Why it is difficult to find something if you do not know what you are looking for

Fundamental limits in current Artificial Intelligence technologies

Luca Gammaitoni

NiPS Laboratory, University of Perugia

October 3rd, 2023 – Algorithmiq, Helsinki

NiPS Laboratory
Noise in Physical Systems

University of Perugia (IT)
AD 1308

NiPS Laboratory
Noise in Physical Systems

Cristina Diamantini, Francesco Cottone,
Igor Neri, Alessandro di Michele, Maurizio Mattarelli,
Giacomo Clementi, Raffella Pellegrini, Luca
Gammaitoni, Paolina Cerlini

ICT-Energy ZEROPOWER www.nipslab.org

WISEPOWER

NiPS Laboratory
Noise in Physical Systems

We are interested in noise and fluctuations.
Energy transformation processes at micro and nano scales, zero power computing
Models of physical processes in the presence of fluctuations

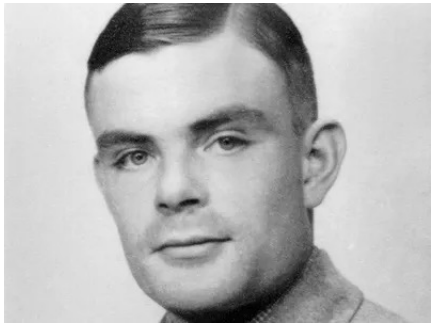
EC Funded projects

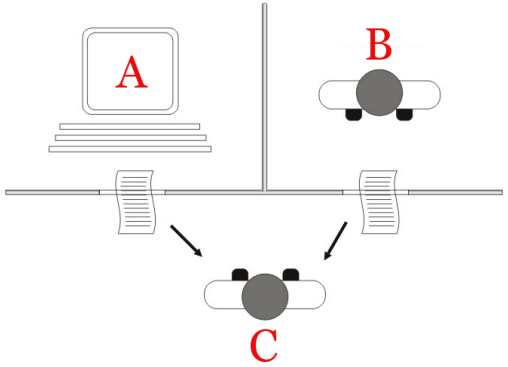
2006-2009 EC (SUBTLE VIFP)
2010-2013 EC (NANOPOWER VIIFP)
2010-2013 EC (ZEROPOWER VIIFP)
2012-2015 EC (LANDAUER VIIFP)
2013-2016 EC (ICT-Energy VIIFP)
2015-2018 EC (Proteus H2020)
2017-2020 EC (OPRECOMP H2020)
2017-2022 EC (ENABLES H2020)

Constraints

Power significantly below 10 mW
Volumes significantly below 1 cm^3

What are we talking about when we talk about Artificial Intelligence?





Turing, Alan (October 1950), "Computing Machinery and Intelligence", Mind, LIX (236): 433–460.

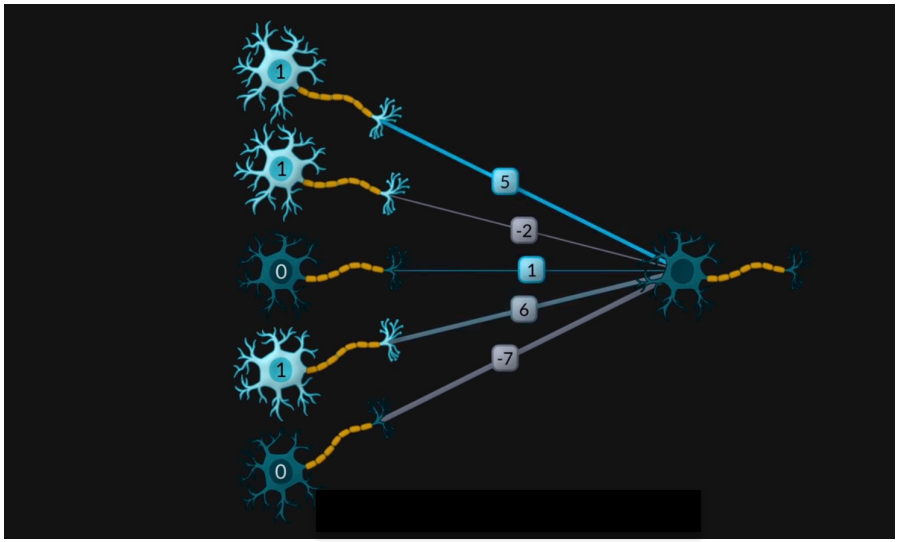
We are mainly talking about a **family of applications** that go by the name of **Machine Learning** (ML) and have had great success in recent years in the sector of **classification** of images, sounds, speech, ... up to the processing of written texts with an application called **Large Language Models** (LLM).

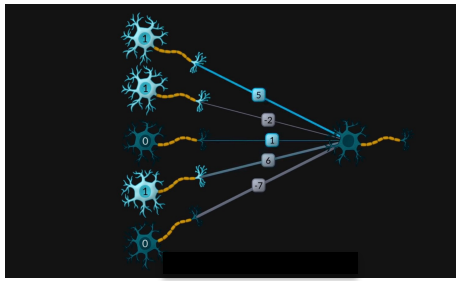
Machine learning

A set of techniques aimed at developing algorithms to classify "objects".

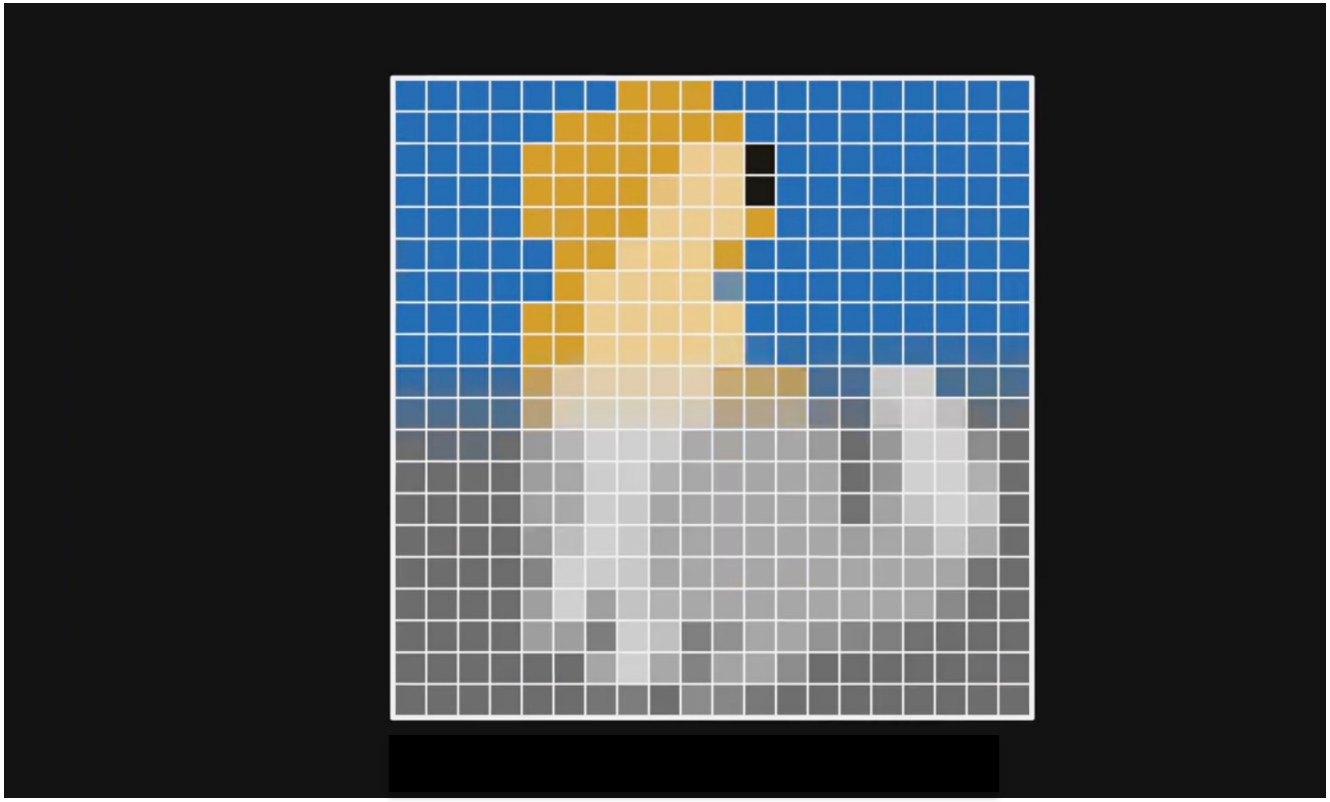
The basic idea originates from an interpretation of the functioning of brain neurons called **Artificial Neural Network** (ANN).

The ancestor of modern ANNs is the "Perceptron" invented in 1943 by two "computational neurobiologists" **Warren McCulloch** and **Walter Pitts** in Chicago and practically implemented in 1958 at the Cornell Aeronautical Laboratory by **Frank Rosenblatt**.



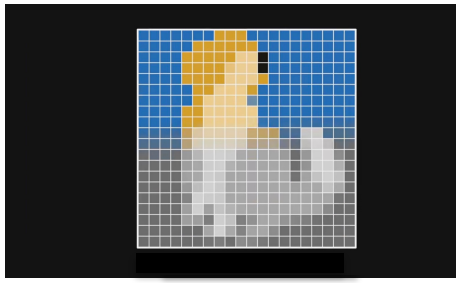


Perceptron



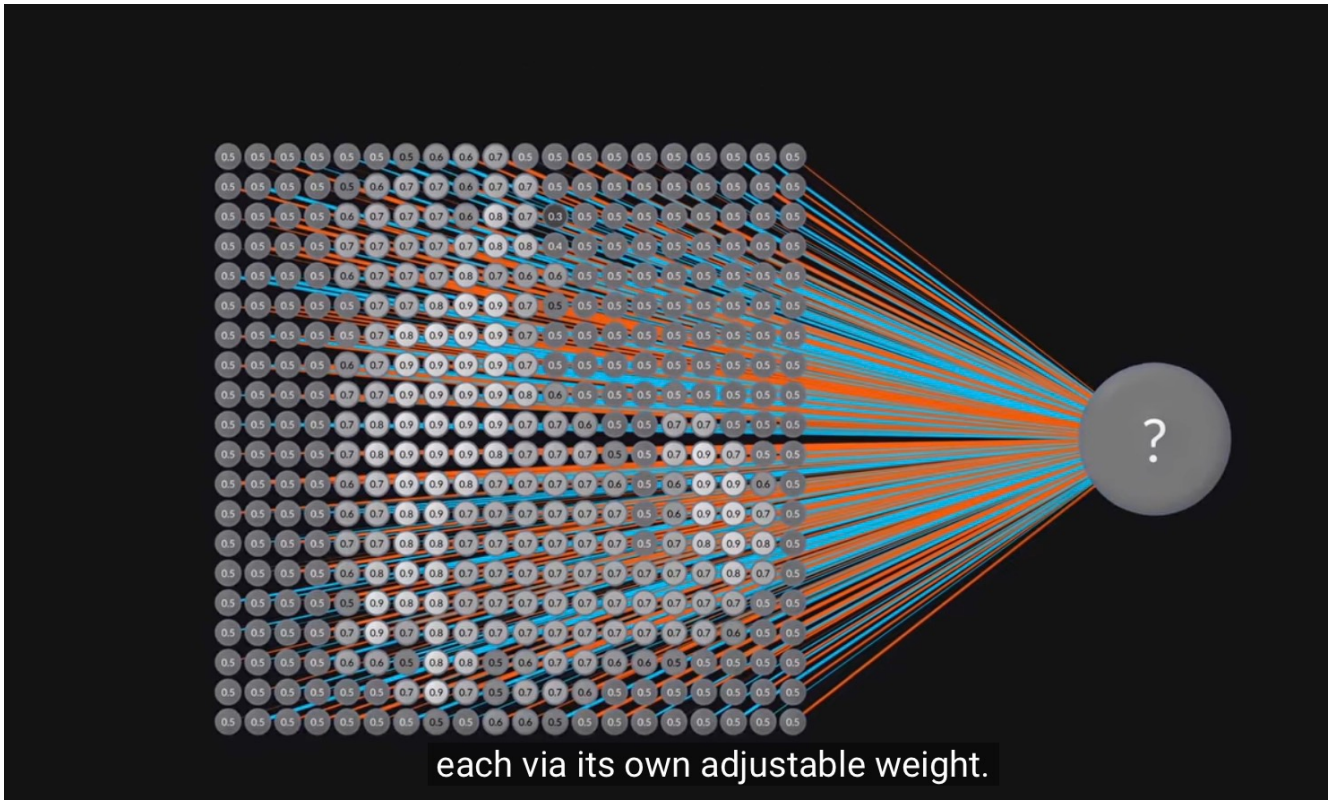
See: https://www.youtube.com/watch?v=GVsUOuSjvcg

NiPS Laboratory
Noise in Physical Systems

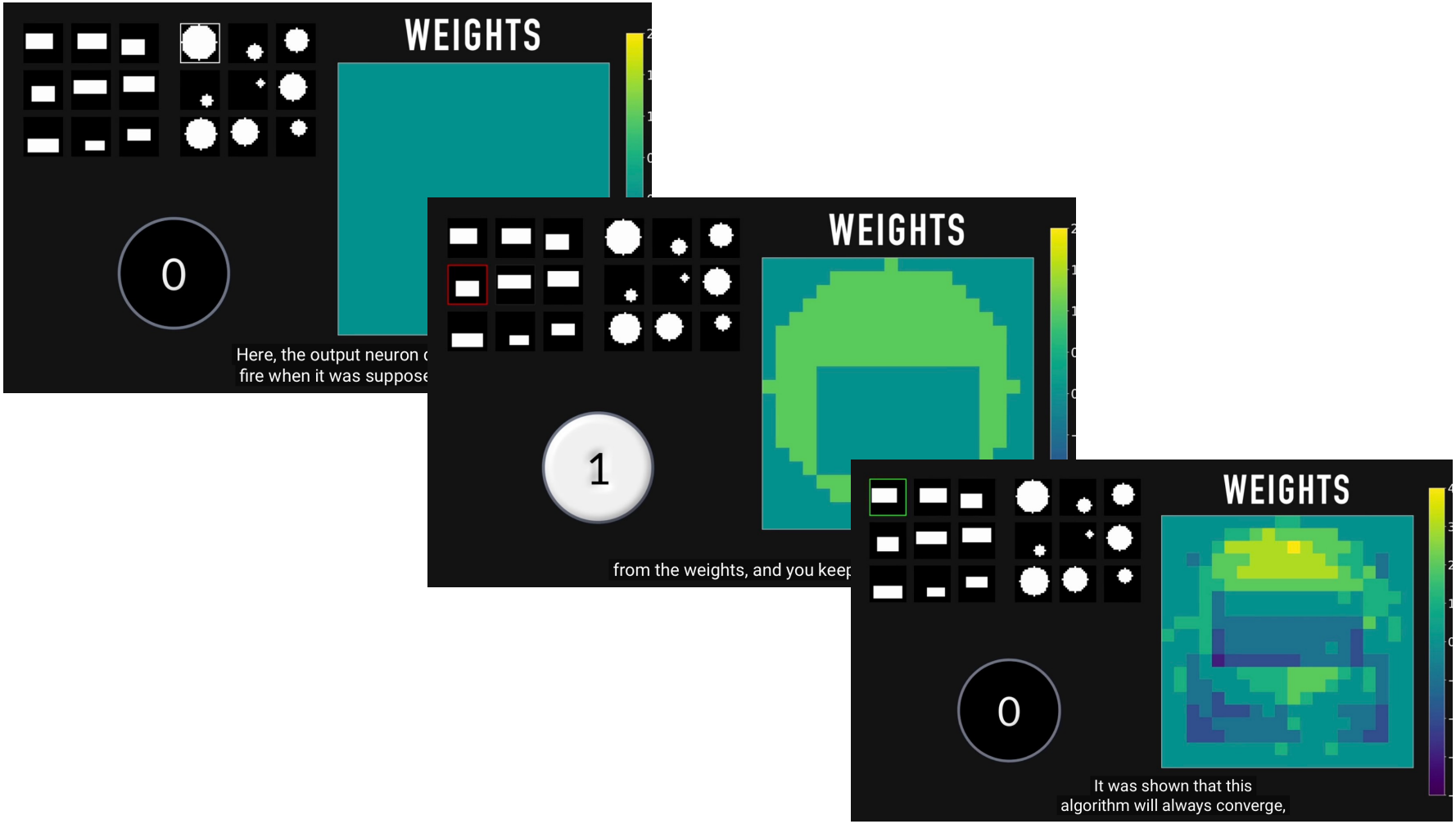


Perceptron

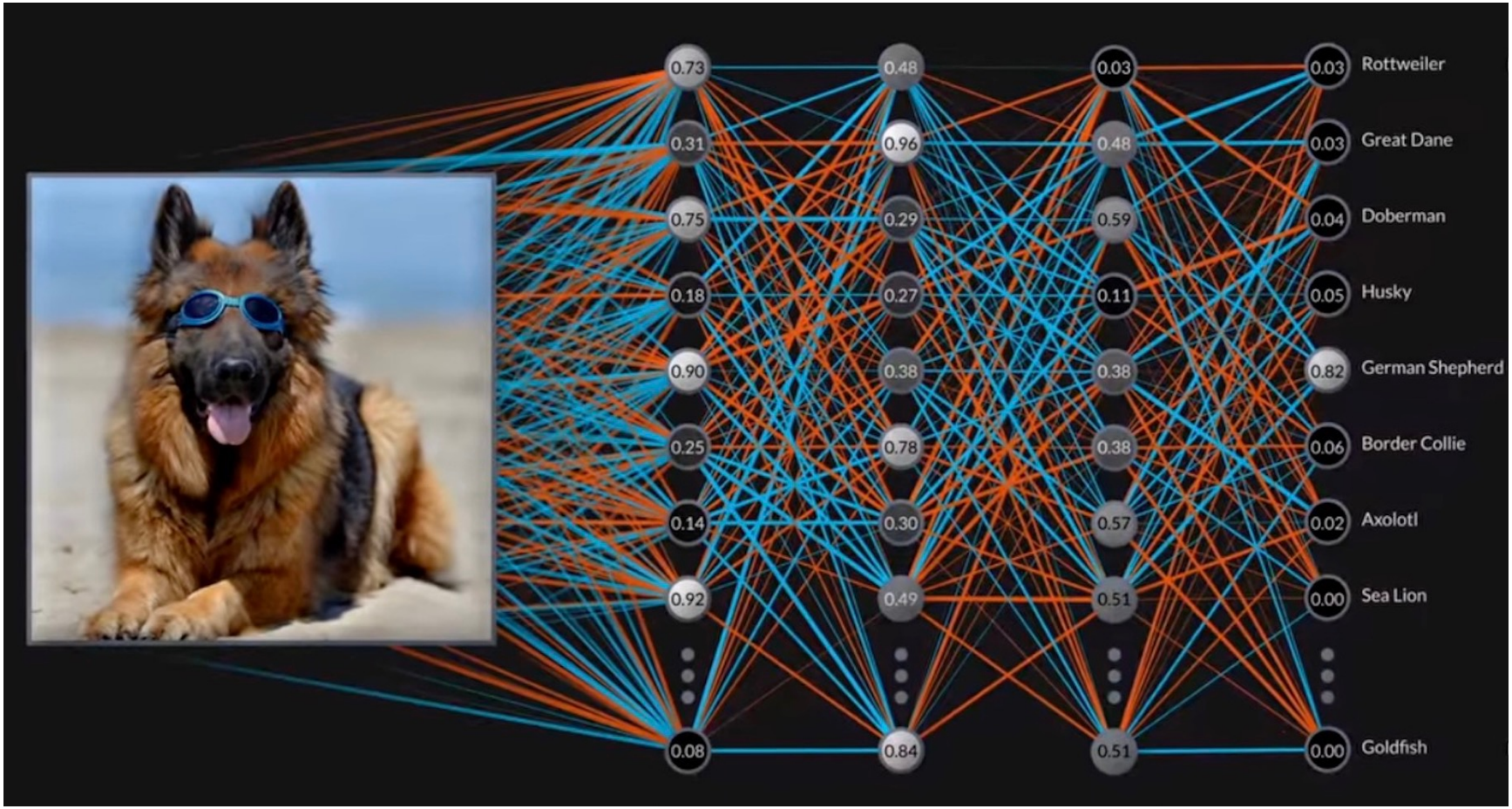
20 x 20 = 400 weights to be adjusted



How do we adjust the weights?

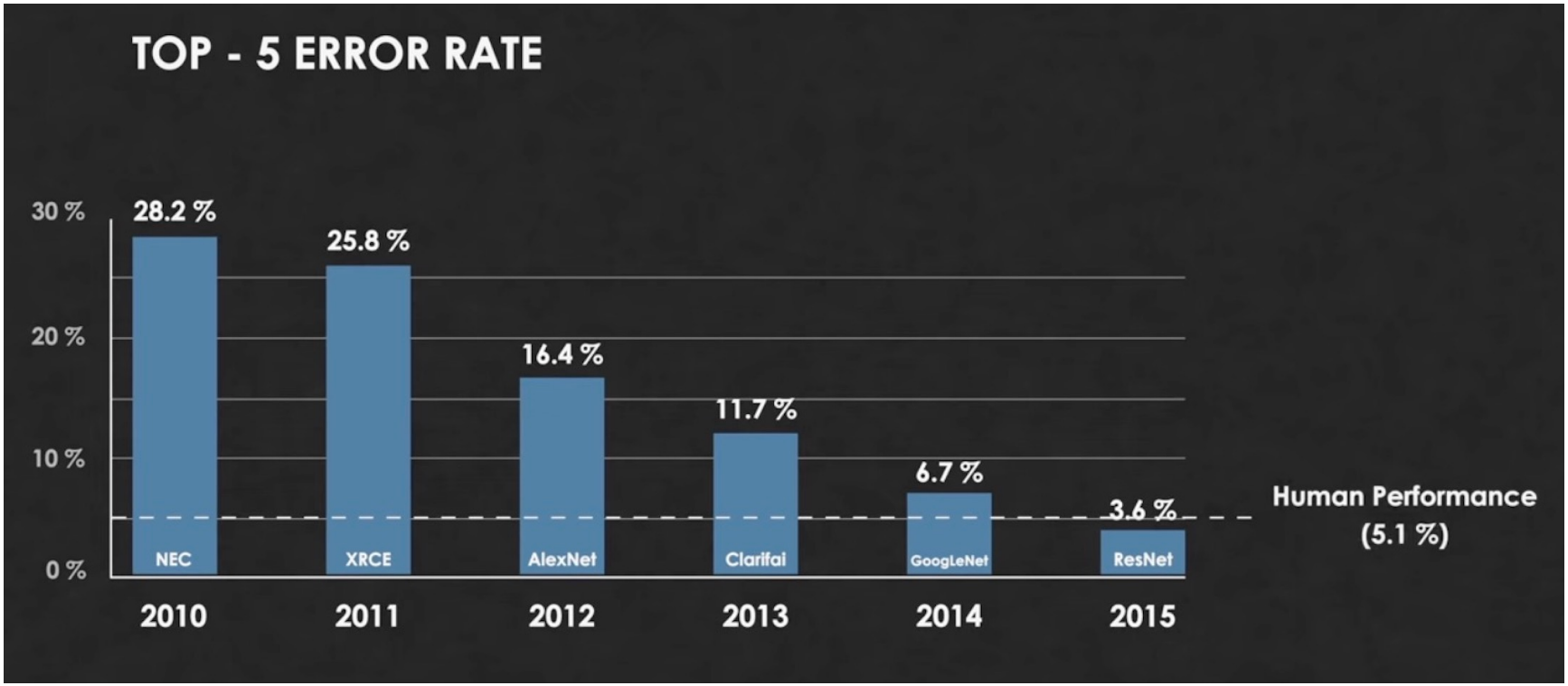


Inserting intermediate layers improves performances



Increases significantly the number of weigths

Inserting intermediate layers improves performances



The “deep learning” approach

From dog and cat recognition to language patterns

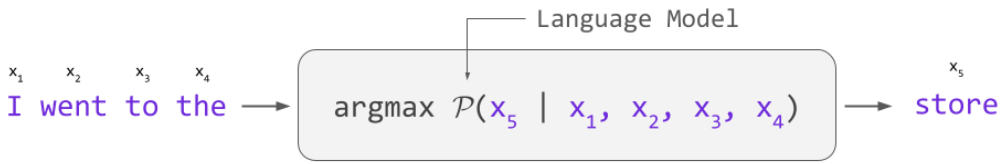
Language Models (LM) are a class of probabilistic models that learn patterns in natural language.

LMs can be used for generative purposes to generate, say, the next event in a story by leveraging their knowledge of these patterns.

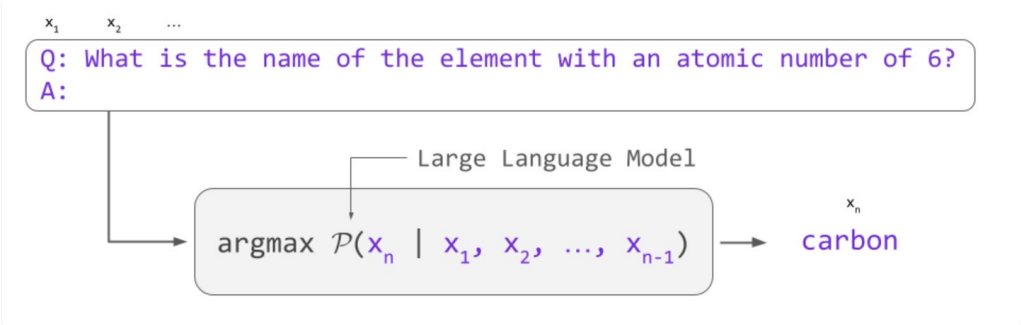
Language Models

Language models define a probability distribution over sequences of words.

They can therefore naturally be used for generative purposes by predicting the most likely next word or words given the start of a text.



Or they can find answers to questions, with the same mechanism

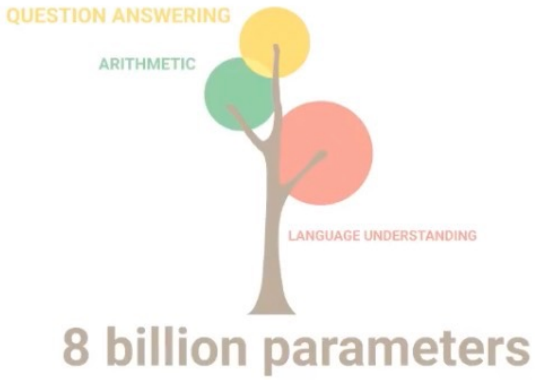


By encoding specific tasks in the model's textual input, *Large* Language Models are capable of completing tasks without finetuning simply via next-word prediction.

See*: Emergent Abilities of Large Language Models,* Ryan O'Connor, AssembliAI, 2023

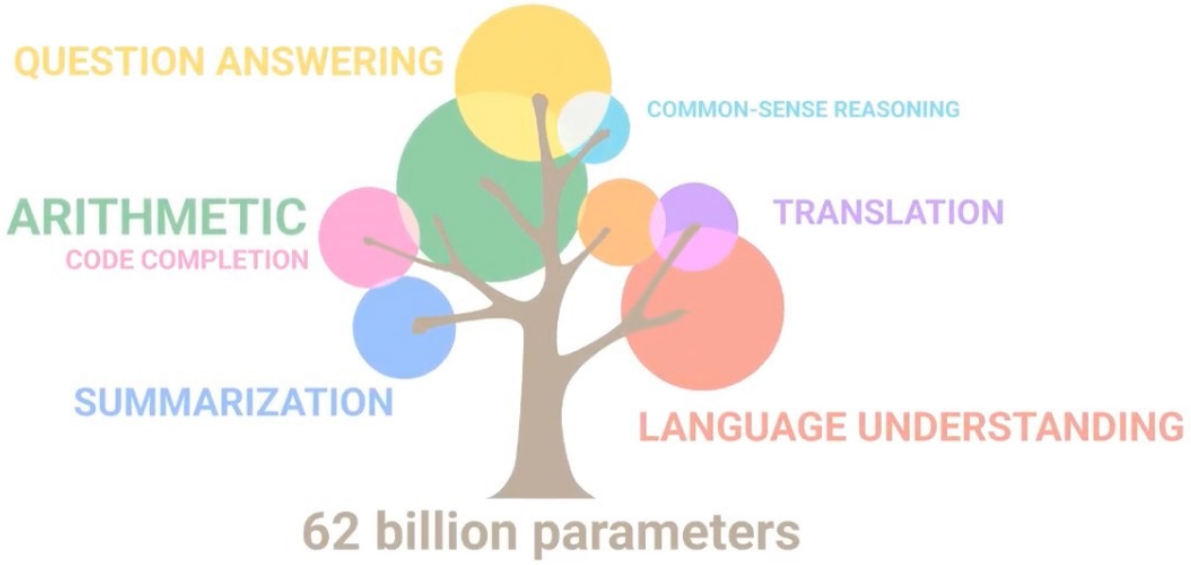
Large Language Models

It has been observed that as the number of ANN parameters increases, the capabilities of Language Models increase



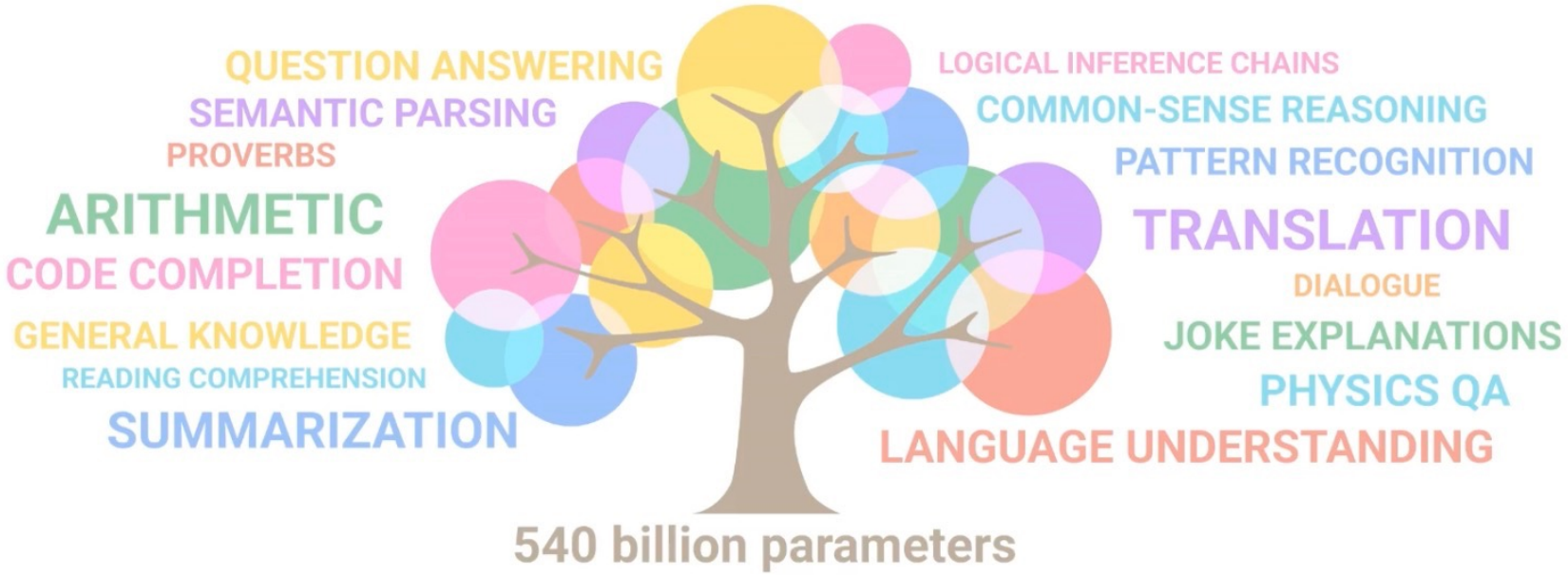
I Large Language Models

It has been observed that as the number of ANN parameters increases, the capabilities of Language Models increase

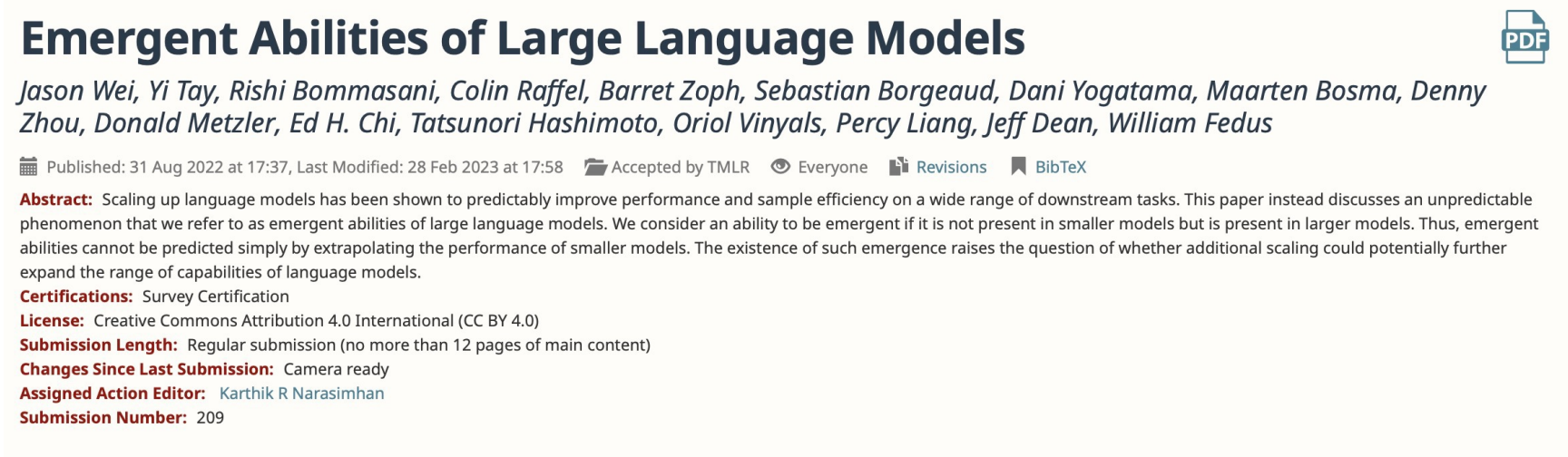


I Large Language Models

It has been observed that as the number of ANN parameters increases, the capabilities of Language Models increase



Emergent abilities



Emergent Abilities of Large Language Models

Jason Wei, Yi Tay, Rishi Bommasani, Colin Raffel, Barret Zoph, Sebastian Borgeaud, Dani Yogatama, Maarten Bosma, Denny Zhou, Donald Metzler, Ed H. Chi, Tatsunori Hashimoto, Oriol Vinyals, Percy Liang, Jeff Dean, William Fedus

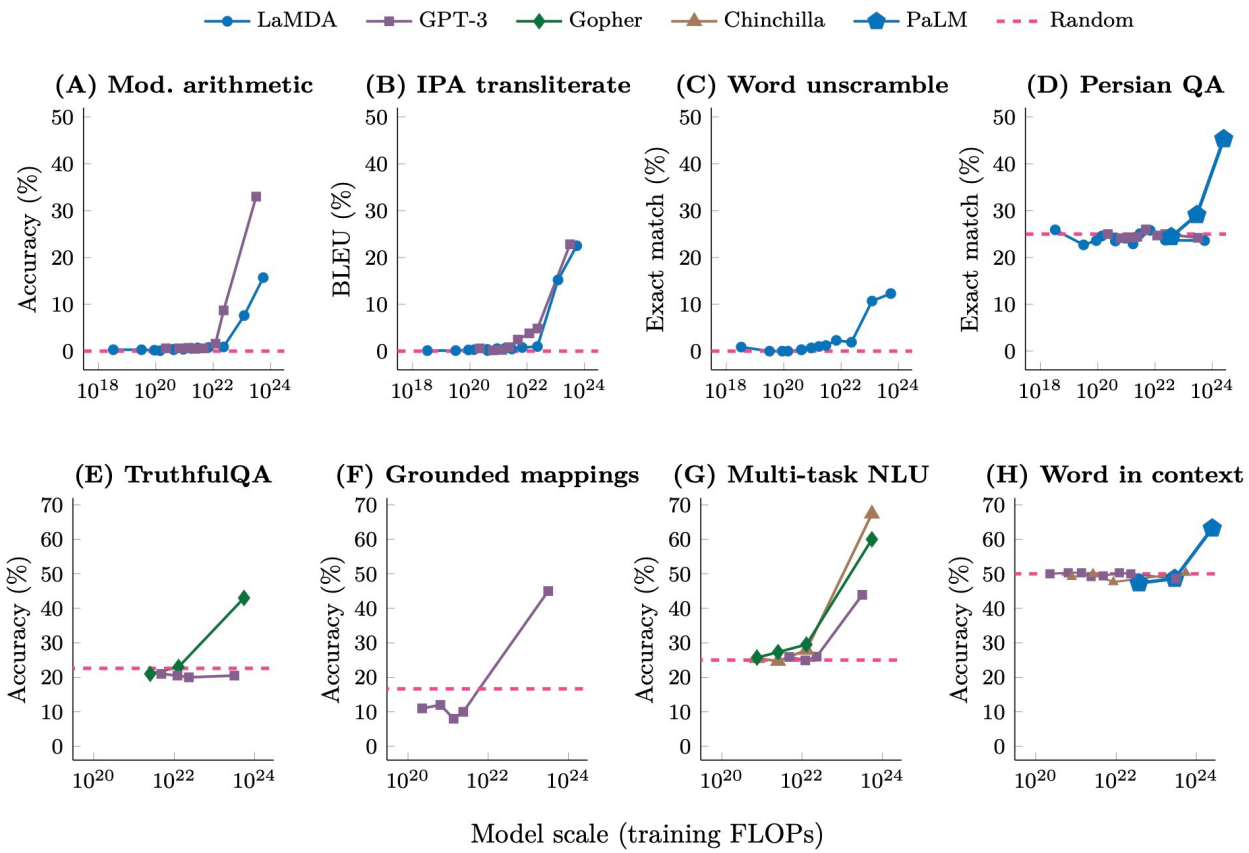
Published: 31 Aug 2022 at 17:37, Last Modified: 28 Feb 2023 at 17:58 Accepted by TMLR Everyone Revisions BibTeX

Abstract: Scaling up language models has been shown to predictably improve performance and sample efficiency on a wide range of downstream tasks. This paper instead discusses an unpredictable phenomenon that we refer to as emergent abilities of large language models. We consider an ability to be emergent if it is not present in smaller models but is present in larger models. Thus, emergent abilities cannot be predicted simply by extrapolating the performance of smaller models. The existence of such emergence raises the question of whether additional scaling could potentially further expand the range of capabilities of language models.

Certifications: Survey Certification
License: Creative Commons Attribution 4.0 International (CC BY 4.0)
Submission Length: Regular submission (no more than 12 pages of main content)
Changes Since Last Submission: Camera ready
Assigned Action Editor: Karthik R Narasimhan
Submission Number: 209

Emergent abilities of large language models are abilities that are not present in smaller-scale models but are present in large-scale models; thus they cannot be predicted by simply extrapolating the performance improvements on smaller-scale models

Emergent abilities

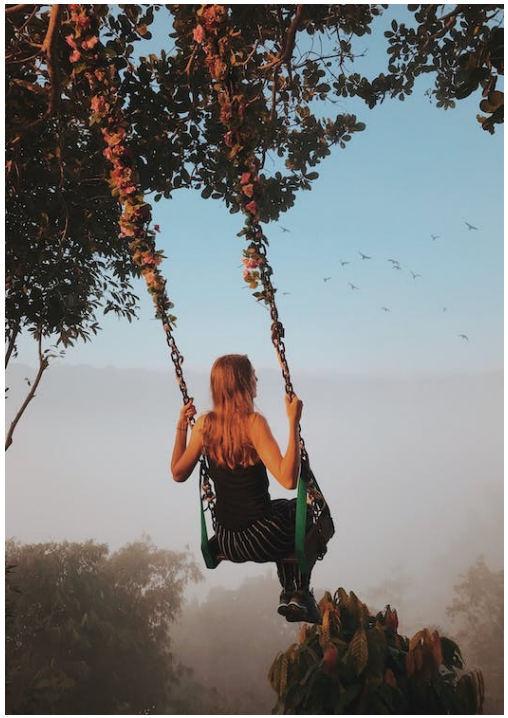


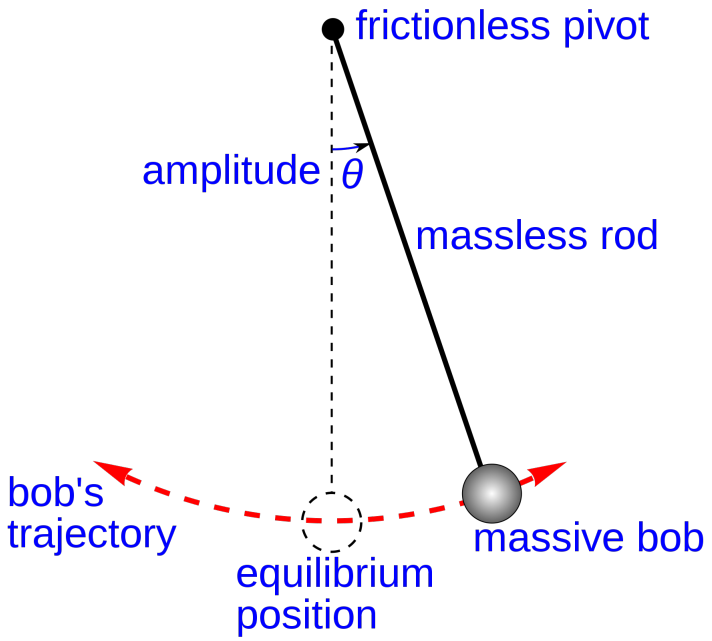
An ability is emergent if it is not present in smaller models but is present in larger models.

Plenty of data. Everywhere.
They must be worth for something.

We are witnessing a paradigm shift

Galileo's paradigm





We are witnessing a paradigm shift

Big data paradigm

Data mining

WIRED

<< Back to Article

WIRED MAGAZINE: 16.07

The End of Theory: The Data Deluge Makes the Scientific Method Obsolete

By Chris Anderson 06.23.08

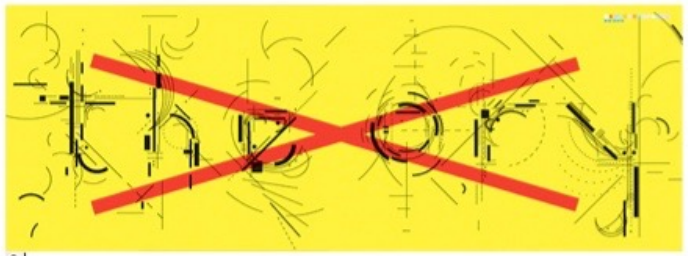


Illustration: Marian Bantjes

THE PETABYTE AGE:
Sensors everywhere. Infinite storage. Clouds of processors. Our ability to capture, warehouse, and understand massive amounts of data is changing science, medicine, business, and technology. As our collection of facts and figures grows, so will the opportunity to find answers to fundamental questions. Because in the era of big data, more isn't just more. More is different.

THE END OF THEORY:
Essay: The Data Deluge Makes the Scientific Method Obsolete

Feeding the Masses
Chasing the Quark
Winning the Lawsuit
Tracking the News
Spotting the Hot Zones
Sorting the World
Watching the Skies
Scanning Our Skeletons
Tracking Air Fares
Predicting the Vote
Pricing Terrorism
Visualizing Big Data

"**All models are wrong**, but some are useful."

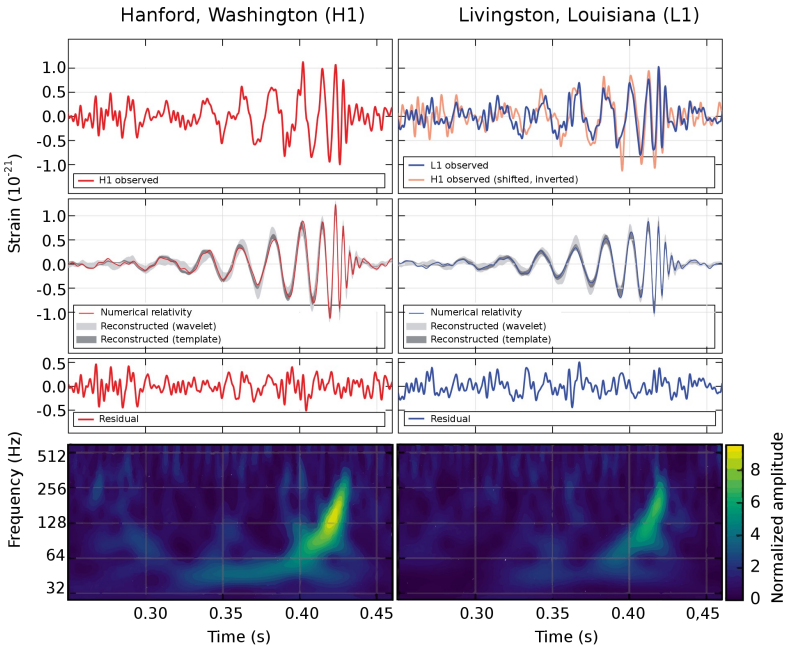
So proclaimed statistician George Box 30 years ago, and he was right. But what choice did we have? Only models, from cosmological equations to theories of human behavior, seemed to be able to consistently, if imperfectly, explain the world around us. Until now. Today companies like Google, which have grown up in an era of massively abundant data, don't have to settle for wrong models. Indeed, they don't have to settle for models at all.

Sixty years ago, digital computers made information readable. Twenty years ago, the Internet made it reachable. Ten years ago, the first search engine crawlers made it a single database. Now Google and like-minded companies are sifting through the most measured age in history, treating this massive corpus as a laboratory of the human condition. They are the children of the Petabyte Age.

The Petabyte Age is different because more is different. Kilobytes were stored on floppy disks. Megabytes were stored on hard disks. Terabytes were stored in disk arrays. Petabytes are stored in the cloud. As we moved along that progression, we went from the folder analogy to the file cabinet analogy to the library analogy to — well, at petabytes we ran out of organizational analogies.

At the petabyte scale, information is not a matter of simple three- and four-dimensional taxonomy and order but of dimensionally agnostic statistics. It calls for an entirely different approach, one that requires us to lose the tether of data as something that can be visualized in its totality. It forces us to view data mathematically first and establish a context for it later. For instance, Google conquered the advertising world with nothing more than applied mathematics. It didn't pretend to know anything about the culture and conventions of advertising — it just assumed that better data, with better analytical tools, would win the day. And Google was right.

Google's founding philosophy is that we don't know why this page is better than that one: If the statistics of incoming links



The idea is intriguing:

To date we have found evidence of gravitational waves because we knew what to expect and went looking for them in an ocean of noise. Now let's try to find something else in the same ocean of noise, something that we don't know if it exists but could be: gravitational signals emitted by new phenomena that we don't even imagine and which could even reveal new laws of Physics.

The idea of looking for something, which we don't know if it exists and exactly what it looks like, is not exactly new. See the theory of CHAOS, starting from the 1980s, and the work of the Dutch Floris Takens and the Belgian David Ruelle.

There are several reasons why the "big data" program, at least in its most radical version, cannot work.

Hosni, H., Vulpiani, A. Forecasting in Light of Big Data. *Philos. Technol.* **31,** 557–569 (2018).

La Biblioteca di Babele

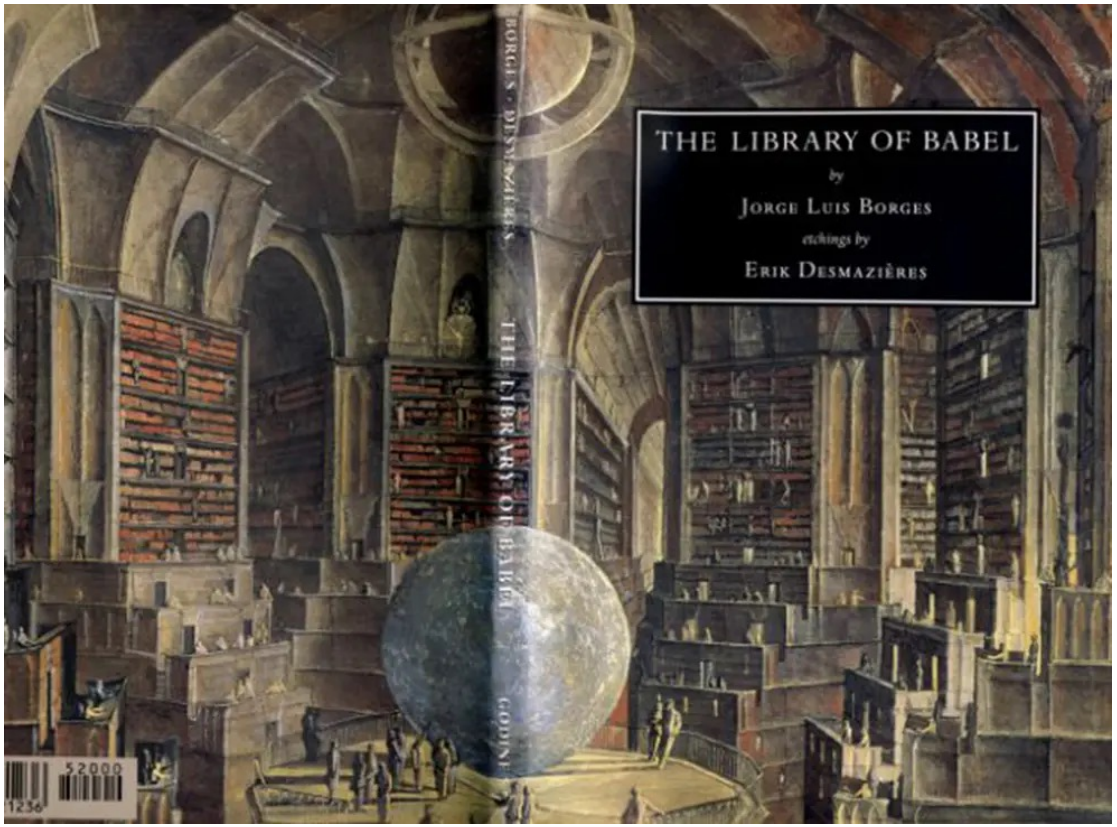
El universo (que otros llaman la Biblioteca) se compone de un número indefinido, y tal vez infinito, de galerías hexagonales, … A cada uno de los muros de cada hexágono corresponden cinco anaqueles; cada anaquel encierra treinta y dos libros de formato uniforme; cada libro es de cuatrocientas diez páginas; cada página, de cuarenta renglones; cada renglón, de unas ochenta letras de color negro.

The universe (which others call the Library) is composed of an indefinite, perhaps infinite, number of hexagonal galleries... Each wall of each hexagon has a shelf with five shelves; each shelf contains thirty-two uniformly sized books; each book is four hundred and ten pages; each page, forty lines; each line, of forty black letters.

The library of Babel, Jorge Luis Borges

From these incontrovertible premises he deduced that the Library is total, and that its shelves record all the possible combinations of twenty-five orthographic symbols (a number, although very vast, not infinite) that is, everything that can be expressed, in all languages. Everything: the detailed history of the future, the autobiographies of the archangels, the faithful catalog of the Library, thousands and thousands of false catalogues, the demonstration of the falsity of these catalogues, the demonstration of the false catalogue, the Gnostic Gospel of Basilides, the commentary of this gospel, the commentary on the commentary on this gospel, the true account of your death, the translation of every book into all languages, the interpolations of every book in all books.

When it was proclaimed that the Library included all books, the first impression was one of extraordinary happiness. All men felt they were masters of an intact and secret treasure. There was no personal or global problem whose eloquent solution did not exist: in some hexagon.



The Library of Babel truly seems like a **Big Data paradise**.
It contains all the information of potential interest to us, the problem is "only" extracting this information, that is, finding the book that interests us...

while the music goes, Alice and Bob exchange secure messages through their entangled spins.

The two words "**entangled spins**" can indicate two very different things, depending on whether they are interpreted using a nineteenth-century dictionary or a twentieth-century dictionary.

In the first case the phrase indicates the confidences that two lovers exchange in whispers while performing a waltz.

In the second case, the phrase indicates that while music is heard in the background, Alice and Bob exchange messages encrypted using quantum cryptography.

?

while the music goes, Alice and Bob exchange secure messages through their entangled spins.

In principle, **it is not possible** to decide which interpretation is correct unless we know which dictionary should be used

19th century dictionary

In the first case the phrase indicates the confidences that two lovers exchange in whispers while performing a waltz.

20th century dictionary

In the second case, the phrase indicates that while music is heard in the background, Alice and Bob exchange messages encrypted using quantum cryptography.

Lucio Lombardo Radice, in his book *L'Infinito*, explains that even if the number of books in the library of Babel is very large but nevertheless finite, **the number of meanings that they can take on is infinite.**

It is called Richard's paradox, after the French logician-mathematician Jules Antoine Richard (1862-1956) who showed how **a finite string of characters potentially corresponds to an infinite number of meanings**.

In our case:

Having a certain amount of experimental data corresponds to having a string of characters.
What is the meaning of that data? Which scientific model do they correspond to? That is: those data are the answer to a scientific question. But which?

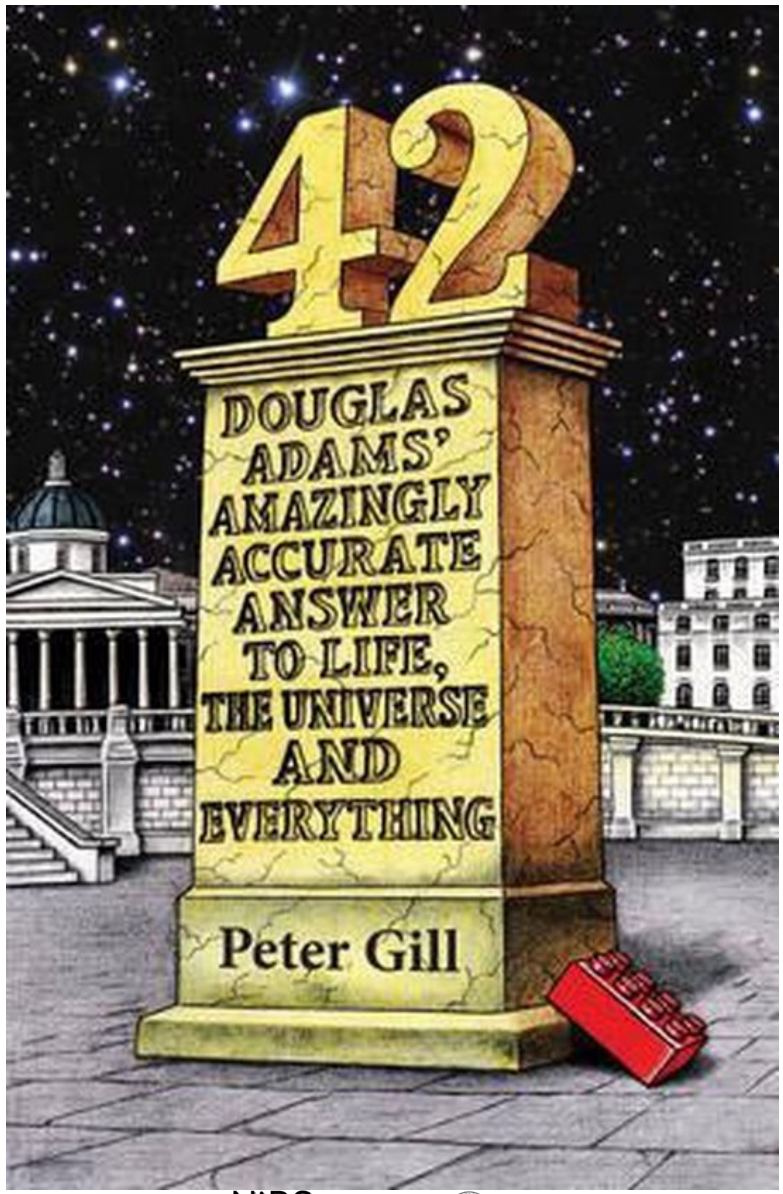
It is obvious that for every possible answer there is an infinite number of questions perfectly compatible with that answer.

But from the data ALONE it is not possible to identify the question.

That is, **you can't find something if you don't know what you're looking for.**

That is, **asking the right question is the really hard part In creating new knowledge...**.

In short, you end up in a situation that reminds you of something….



Conclusions

Take home messages:

1 Current ML algorithms are highly efficient and useful classification schemes. **Alone they cannot generate new knowledge**, that is, extract meanings from strings (even of many characters).

2 Scientific knowledge arises from the work of scientists who build models, that is, they struggle to find meaningful questions to answer through experiments carried out by questioning the world and designed for this purpose.

These things are talked about (also) in:

- L. Gammaitoni, A. Vulpiani, Perchè è difficile prevedere il futuro, Dedalo ed., 2019.
- L. Gammaitoni, On the concept of time and other accidents: simple scientific digressions for curious people, Amazon, 2022.