TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Introduction: The 3 Pillars

Algorithms, Data and Security
A.Y. 2023/24

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Global Governance, 3rd year
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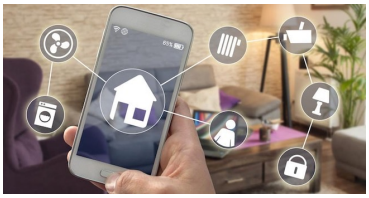
The 3 course pillars

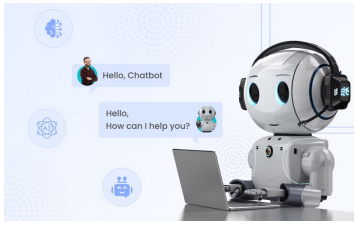
Algorithms, Data and Security

- Why should we care?
- Technology (digital innovation) is changing and shaping our world

The IT revolution

- Smart living
- Smart cities
- AI and automation
- Future of work
- New experiences





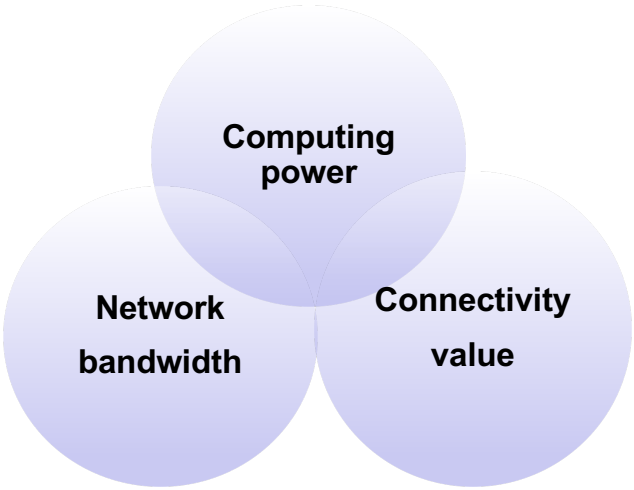
Why IT sector is so important?

- Largest phone companies?
- Most valuable retailer?
- Most popular media companies?
- Largest movie house?
- Largest software vendors?
- Largest taxi company?
- Largest accommodation provider?

Why IT sector is so important?

- Largest phone companies? *No telco infrastructure (Skype, Telegram, WeChat, WhatsApp)*
- Most valuable retailer? *Carries no stock (Alibaba)*
- Most popular media companies? *Create no content (Facebook, Instagram, TikTok, Youtube)*
- Largest movie house? *Owns no cinema (Netflix)*
- Largest software vendors? *Write no app (Apple, Google)*
- Largest taxi company? *Owns no car (Uber)*
- Largest accommodation provider? *Owns no property (Airbnb)*

Why is it possible?



Computing power

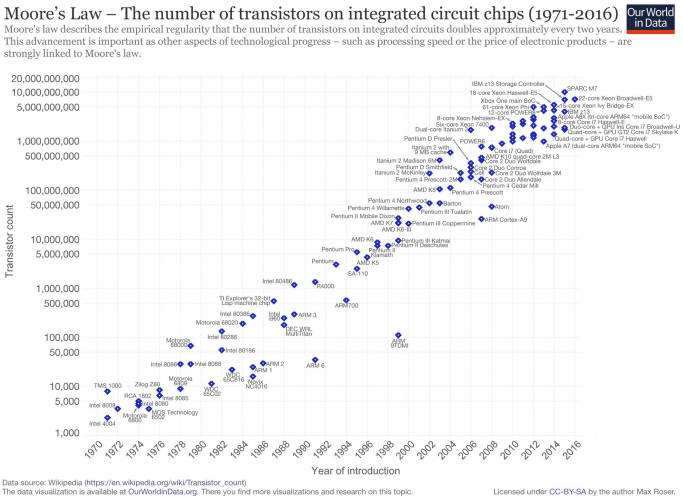
- Moore's law

  The number of transistors on a computer chip double approximately every 18 months

  – Began to show signs of slowing in 2015-2017

  – But we have multicore computing architectures

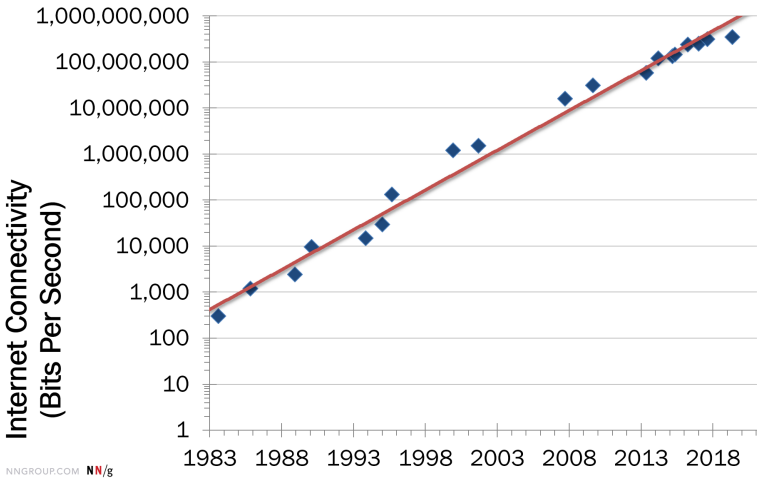
- Computers get
  – Smaller
  – Cheaper
  – Power efficient
  – Faster



Network bandwidth

- Nielsen's law

  Users' bandwidth grows by 50% per year



Network bandwidth

- With 5G we have super-fast low latency Internet everywhere
  - Faster than typical home Internet connection
  - Wireless
- How fast is 5G?
  - 4G tops out at a theoretical 100 megabits per second (Mbps)
  - 5G tops out at 10 *giga*bits per second (Gbps)
    - 100x faster than current 4G (theoretical maximum speed)

Connectivity value

- Metcalfe's law

  The value of a telecommunications network is proportional to the square of the number of connected users of the system

  Networking is *socially* and *economically* interesting

facebook Google twitter Instagram

What is an algorithm?

- Informal definition
- Sequence of instructions, given step by step, that could be executed "easily" and so that they produce a desired result (output)

Example of an algorithm

1. If you have questions about this class, please check the course web site (solved in 80% of cases)
2. If you do not find your answer on the web site, please ask the instructor during class
3. If you cannot check the web site, or you cannot attend classes?

What is an algorithm?

- How to solve a problem: compute (efficiently) output from input
- Problem: Wish to prepare a chocolate cake
- How to solve this problem? Recipe!

Input

200g golden caster sugar

200g unsalted butter, softened plus extra for the tins

4 large eggs

200g self-raising flour

2 tbsp cocoa powder

1 tsp baking powder

½ tsp vanilla extract

2 tbsp milk

Recipe and you!

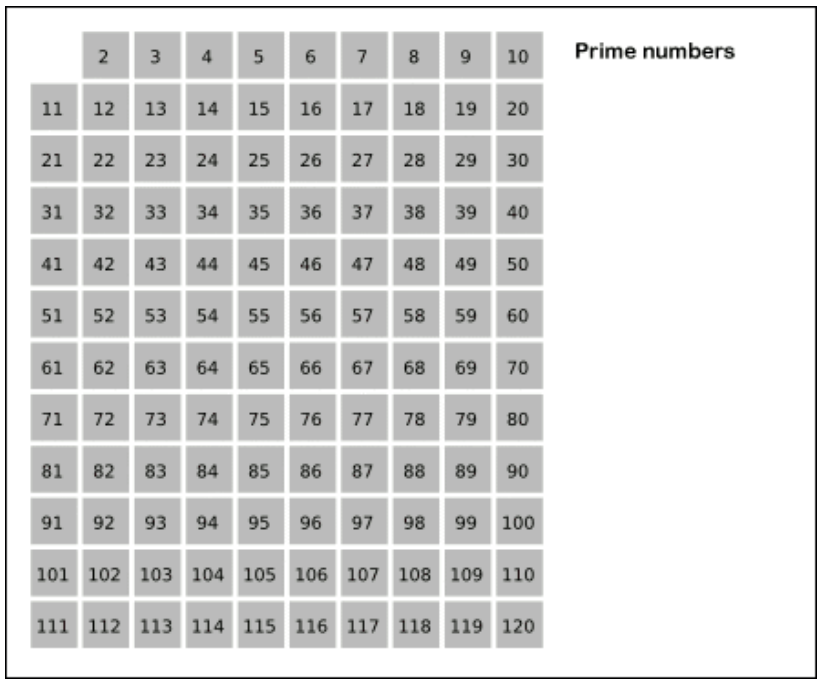
Output

A classical algorithm

- Eratosthenes' sieve (275-195 BC): output all primes ≤ n

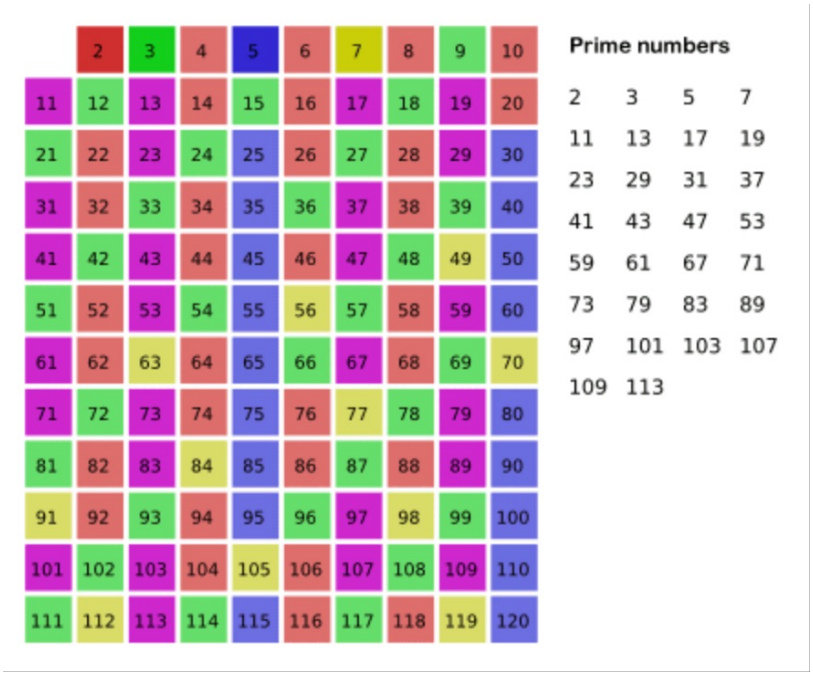
1. Prepare a list of natural numbers: 2, 3, …, n
2. Start from k = 2
3. Mark all multiples of k between k^2 and n (they cannot be prime!)
4. Replace k with smallest unmarked number > k
5. If ($k^2 \leq n$) go back to step 3
6. Output all unmarked numbers

Eratosthenes' sieve: example with n=120



Eratosthenes' sieve: example with n=120

- See animation
  https://en.wikipedia.org/wiki/Sieve_of_Eratosthenes

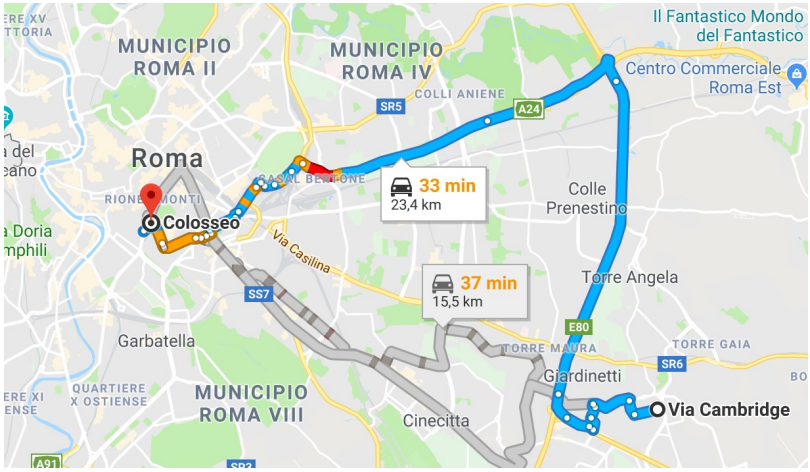


Other examples

- Count the number of objects that have distinct values (e.g., b, a, b, c, g, d, d, g)
- Sort a list of objects
- Search on Google
  - We will study PageRank, invented by Google's founders to rank web pages in search results
  - Now used in bibliometrics, social and information network analysis, and for link prediction and recommendation

Other examples

- Find the shortest distance: Google Maps uses the shortest path algorithm invented by Dijkstra



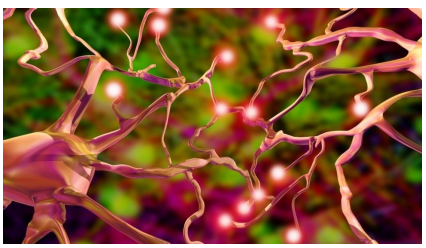
Other examples

- AlphaGo beats the world's top Go player
  - Go: sophisticated board game, more complex than chess for computers
  - AlphaGo: computer program that plays Go
    - Its algorithm finds the moves based on knowledge previously "learned" by machine learning, specifically by an artificial neural network

www.nytimes.com/2017/05/23/business/google-deepmind-alphago-go-champion-defeat.html

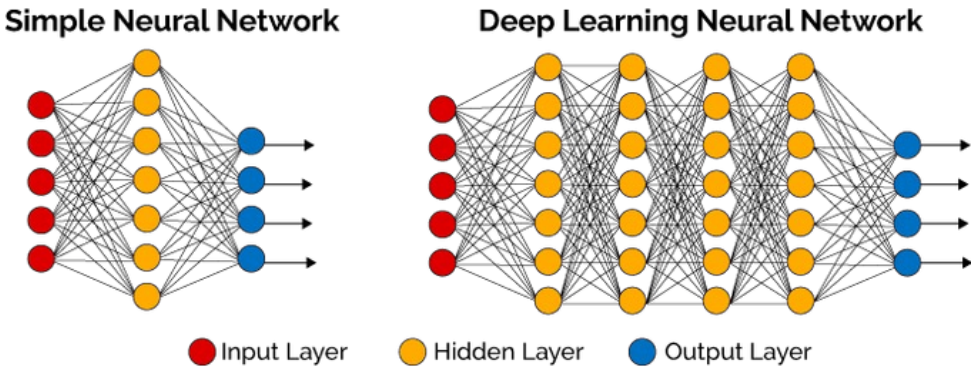
Artificial neural network

- Artificial neural network: computing system inspired by biological neural networks that constitute animal brains
  - It "learns" to perform tasks by considering examples, generally without being programmed with task-specific rules
    - E.g., in image classification, a neural network might learn to identify images that contain cats or dogs by analyzing a set of images labeled as "cat" or "dog" and using the results to identify cats or dogs in new images



Artificial neural network

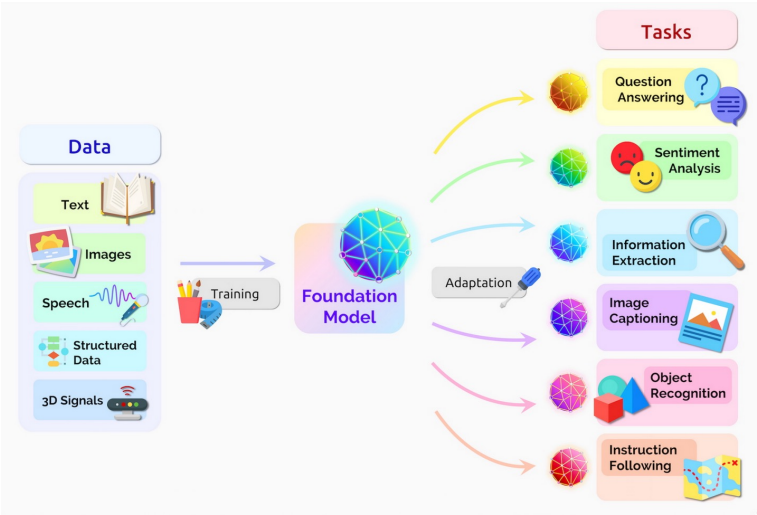
- Neural network works by making links between massive numbers of nodes
  - Hidden layers perform nonlinear transformations of inputs entered into the network



Transformer model

- A neural network that learns context and thus meaning by tracking relationships in sequential data like the words in this sentence

Aka foundation model:
"The sheer scale and scope of foundation models over the last few years have stretched our imagination of what is possible"
crfm.stanford.edu/report.html



Algorithms and Big Data

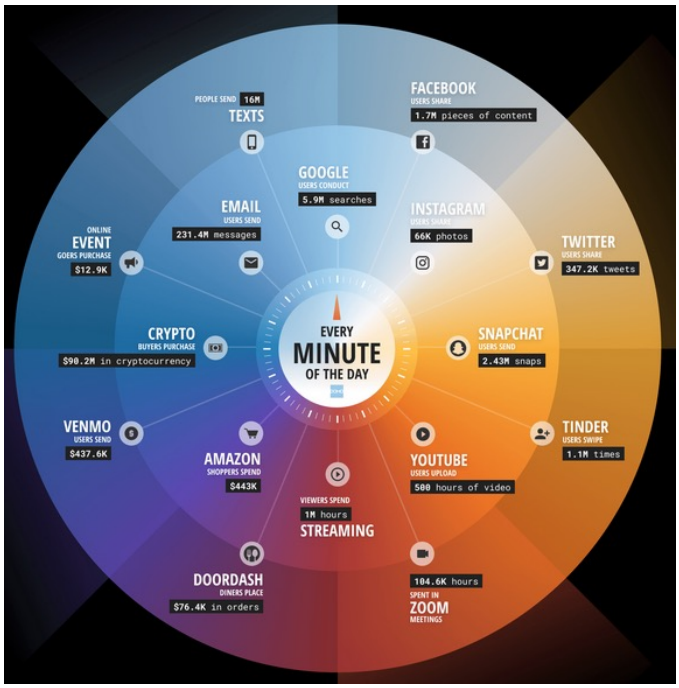
- Algorithms more important today because of Big Data
  - The Economist, 2010: The Data Deluge
  - NYT in 2012: The Age of Big Data

Why Big Data?

How much data is created every single minute of the day?

Global Internet population in Jan. 2024: 5.35 billion (66.2% of world population)

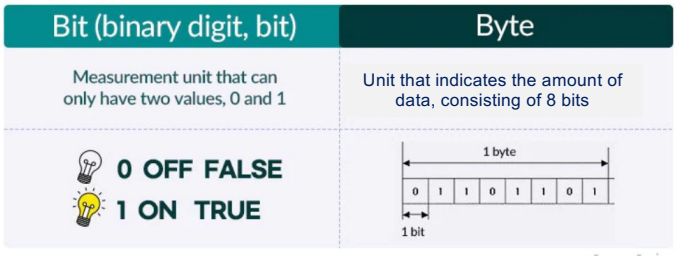
1 billion in 2005



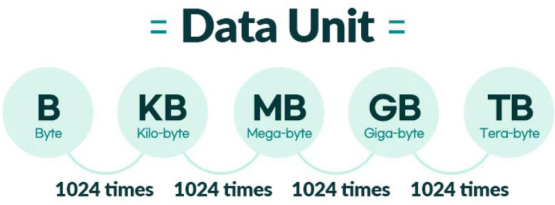
Source: www.domo.com/data-never-sleeps

Demystifying data units

- Bit and byte



- Each byte unit is 1,024 times the previous



Unit	Definition	Storage space size
Bit	0 or 1	Yes/No
1 Byte	8 bit	Alphabets and one number
1 kilobyte (KB)	1,024 Byte	A few paragraphs
1 megabyte (MB)	1,024 KB	One minute-long MP3 song
1 gigabyte (GB)	1,024 MB	30 minute-long HD movie
1 terabyte (TB)	1,024 GB	About 200 FHD movies

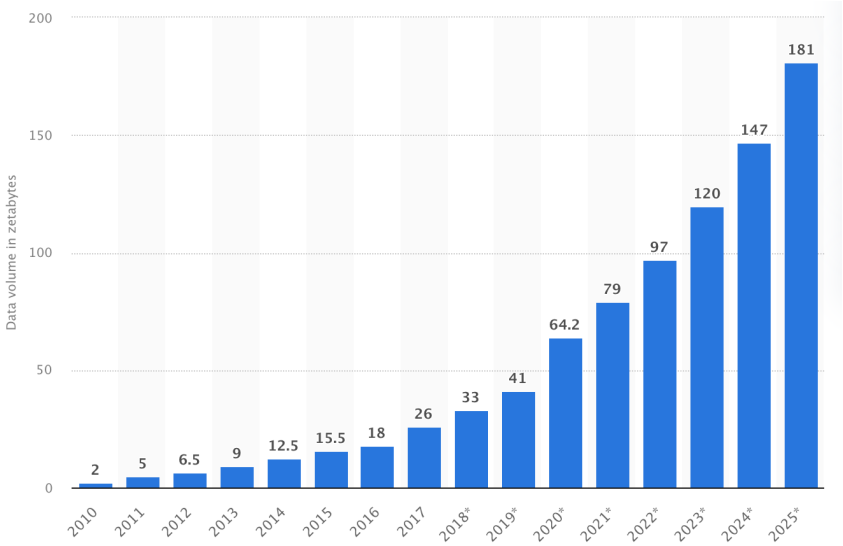
How much data?

- Big data volume: from Terabytes to Zettabytes
  - How big is a Zettabyte?
  - 1 ZB = 2^{70} B = $(2^{10})^7$ B ≈ $(10^3)^7$ B = 10^{21} B
    - Remember that $2^{10} = 1024 \approx 10^3$
    - Also, 1 ZB = 2^{70} B = 2^{40} 2^{30} B = 2^{40} GB, being 2^{30} B = 1 GB
- 120 Zettabytes of data generated by 2023

120 Zettabytes ($120x2^{70} \approx 120x10^{21}$) …
≈ 120,000 Exabytes ($120,000x10^{18}$) ...
≈ 120,000,000 Petabytes ($120,000,000x10^{15}$) ...
≈ 120,000,000,000 Terabytes ($120,000,000,000x10^{12}$) …
≈ 120,000,000,000,000 Gigabytes ($120,000,000,000,000x10^{9}$) …
≈ 120,000,000,000,000,000,000,000 bytes!

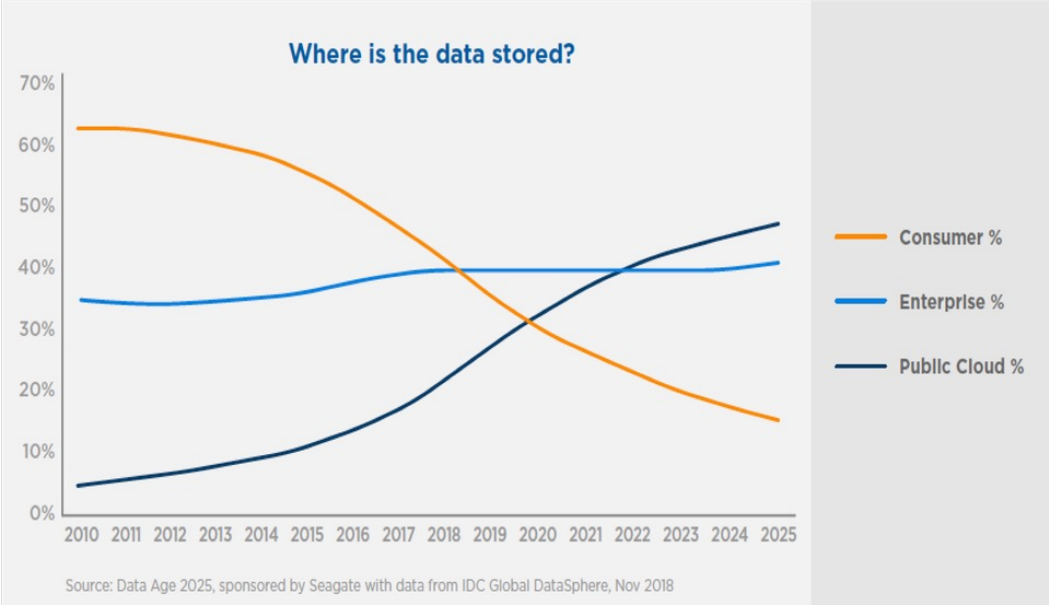
How much data?

- Recent explosion in data volume
  - In 2013: 90% of all the data in the world was generated over the last two years
  - 60x growth from 2010 to 2023



Where is data stored?

- Data is increasingly stored in Cloud servers
- Where are Cloud servers located?

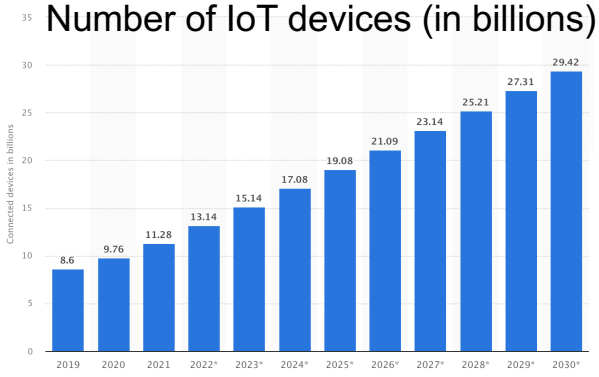


Big data statistics and economic impact

- Every person generated roughly 1.7 MB per second
- Internet users generate about 2.5 EB of data each day
- Google, Facebook, Microsoft, and Amazon store at least 1,2 EB of users data
- Big data and analytics software and cloud services market reached $90 billion in 2021 and it is expected to more than double by 2026 (IDC)
- 91% of organizations are investing in Big Data and AI
- Using Big Data and machine learning algorithms, Netflix saves $1 billion per year on customer retention

Big data driving factors

- Big Data is growing fast
  - Smartphones
  - Social networks
  - Internet of Things (IoT)



- Exponential growth in unstructured data

Source: Human-Computer Interaction & Knowledge Discovery in Complex Unstructured, Big Data

How Big? IoT impact

- IoT is everywhere and largely contributes to increase Big Data challenges
  - Proliferation of data sources: by 2023 over 15 billion IoT devices installed worldwide
- Example: self-driving cars
  - Just one autonomous car can generate up to 4 TB of data/day

Big Data definitions

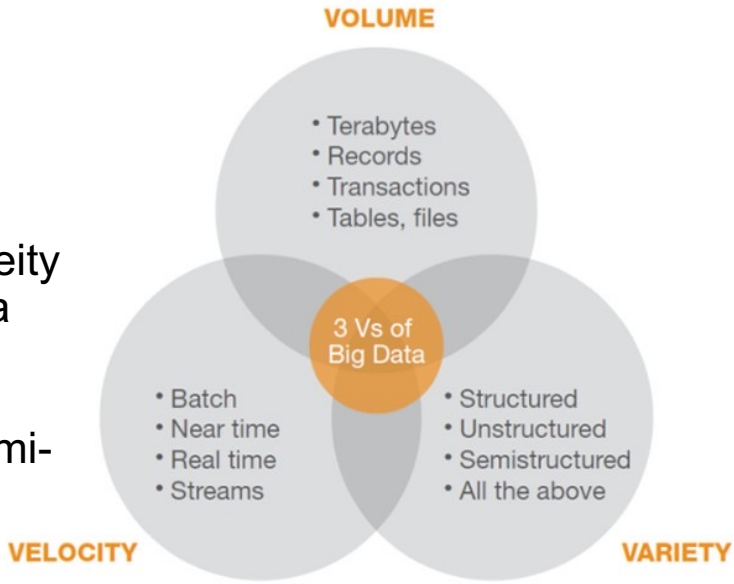
Different definitions

- "Big data refers to data sets whose size is beyond the ability of typical database software tools to capture, store, manage and analyze." *The McKinsey Global Institute, 2012*
- "Big data is a field that treats ways to analyze, systematically extract information from, or otherwise deal with data sets that are too large or complex to be dealt with by traditional data-processing application software." *Wikipedia, 2020*
- "Big data is mostly about taking numbers and using those numbers to make predictions about the future. The bigger the data set you have, the more accurate the predictions about the future will be." *Anthony Goldbloom, Kaggle's founder*

3V model for Big Data

1. **Volume**: data size challenging to store and process (how to index, retrieve)
2. **Variety**: data heterogeneity because of different data types (text, audio, video, record) and degree of structure (structured, semi-structured, unstructured data)
3. **Velocity**: data generation rate and analysis rate

- Defined in 2001 by D. Laney



The extended (3+n)V model

4. **Value**: Big data can generate huge competitive advantages
   - "Big data technologies describe a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling high-velocity capture, discovery, and/or analysis." (IDC, 2011)
   - "The bigger the data set you have, the more accurate the predictions about the future will be" (A. Goldbloom)
5. **Veracity**: uncertainty of accuracy and authenticity of data
6. **Variability**: data flows can be highly inconsistent, with periodic peaks
7. **Visualization**

Big Data visualization

- Presentation of data in a pictorial and graphical format
- Why? Our brain processes images 60,000x faster than text
- Some example

The downside

- Every day more data to process and store
- How much energy do we consume?
  - In 2022, data centers that power all computers, including Amazon's cloud and Google's search engine, used about 1% to 1.3% of world's current electricity use
  - Cryptocurrency mining used another 0.4%
  - By 2027 AI servers could use between 85 to 134 terawatt hours (Twh) annually
    - That's similar to what Argentina, the Netherlands and Sweden each use in a year, and is about 0.5% of world electricity

Data structures

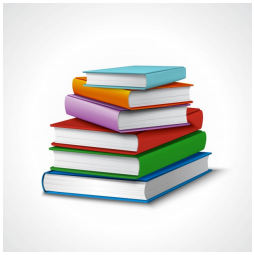
- Structure to organize data
- Support some operations
- Example: stack

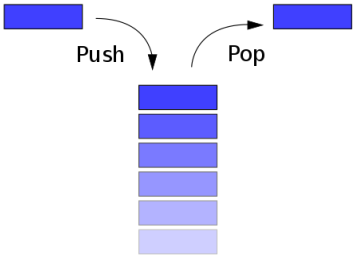
  Supports 3 basic operations:

  Insert (“push”)

  Delete (“pop”)

  Display content of top item (“peek”)





What about security?

- IT and data everywhere

IT and data everywhere

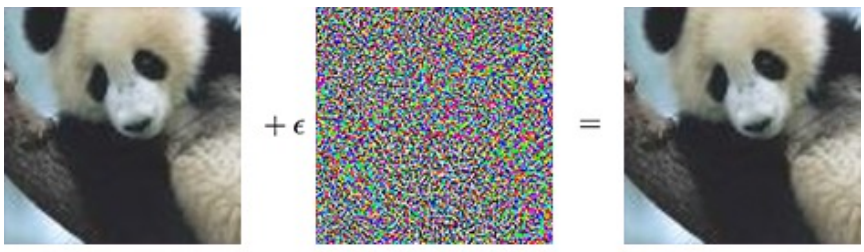
- New cybersecurity threats

Self-driving cars

IoT wearables

Attacking Machine Learning algorithms

- Adversarial examples are inputs to a machine learning model (e.g., neural network) that an attacker has intentionally designed to cause the model to make a mistake
  - Like optical illusion
  - Changing only 0.04% of the pixel values in the input image (undetected by human eyes), the neural network changes its solution from the correct classification “panda” to an incorrect “gibbon” classification

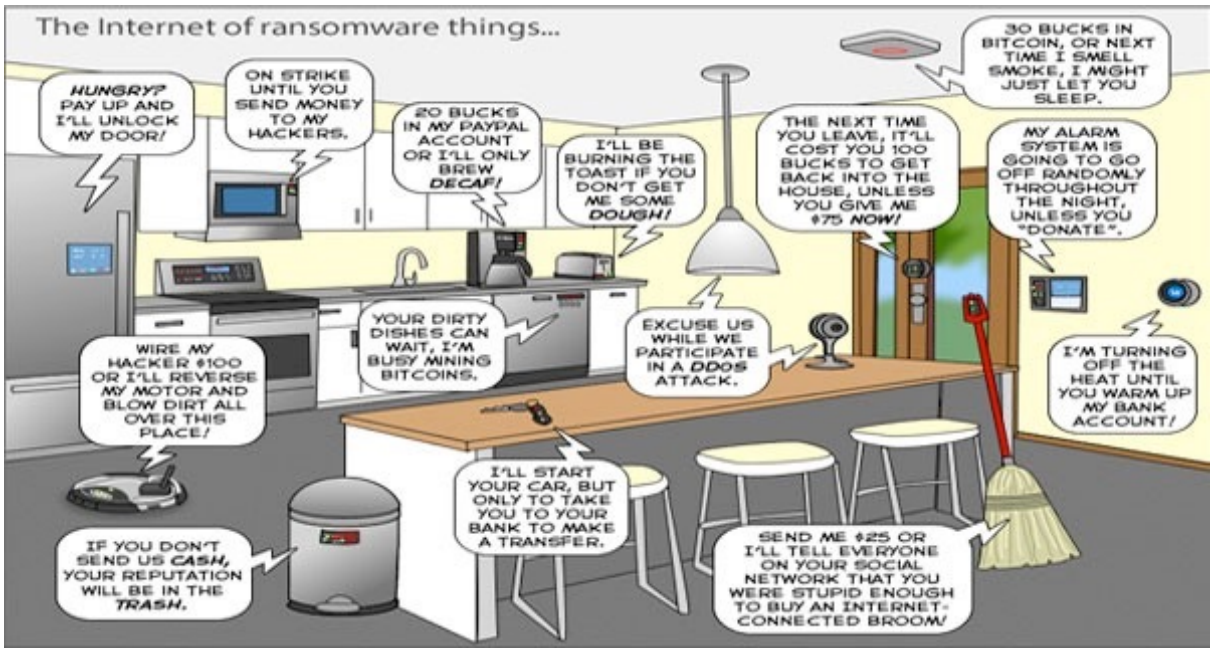


“panda”
57.7% confidence

“gibbon”
99.3% confidence

This is a gibbon!

Internet of Things and ransomware



Ransomware: kind of malware that withholds some digital assets from victims and asks for payment for the assets' release