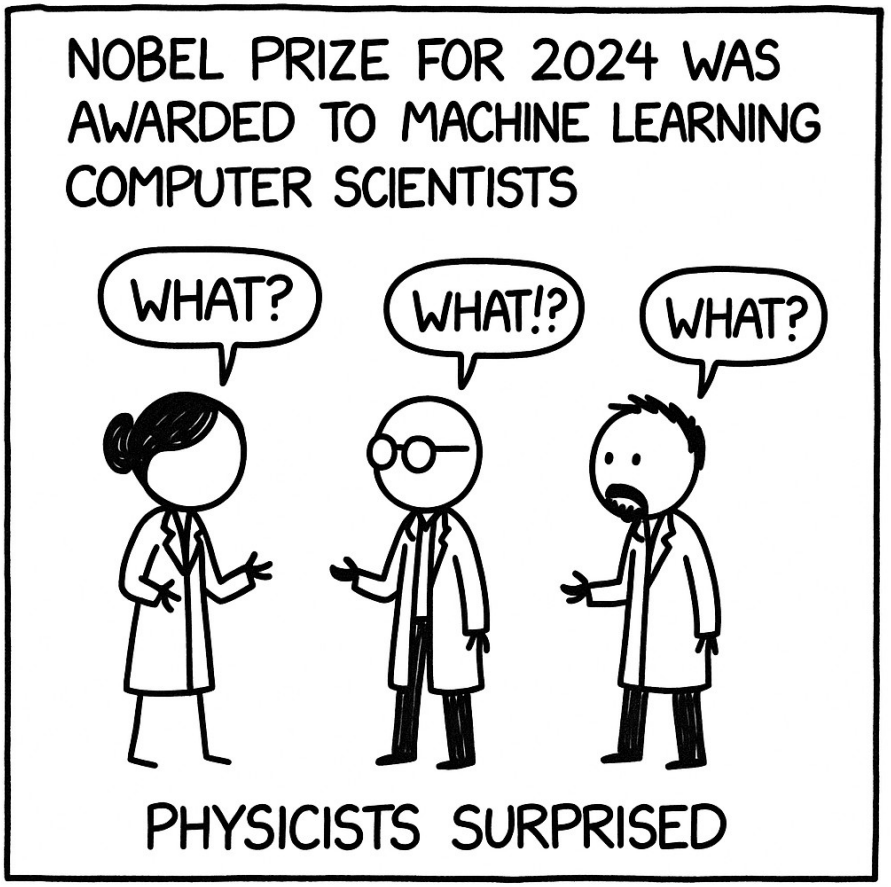
The Nobel Prize in Physics 2024

Artur Kalinowski
University of Warsaw



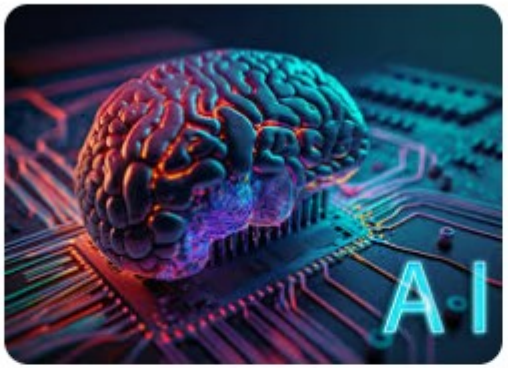
ChatGPT

A prompt:

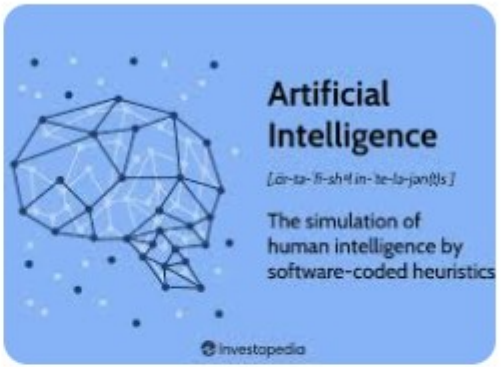
> **Stwórz obraz** "physicists surprised that Nobel prize for 2024 was awarded to machine learning computer scientists. Cartoon, like xkcd"

Random images from Internet on what is happening:

SHRM
Artificial Intelligence in the Workplace



UCF Business Incubation Program - ...
What is Artificial Intelligence (AI) a...



Investopedia
Artificial Intelligence (AI): What It I...

Britannica
Artificial intelligence (A...

Great Learning
What is Artificial Intelligence (AI)?

GeeksforGeeks
What is Artificial Intelligence? - GeeksforGeeks

Alma Mater Europaea
PhD in Artificial Intelligence

A prompt:

> **Stwórz obraz** "physicists surprised that Nobel prize for 2024 was awarded to machine learning computer scientists. Cartoon, like xkcd"

What really is happening:

```python
import matplotlib.pyplot as plt

def get_image_for_coordinates(z):
    """
    Get the image for the given coordinates.

    :param z: The coordinates of the image.
    :return: The image for the given coordinates.
    """
    # Placeholder function to simulate getting an image
    return f"Image for coordinates {z}"


z = "physicists  surprised that Nobel prize for 2024 was awarded " \
    "to machine learning computer scientists. Cartoon, like xkcd"
image = get_image_for_coordinates(z)
plt.imshow(image)
```

2024 Nobel Prize in ~~Computing~~ Physics awarded:

“for foundational discoveries and inventions that enable machine learning with artificial neural networks”

in other words:

“for foundational discoveries and inventions” that allow to algorithmically find numerical parametrization of intellectual activities

The laureate: John Hopfield

Nobel Prize Outreach

Born in 1933,
Chicago, USA

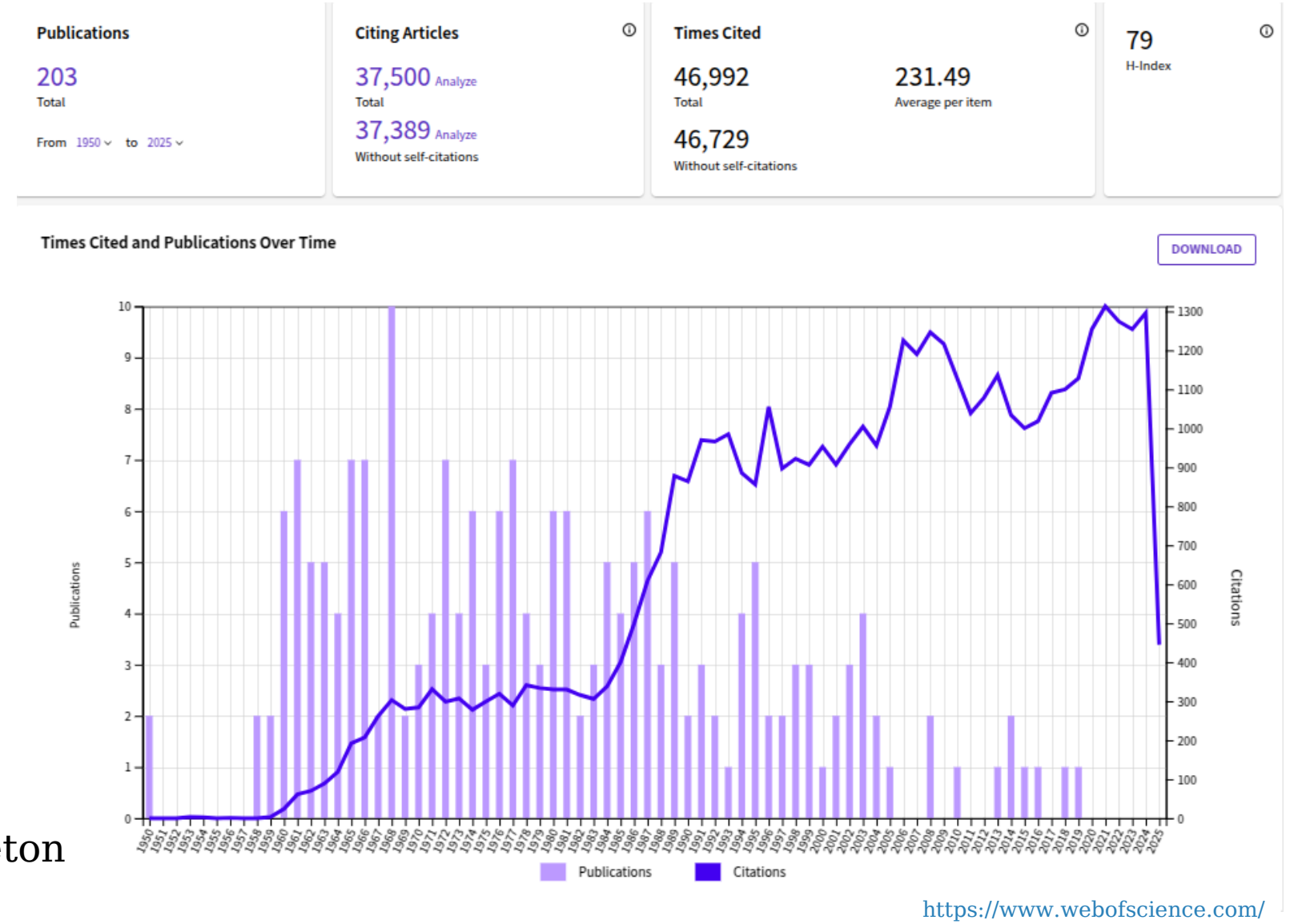
Currently prof. emeritus at Princeton University

The laureate: John Hopfield

Nobel Prize Outreach

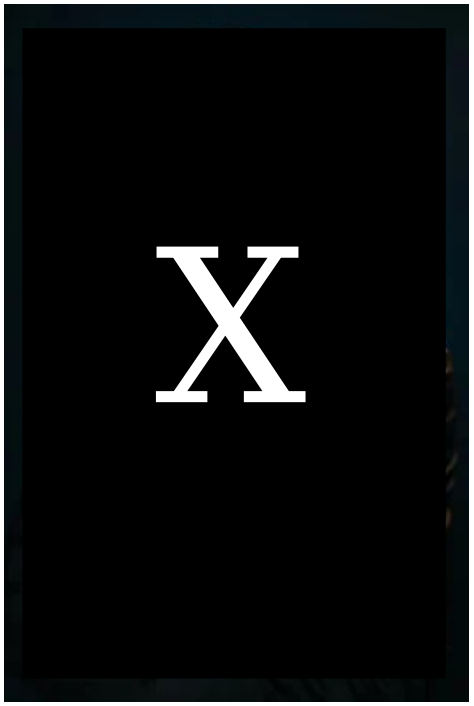
Born in 1933, Chicago, USA

Currently prof. emeritus at Princeton University



https://www.webofscience.com/

A random person from FUW



A random person from FUW

Publications
1,056
Total
From 1900 to 2025

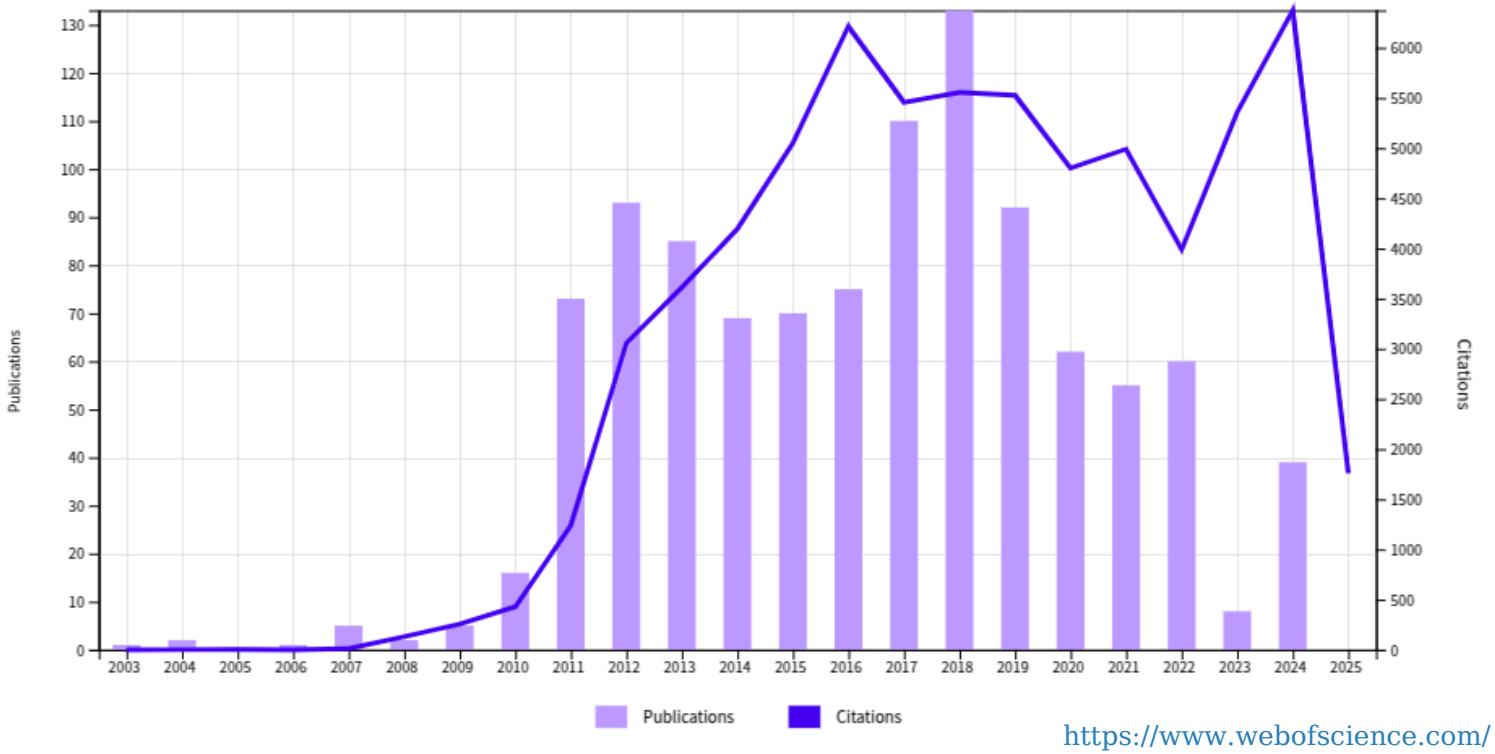
Citing Articles
27,424 Analyze
Total
26,391 Analyze
Without self-citations

Times Cited
67,995
Total
64.39
Average per item
58,989
Without self-citations

115
H-Index

Times Cited and Publications Over Time

DOWNLOAD



https://www.webofscience.com/

John Hopfield: top cited publications

Nobel Prize Outreach

Born in 1933, Chicago, USA

Currently prof. emeritus at Princeton University

Neural networks and physical systems with emergent collective computational abilities
(1982)

Neurons with graded response have collective computational properties like those of 2-state neurons
(1984)

Neural computation of decisions in optimization problems
(1985)

From molecular to modular cell biology
(1999)

Theory of the contribution of excitons to the complex dielectric constant of crystals
(1958)

Simple neural optimization networks - an A/D converter, signal decision circuit, and a linear-programming circuit
(1986)

https://www.webofscience.com/

John Hopfield: top cited publications

Nobel Prize Outreach

Born in 1933, Chicago, USA

Currently prof. emeritus at Princeton University

Neural networks and physical systems with emergent collective computational abilities
(1982)

Neurons with graded response have collective computational properties like those of 2-state neurons
(1984)

Neural computation of decisions in optimization problems
(1985)

From molecular to modular cell biology
(1999)

Theory of the contribution of excitons to the complex dielectric constant of crystals
(1958)

Simple neural optimization networks - an A/D converter, signal decision circuit, and a linear-programming circuit
(1986)

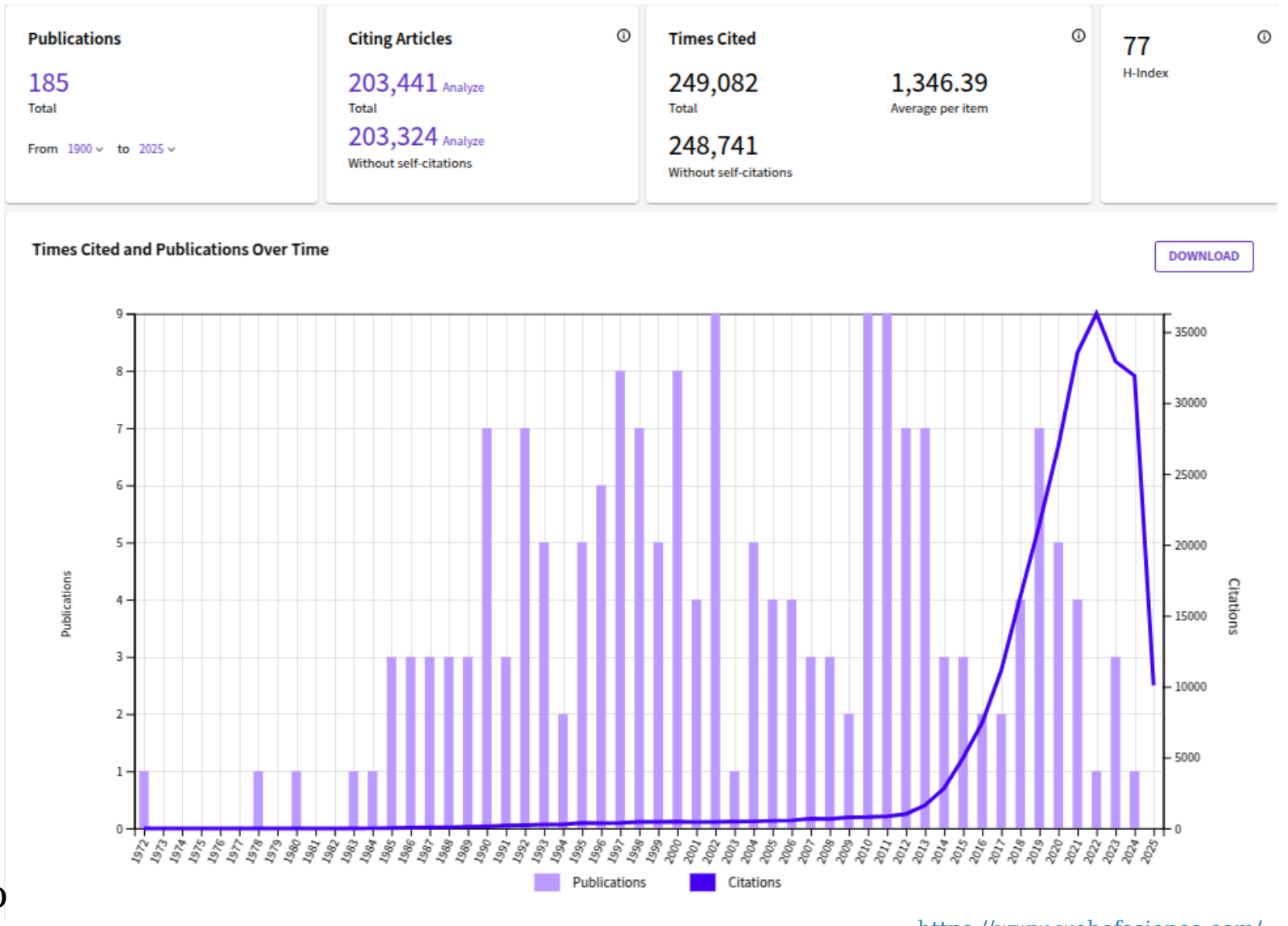
https://www.webofscience.com/

The laureate: Goeffrey Hinton

Nobel Prize Outreach

Born in 1947, London, UK

Currently prof. emeritus at University Toronto



https://www.webofscience.com/

Goeffrey Hinton: top cited publications

https://www.webofscience.com/

Nobel Prize Outreach

Born in 1947, London, UK

Currently prof. emeritus at University Toronto

ImageNet Classification with Deep Convolutional Neural Networks **(2017)**

Visualizing Data using t-SNE
(2008)

Dropout: A Simple Way to Prevent Neural Networks from Overfitting
(2014)

Deep learning
(2015)

Learning representations by back-propagating errors
(1986)

Reducing the dimensionality of data with neural networks
(2006)
...

A learning algorithm for Boltzmann machines
(1985)

Goeffrey Hinton: top cited publications

https://www.webofscience.com/

Nobel Prize Outreach

Born in 1947,
London, UK

Currently prof. emeritus at University Toronto

ImageNet Classification with Deep Convolutional Neural Networks **(2017)** – **73 000 citations**

Visualizing Data using t-SNE – **31 000 citations** **(2008)**

Dropout: A Simple Way to Prevent Neural Networks from Overfitting – **27 000 citations** **(2014)**

Most cited physics publications in physics

iNSPIRE

The Large N limit of superconformal field theories and supergravity **(1997)**
– **20 000 citations**

GEANT4 - A Simulation Toolkit **(2002)**
– 20 000 citations

Observational evidence from supernovae for an accelerating universe and a cosmological constant **(1998)**
– 17 000 citations

Planck 2018 results. VI. Cosmological parameters **(2018)**
– 17 000 citations

Measurements of Ω and Λ from 42 High Redshift Supernovae **(1998)**
– 17 000 citations

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC **(2012)**
– 16 000 citations

Most cited physics publications in physics

iNSPIRE

The Large N limit of superconformal field theories and supergravity **(1997)**
– **20 000 citations**

GEANT4 - A Simulation Toolkit **(2002)**
– **20 000 citations**

Observatio a
cosmologic
– **17 000 c**

Planck 201
– **17 000 c**

a top level ML article on image classification is worth 3.5 top level articles on physics

Measurements of Ω and Λ from 42 High Redshift Supernovae **(1998)**
– **17 000 citations**

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC **(2012)**
– **16 000 citations**

Most important journals in...

Physics:

Categories > **Physics & Mathematics** > Subcategories

Google Scholar

	Publication	h5-index	h5-median
1.	Physical Review Letters	210	282
2.	Physical Review D	169	216
3.	The Astrophysical Journal	167	239
4.	Journal of High Energy Physics	155	197
5.	Monthly Notices of the Royal Astronomical Society	153	215
6.	Nature Physics	145	229

5-year Hirsch index

Machine learning:

Categories > Engineering & Computer Science > **Artificial Intelligence**

Google Scholar

	Publication	h5-index	h5-median
1.	Neural Information Processing Systems	337	614
2.	International Conference on Learning Representations	304	584
3.	International Conference on Machine Learning	268	424
4.	AAAI Conference on Artificial Intelligence	220	341
5.	Expert Systems with Applications	165	228
6.	IEEE Transactions On Systems, Man And Cybernetics Part B, Cybernetics	155	212

Most important journals in...

Physics:

Categories > **Physics & Mathematics** > Subcategories

Google Scholar

	Publication	h5-index	h5-median
1.	Physical Review Letters		
2.	Physical Review D		
3.	The Astrophysical Journal		
4.	Journal of High Energy Physics		
5.	Monthly Notices of the Royal Astronomical Society		
6.	Nature Physics		

NeurIPS: The Conference and Workshop on Neural Information Processing Systems is a machine learning and computational neuroscience conference held every December. It is one of the three primary conferences of high impact in machine learning and artificial intelligence research.

Wikipedia

Machine learning:

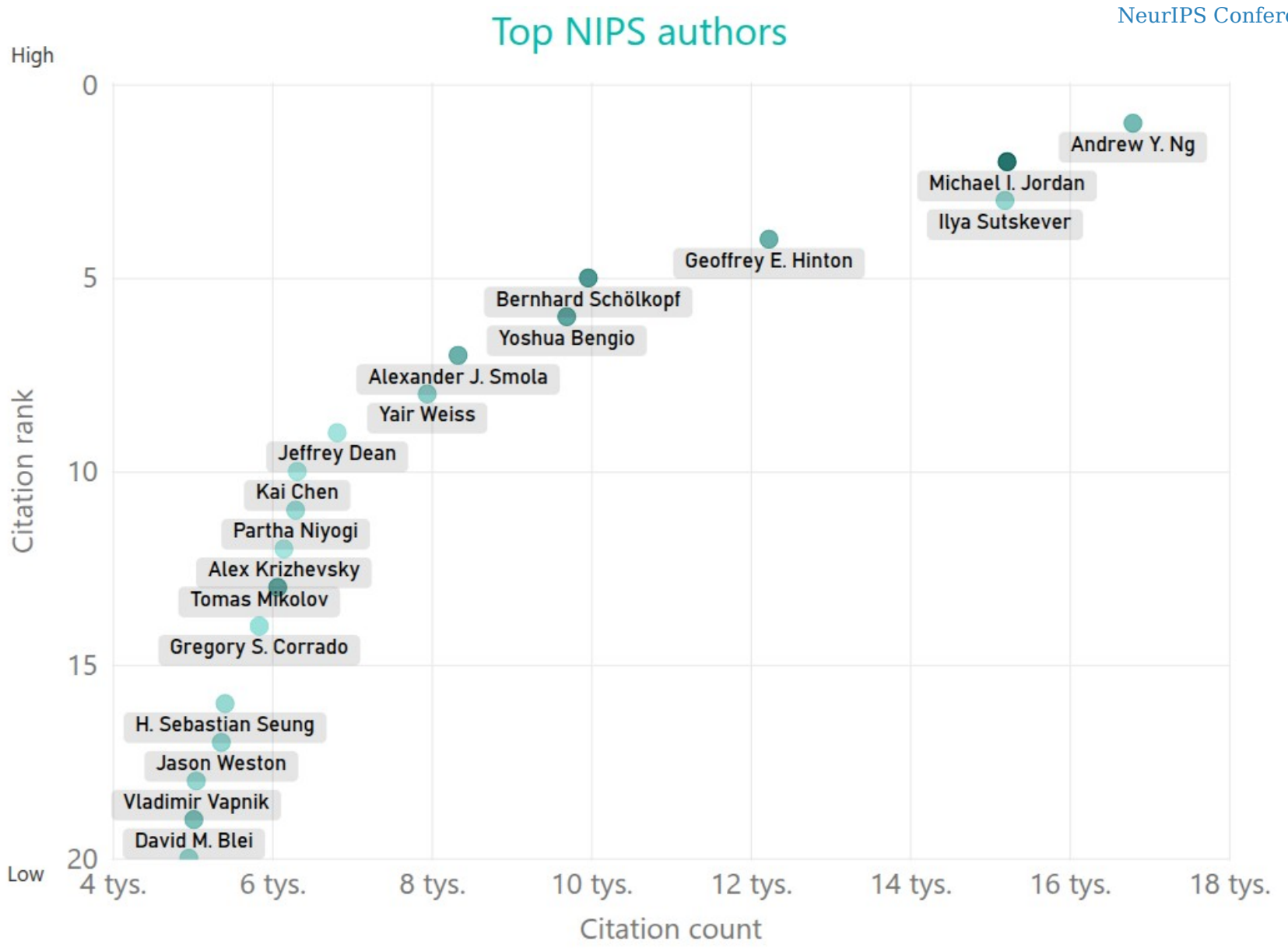
Categories > Engineering & Computer Science > **Artificial Intelligence**

Google Scholar

	Publication	h5-index	h5-median
1.	Neural Information Processing Systems	337	614
2.	International Conference on Learning Representations	304	584
3.	International Conference on Machine Learning	268	424
4.	AAAI Conference on Artificial Intelligence	220	341
5.	Expert Systems with Applications	165	228
6.	IEEE Transactions On Systems, Man And Cybernetics Part B, Cybernetics	155	212

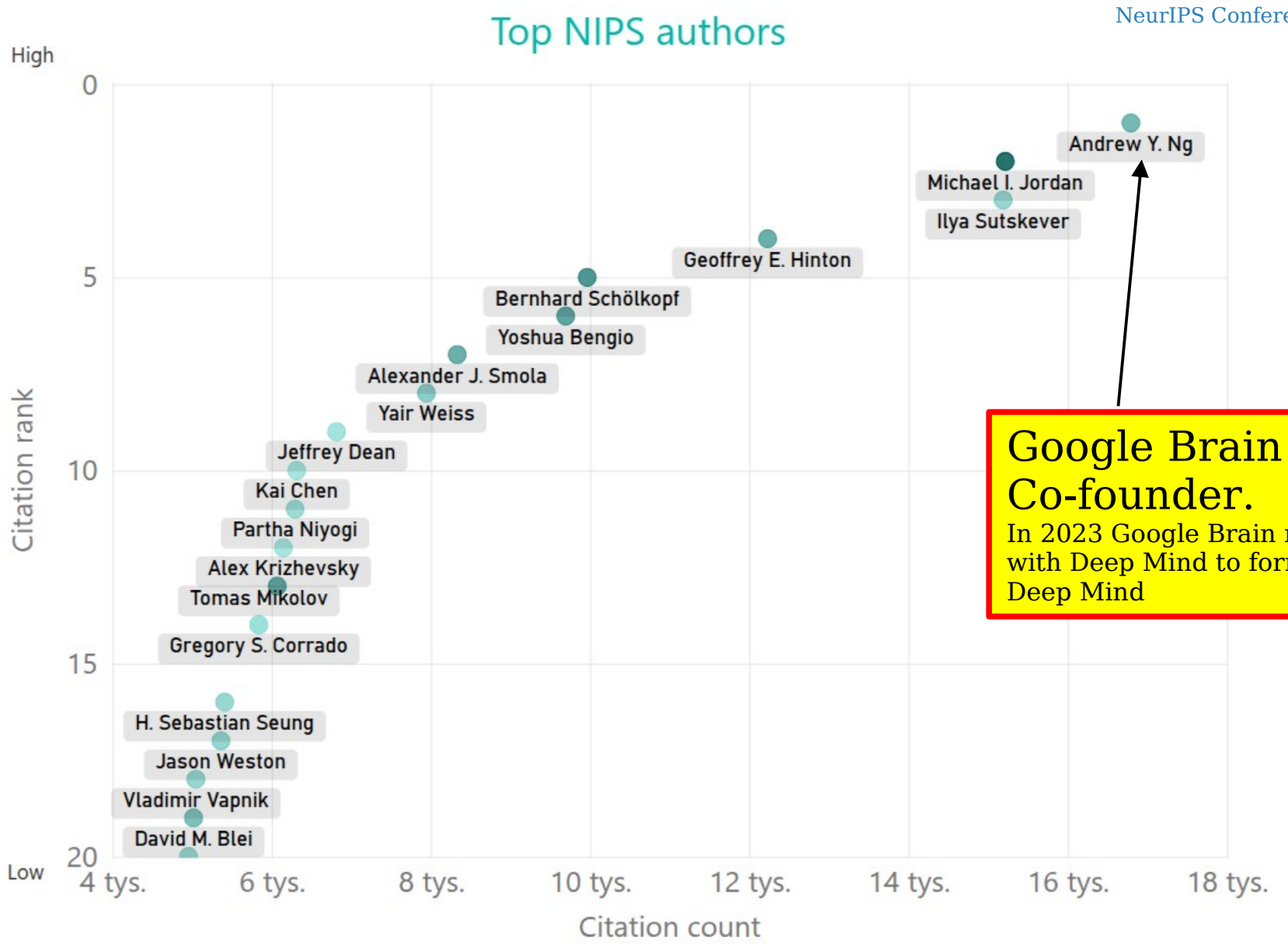
NeurIPS statistics

NeurIPS Conference Analytics



NeurIPS statistics

NeurIPS Conference Analytics

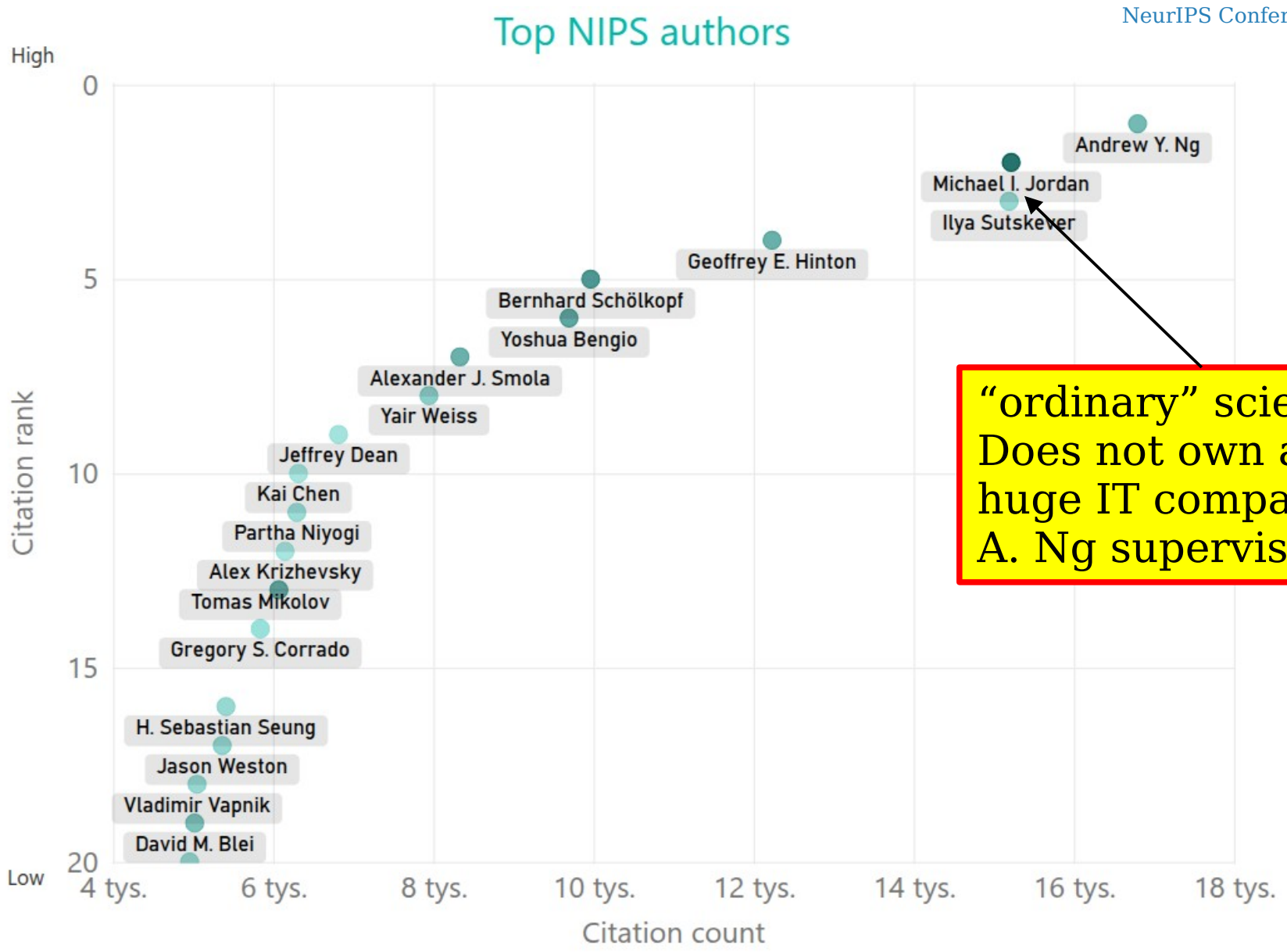


Google Brain Co-founder.

In 2023 Google Brain merged with Deep Mind to form Google Deep Mind

NeurIPS statistics

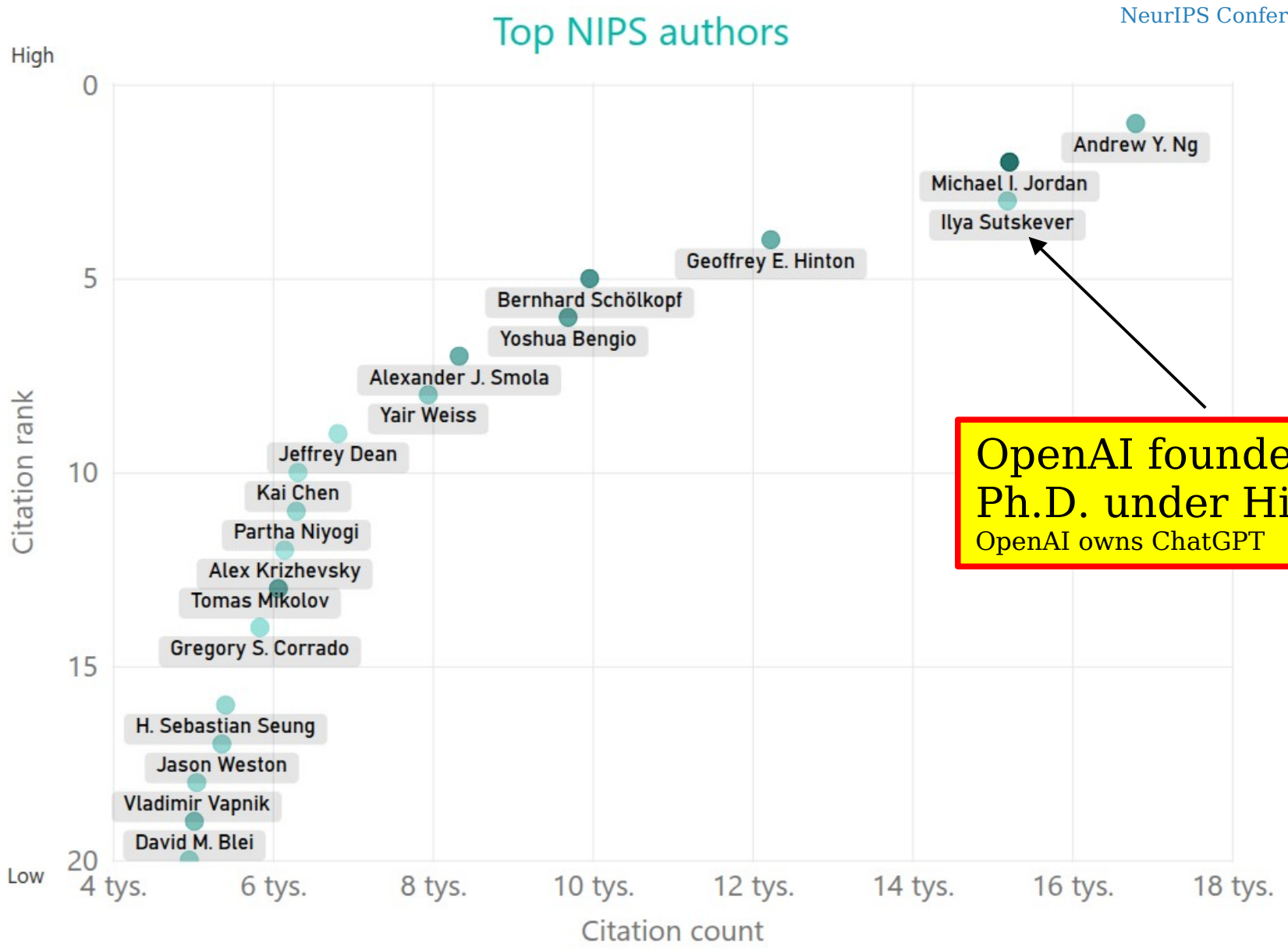
NeurIPS Conference Analytics



"ordinary" scientist
Does not own any huge IT company.
A. Ng supervisor

NeurIPS statistics

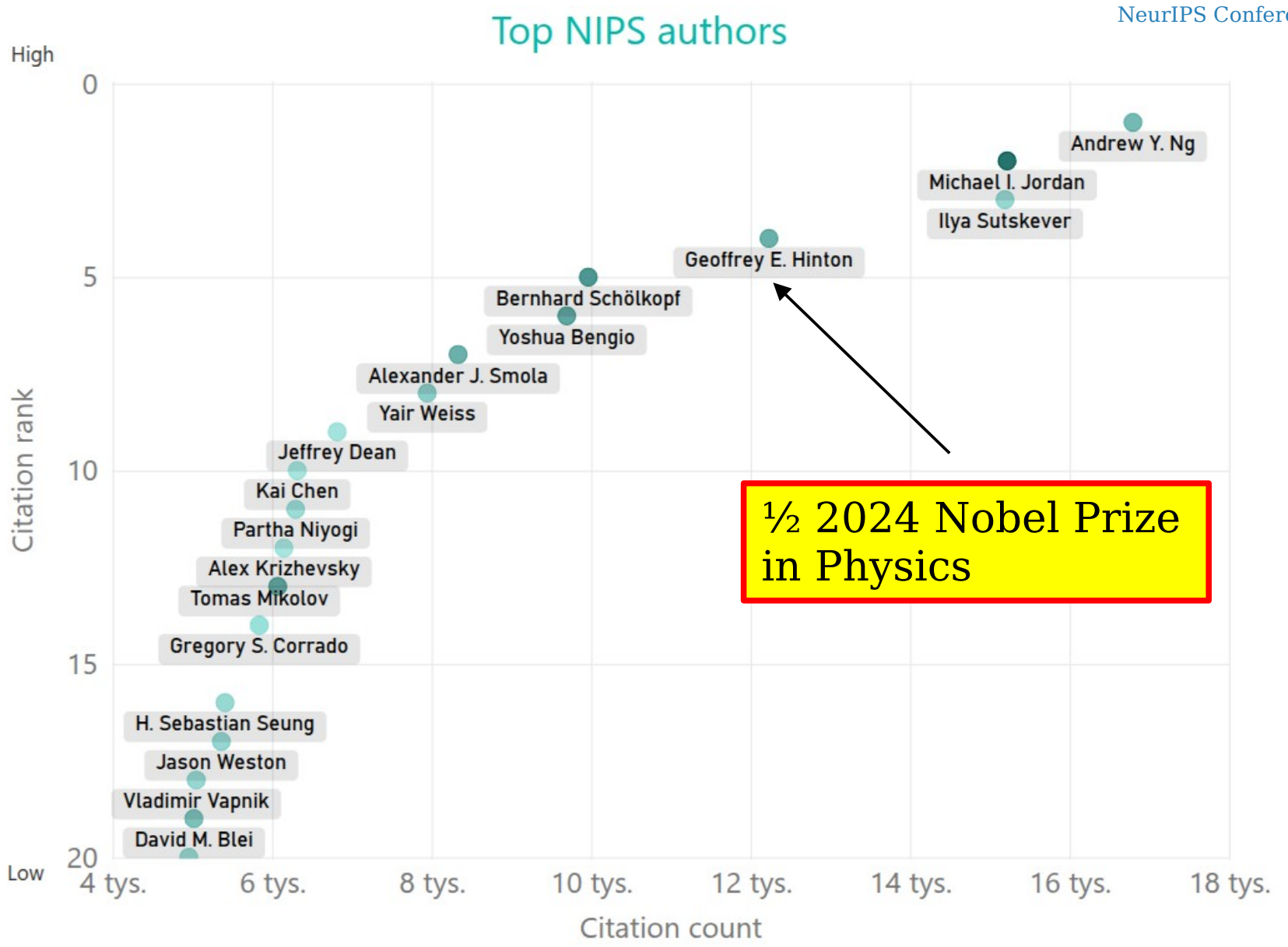
NeurIPS Conference Analytics



OpenAI founder.
Ph.D. under Hinton
OpenAI owns ChatGPT

NeurIPS statistics

NeurIPS Conference Analytics



NeurIPS statistics

NeurIPS Conference Analytics

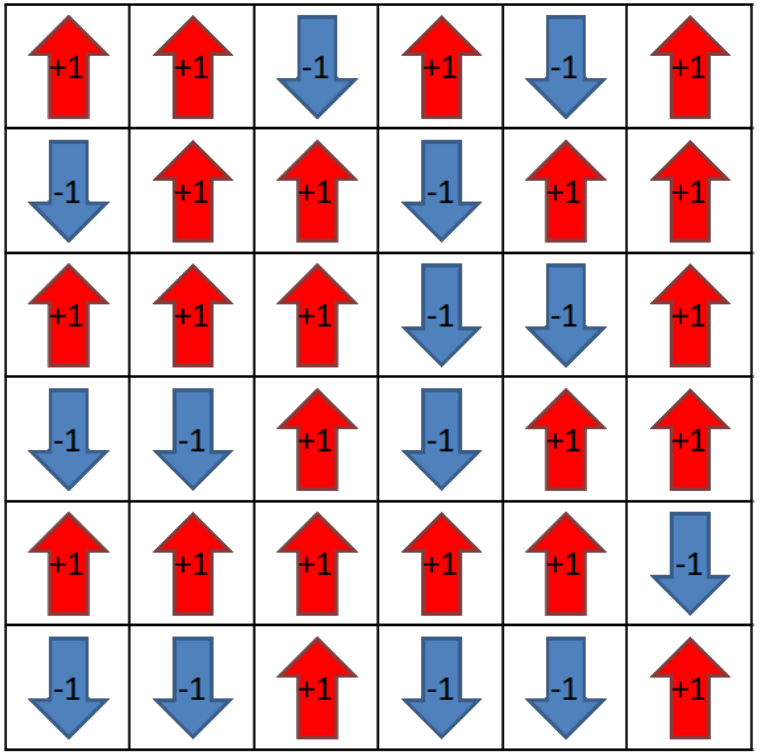
Top institutions

# of NIPS Papers	M..	Institution Name	# of Citations Received
512		Massachusetts Institute of Technology	31 417
402		University of California, Berkeley	26 838
202		University of Toronto	23 704
405		Stanford University	23 311
342		Google	20 117
422		Carnegie Mellon University	15 663
340		Microsoft	15 471
269		Max Planck Society	11 692
80		Université de Montréal	10 456
112		Hebrew University of Jerusalem	10 452
256		Princeton University	10 030
181		University College London	8 348
109		California Institute of Technology	7 865
17		Bell Labs	7 767
62		University of Chicago	7 550
168		University of California, San Diego	7 286
34		AT&T Labs	5 718
133		University of Pennsylvania	5 509
78		New York University	5 360
165		University of Texas at Austin	5 214

The Ising model

https://www.tbeardsley.com/projects/montecarlo/ising2d

Let us consider a 2D lattice of interacting particles with two states, eg. spin ½ objects



The energy (Hamiltonian) of the system is given by the energies of mutual interactions:

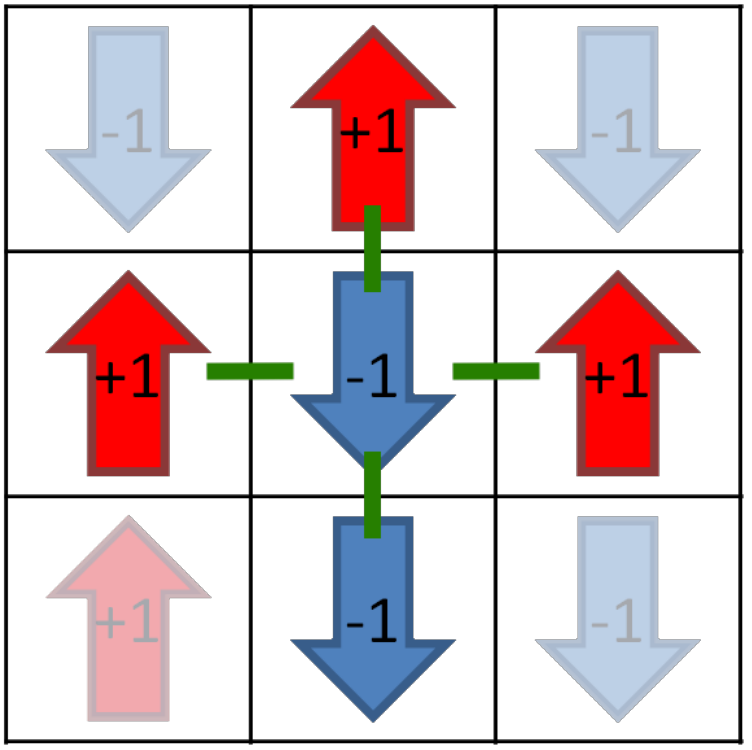
$$E = -\sum_{i,j} w_{ij} S_i S_j - \mu \sum_i h_i S_i$$

The Ising model

The energy (Hamiltonian) of the system is given by the energies of mutual interactions:

$$E = -\sum_{i,j} w_{ij} S_i S_j - \mu \sum_i h_i S_i$$

Interaction between particles.
In the Ising the interaction is short range:



https://www.tbeardsley.com/projects/montecarlo/ising2d

The Ising model

The energy (Hamiltonian) of the system is given by the energies of mutual interactions:

$$E = -\sum_{i,j} w_{ij} S_i S_j - \mu \sum_i h_i S_i$$

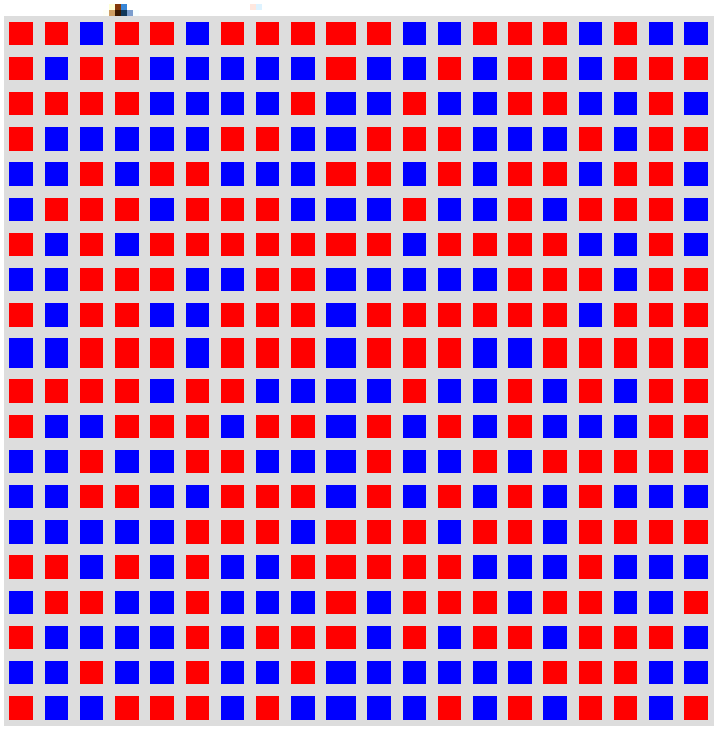
Self interaction, or interaction with external field if h = *const.*
We will neglect it in from now on.

The Ising model

In absence of external field there is a two-fold degenerate ground state:

$$\forall_i S_i = +1 \quad \text{or} \quad \forall_i S_i = -1$$

Random configuration



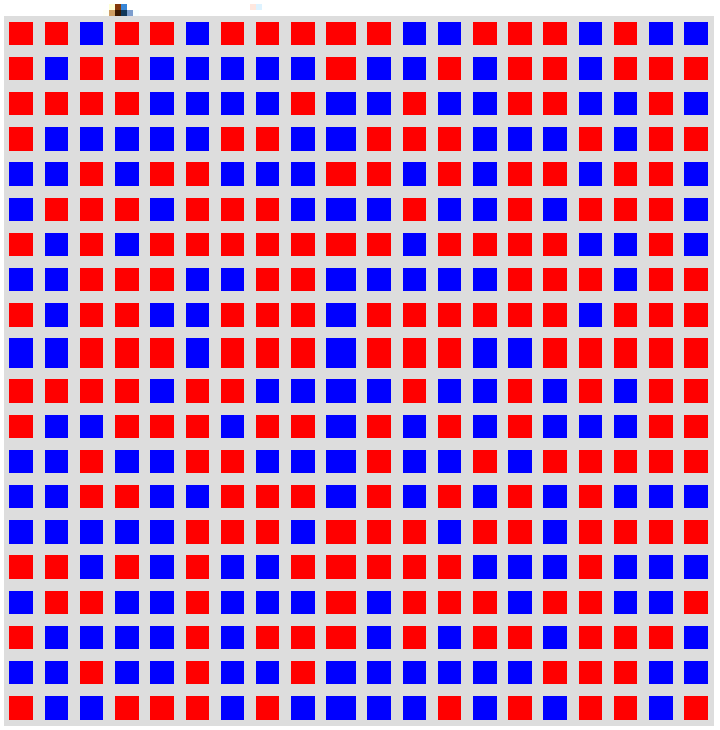
Time evolution

The Ising model

In absence of external field there is a two-fold degenerate ground state:

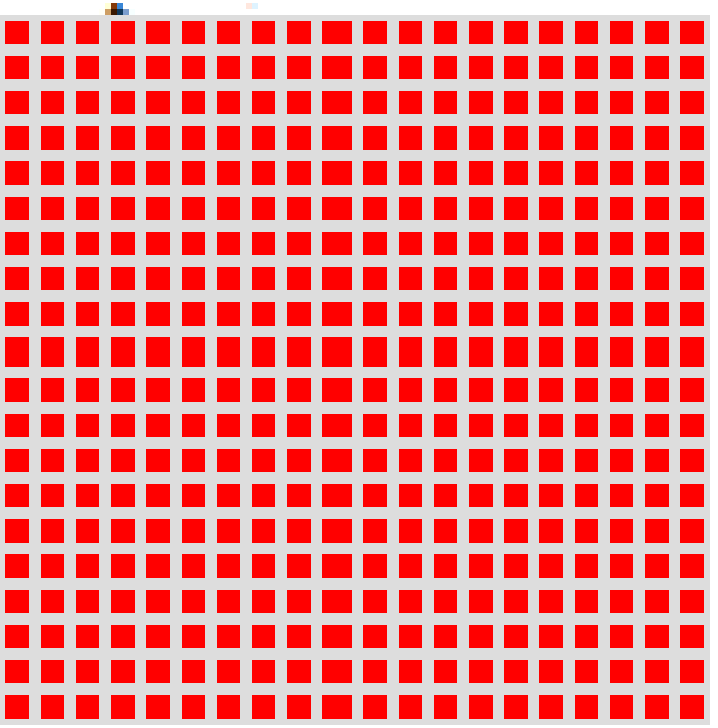
$$\forall_i S_i = +1 \quad \text{or} \quad \forall_i S_i = -1$$

Random configuration



Time evolution

Ground state configuration



A spin glass model

spin glass – magnetic material in which a random (disordered) spin orientation is preserved in low temperatures.

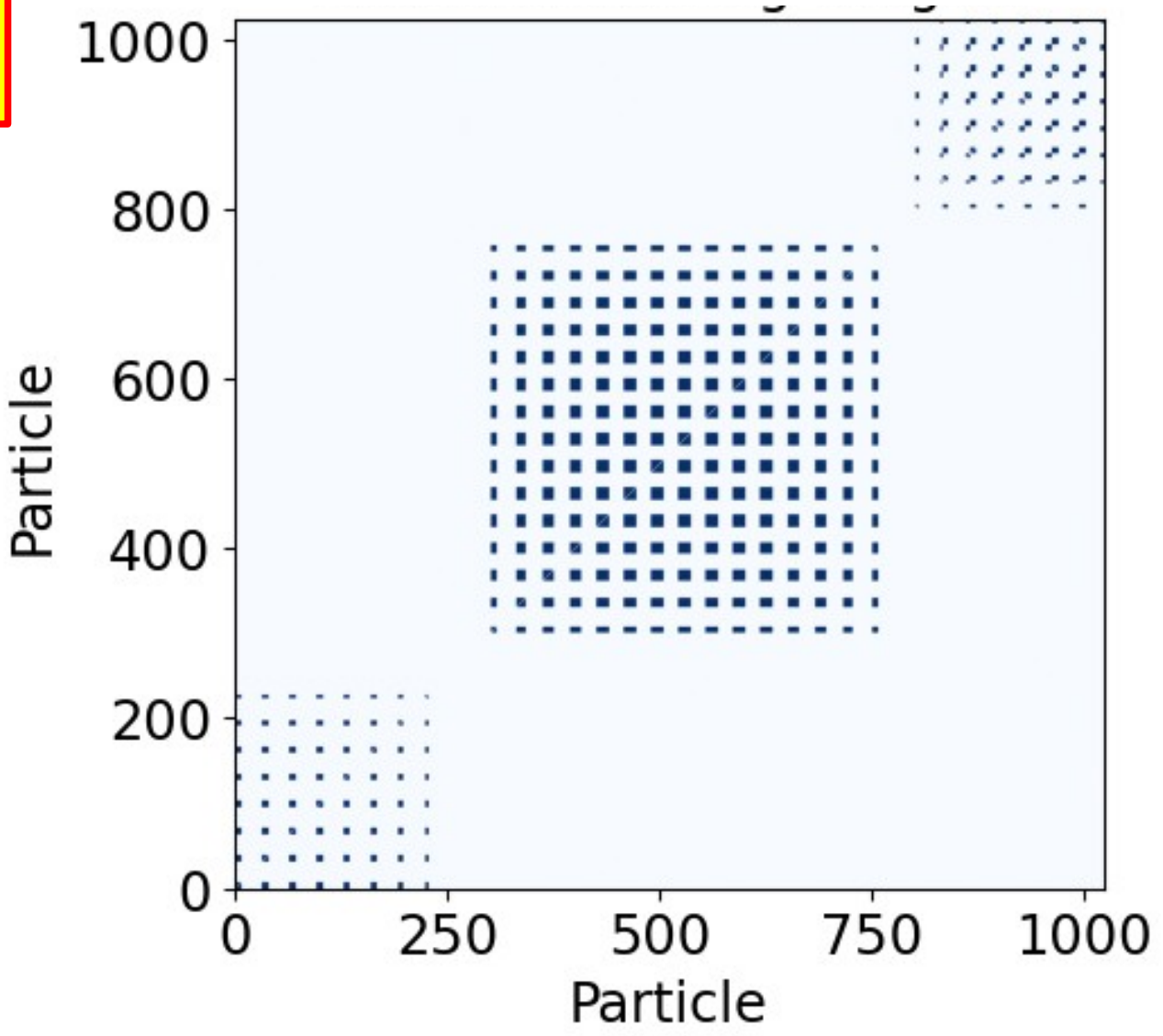
The energy (Hamiltonian) of the system is given by the energies of mutual interactions:

$$E = -\sum_{i,j} w_{ij} S_i S_j$$

In the spin glass the interaction is **long** range, **random**, and of **different signs**.

A spin glass model

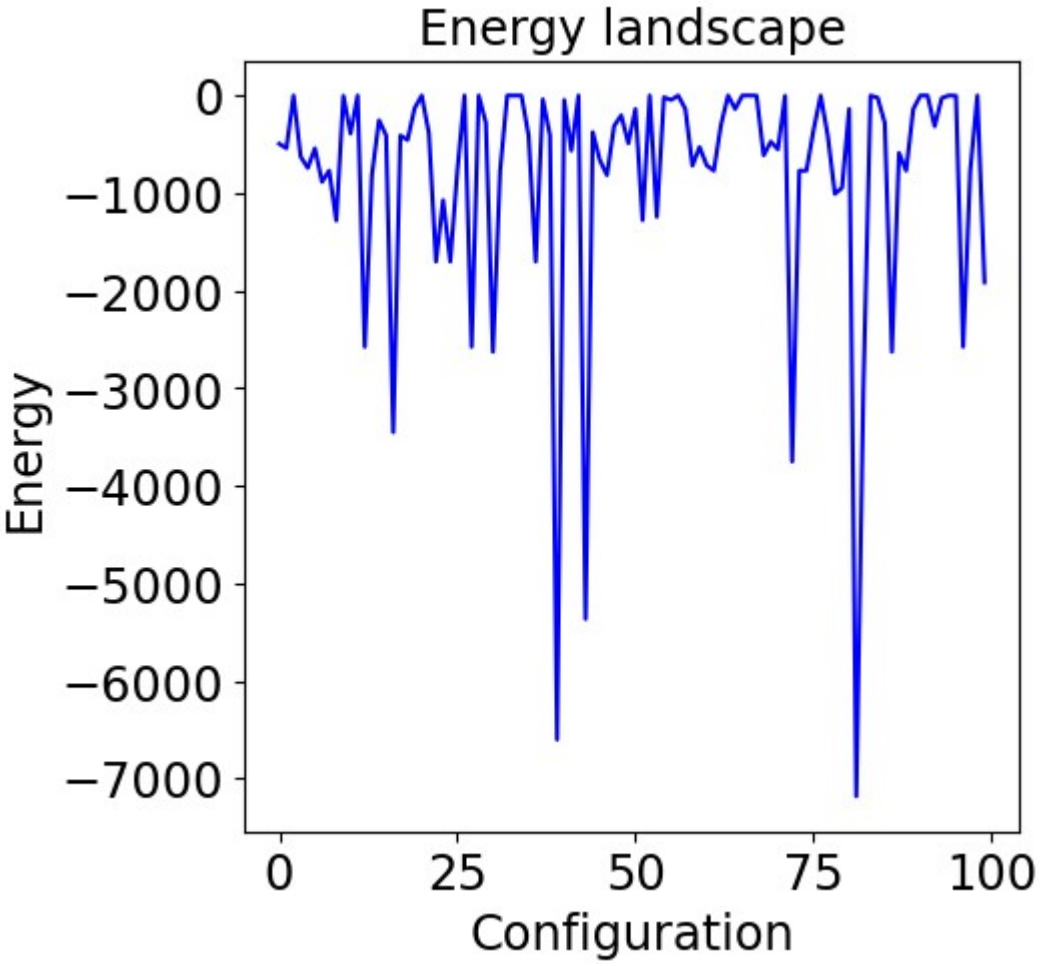
Example: weights for interaction matrix between 1024 “particles”:



A spin glass model

High degeneracy of ground state, many local minima with energy close to the ground one.

$$E = -\sum_{i,j} w_{ij} S_i S_j$$



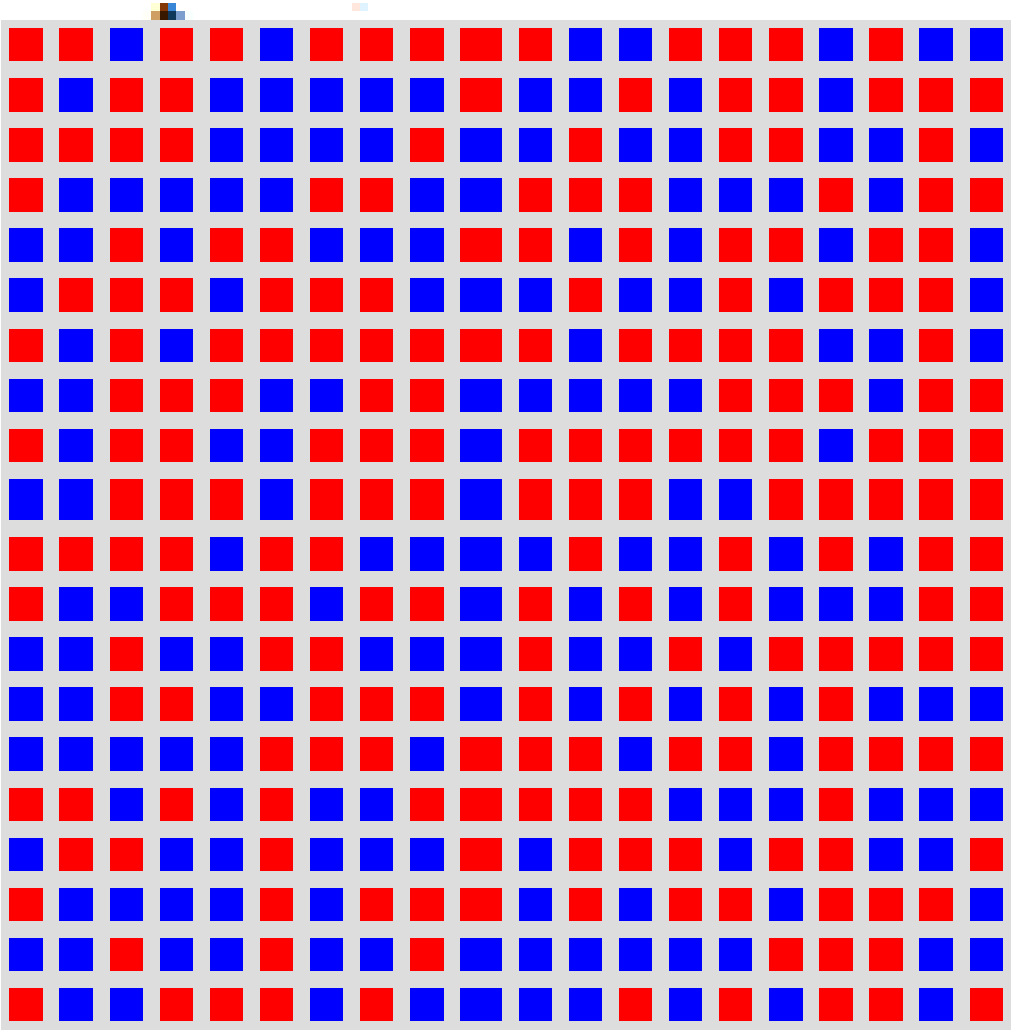
A spin configuration → pattern

Physics:

this is a spin configuration

Machine learning:

this is a pattern



A spin glass model → Hopfield network

- particle → **neuron**
- spin orientation → **activation function output**
- interaction strength → **weight**
- local minium energy state → **pattern stored in the network**

Hopfield network

$$f_j\left(w_{ij}\,x_i\right)=y$$

$\mathbf{x_i}$ - values of other neurons.

Hopfield network

$$f_j\left(w_{ij}\, x_i\right) = y$$

w_i – weights, map of neurons interconnections

Hopfield network

$$f_j\left(w_{ij}\,x_i\right)=y$$

f – activation function. In the Hopfield network we have:

f = sgn(x)

Hopfield network

$$f_j\left(w_{ij}\,x_i\right)=y$$

y – neuron state, the output value

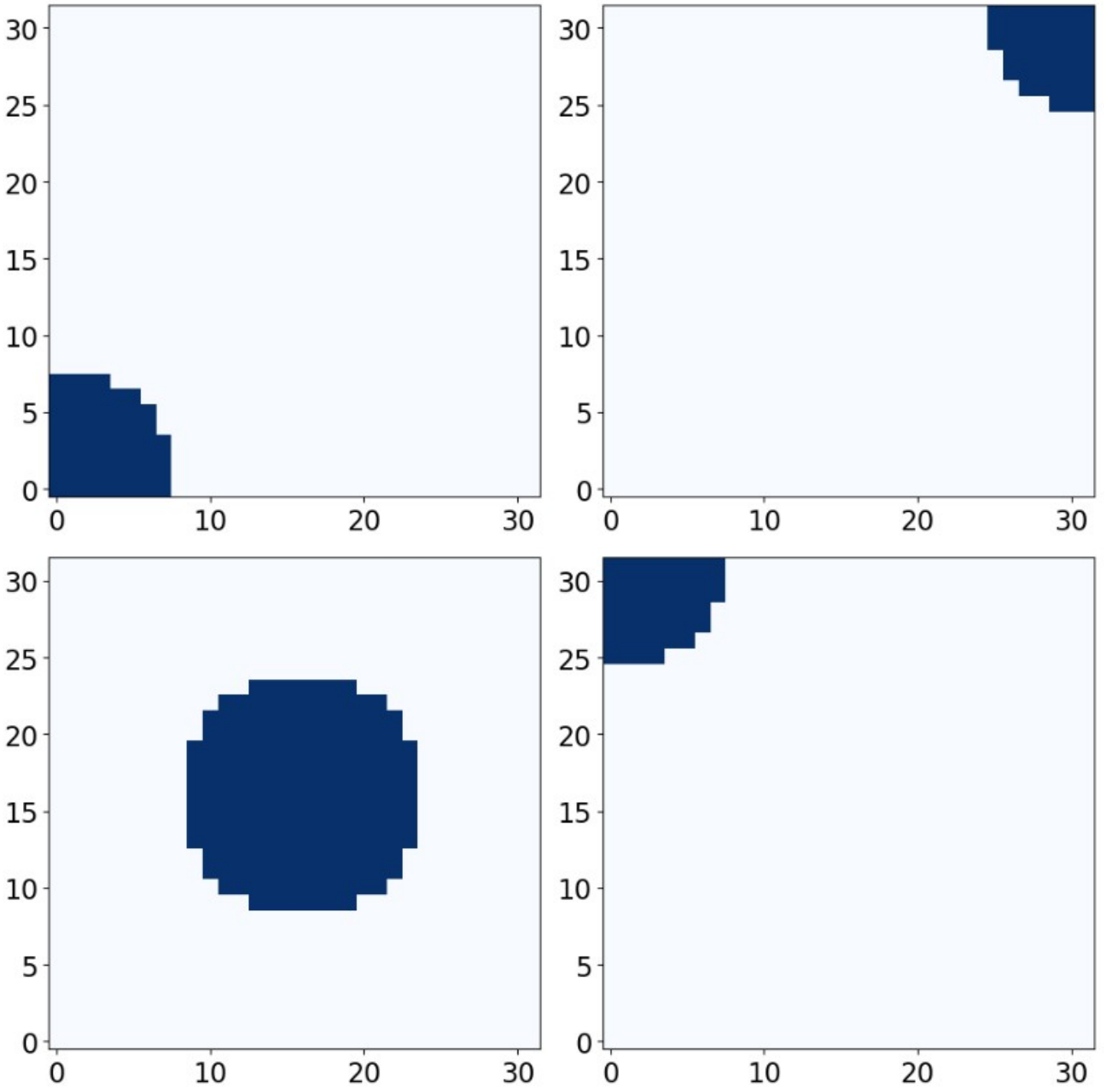
Hopfield network

$$f_j\left(w_{ij}\,x_i\right)=y \qquad E=-\sum_{i,j} w_{ij} S_i S_j$$

```
1  def Hopfield_model(x, w):
2      output = tf.matmul(x, w)
3      output = tf.sign(output)
4      energy = tf.reduce_sum(-tf.matmul(x, w) * x, axis=1)
5      return output, energy
6
```

Hopfield network – content addressable memory

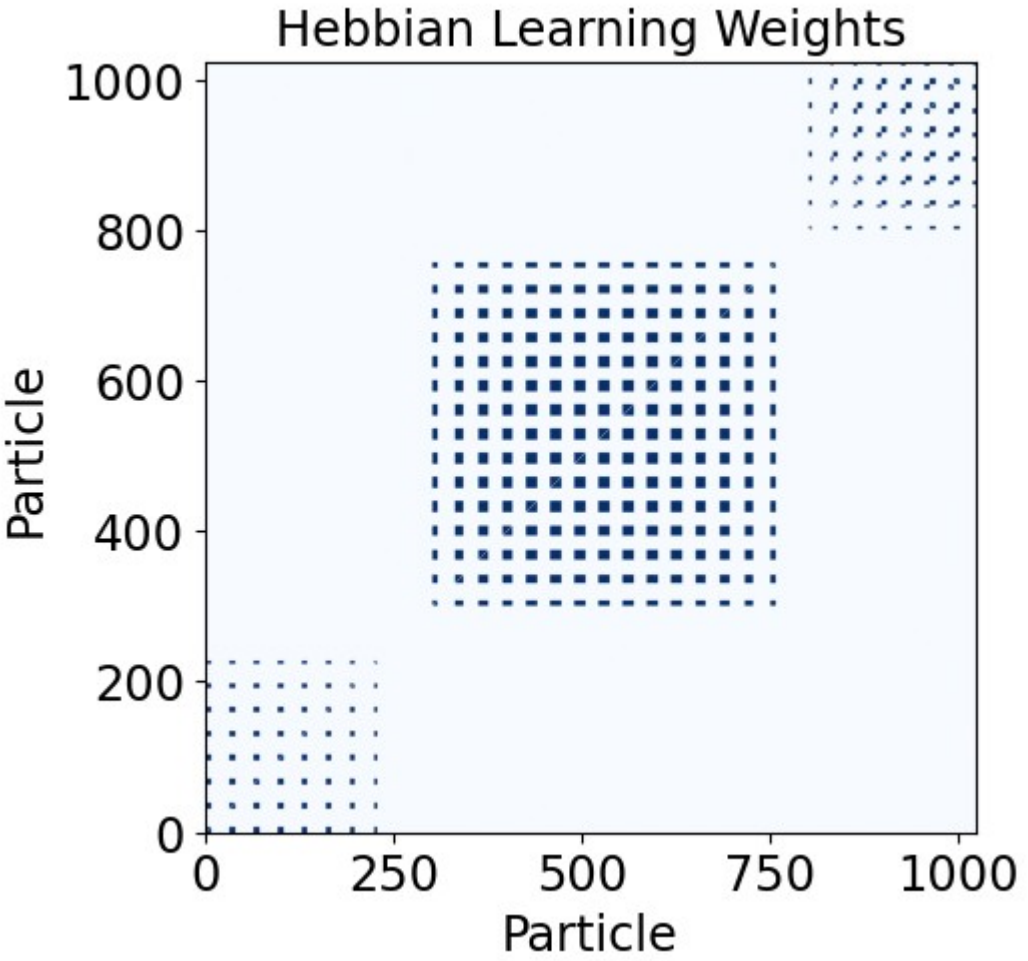
Example: patterns stored in the network:



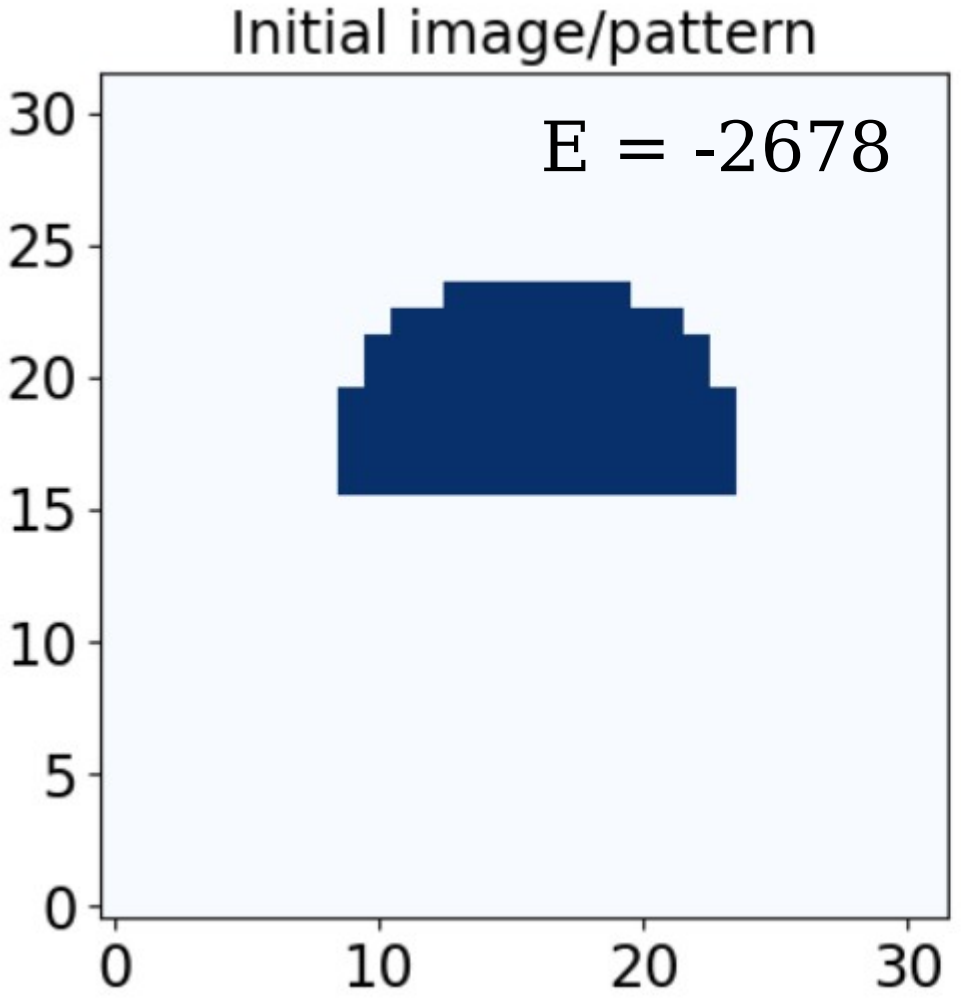
Hopfield network – content addressable memory

Network weights set according to **Hebbian rule:**

“neurons that file together wire together”

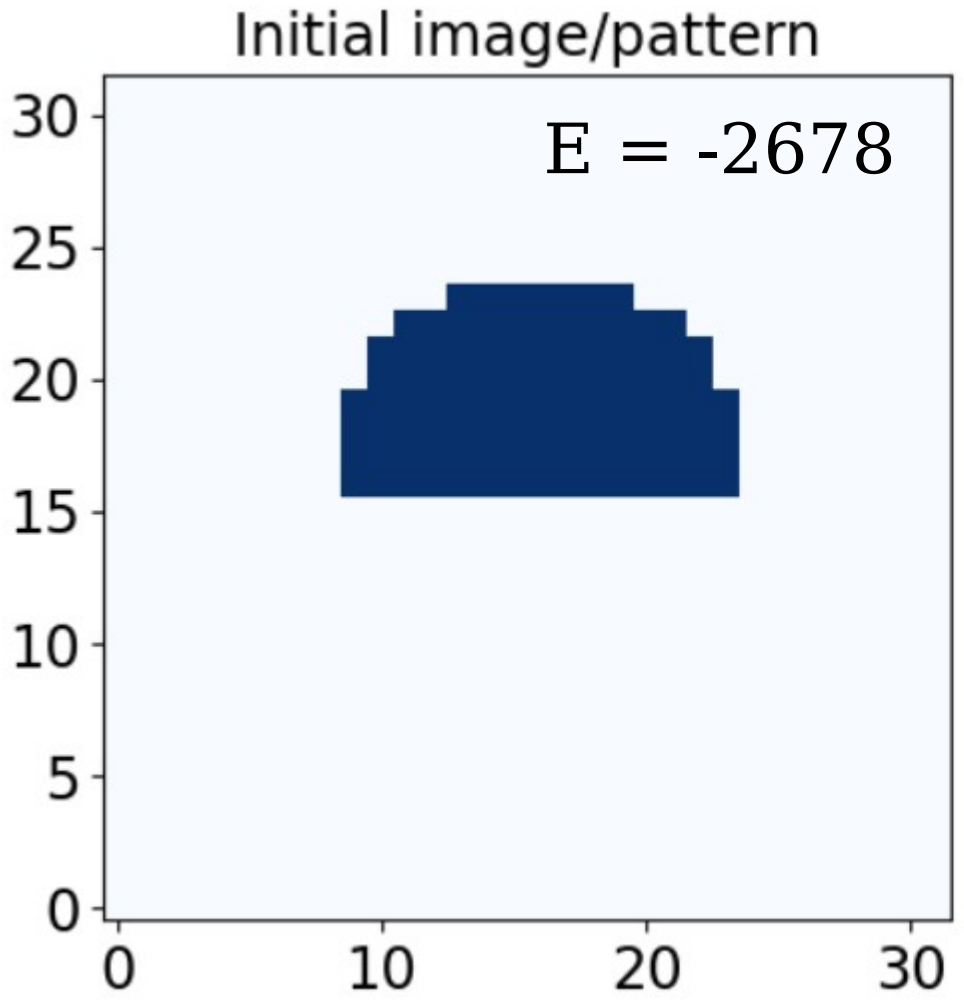


Content addressable memory



Initialize the neurons state with some pattern

Content addressable memory

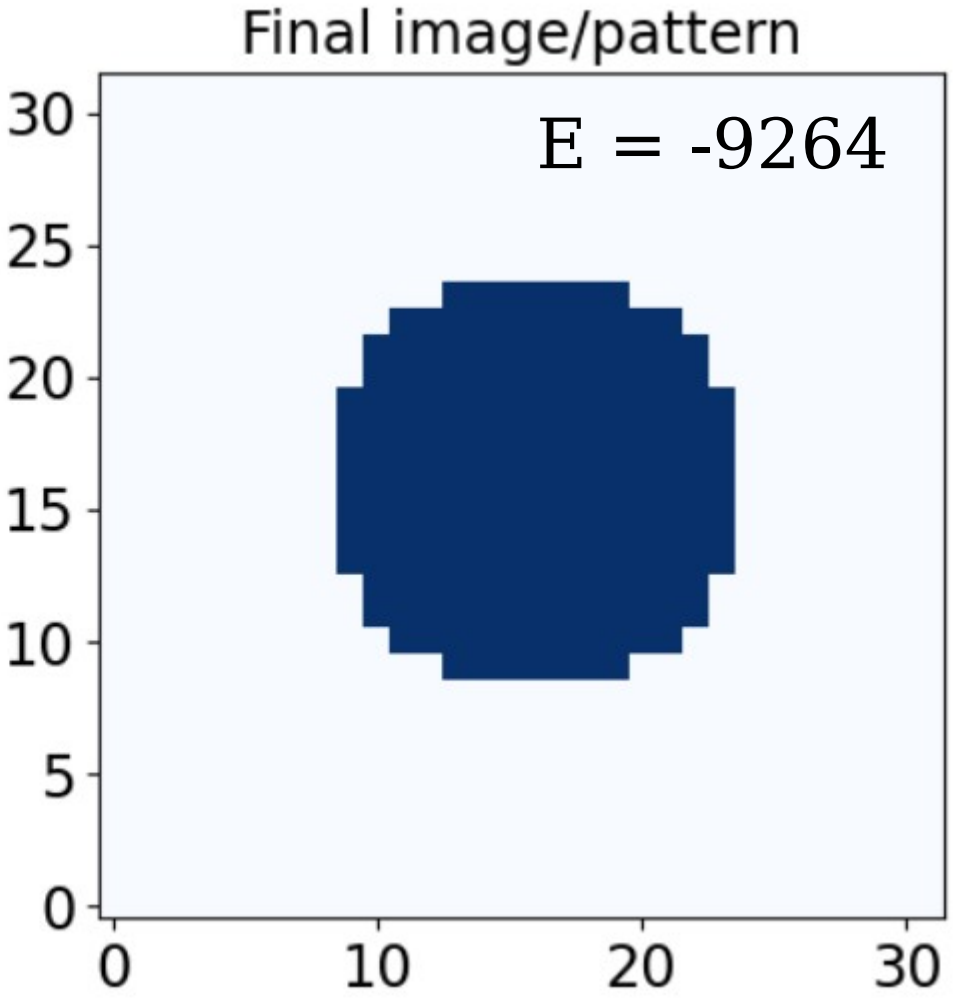


Initialize the neurons state with some pattern

Evolve the system according to neuron activation formula:

$$f\left(w_i x_i\right) = y$$

Content addressable memory



Initialize the neurons state with some pattern

Evolve the system according to neuron activation formula:

$$f\left(w_i x_i\right) = y$$

Until a local minimum “energy” state is reached.

Boltzmann machines

Weights in complicated networks found as a state of thermal equilibrium (=stationary state) of neurons.

Boltzmann machines

Weights in complicated networks found as a state of thermal equilibrium (=stationary state) of neurons.

Between 2006 and 2011 Restricted Boltzmann Machines (RMBs) were used to initialize weights for neural networks.

- Stacked RBMs were like an enzyme.
  - They helped researchers to make the transition to deep learning, but once this transition was achieved they were no longer needed.

G. Hinton, Nobel lecture

Boltzmann machines

Weights in complicated networks found as a state of thermal equilibrium (=stationary state) of neurons.

Be ines
(R
net

Both Hopfield networks and Boltzmann machines are not used anymore in a main stream machine learning.

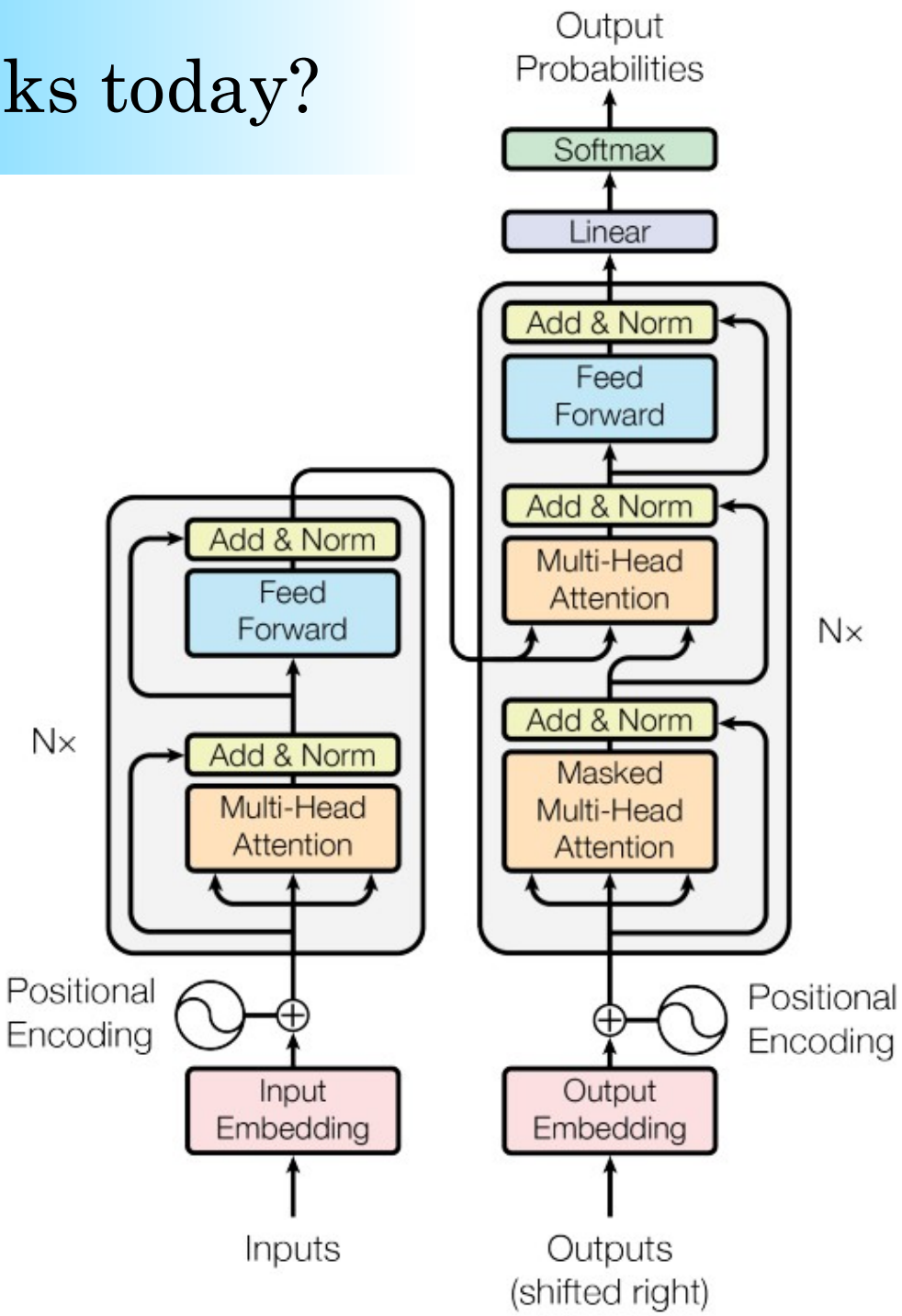
- Stacked RBMs were like an enzyme.
  - They helped researchers to make the transition to deep learning, but once this transition was achieved they were no longer needed.

G. Hinton, Nobel lecture

How ML looks today?

Neural network: a huge multidimensional function family, defined by:

- **structure**

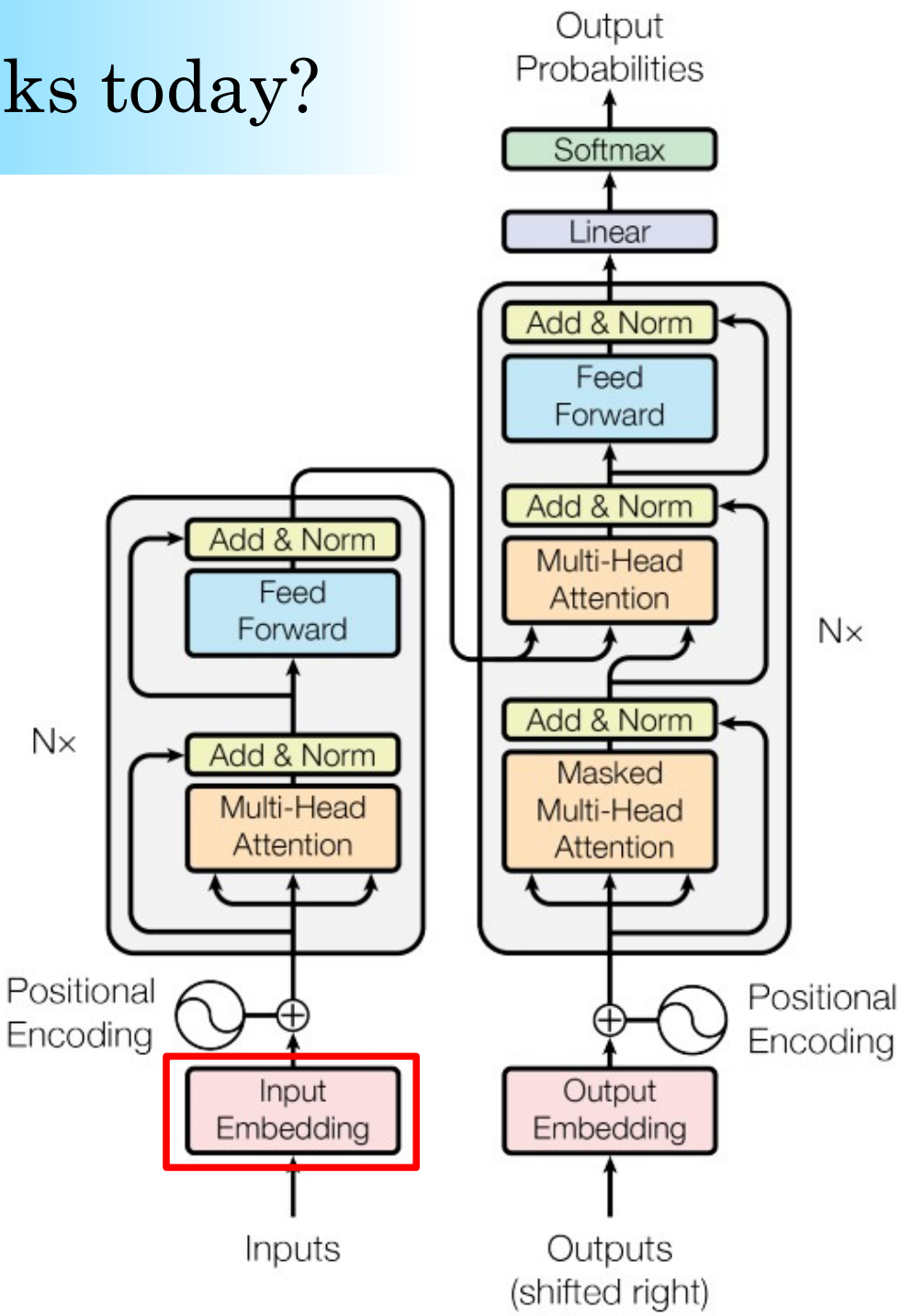


arXiv:1706.03762 [cs.CL]

How ML looks today?

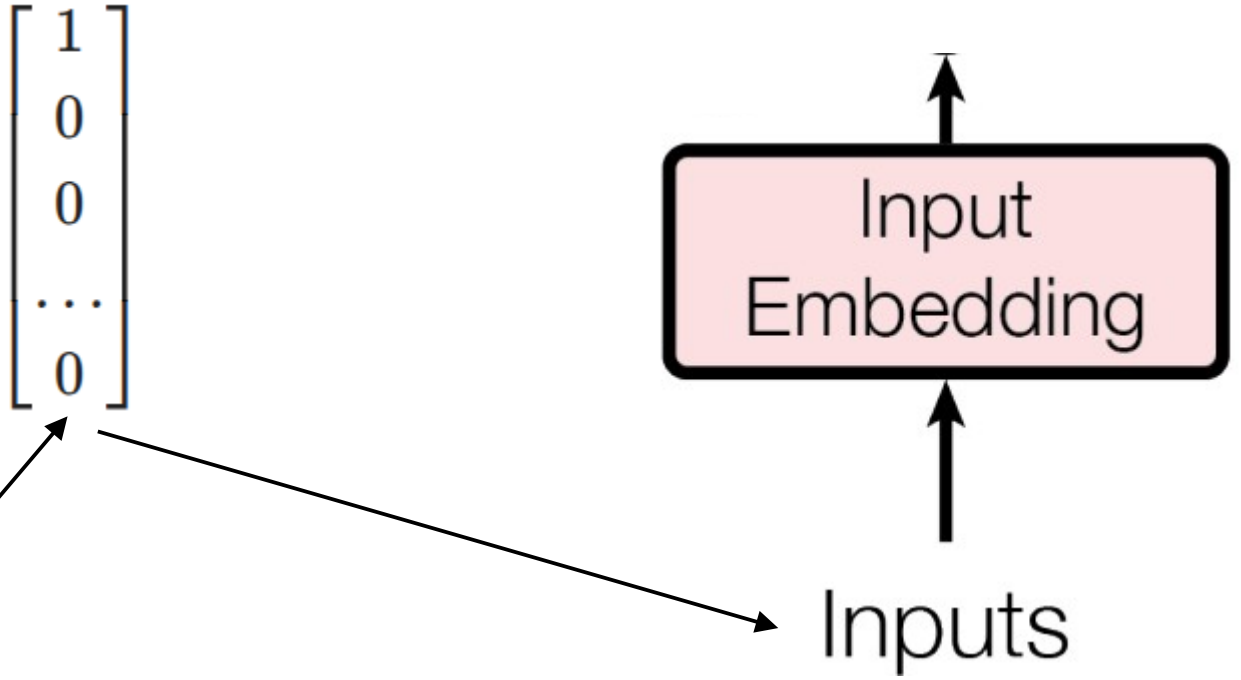
Neural network: a huge multidimensional function family, defined by:

- **structure**



arXiv:1706.03762 [cs.CL]

Building block - embedding



$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ \dots \\ 0 \end{bmatrix}$$

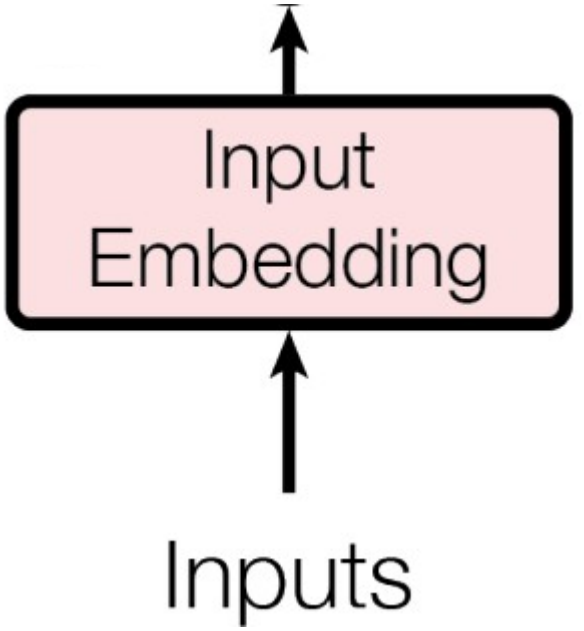
Human readable representation, i.e index of a word on vocabulary:

How GPT works?

$$= (18246, 789, 19357)$$

Building block - embedding

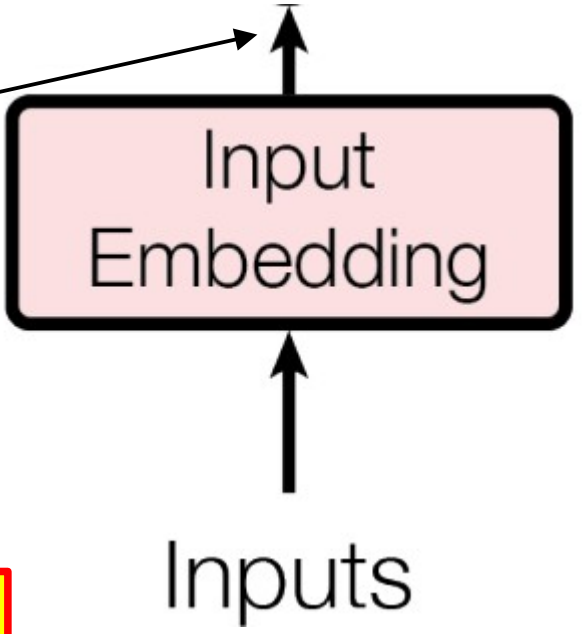
$$\begin{bmatrix} a_0 & b_0 & c_0 & \dots \\ a_1 & b_1 & c_1 & \dots \\ a_2 & b_2 & c_2 & \dots \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 0 \\ 0 \\ \dots \\ 0 \end{bmatrix}$$



Matrix translating between representations. Matrix elements, “weights”, found during the “training”.

Building block - embedding

$$\begin{bmatrix} a_0 & b_0 & c_0 & \dots \\ a_1 & b_1 & c_1 & \dots \\ a_2 & b_2 & c_2 & \dots \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 0 \\ 0 \\ \dots \\ 0 \end{bmatrix} = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}$$



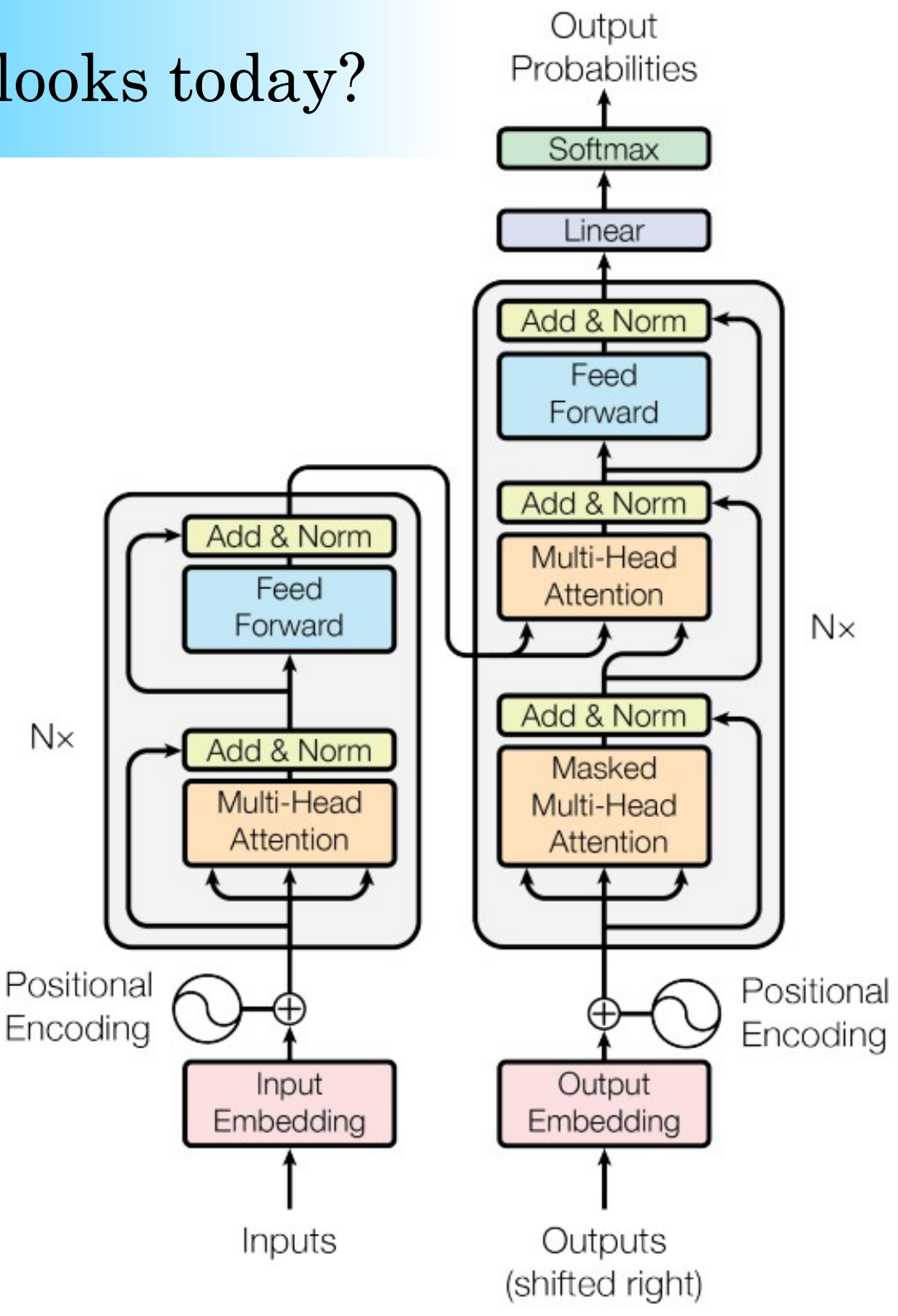
Machine readable representation. Here 3- dimensional vector. In reality this is often 512 or more dimensional vector

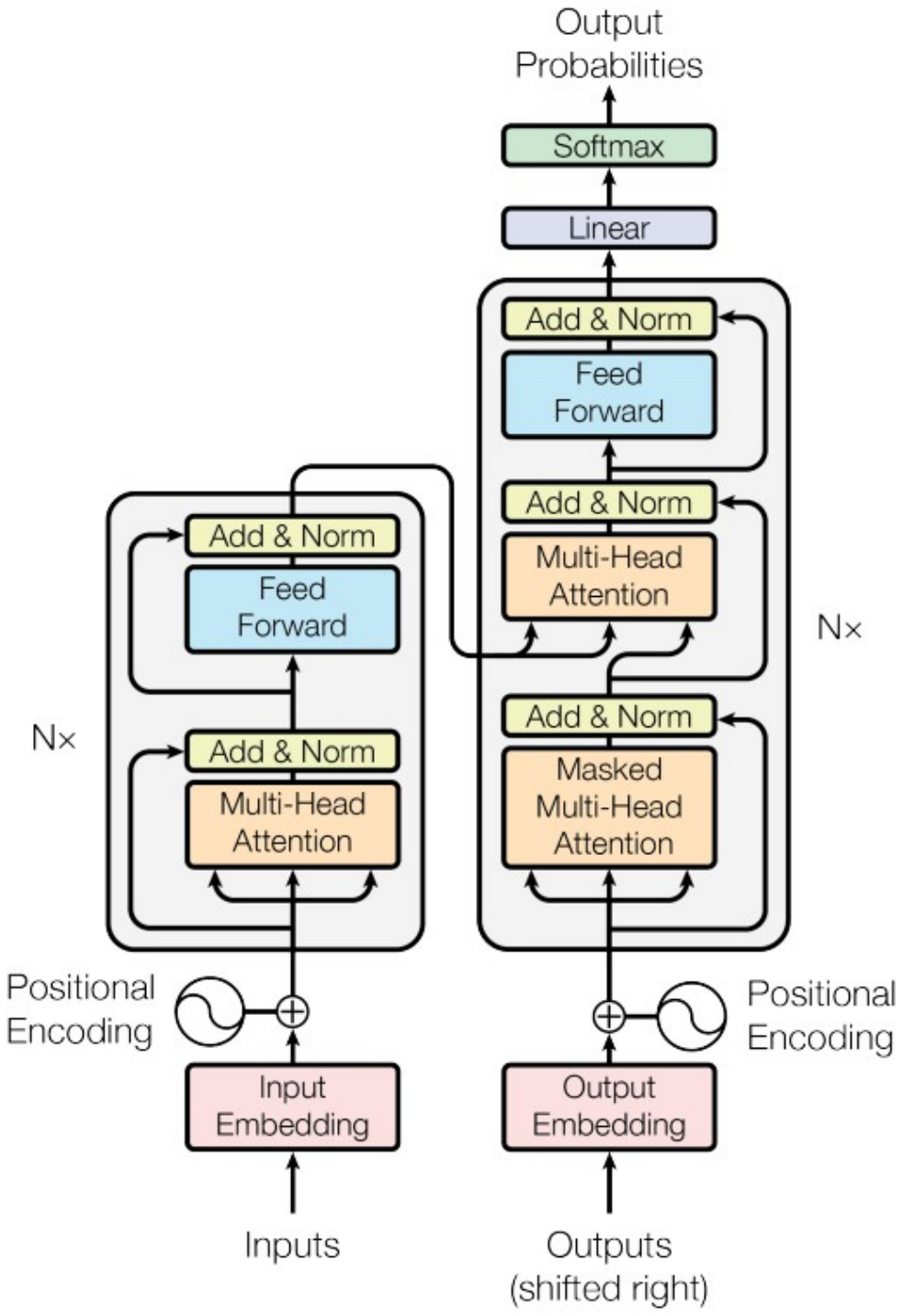
How ML looks today?

Neural network: a huge multidimensional function family, defined by:

- **structure**
- **weights** – all the parameters of linear operations, ie. embedding matrix. ChatGPT 4 has **$1.76 \cdot 10^{12}$ parameters**

Source: rumors

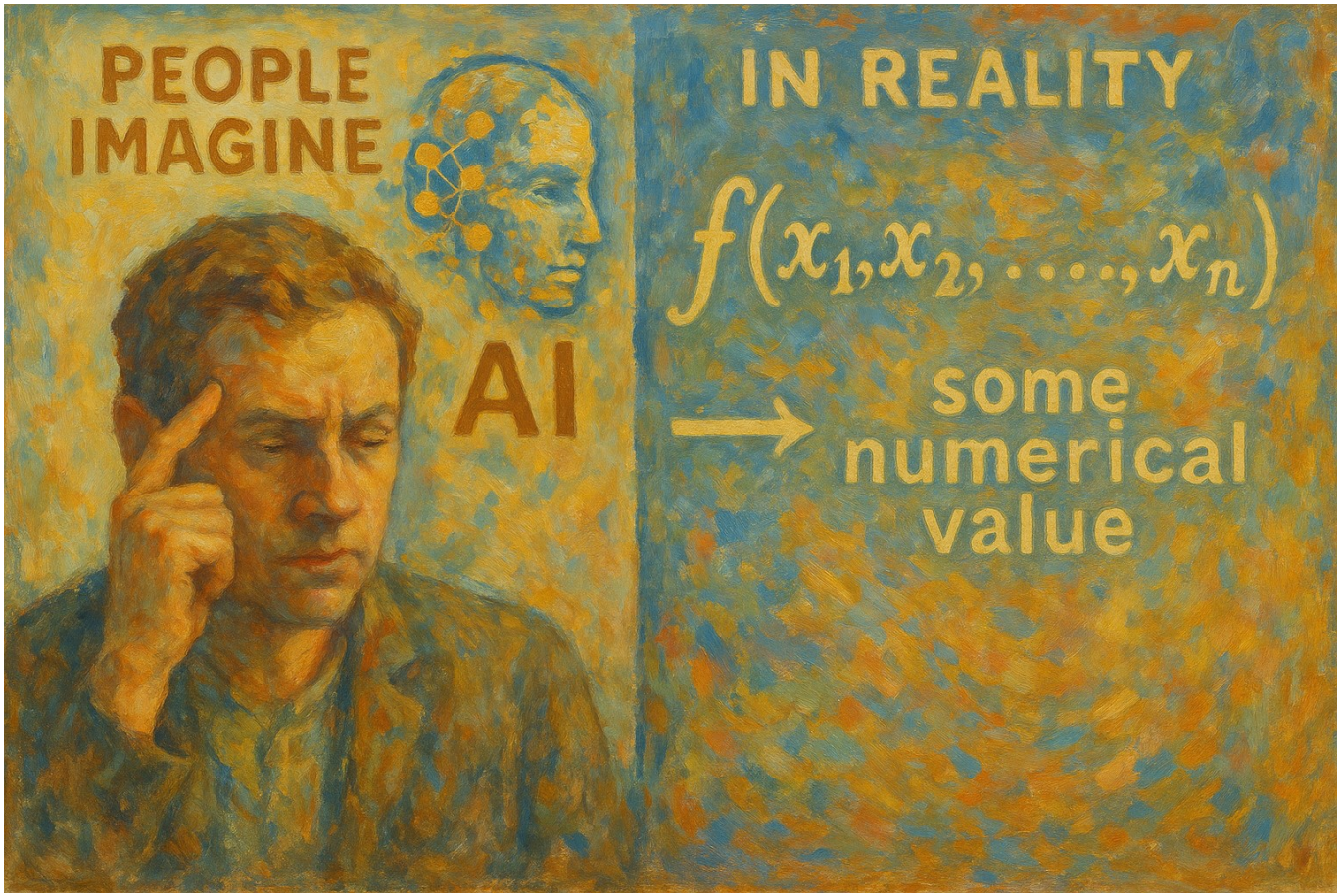




$$\approx p\left(\text{"Izmael"} \middle| \text{"Call me:"}\right)$$

Private comment: many phenomena in Nature have similar mathematical description, but is this a reason to #physics everything?

Advice: Every time you hear/read that "**AI said …**"
Think: "**Function 4O returned value 44**"



ChatGPT