Introduction to Big Data

Lesson 1 — Data-intensive computing

Arthur Katossky & Rémi Pépin

ENSAI (Rennes, France)

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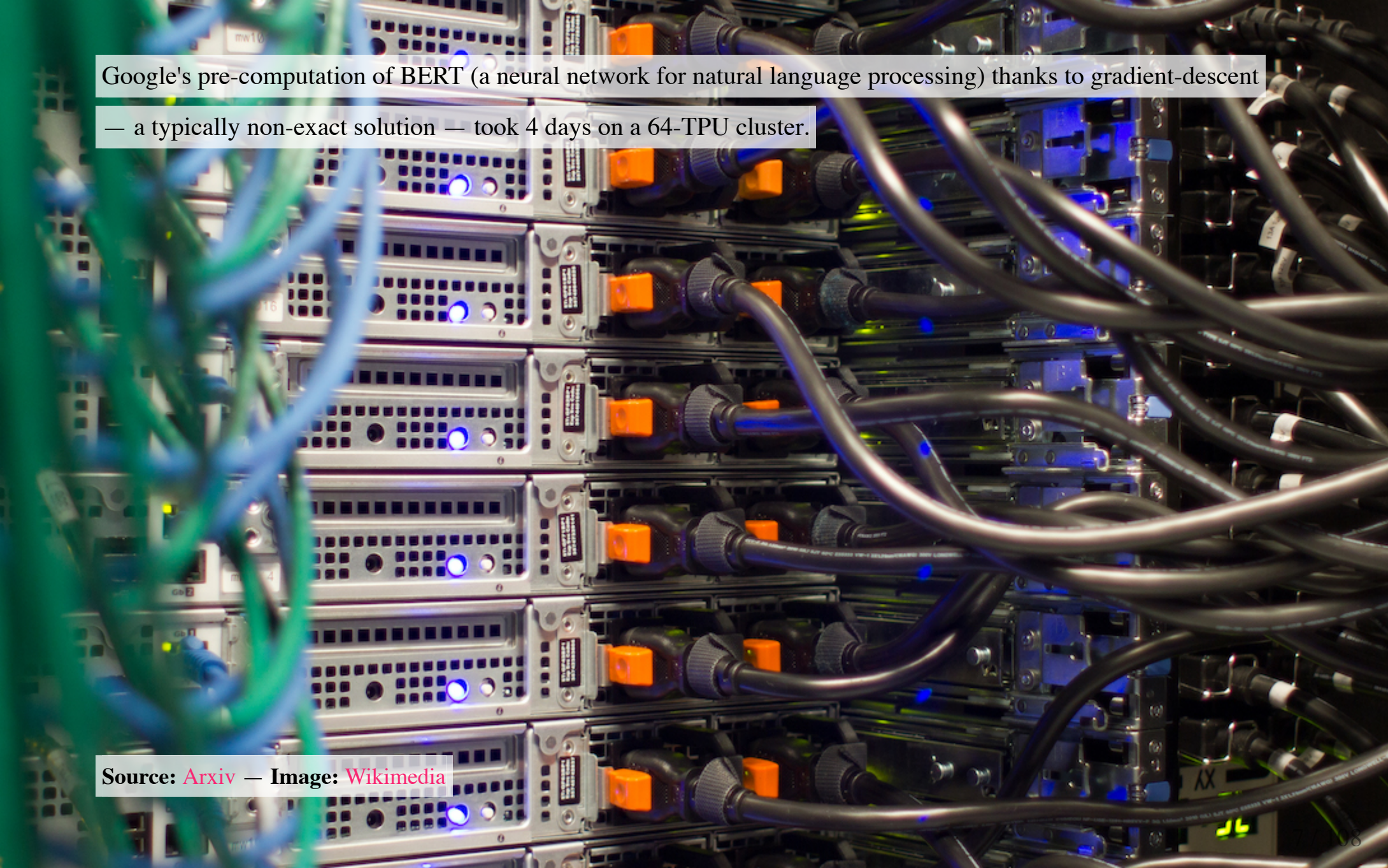
Forewords

Motivation

Machine-learning algorithms do not scale well.

- exact solutions do not scale // ex: matrix inversion is of $O(n^3)$ complexity
- approximate solutions do not scale either



Google's pre-computation of BERT (a neural network for natural language processing) thanks to gradient-descent — a typically non-exact solution — took 4 days on a 64-TPU cluster.

Source: Arxiv — **Image:** Wikimedia

Motivation

Machine-learning algorithms do not scale well.

- exact solutions do not scale // ex: matrix inversion is of $O(n^3)$ complexity
- approximate solutions do not scale either

One would thus consider how these computation procedures may be accellerated.

- Using algorithmic tricks?
- Using more memory?
- Parallelizing on several computers?
- Relaxing our precision requirements? ...

These are many many solutions... and each of this problems is far from trivial!

Computing a median can prove challenging to speed up!

Goal

At the end of this course, you will:

- understand the potential bottlenecks of data-intensive processes
- choose between concurrent solutions for dealing with such bottlenecks
- understand the map-reduce principle and have practical experience with Spark on HDFS
- have an overview of the cloud computing ecosystem and practical experience with one provider (AWS)
- get a glimpse over the *physical*, *ethical*, *economical*, *financial*, *environmental*, *statistical*, *political*... challenges, limitations and dangers of the suggested solutions

Outline & schedule

Courses:

- **Course 0:** Introduction to cloud computing (1h30, March 3)
- **Course 1:** Data-intensive computing in a nutshell (3h, February 18)
- **Course 2:** Parallelized computing and distributed computing (3h, March 2)

Tutorials:

- **Tutorial 0:** Hands-on AWS (1h30, March 3)
- **Tutorial 1:** Hands-on Spark (3h, March 18)
- **Tutorial 2:** How to optimize a statistical algorithm? (3h, March 4)
- **Tutorial 3:** How to compute a statistical summary over distributed data? (3h, March 11)
- **Tutorial 4:** Coping with APIs, data streams and exotic formats (3h, March 25)

Evaluation

- Multiple-choice questionnaire at the beginning of every tutorial
- 1 short tutorial report (tutorial 1)
- Desk examination (most probably multiple-choice questionnaire)

Material

Course and tutorial material will be available on Moodle.

From "Big Data" to "Large Scale"

What is "Big Data" ?

What is "Big Data" ?

The term started to be used in the 1990's and is a ill-defined notion.

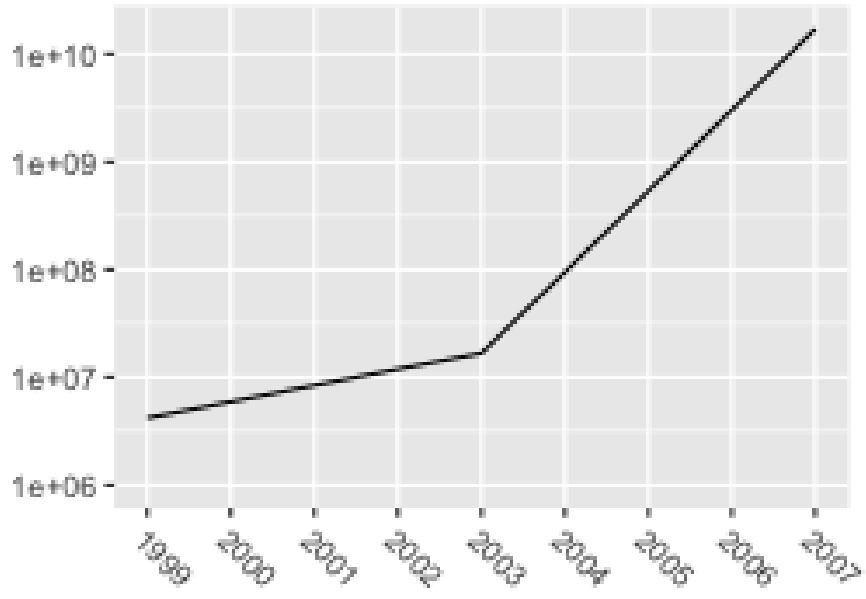
Big Data broadly refers to data that **cannot be managed by commonly-used software**.

What is "Big Data" ?

Line and row limits of Microsoft's Excel tablesheet

	Version	Lines	Columns
until 1995	7.0	16 384	256
until 2003	11.0	65 536	256
from 2007	12.0	1 048 576	16 384

Max. number of items stored in one tablesheet



What is "Big Data" ?

Size is **not** the only thing that matters.

In a tablesheet program, what kind of information can't you store properly?

- relationnal data
- images, long texts
- unstructured data (ex: web page)
- rapidly varying data (ex: tweeter feed)

What is "Big Data" ?

You will often find the reference to the "3 V's of Big Data"

- **V**olume
- **V**elocity
- **V**ariety[1]

[1]: not really treated in this course

How big is "Big Data" ?

Large-scale computing

The limits to storage and computing

Computer science survival kit

A computer can be abstracted by four key components:

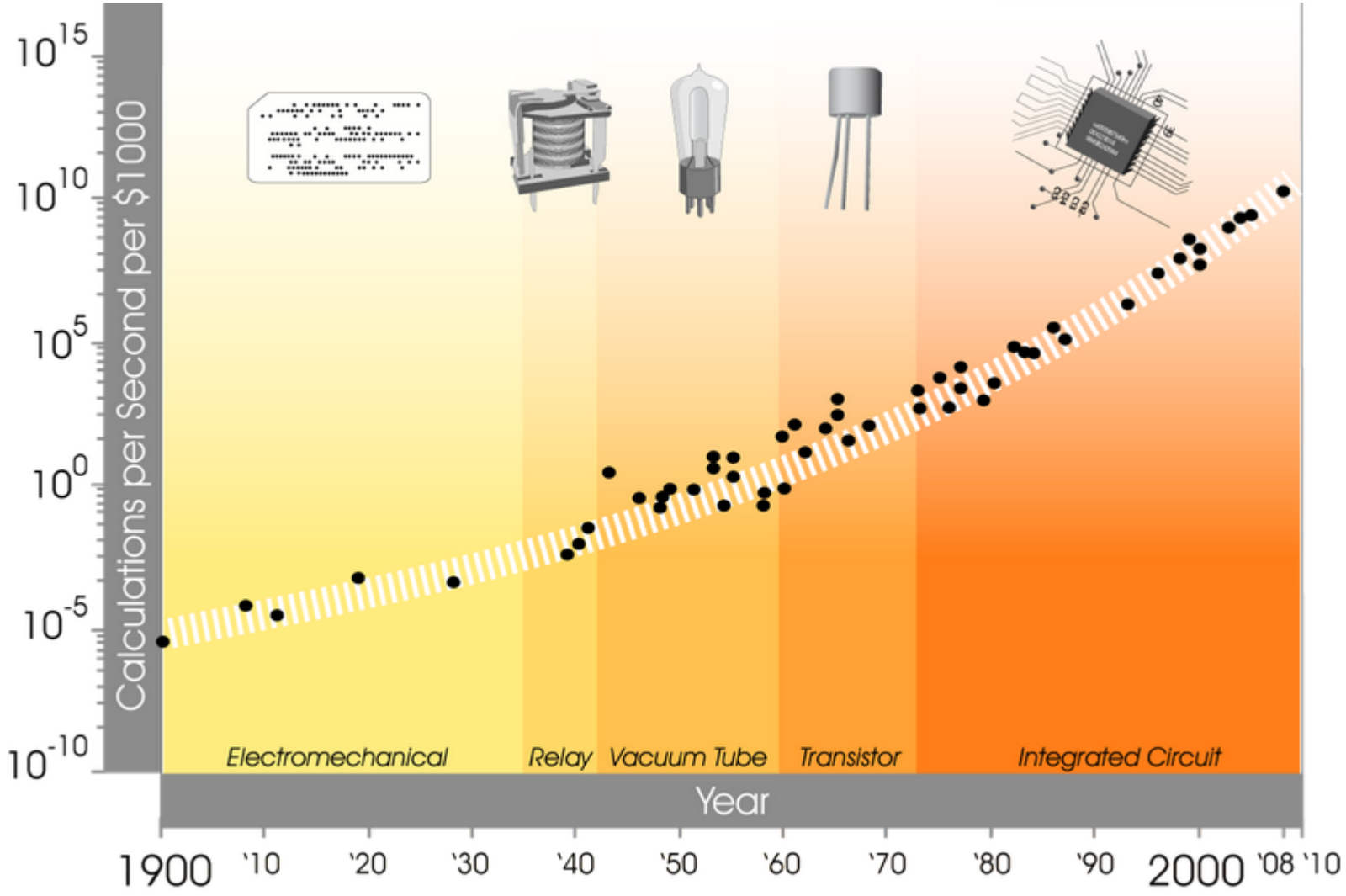
- processing (FR: processeurs)
- memory (FR: mémoire vive)
- storage (FR: stockage)
- wiring / network (FR: connexions / réseau)

Processors

Processors

What is important for us to know?

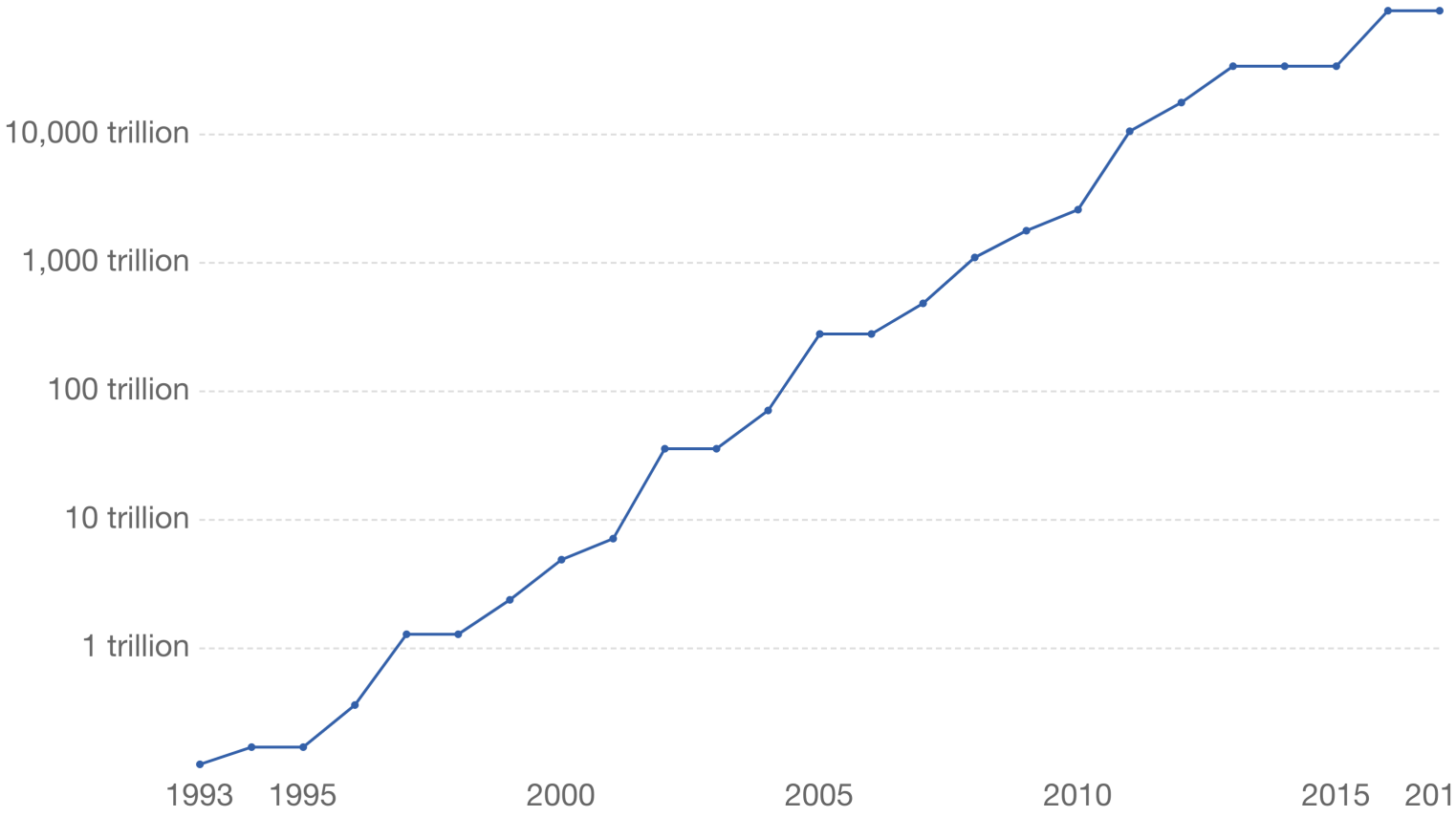
- computation happens *physically*
- programs must be converted to machine-code
- instructions are stored sequentially in a stack / thread
- multiple processors may share a stack, or have each their own
- processors can be specialized



Source: Kurzweil (link) via Our World in Data (link)

Supercomputer Power (FLOPS)

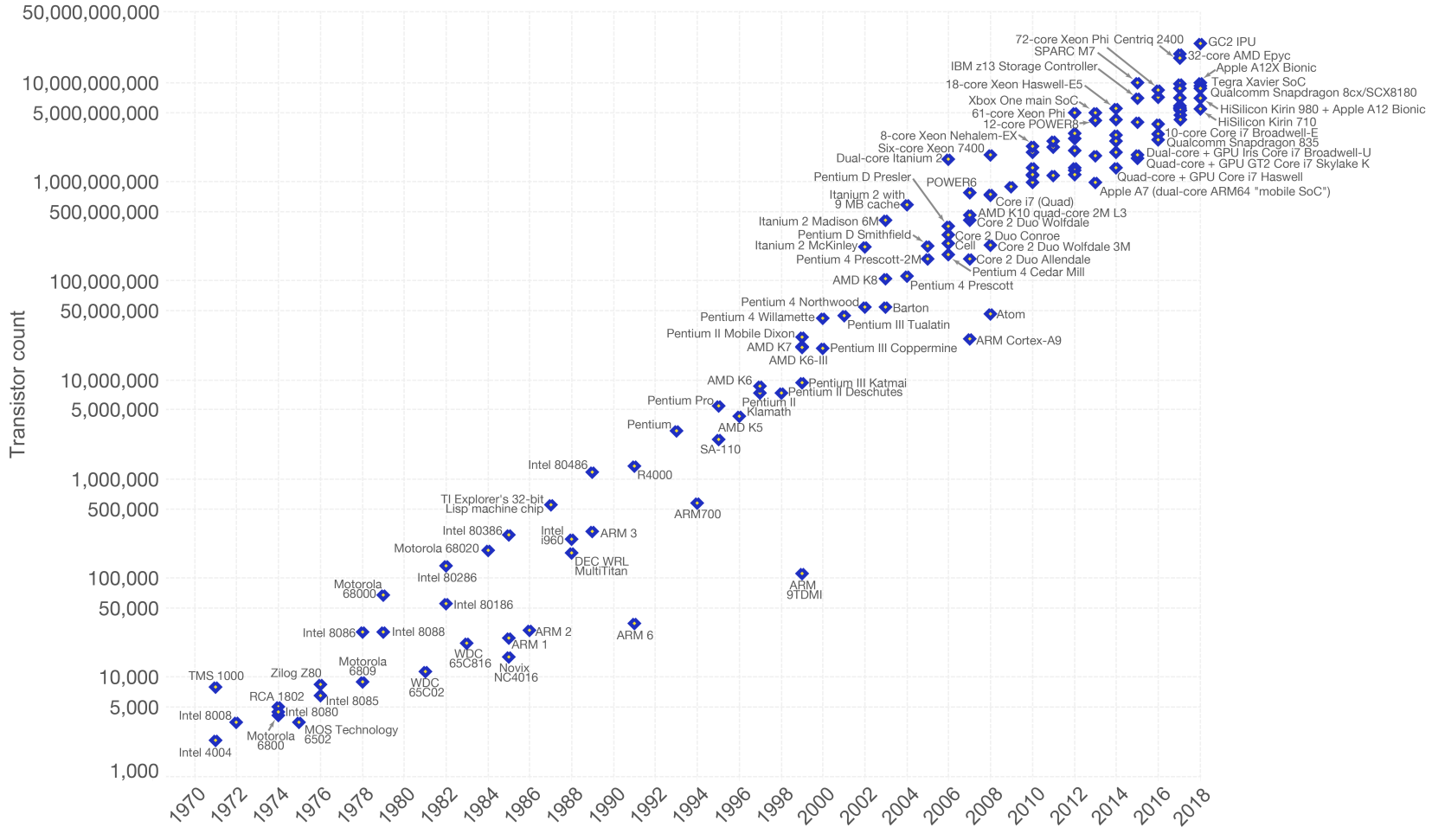
The growth of supercomputer power, measured as the number of floating-point operations carried out per second (FLOPS) by the largest supercomputer in any given year. (FLOPS) is a measure of calculations per second for floating-point operations. Floating-point operations are needed for very large or very small real numbers, or computations that require a large dynamic range. It is therefore a more accurate measured than simply instructions per second.



Source: TOP500 Supercomputer Database

Moore’s Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Processors

Processing is a limitting factor.

Memory

Memory

What is important for us to know ?

- moving data around takes time
- memory is fast (ns)
- memory is volatile
- memory-processor units are **heavily** optimized

Memory

Memory is a limitting factor.

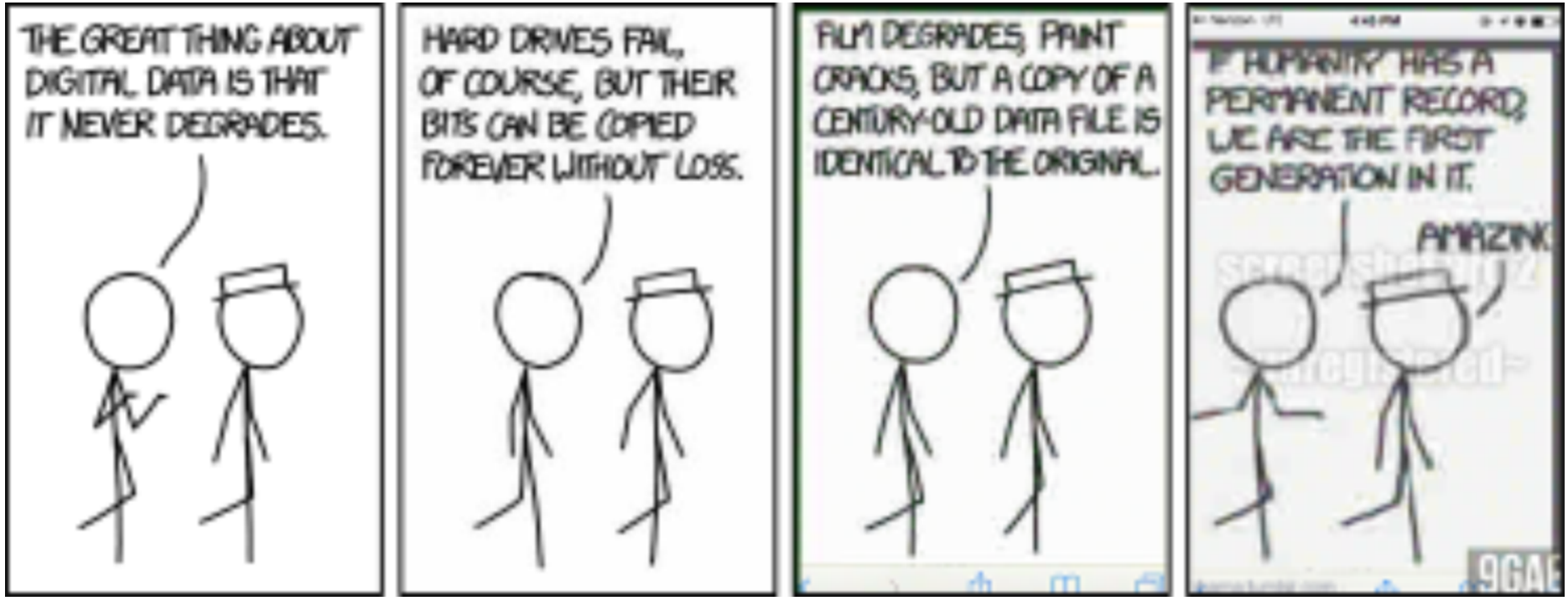
Storage

Storage

What is important for us to know ?

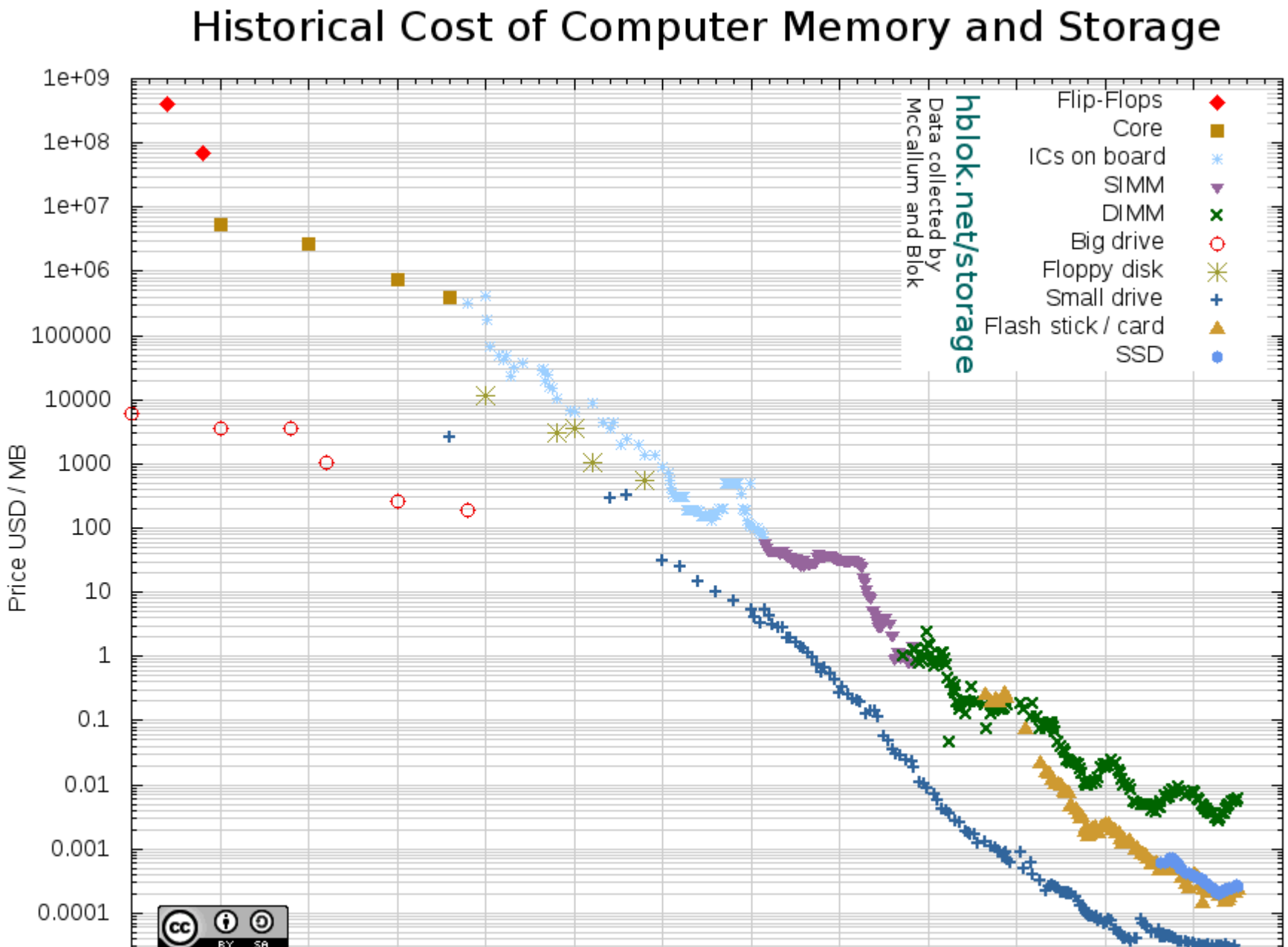
- storage is faillible
- writing and reading is slow (ms)
- data is always cached for computation

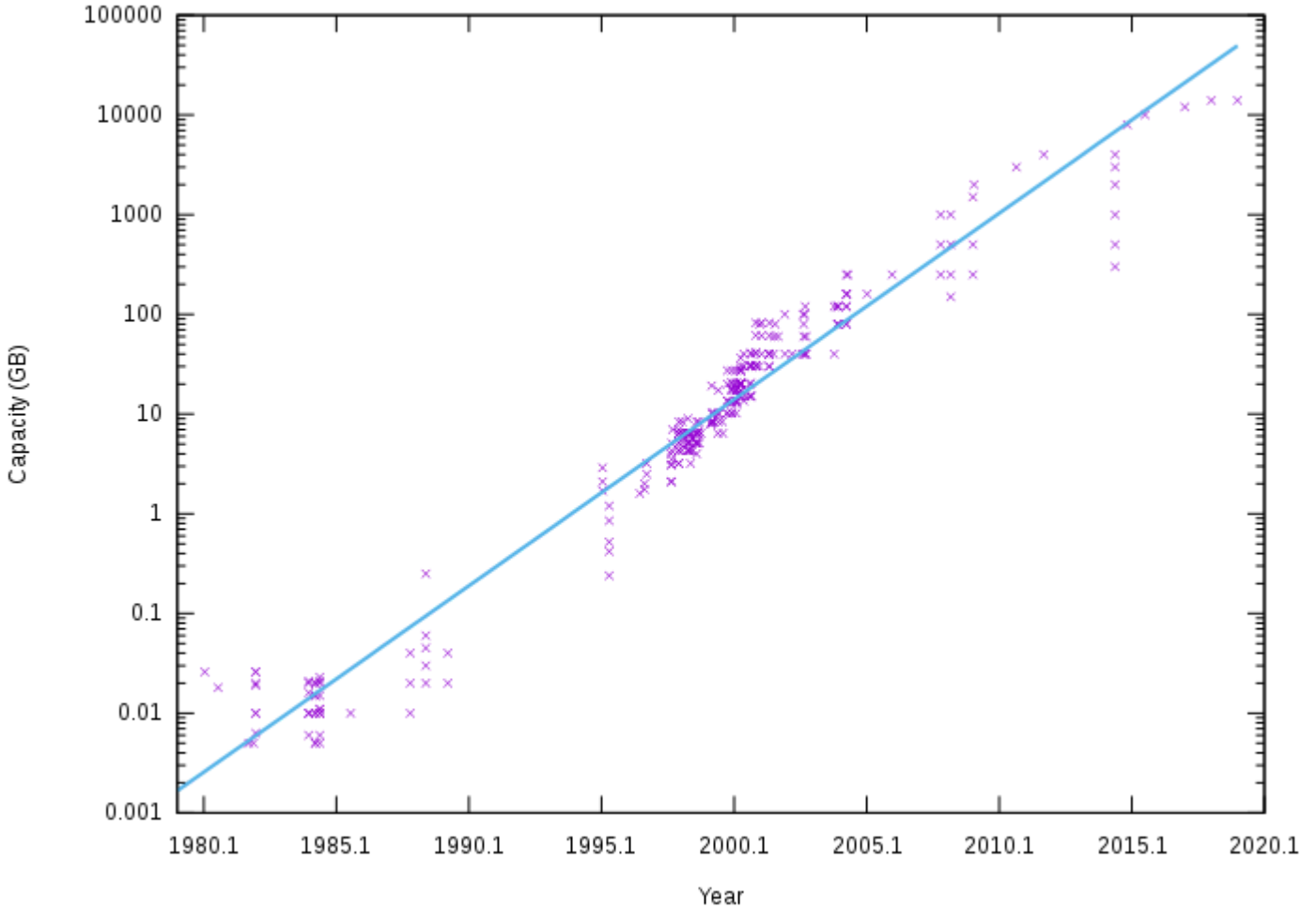
Storage


THE GREAT THING ABOUT DIGITAL DATA IS THAT IT NEVER DEGRADES.
HARD DRIVES FAIL, OF COURSE, BUT THEIR BITS CAN BE COPIED FOREVER WITHOUT LOSS.
FILM DEGRADES, PAINT CRACKS, BUT A COPY OF A CENTURY-OLD DATA FILE IS IDENTICAL TO THE ORIGINAL.
IF HUMANITY HAS A PERMANENT RECORD, WE ARE THE FIRST GENERATION IN IT.
AMAZING
9GAG

Storage

Storage is a limitting factor.


Historical Cost of Computer Memory and Storage
Price USD / MB
1e+09
1e+08
1e+07
1e+06
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
hblok.net/storage
Data collected by
McCallum and Blok
Flip-Flops
Core
ICs on board
SIMM
DIMM
Big drive
Floppy disk
Small drive
Flash stick / card
SSD


100000
10000
1000
100
10
1
0.1
0.01
0.001
Capacity (GB)
1980.1
1985.1
1990.1
1995.1
2000.1
2005.1
2010.1
2015.1
2020.1
Year

Network

Interpreting vs. compiling

Challenges with large-scale machine-learning

What if ... ?

What if data is too big to fit in RAM ?

1. do less (filter, sample)
2. buy more/bigger memory
3. do things in chunks (stream, pipeline)
4. distribute the data

What if ... ?

What if file is too big for file system ?

1. do less (filter, sample)
2. change file system
3. cut file into pieces and process in chunk
4. go on databases, that's what they are made for
5. go on cloud, they take care of the problems for you

What if file is too big for file system ?

Q: How much data can I store?

The total volume of data and number of objects you can store are unlimited. Individual Amazon S3 objects can range in size from 1 byte to 5 terabytes. The largest object that can be uploaded in a single PUT is 5 gigabytes. For objects larger than 100 megabytes, customers should consider using the Multipart Upload capability.

What if file is too big for file system ?

General Availability: Larger Block Blobs in Azure Storage

Posted on December 22, 2016

Michael Hauss, Program Manager, Azure Storage

Azure Blob Storage is a massively scalable object storage solution capable of storing and serving tens to hundreds of petabytes of data per customer across a diverse set of data types including media, documents, log files, scientific data and much more. Many of our customers use Blobs to store very large data sets, and have requested support for larger files. The introduction of larger Block Blobs increases the maximum file size from 195 GB to 4.77 TB. The increased blob size better supports a diverse range of scenarios, from media companies storing and processing 4K and 8K videos to cancer researchers sequencing DNA.

What if file is too big for file system ?

- There is a maximum size limit of 5 TB for individual objects stored in Cloud Storage.

What if ... ?

What if data is too big to fit on disk ?

1. store less (sample, filter)
2. buy bigger physical disk
3. buy a storage server
4. rent storage space in the cloud
5. distribute data yourself on serval nodes

What if ... ?

What if computation takes ages ?

1. do less (filter, sample), especially in development stages
2. do less (less tests, less formatting)
3. go low-level (compiling ... or building chips!)
4. profile your code (how does it scale ? where are the bottlenecks?)
5. buy bigger or more cores
6. rent cores on the cloud
7. avoid i/o or network operations
8. **parallelize on non-local nodes**

*

**

What if ... ?

What if computation / storage is too expensive ?

1. store or compute less (filter, sample)
2. consider cloud computing
3. be carefull with databases requests
4. go from RAM to disk
5. use smaller but moany computing units (ex: scientific grids)

What if ... ?

What if data i/o is too fast ?

1. for computing: stream / pipeline
2. for storage: fast databases

Other issues with Large-Scale Machine-Learning

Statistical issues

Environmental issues

Political issues

Today's conclusion

1. MOST DATA IS SMALL BUT COMPUTATION ON IT CAN STILL BE A CHALLENGE
2. DISTIBUTING DOES NOT HELP ; DO IT ONLY IF YOU CAN'T AVOID IT
3. SAMPLING IS OFTEN A VERY GOOD SOLUTION
4. THERE ARE MANY MANY WAYS TO SPEED UP A COMPUTATION
5. THERE ARE ENVIRONMENTAL, ECONOMICAL, ETHICAL AND STATISTICAL CHALLENGES WITH THE ACCUMULATION OF SUCH A QUANT