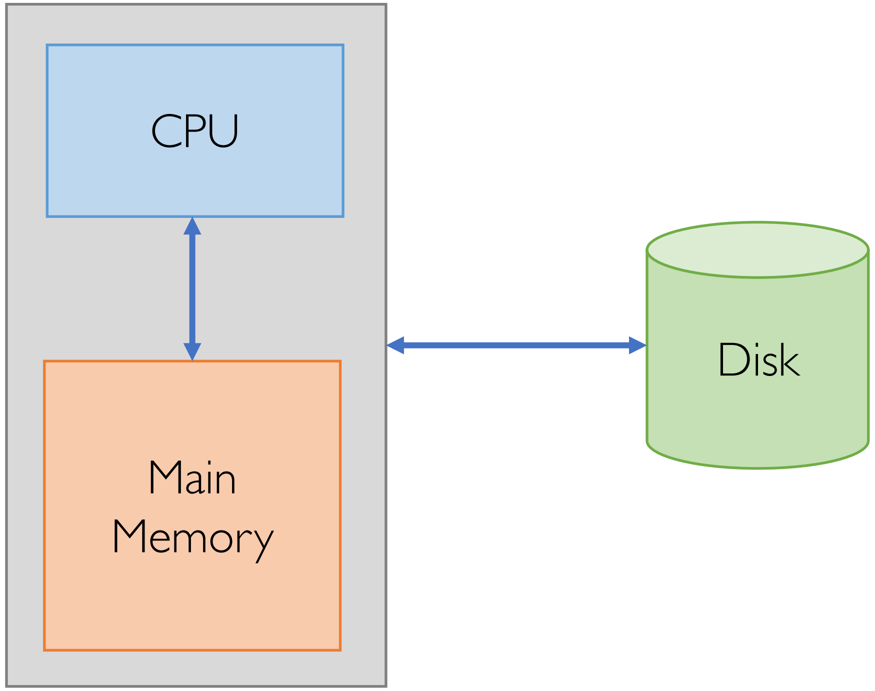
What Will We Learn?

- 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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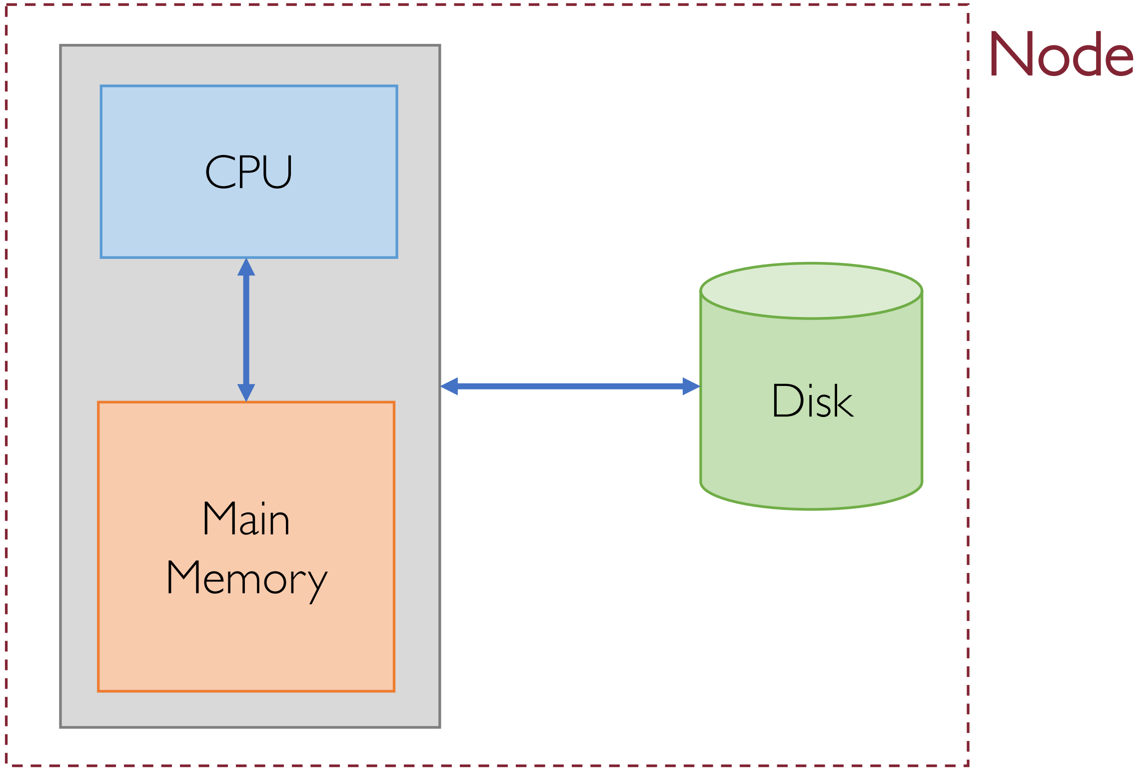
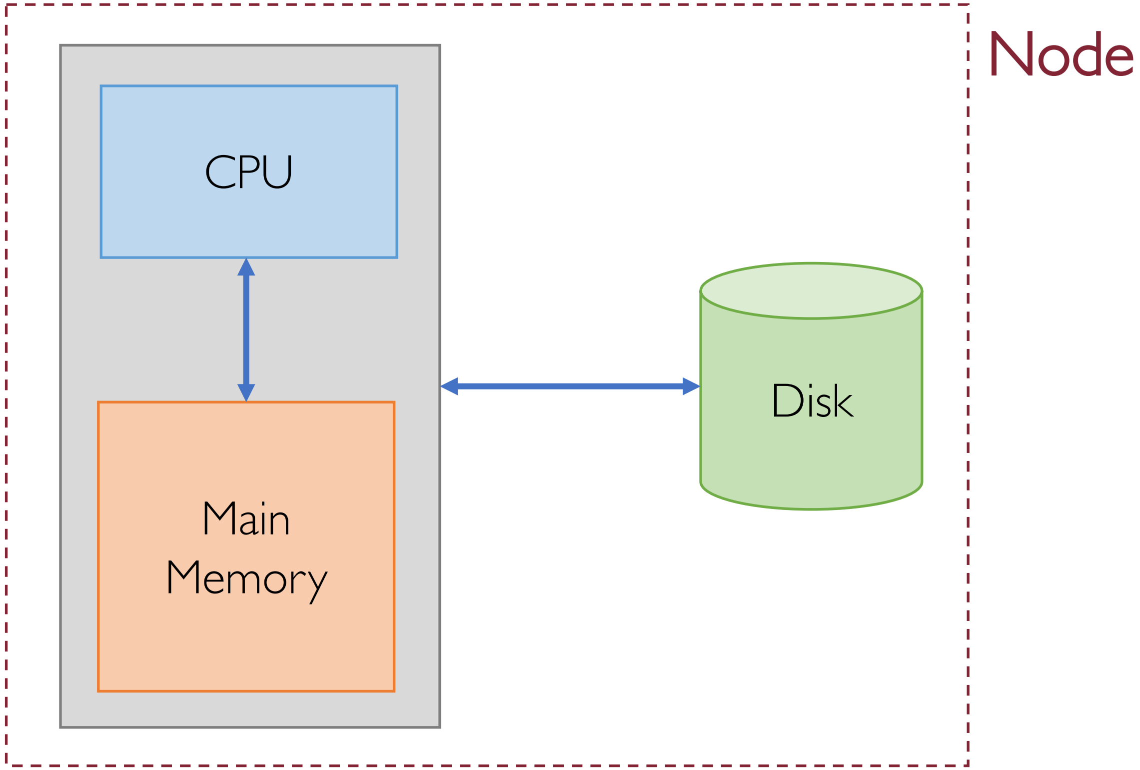


The Single-Node Architecture

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



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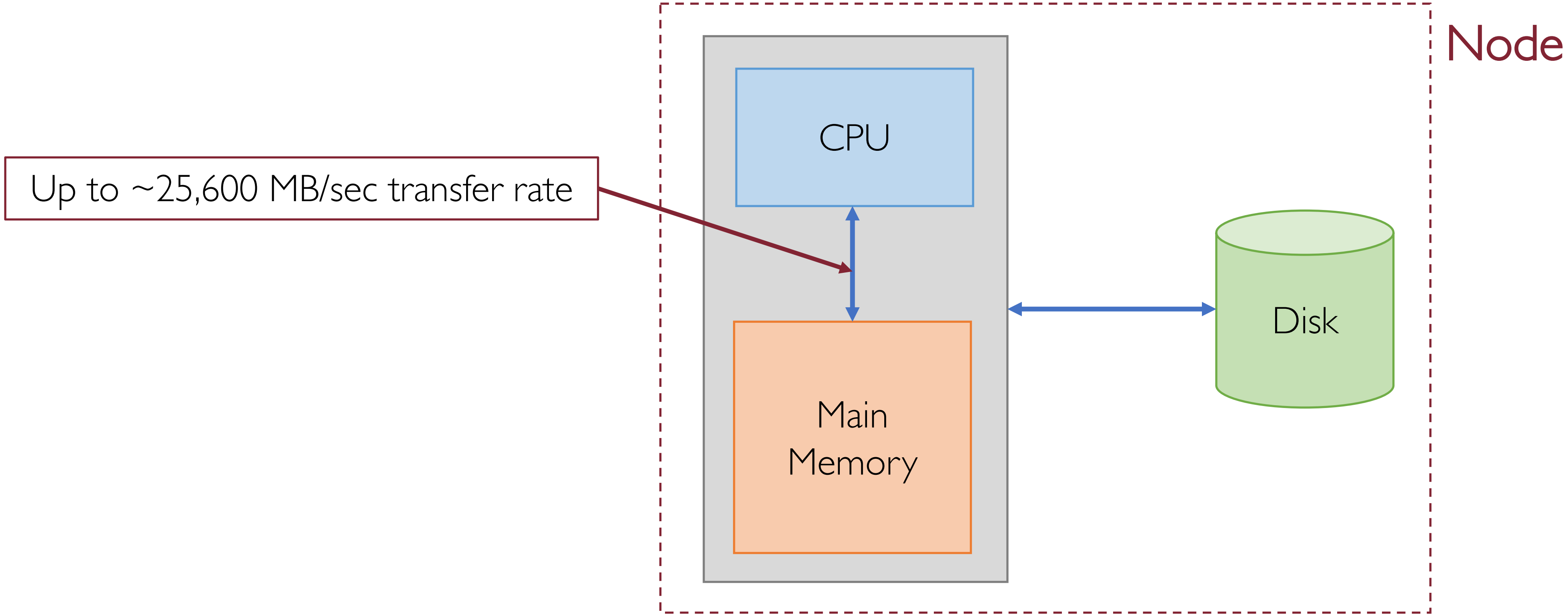

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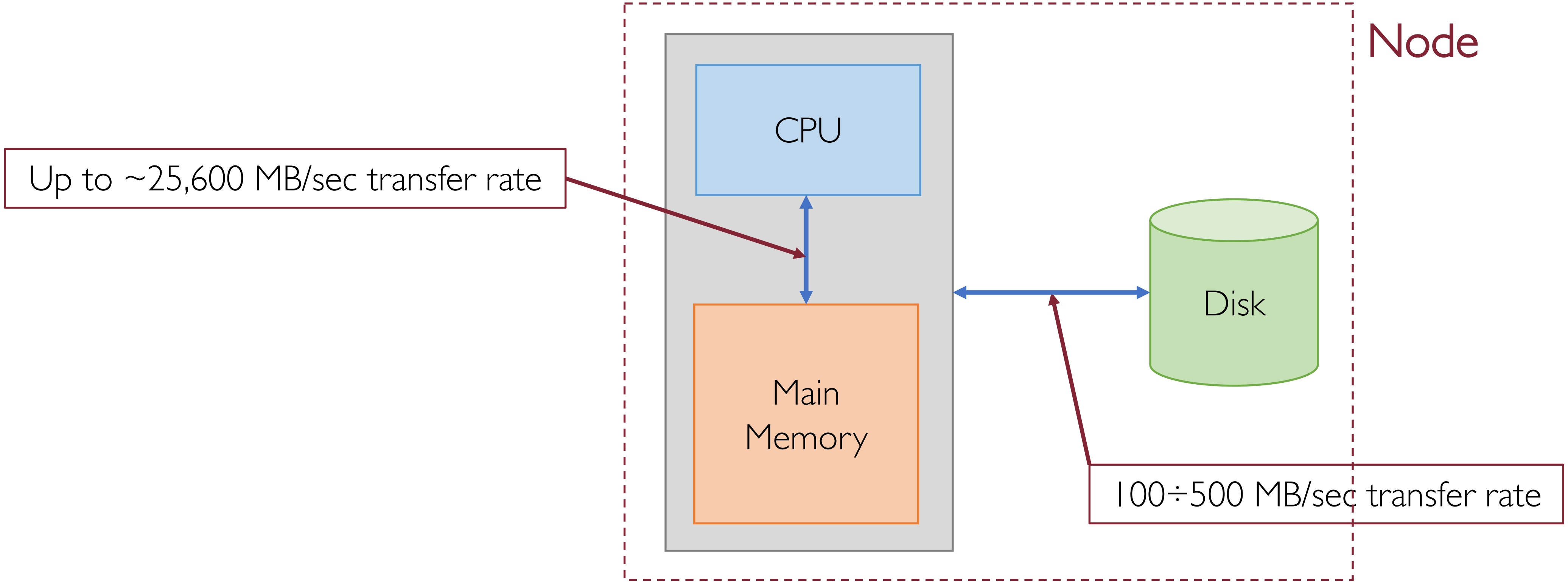

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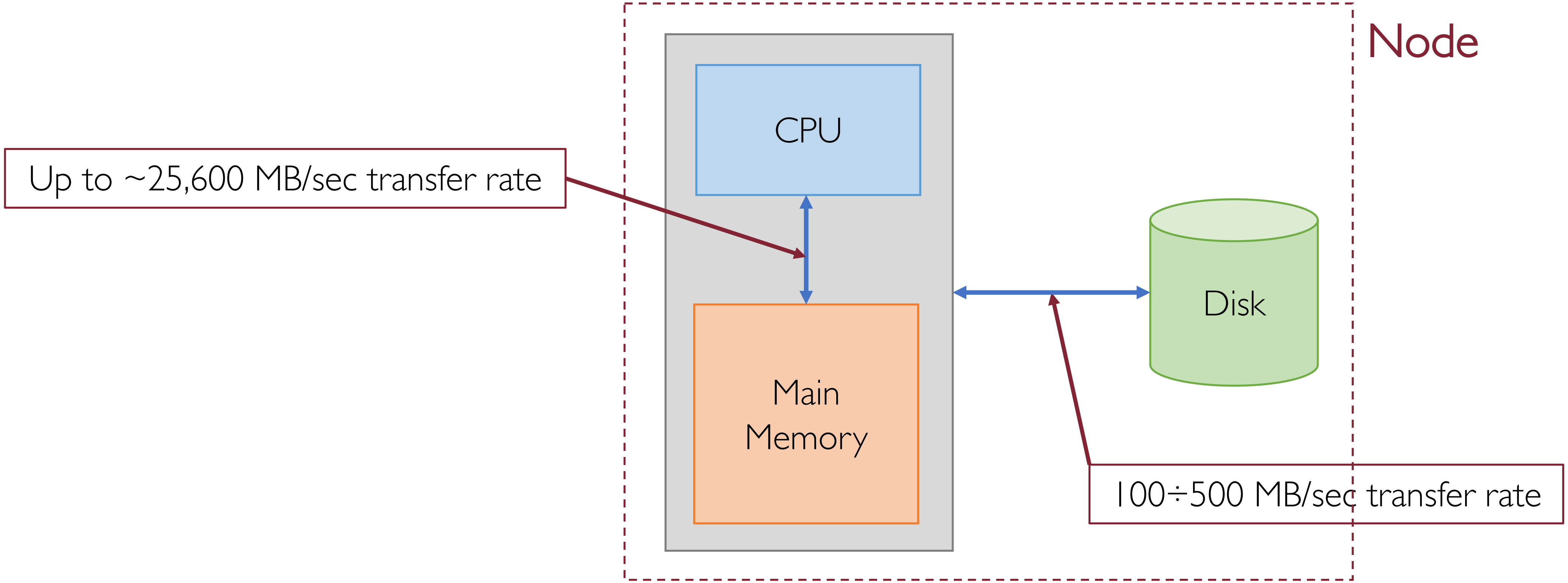

2 orders of magnitude difference between data transfer rate

Example: Google (Toy) Index

- Assuming the disk transfer rate is 100 MB/sec the total time to read the entire index will be:

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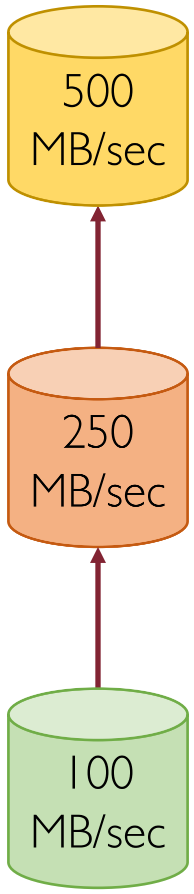
- Single-node architecture is clearly not enough here
  - Scaling Up vs. Scaling Out

Scaling Up/Vertical Scaling

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



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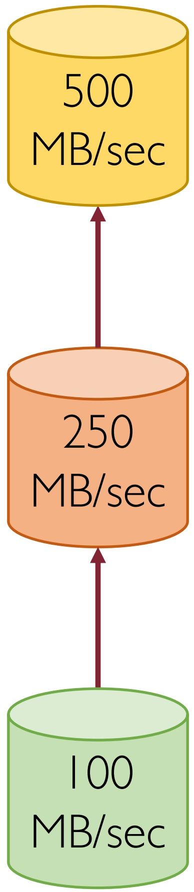

Scaling Up/Vertical Scaling

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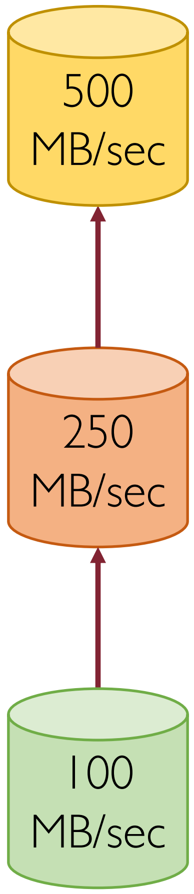
  - Easiest solution
- CON
  - Improvement is physically-limited (e.g., 2.5x or 5x)
  - Expensive



Scaling Out/Horizontal Scaling

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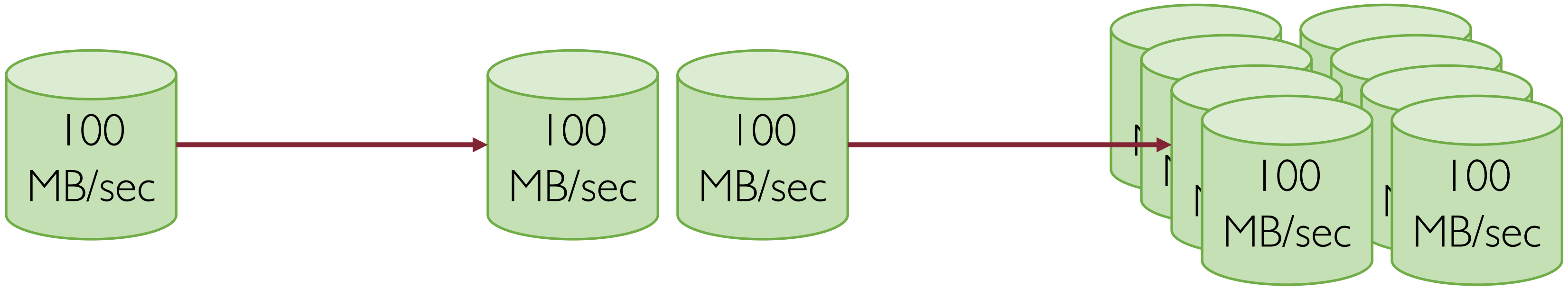

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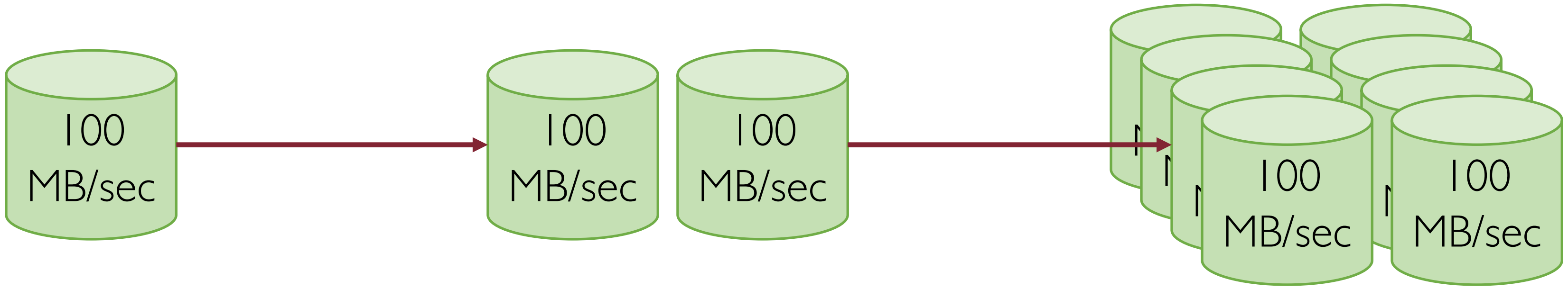

Scaling Out/Horizontal Scaling

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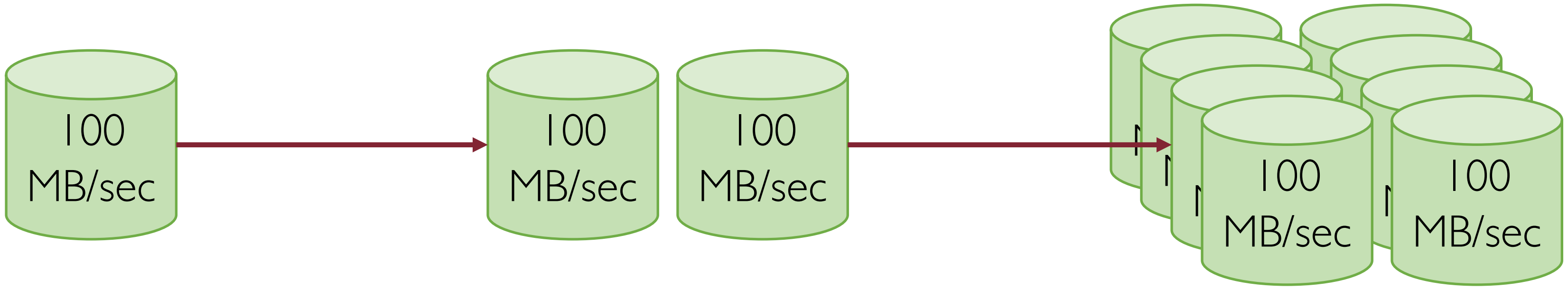
- CON
  - Extra overhead required to manage parallel work



Cluster Architecture

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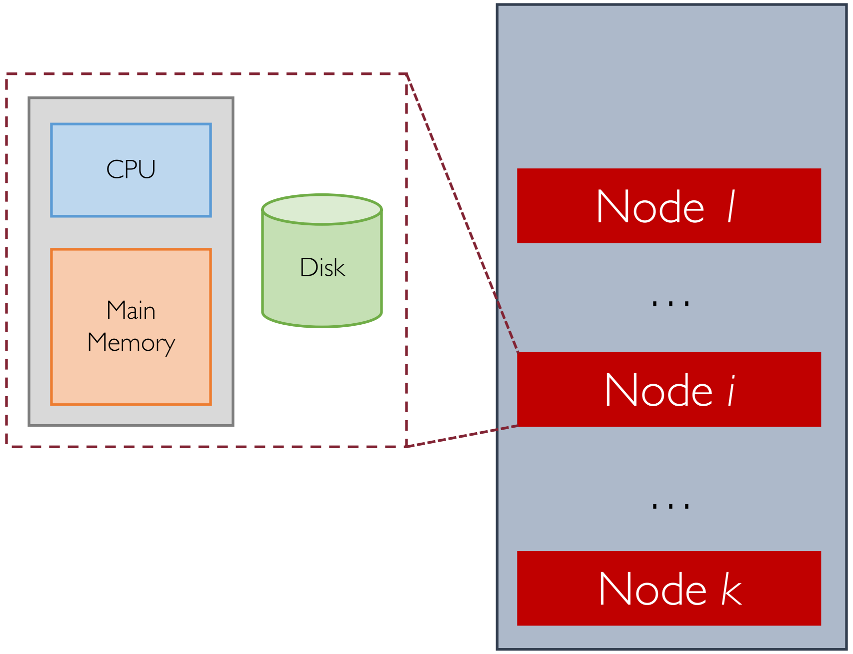
- A lot of commodity nodes communicating with each other
- Each group of 16÷64 nodes is arranged in a so-called rack
- A cluster is made of multiple racks
- Network switches enabling node communication
  - 1 Gbps (inter-rack)
  - 2÷10 Gbps (intra-rack)

Cluster Architecture



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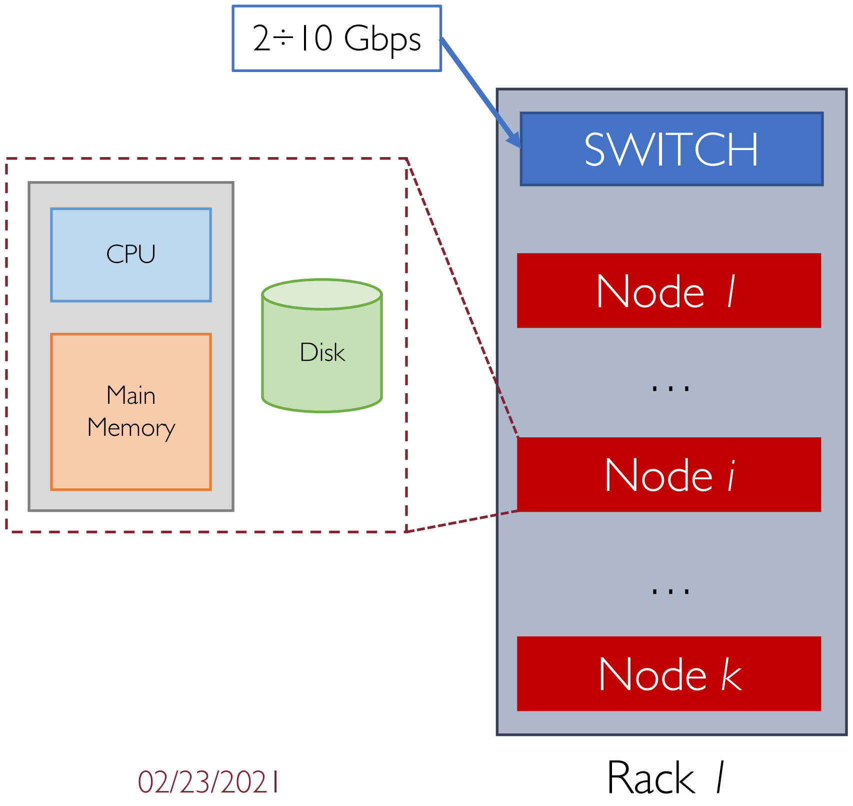

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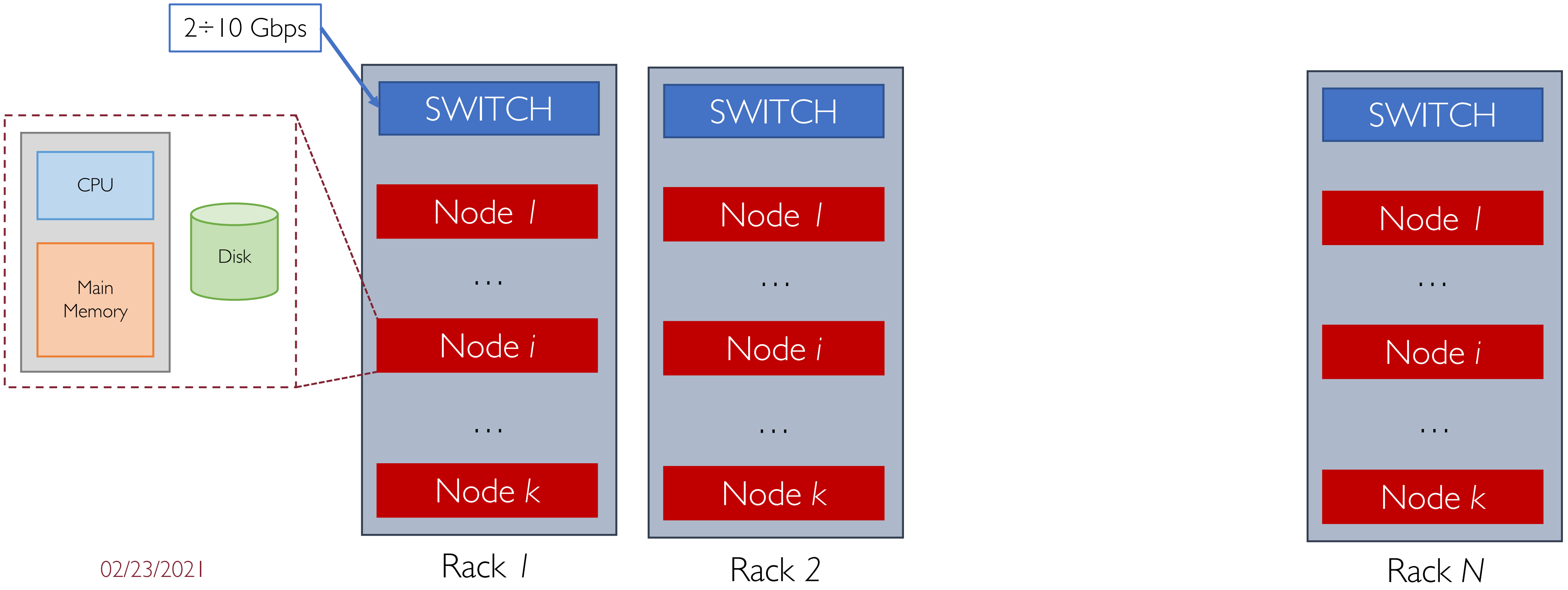

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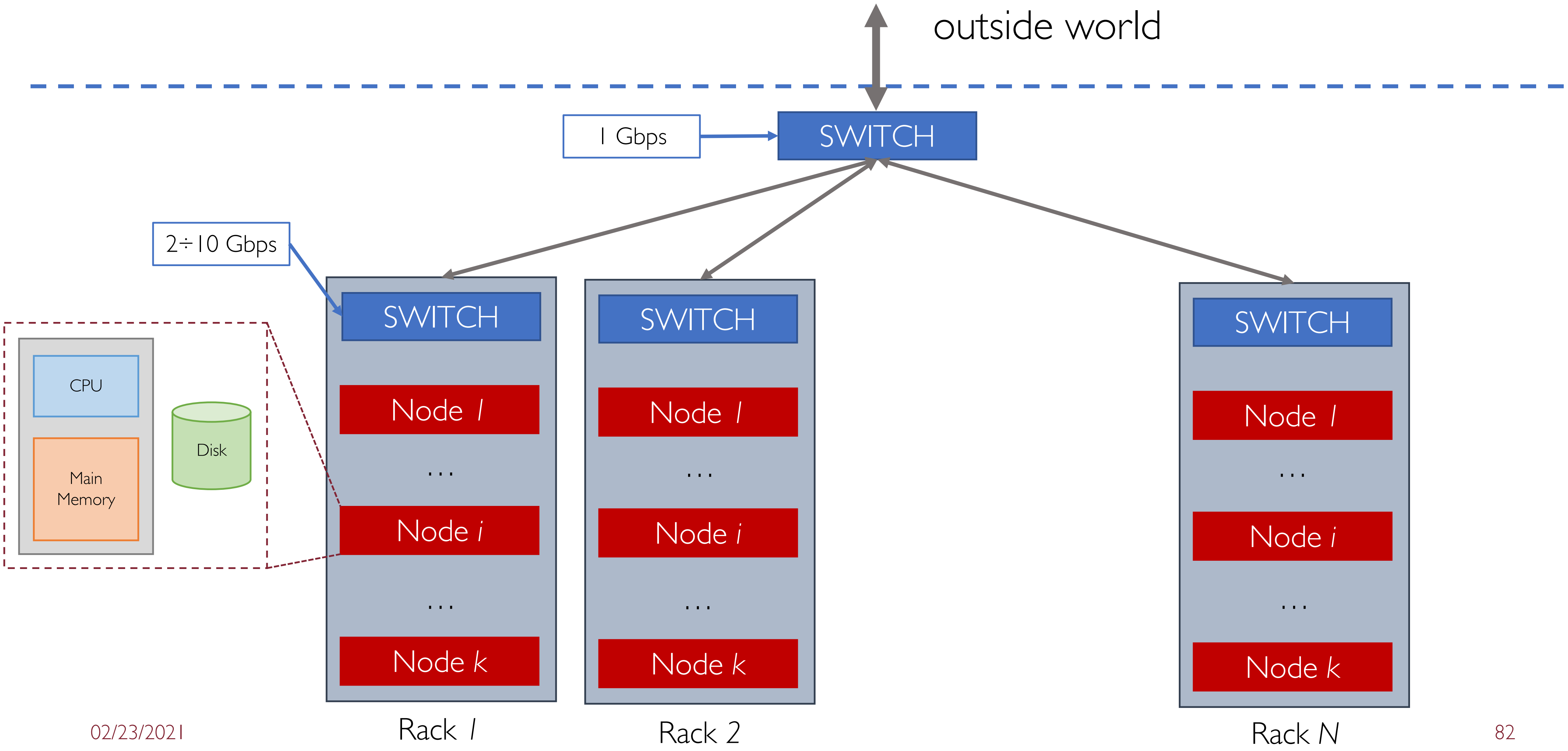

Cluster Architecture: Challenges

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  - Minimize network communication bottleneck
  - Ease distributed programming model

Challenge: Node Failure

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- Each node has a Mean Time To Failure (MTTF) = 3 years ~ 1,000 days

$$\boxed{p = P(\text{node}_i \text{ fails}) = 1/1{,}000 = 0.001}$$

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

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$$E[T] = Np$$

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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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- Traditional algorithms/techniques often don't scale very well
- There is the need for new "tools" which allow storing, managing, and analyzing big data painlessly