A Historical Overview of Artificial Intelligence (AI)

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Course Infomation

- Course web:
  - https://yao-lab.github.io/aifin/2021/
- Time and Venure:
  - Lecture: **Mon, 7:30-10:20pm**, **Rm 4619, Lift 31-32**
- Instructor:
  - Yuan Yao <yuany@ust.hk> (https://yao-lab.github.io/)
- Teaching Assistant:
  - CAO He : hcaoaf@connect.ust.hk
  - LIU Xuantong : xliude@connect.ust.hk

Course Schedule

Session	Topic	Application & Case Study
1	– Overview of History and Supervised learning	
2	– Introduction to Linear Regression and Classification	– Price and Default Risk Prediction
3	– Model Assessment and Selection with Regularization: Ridge Regression and LASSO	– Model selection and causal recovery
4	– Decision Trees, Random Forests and Boosting	– Credit analysis
5	– Support Vector Machines	– Tutorial on Machine Learning with Python
6	– An Introduction to Convolutional Neural Networks	– Price change patterns
7	– Transfer Learning and Neurostyle	– Google deep dream
8	– An Introduction to Recurrent Neural Networks (RNN) and Long Short Term Memory (LSTM)	– Time series prediction
9	– Introduction to Unsupervised Learning: PCA, AutoEncoder, VAE and GANs	– Robust factor analysis – Anomaly detection
10	– An Introduction to Reinforcement Learning	– Deep Reinforcement Learning in Trading
11	– Projects and Class Wrap	

Note: Details may change depending on class progress, development of relevant technologies, as well as information and feedback from students' surveys.

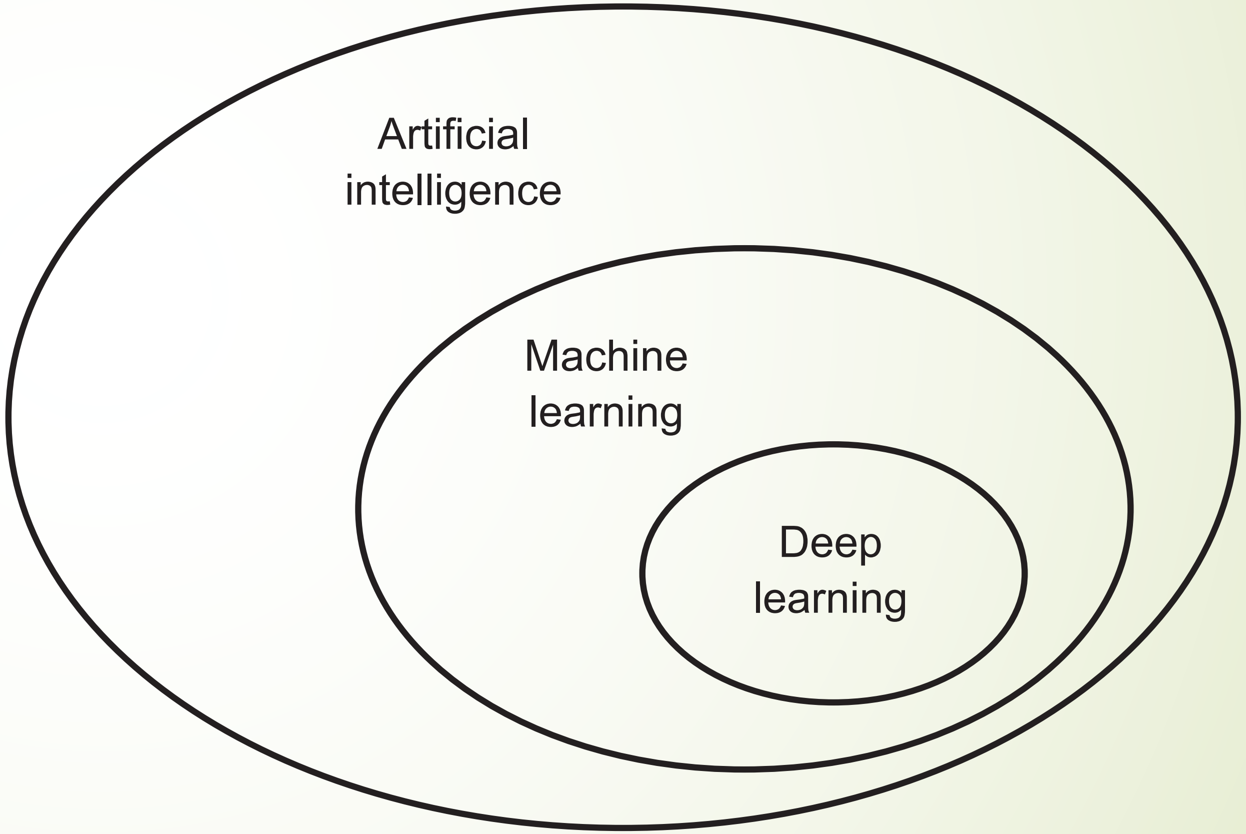
A Brief History of AI, Machine Learning, and Deep Learning

If you asked ChatGPT (3.5):

- **Title: A Historical Overview of Artificial Intelligence (AI)**
- Introduction:
  Artificial Intelligence (AI) has a rich and fascinating history that spans several decades. This article provides a comprehensive overview of the historical milestones and key developments in the field of AI. By tracing the evolution of AI from its inception to the present day, we gain valuable insights into the progression of this groundbreaking discipline.
- The Birth of AI:
  The origins of AI can be traced back to the Dartmouth Conference in 1956, where the term "artificial intelligence" was first coined. This event marked the beginning of a new era, with researchers envisioning the possibility of creating machines that could exhibit intelligent behavior.
- Early AI Approaches:
  In the 1950s and 1960s, researchers explored various approaches to AI, such as symbolic reasoning and logical inference. The development of the Logic Theorist program by Allen Newell and Herbert Simon and the General Problem Solver by Newell and J.C. Shaw were significant milestones during this period.
- The Rise of Machine Learning:
  In the 1980s and 1990s, there was a shift in focus towards machine learning approaches within AI. The emergence of expert systems and the development of algorithms like the backpropagation algorithm for training neural networks led to significant advancements in pattern recognition and decision-making.
- Knowledge-Based Systems:
  During the 1980s, knowledge-based systems gained prominence in AI research. These systems utilized expert knowledge and rule-based reasoning to solve complex problems. The development of the MYCIN system for medical diagnosis and the DENDRAL system for chemical analysis were notable achievements in this era.
- AI Winter and Resurgence:
  In the late 1980s and early 1990s, AI faced a period of reduced funding and disillusionment, known as the "AI winter." However, advancements in computing power and the emergence of new techniques, such as Bayesian networks and support vector machines, sparked a resurgence of interest in AI research in the late 1990s.
- Big Data and Deep Learning:
  In recent years, the availability of vast amounts of data and the development of powerful computational resources have revolutionized AI. Deep learning, a subfield of machine learning focused on neural networks with multiple layers, has achieved remarkable success in areas such as image and speech recognition, natural language processing, and autonomous vehicles.
- AI in the Present and Future:
  AI is now an integral part of our daily lives, with applications ranging from virtual assistants and recommendation systems to autonomous robots and self-driving cars. The field continues to evolve rapidly, with ongoing research in areas like explainable AI, reinforcement learning, and ethical considerations surrounding AI deployment.
- Conclusion:
  The historical journey of AI showcases the remarkable progress made in this field. From its early beginnings to the present day, AI has transformed the way we interact with technology and holds immense potential for future advancements. By understanding its history, we gain a deeper appreciation for the challenges overcome and the possibilities that lie ahead in the exciting world of artificial intelligence.

Artificial Intelligence, Machine Learning, and Deep Learning

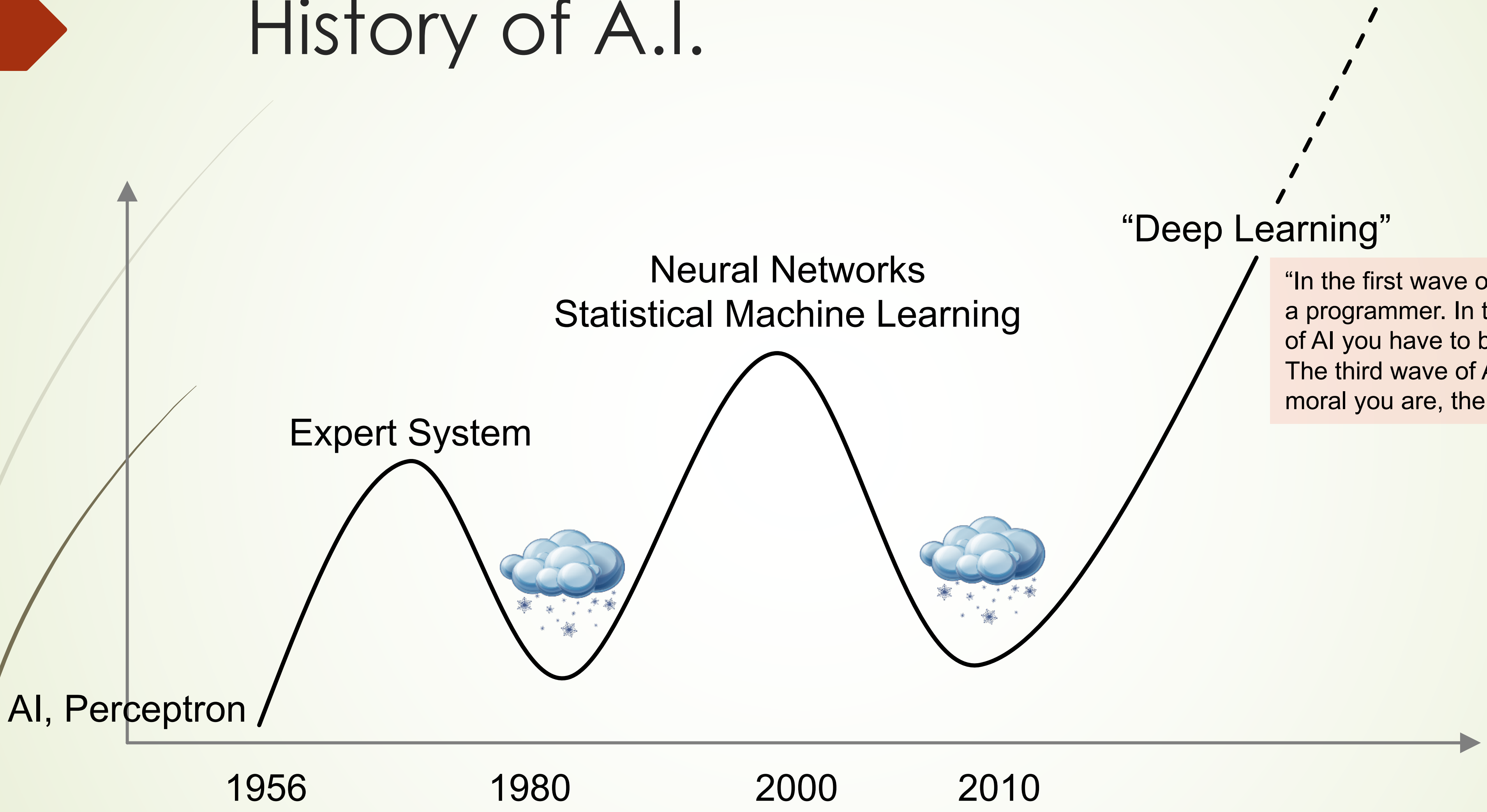
- AI is born in 1950s, when a handful of pioneers from the nascent field of computer science started asking **whether computers could be made to "think"**—a question whose ramifications we're still exploring today.



A brief history of AI

- **1943:** McCulloch & Pits proposed a boolean circuit model of neurons
- **1949:** Donald Hebb proposed **Hebbian learning rule**.
- **1950:** Alan Turing published **"Computing Machinery and Intelligence"** with **Turing test**.
- **1956:** John McCarthy at the Dartmouth Conference coined terminology "**Artificial Intelligence**"
- **1957**: Rosenblatt invented **Perceptron**
- **1960s:** golden years till **1969 Minsky-Papert's** critical book **Perceptron**
- **1970s**: the first AI winter
- **1980s**: boom of AI with **Expert System**
- **1990s:** the second AI winter, rise of **statistical machine learning**
- **1997: IBM Deep Blue** beats world chess champion Kasparov
- **2012:** return of neural networks as **deep learning** (speech, ImageNet in computer vision, NLP, …)
- **2016-2017: Google AlphaGo "Lee" and Zero**
- **2020: Google AlphaFold**
- …

History of A.I.

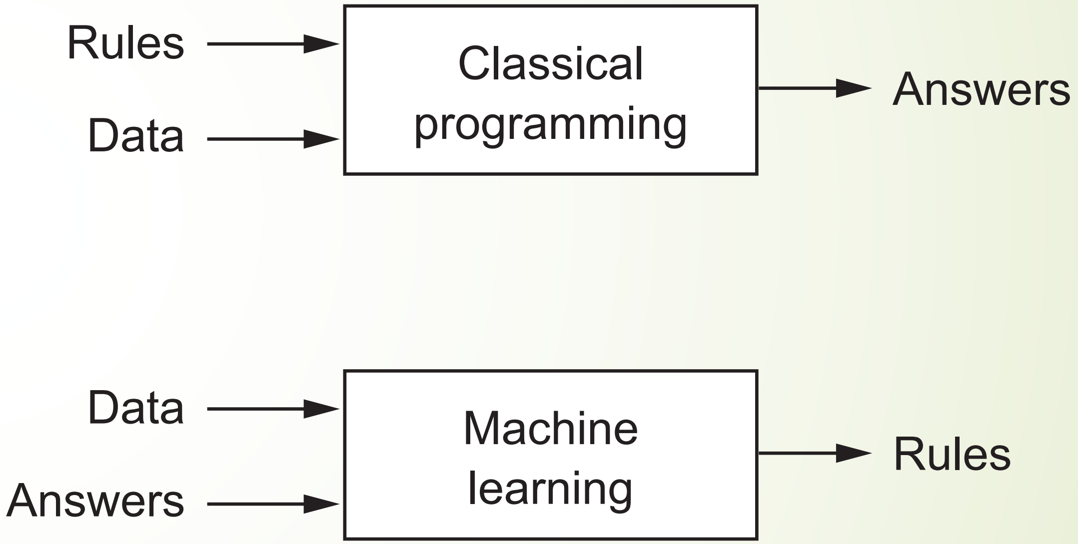


"In the first wave of AI you had to be a programmer. In the second wave of AI you have to be a data scientist. The third wave of AI—the more moral you are, the better."

Source: Dr. Lee Kai-Fu • Sinovation Ventures and 2018 Conference on Neural Information Processing Systems

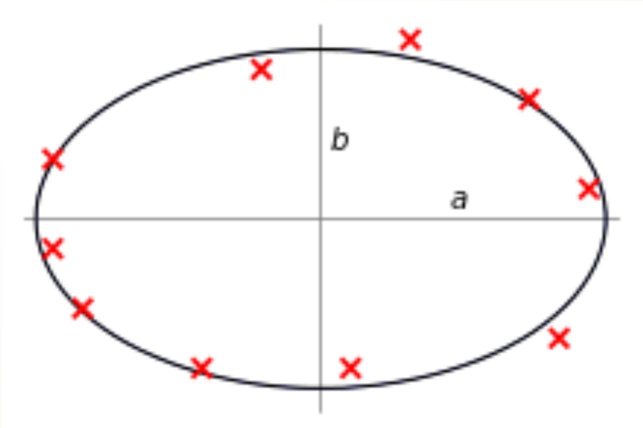
Statistical Machine Learning is a new paradigm of computer programming

- During 1950s-1980s, two competitive ideas of realizing AI exist
  - Rule based inference, or called **Expert System**
  - Statistics based inference, or called **Machine Learning**
- 1990s- Machine Learning becomes dominant



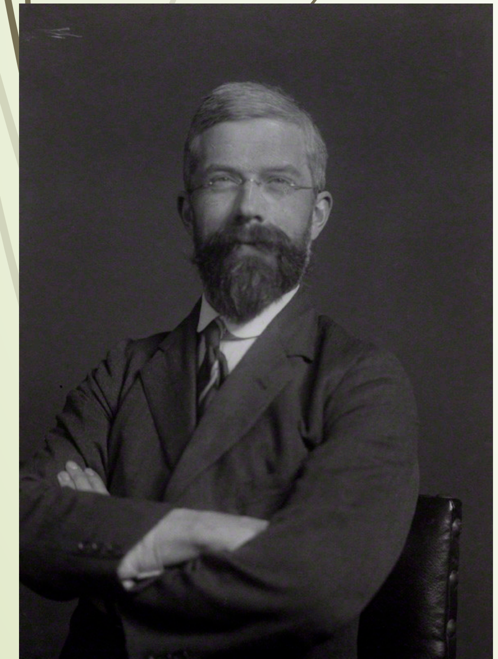
The 1st machine learning method: Least Squares

- Invention:
  - **Carl Friederich Gauss** (~1795/1809/1810),
  - Adrien-Marie Legendre (1805)
  - Robert Adrain (1808)
- Application:
  - Prediction of the location of asteroid Ceres after it emerged from behind the sun (Franz Xaver von Zach 1801)
  - Orbits of planets, Newton Laws
  - Statistics,
  - …



Fisher's Maximum Likelihood Principle (1912-1922)

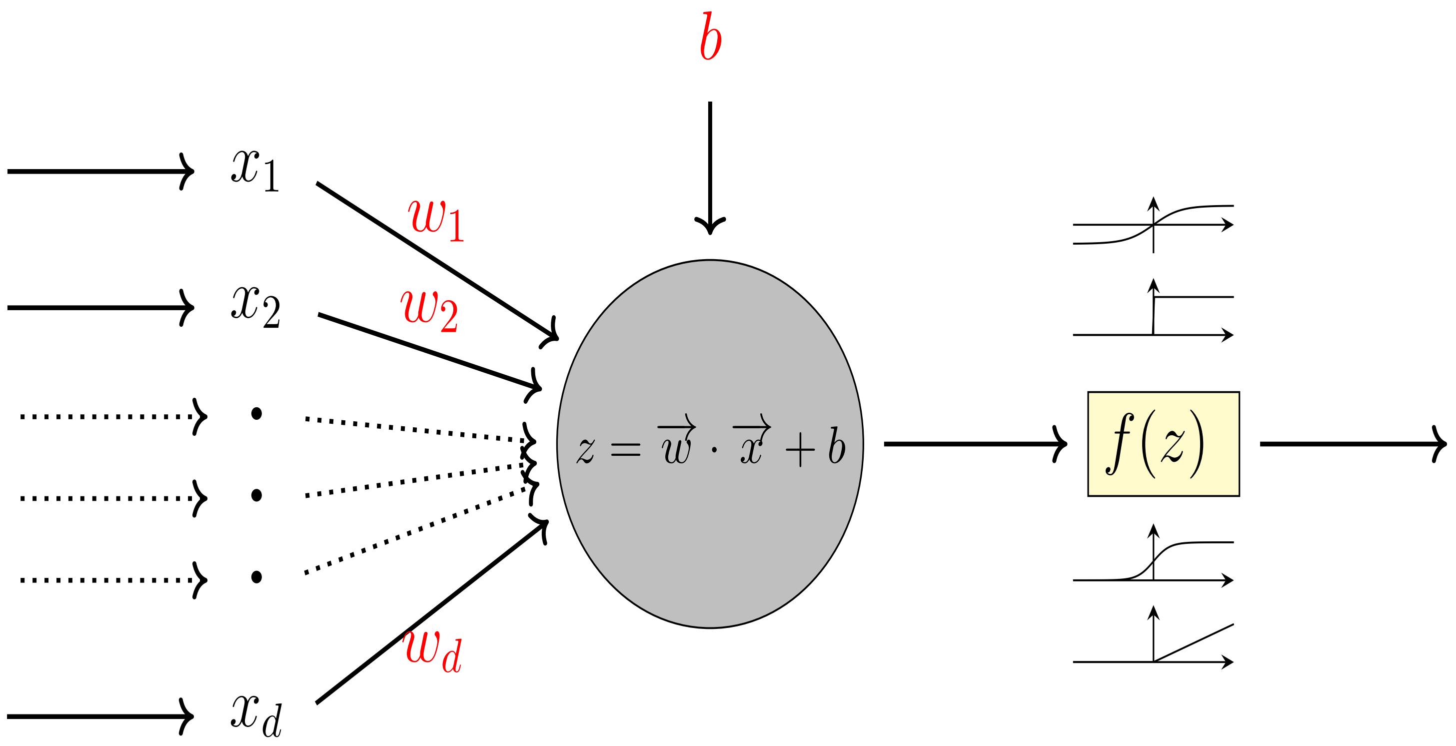
- **The least square method is the maximum likelihood estimate** (most probable values of the unknown parameters) when the noise is Gaussian.



- Fisher, R. A. (1912) **On an absolute criterion for fitting frequency curves**. *Messenger of Mathematics* 41:155-160.
- Fisher, R. A. (1922). **On the mathematical foundations of theoretical statistics**. *Philos. Trans. Roy. Soc. London Ser. A* 222:309-368.
- Aldrich, John (1997). **R. A. Fisher and the Making of Maximum Likelihood 1912 -- 1922**. *Statistical Science*, 12(3):162-176.

The 1st neural network: Perceptron

- Invented by Frank Rosenblatt (1957)



The Perceptron Algorithm for classification

$$\ell(w) = -\sum_{i \in \mathcal{M}_w} y_i \langle w, \mathbf{x}_i \rangle, \quad \mathcal{M}_w = \{i : y_i \langle \mathbf{x}_i, w \rangle < 0, y_i \in \{-1, 1\}\}.$$

The Perceptron Algorithm is a *Stochastic Gradient Descent* method (**Robbins-Monro 1951**, *Ann. Math. Statist*. 22(3): 400-407):

$$\begin{aligned} w_{t+1} &= w_t - \eta_t \nabla_i \ell(w) \\ &= \begin{cases} w_t - \eta_t y_i \mathbf{x}_i, & \text{if } y_i w_t^T \mathbf{x}_i < 0, \\ w_t, & \text{otherwise.} \end{cases} \end{aligned}$$

Finiteness of Stopping Time and Margin

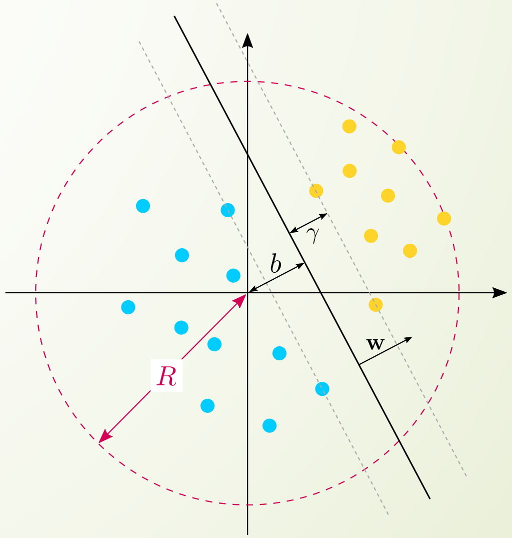
The perceptron convergence theorem was proved by Block (1962) and Novikoff (1962). The following version is based on that in Cristianini and Shawe-Taylor (2000).

Theorem 1 (Block, Novikoff). *Let the training set $S = \{(\mathbf{x}_1, t_1), \ldots, (\mathbf{x}_n, t_n)\}$ be contained in a sphere of radius R about the origin. Assume the dataset to be linearly separable, and let $\mathbf{w}_{\text{opt}}$, $\|\mathbf{w}_{\text{opt}}\| = 1$, define the hyperplane separating the samples, having functional margin $\gamma > 0$. We initialise the normal vector as $\mathbf{w}_0 = \mathbf{0}$. The number of updates, k, of the perceptron algorithms is then bounded by*

$$k \leq \left(\frac{2R}{\gamma}\right)^2 . \tag{10}$$

Input ball: $R = \max_i \|\mathbf{x}_i\|.$

Margin: $\gamma := \min_i y_i f(x_i)$



Hilbert's 13th Problem

Algebraic equations (under a suitable transformation) of degree up to 6 can be solved by functions of two variables. What about

$$x^7 + ax^3 + bx^2 + cx + 1 = 0?$$

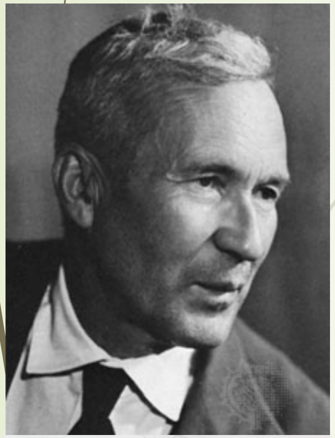
Hilbert's conjecture: $x(a, b, c)$ cannot be expressed by a superposition (sums and compositions) of bivariate functions.

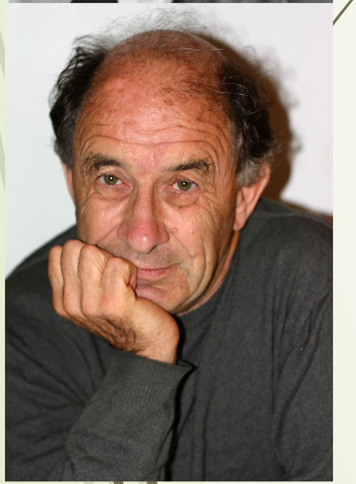
Question: can every continuous (analytic, C^∞, etc) function of n variables be represented as a superposition of continuous (analytic, C^∞, etc) functions of $n-1$ variables?

Theorem (D. Hilbert)

There is an analytic function of three variables that cannot be expressed as a superposition of bivariate ones.

Kolmogorov's Superposition Theorem





Theorem (A. Kolmogorov, 1956; V. Arnold, 1957)

Given $n \in \mathbb{Z}^+$, *every* $f_0 \in C([0,1]^n)$ *can be reprensented as*

$$f_0(x_1, x_2, \cdots, x_n) = \sum_{q=1}^{2n+1} g_q\left(\sum_{p=1}^{n} \phi_{pq}(x_p)\right),$$

where $\phi_{pq} \in C[0,1]$ *are increasing functions independent of* f_0 *and* $g_q \in C[0,1]$ *depend on* f_0.

- Can choose g_q to be all the same $g_q \equiv g$ (Lorentz, 1966).
- Can choose ϕ_{pq} to be Hölder or Lipschitz continuous, but not C^1 (Fridman, 1967).
- Can choose $\phi_{pq} = \lambda_p \phi_q$ where $\lambda_1, \cdots, \lambda_n > 0$ and $\sum_p \lambda_p = 1$ (Sprecher, 1972).

If *f* is a multivariate continuous function, then *f* can be written as a superposition of composite functions of mixtures of continuous functions of single variables:
finite **composition** of continuous functions of a **single variable** and the **addition**.

Kolmogorov's Exact Representation is not stable or smooth

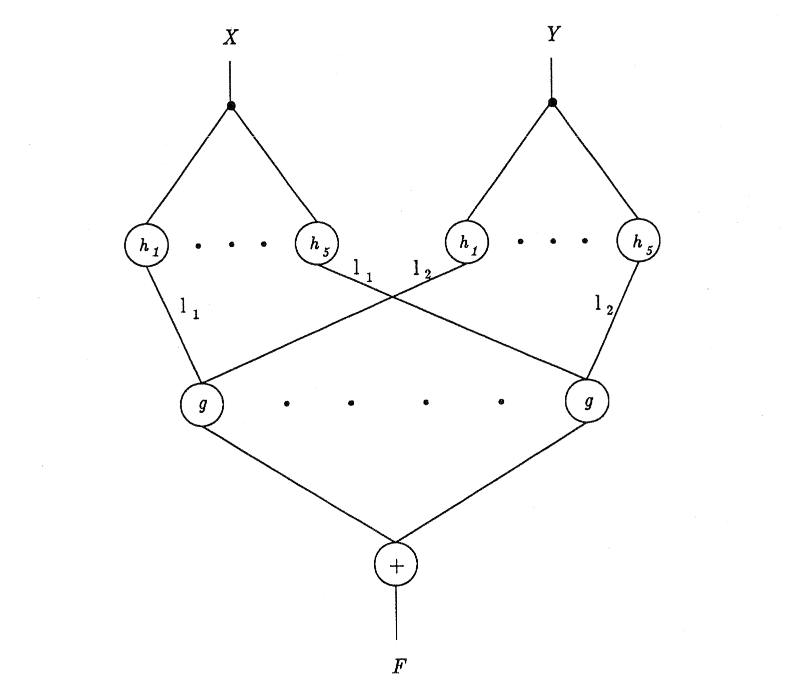


Figure 1: The network representation of an improved version of Kolmogorov's theorem, due to Kahane (1975). The figure shows the case of a bivariate function. The Kahane's representation formula is $f(x_1, \ldots, x_n) = \sum_{q=1}^{2n+1} g[\sum_{p=1}^{n} l_p h_q(x_p)]$ where h_q are strictly monotonic functions and l_p are strictly positive constants smaller than 1.

- [Girosi-Poggio'1989] Representation Properties of Networks: Kolmogorov's Theorem Is Irrelevant, https://www.mitpressjournals.org/doi/pdf/10.1162/neco.1989.1.4.465
- Lacking smoothness in *h* and *g* [Vitushkin'1964] fails to guarantee the **generalization ability (stability)** against noise and perturbations
- The representation is **not universal** in the sense that *g* and *h* both depend on the function F to be represented.

Universal Approximate Representation

[Cybenko'1989, Hornik et al. 1989, Poggio-Girosi'1989, ...]

For continuous $f : [0,1]^N \to \mathbb{R}$ and $\varepsilon > 0$ there exists

$$
\begin{aligned}
F(x) &= \alpha^\top \sigma(Wx + \beta) \\
&= \sum_i \alpha_i \sigma\left(\sum_j W_{i,j}\, x_j + \beta_i\right)
\end{aligned}
$$

such that for all x in $[0,1]^N$ we have $|F(x) - f(x)| < \varepsilon$.

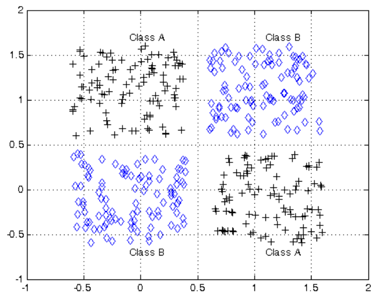
Complexity (regularity, smoothness) thereafter becomes the central pursuit in Approximation Theory.

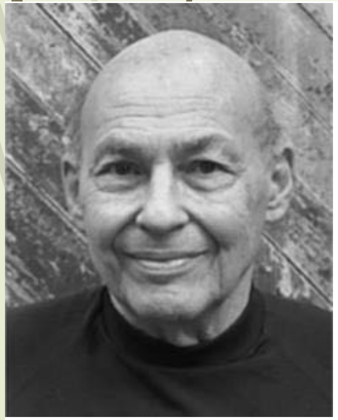
Locality or Sparsity of Computation

Minsky and Papert, 1969

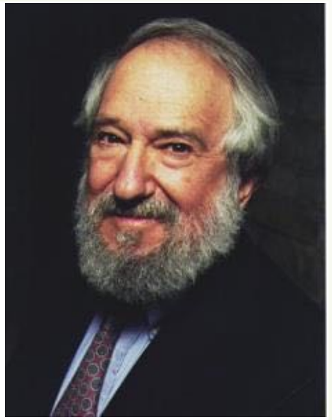
Perceptron can't do **XOR** classification

Perceptron needs infinite global information to compute **connectivity**





Marvin Minsky

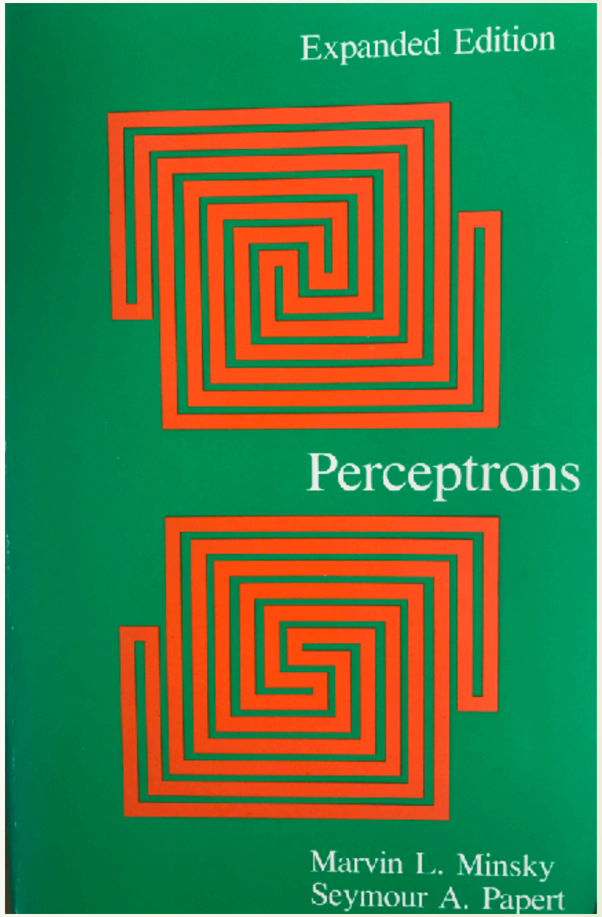


Seymour Papert

Locality or **Sparsity** is important:

Locality in time?

Locality in space?

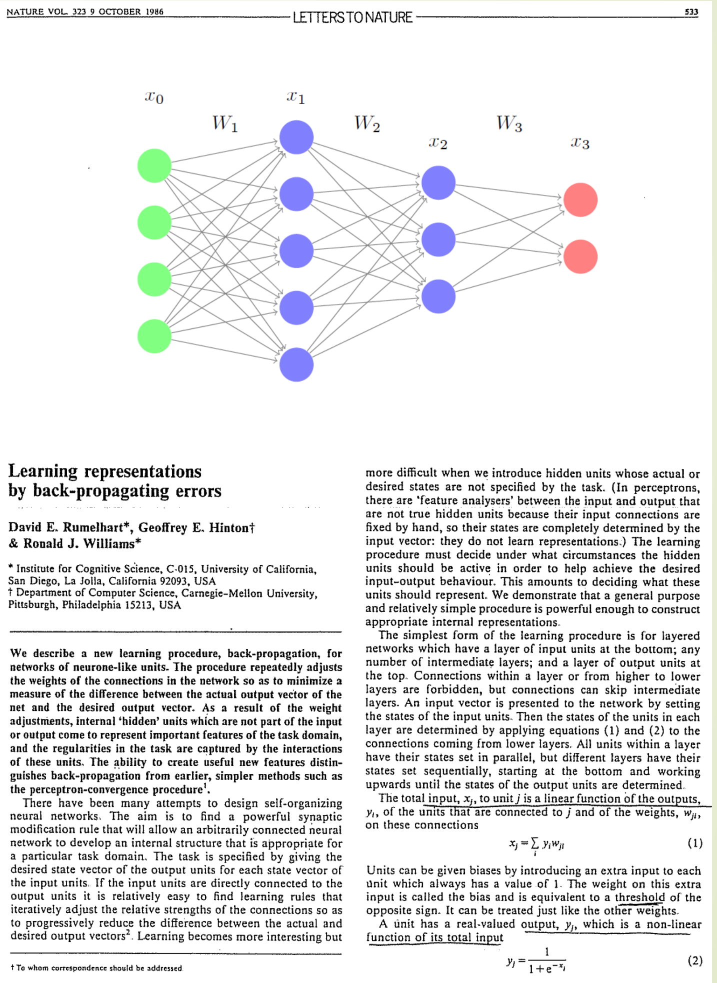


Multilayer Perceptrons (MLP) and Back-Propagation (BP) Algorithms

D.E. Rumelhart, G. Hinton, R.J. Williams (1986)
Learning representations by back-propagating errors, Nature, 323(9): 533-536

BP algorithms as **stochastic gradient descent** algorithms (**Robbins–Monro 1950; Kiefer-Wolfowitz 1951**) with Chain rules of Gradient maps

Deep network may classify **XOR**. Yet **topology**?



NATURE VOL. 323 9 OCTOBER 1986 — LETTERS TO NATURE — 533

Learning representations by back-propagating errors

David E. Rumelhart*, Geoffrey E. Hinton† & Ronald J. Williams*

* Institute for Cognitive Science, C-015, University of California, San Diego, La Jolla, California 92093, USA
† Department of Computer Science, Carnegie-Mellon University, Pittsburgh, Philadelphia 15213, USA

We describe a new learning procedure, back-propagation, for networks of neurone-like units. The procedure repeatedly adjusts the weights of the connections in the network so as to minimize a measure of the difference between the actual output vector of the net and the desired output vector. As a result of the weight adjustments, internal 'hidden' units which are not part of the input or output come to represent important features of the task domain, and the regularities in the task are captured by the interactions of these units. The ability to create useful new features distinguishes back-propagation from earlier, simpler methods such as the perceptron-convergence procedure[1].

There have been many attempts to design self-organizing neural networks. The aim is to find a powerful synaptic modification rule that will allow an arbitrarily connected neural network to develop an internal structure that is appropriate for a particular task domain. The task is specified by giving the desired state vector of the output units for each state vector of the input units. If the input units are directly connected to the output units it is relatively easy to find learning rules that iteratively adjust the relative strengths of the connections so as to progressively reduce the difference between the actual and desired output vectors[2]. Learning becomes more interesting but more difficult when we introduce hidden units whose actual or desired states are not specified by the task. (In perceptrons, there are 'feature analysers' between the input and output that are not true hidden units because their input connections are fixed by hand, so their states are completely determined by the input vector: they do not learn representations.) The learning procedure must decide under what circumstances the hidden units should be active in order to help achieve the desired input–output behaviour. This amounts to deciding what these units should represent. We demonstrate that a general purpose and relatively simple procedure is powerful enough to construct appropriate internal representations.

The simplest form of the learning procedure is for layered networks which have a layer of input units at the bottom; any number of intermediate layers; and a layer of output units at the top. Connections within a layer or from higher to lower layers are forbidden, but connections can skip intermediate layers. An input vector is presented to the network by setting the states of the input units. Then the states of the units in each layer are determined by applying equations (1) and (2) to the connections coming from lower layers. All units within a layer have their states set in parallel, but different layers have their states set sequentially, starting at the bottom and working upwards until the states of the output units are determined.

The total input, x_j, to unit j is a linear function of the outputs, y_i, of the units that are connected to j and of the weights, w_{ji}, on these connections

$$x_j = \sum_i y_i w_{ji} \qquad (1)$$

Units can be given biases by introducing an extra input to each unit which always has a value of 1. The weight on this extra input is called the bias and is equivalent to a threshold of the opposite sign. It can be treated just like the other weights.

A unit has a real-valued output, y_j, which is a non-linear function of its total input

$$y_j = \frac{1}{1+e^{-x_j}} \qquad (2)$$

† To whom correspondence should be addressed

We address complexity and geometric invariant properties first.

Parallel Distributed Processing

by Rumelhart and McClelland, 1986

Minsky and Papert set out to show which functions can and cannot be computed by this class of machines. They demonstrated, in particular, that such perceptrons are unable to calculate such mathematical functions as parity (whether an odd or even number of points are on in the retina) or the topological function of connectedness (whether all points that are on are connected to all other points that are on either directly or via other points that are also on) without making use of absurdly large numbers of predicates. The analysis is extremely elegant and demonstrates the importance of a mathematical approach to analyz-

of multilayer networks that compute parity). Similarly, it is not difficult to develop networks capable of solving the connectedness or inside/outside problem. Hinton and Sejnowski have analyzed a version of such a network (see Chapter 7).

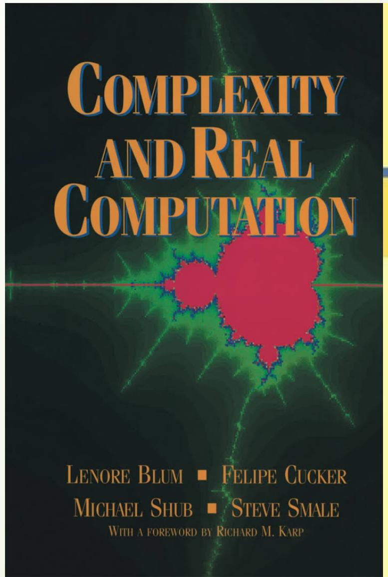
Essentially, then, although Minsky and Papert were exactly correct in their analysis of the *one-layer perceptron,* the theorems don't apply to systems which are even a little more complex. In particular, it doesn't apply to multilayer systems nor to systems that allow feedback loops.

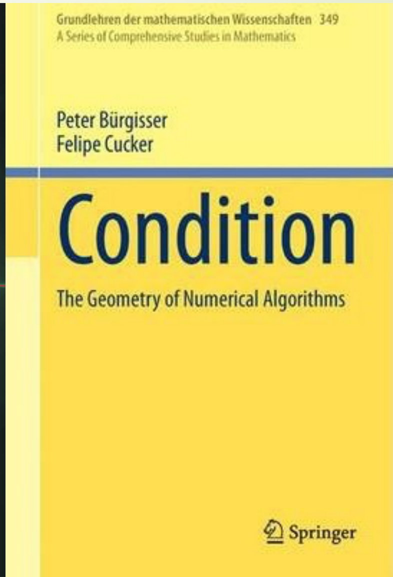
Topology can be learned with finite information if the manifold is *stable*

Blum-Shub-Smale models of Real Computation

A Model of Real Computation

- Starting from **Blum, Shub, Smale** (1989)
- It admits inputs and operations (addition, substraction, multiplication, and (in the case of fields) division) of **real (complex) numbers** with *infinite precision*
- “The key importance of the **condition number**, which measures the closeness of a problem instance to the manifold of ill-posed instances, is clearly developed.” – Richard Karp





The Condition Number of a Manifold

Throughout our discussion, we associate to $\mathcal{M}$ a condition number $(1/\tau)$ where τ is defined as the largest number having the property: The open normal bundle about $\mathcal{M}$ of radius r is embedded in $\mathbb{R}^N$ for every $r < \tau$. Its image Tub_τ is a tubular neighborhood of $\mathcal{M}$ with its canonical projection map

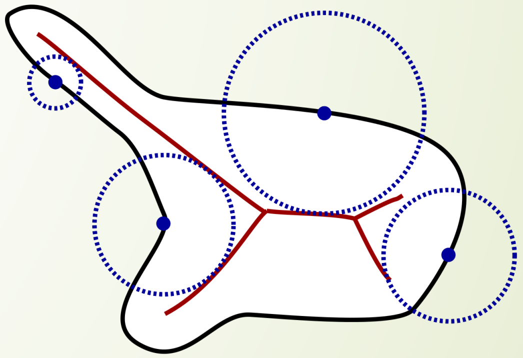
$$\pi_0 : \mathrm{Tub}_\tau \to \mathcal{M}.$$

Smallest Local Feature Size

$$G = \left\{x \in \mathbb{R}^N \text{ such that } \exists \text{ distinct } p, q \in \mathcal{M} \text{ where } d(x, \mathcal{M}) = \|x - p\| = \|x - q\|\right\},$$

where $d(x, \mathcal{M}) = \inf_{y \in \mathcal{M}} \|x - y\|$ is the distance of x to $\mathcal{M}$. The closure of G is called the medial axis and for any point $p \in \mathcal{M}$ the local feature size $\sigma(p)$ is the distance of p to the medial axis. Then it is easy to check that

$$\tau = \inf_{p \in \mathcal{M}} \sigma(p).$$



Find Homology with Finite Samples

[Niyogi, Smale, Weinberger (2008)]

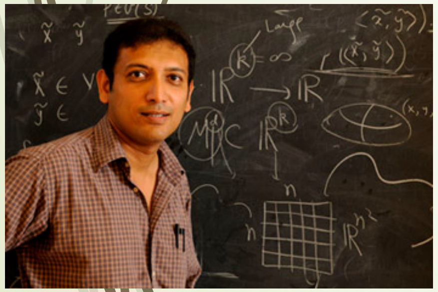
Theorem 3.1 *Let $\mathcal{M}$ be a compact submanifold of $\mathbb{R}^N$ with condition number τ. Let $\bar{x} = \{x_1, \ldots, x_n\}$ be a set of n points drawn in i.i.d. fashion according to the uniform probability measure on $\mathcal{M}$. Let $0 < \epsilon < \tau/2$. Let $U = \bigcup_{x \in \bar{x}} B_\epsilon(x)$ be a correspondingly random open subset of $\mathbb{R}^N$. Then for all*

$$n > \beta_1 \left(\log(\beta_2) + \log\left(\frac{1}{\delta}\right) \right),$$

the homology of U equals the homology of $\mathcal{M}$ with high confidence (probability $>1 - \delta$).

$$\beta_1 = \frac{vol(\mathcal{M})}{(\cos^k(\theta_1))vol(B^k_{\epsilon/4})} \quad and \quad \beta_2 = \frac{vol(\mathcal{M})}{(\cos^k(\theta_2))vol(B^k_{\epsilon/8})}.$$

Here k is the dimension of the manifold $\mathcal{M}$ and $vol(B^k_\epsilon)$ denotes the k-dimensional volume of the standard k-dimensional ball of radius ϵ. Finally, $\theta_1 = \arcsin(\epsilon/8\tau)$ and $\theta_2 = \arcsin(\epsilon/16\tau)$.



Partha Niyogi@Chiccago, 1967-2010

Convolutional Neural Networks: shift invariances and locality

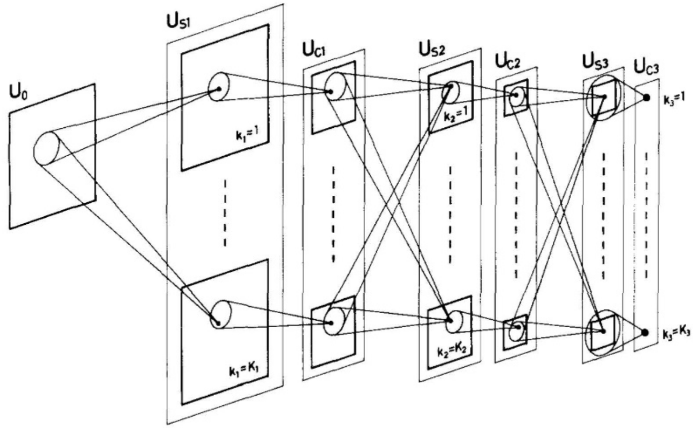
- Can be traced to *Neocognitron* of Kunihiko Fukushima (1979)
- Yann LeCun combined convolutional neural networks with back propagation (1989)
- Imposes **shift invariance** and **locality** on the weights
- Forward pass remains similar
- Backpropagation slightly changes – need to sum over the gradients from all spatial positions

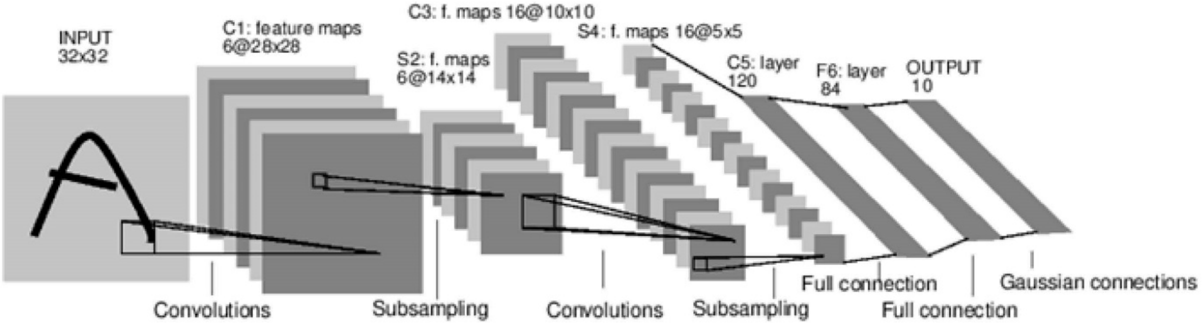
Biol. Cybernetics 36, 193–202 (1980)

Neocognitron: A Self-organizing Neural Network Model for a Mechanism of Pattern Recognition Unaffected by Shift in Position

Kunihiko Fukushima

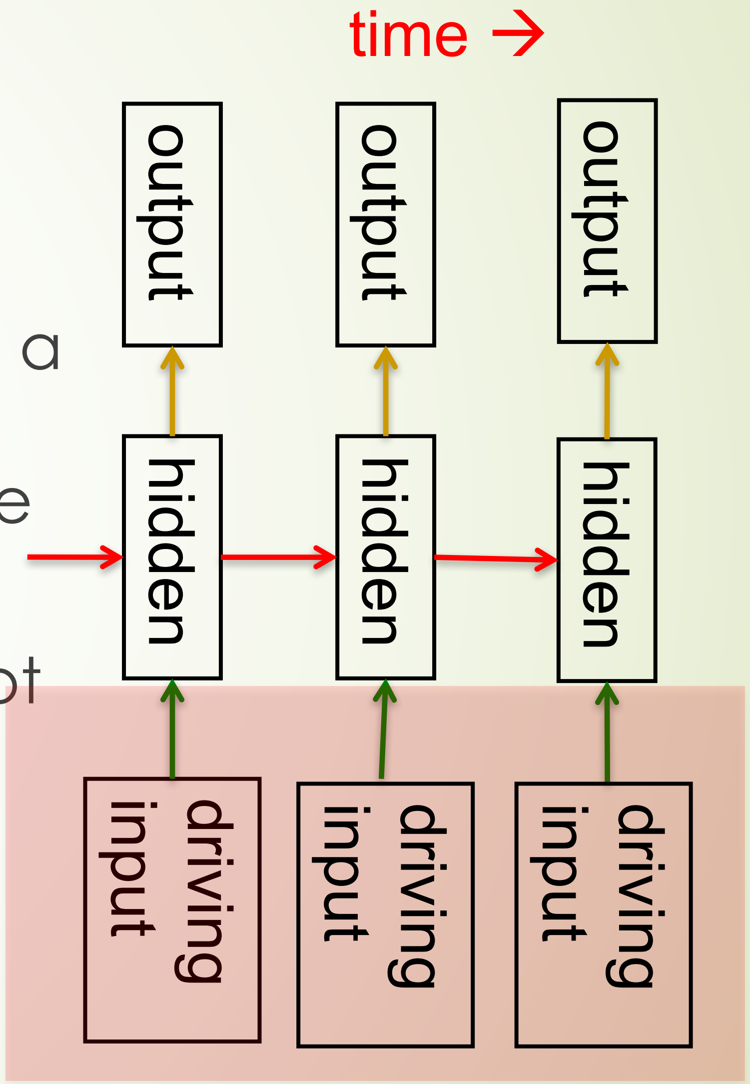
NHK Broadcasting Science Research Laboratories, Kinuta, Setagaya, Tokyo, Japan





Time series: Linear Dynamical Systems (1940s-)

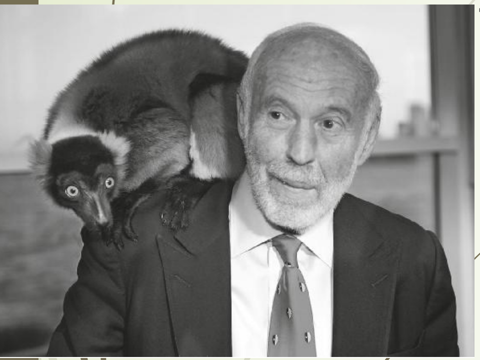
- The hidden state has linear dynamics with Gaussian noise and produces the observations using a linear model with Gaussian noise.
- Kalman Filter: A linearly transformed Gaussian is a Gaussian. So the distribution over the hidden state given the data so far is Gaussian. It can be computed using "Kalman filtering".
- To predict the next output (so that we can shoot down the missile) we need to infer the hidden state.



$$h_t = W_{hh} h_{t-1} + W_{hx} x_t + \epsilon_t^h$$

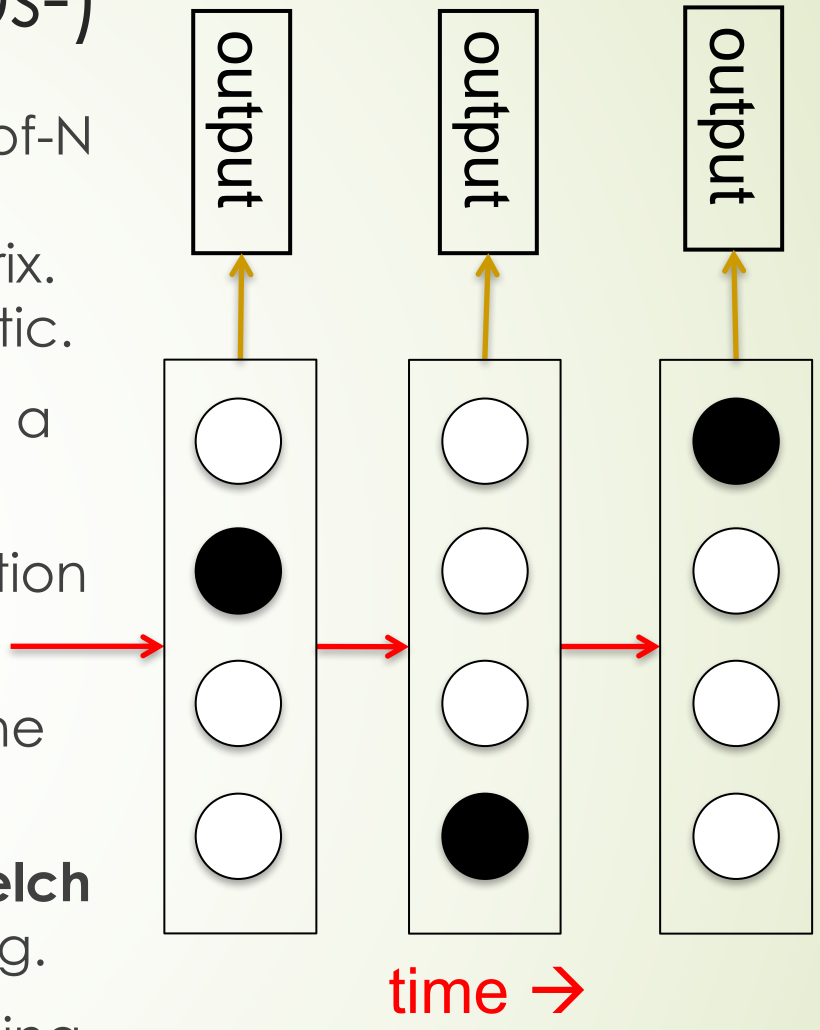
$$y_t = W_{yh} h_t + W_{yx} x_t + \epsilon_t^y$$

Hidden Markov Models (1970s-)



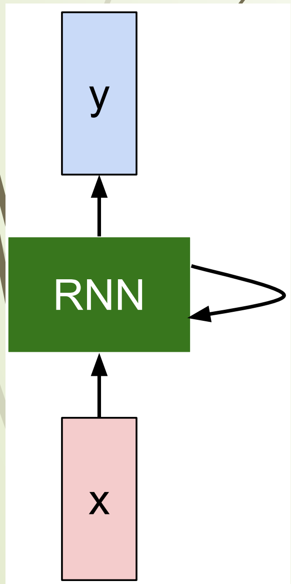
- Hidden Markov Models have a discrete one-of-N hidden state. Transitions between states are stochastic and controlled by a transition matrix. The outputs produced by a state are stochastic.
  - We cannot be sure which state produced a given output. So the state is “hidden”.
  - It is easy to represent a probability distribution across N states with N numbers.
- To predict the next output we need to infer the probability distribution over hidden states.
  - HMMs have efficient algorithms (**Baum-Welch or EM Algorithm**) for inference and learning.
  - **Jim Simons** hires Lenny Baum as the founding member of Renaissance Technologies in 1979

Lenny Baum became a devoted Go player despite his deteriorating eyesight.



Recurrent Neural Networks (1986-)

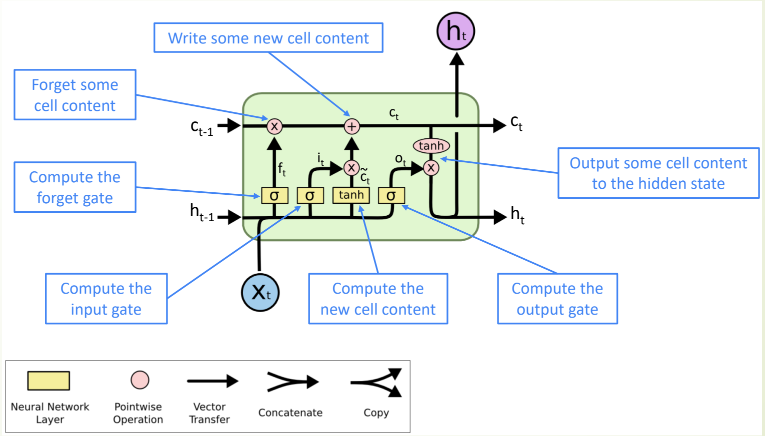
- **The issue of a hidden Markov model (HMM)**:
  - At each time step it must select one of its hidden states. So with N hidden states it can only remember log(N) bits about what it generated so far.
- RNNs are very powerful, because they combine two properties:
  - Distributed hidden state that allows them to store a lot of information about the past efficiently.
  - Non-linear dynamics that allows them to update their hidden state in complicated ways.
- Rumelhart et al. enables training by **BP** algorithm
  - With enough neurons and time, RNNs can compute anything that can be computed by your computer.



$$h_t = \sigma_h(W_{hh}h_{t-1} + W_{hx}x_t)$$
$$y_t = \sigma_y(W_{yh}h_t)$$

Long-Short-Term-Memory (LSTM)

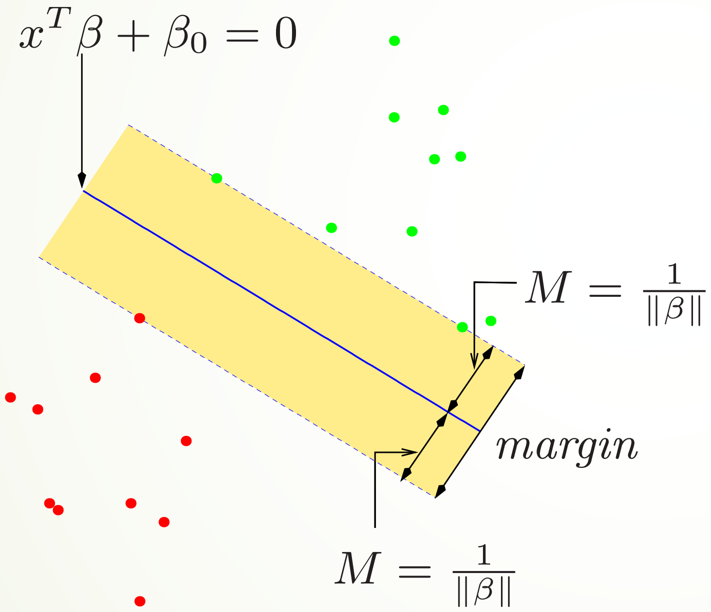
- Sepp Hochreiter; Jürgen Schmidhuber (1997). "Long short-term memory". *Neural Computation*. **9** (8): 1735–1780. (https://www.bioinf.jku.at/publications/older/2604.pdf)
- Introduction of short path to learn deep networks without vanishing gradient problem.

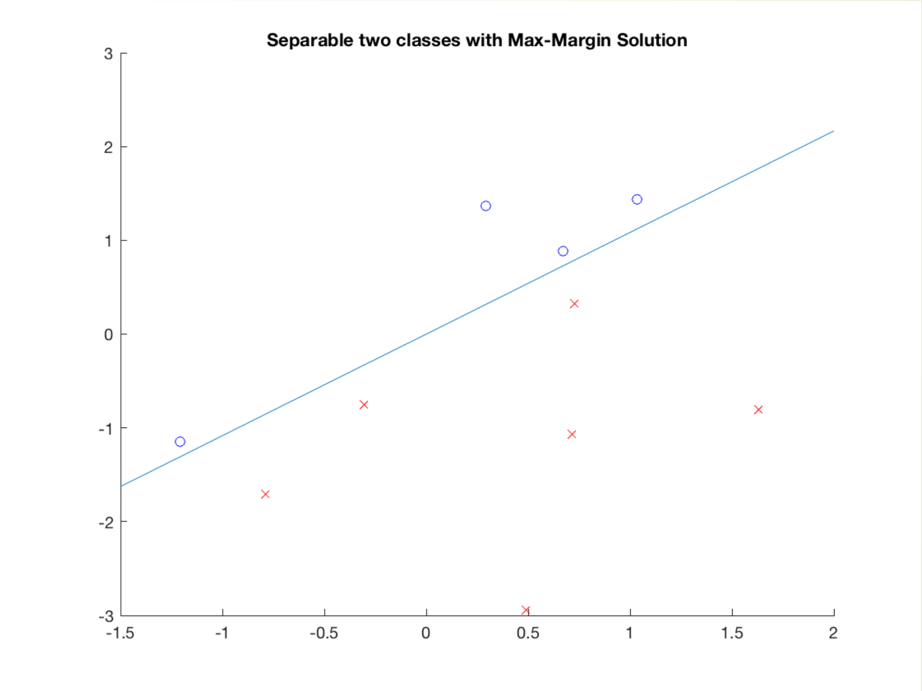


Max-Margin Classifier (SVM)

$$\text{minimize}_{\beta_0,\beta_1,\ldots,\beta_p} \|\beta\|^2 := \sum_j \beta_j^2$$

subject to $y_i(\beta_0 + \beta_1 x_{i1} + \ldots + \beta_p x_{ip}) \geq 1$ for all i





Vladmir Vapnik, 1994

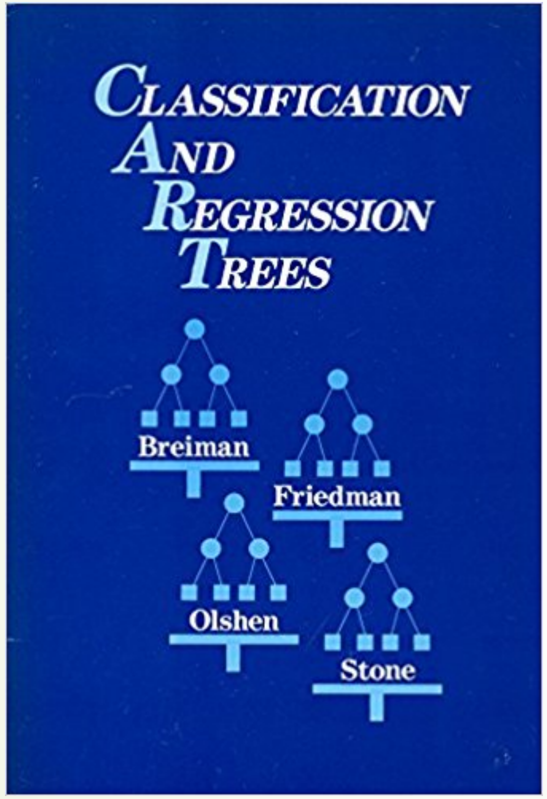
MNIST Dataset Test Error
LeCun et al. 1998

Simple SVM performs as well as Multilayer Convolutional Neural Networks which need careful tuning (LeNets)

Dark era for NN: 1998-2012

2000-2010: The Era of SVM, Boosting, … as nights of Neural Networks

Decision Trees and Boosting



- Breiman, Friedman, Olshen, Stone, (1983): CART
- ``The Boosting problem'' (M. Kearns & L. Valiant): **Can a set of weak learners create a single strong learner?** (三个臭皮匠顶个诸葛亮？)
- Breiman (1996): Bagging
- Freund, Schapire (1997): **AdaBoost** ("the best off-the-shelf algorithm" by Breiman)
- Breiman (2001): **Random Forests**

Restricted Boltzman Machine, 2006 (Deep Learning)

- **Hinton and Salakhutdinov,** Reducing the Dimensionality of Data with Neural Networks, ***Science*, 2006**
- Reinvigorating research in Deep Learning
- Shows importance of ***pretraining (greedy layer-wise, a.k.a. block coordinate descent)***

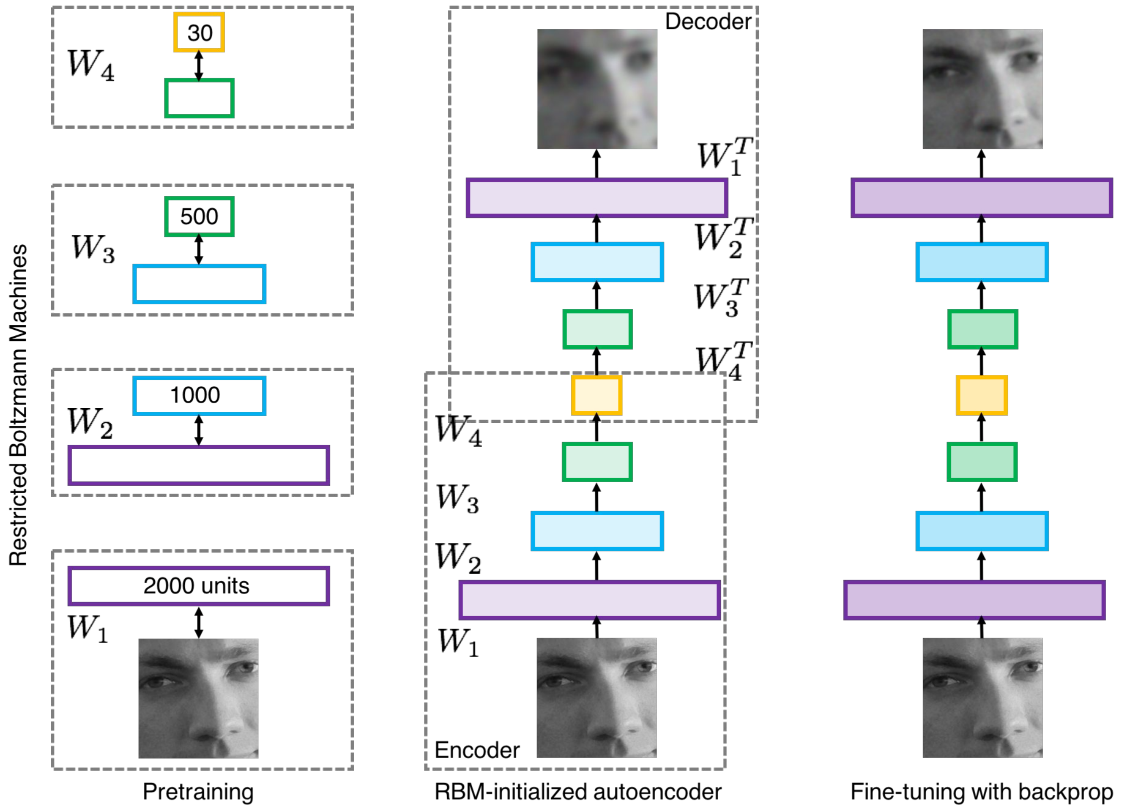
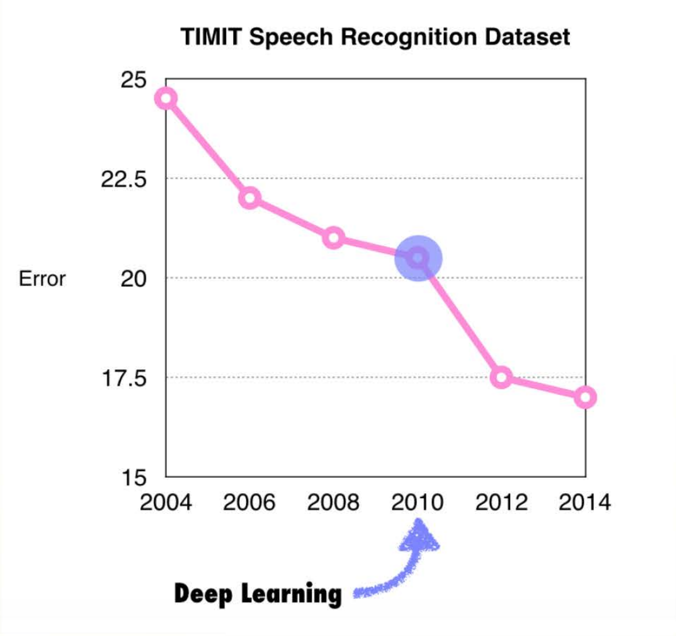


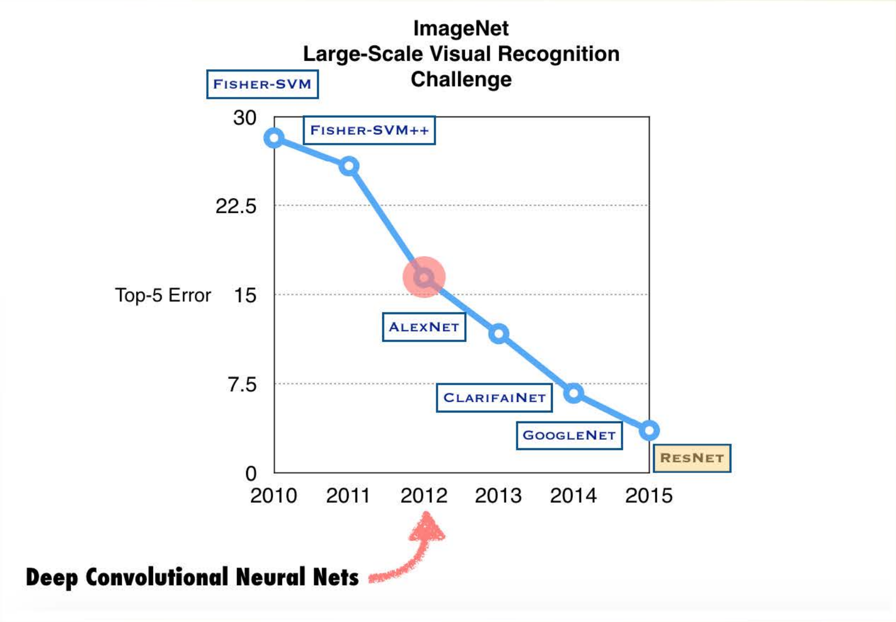
Illustration of Hinton and Salakhutdinov 2006 by Lane McIntosh, copyright CS231n 2017

Around the year of 2012: return of NN as `deep learning’

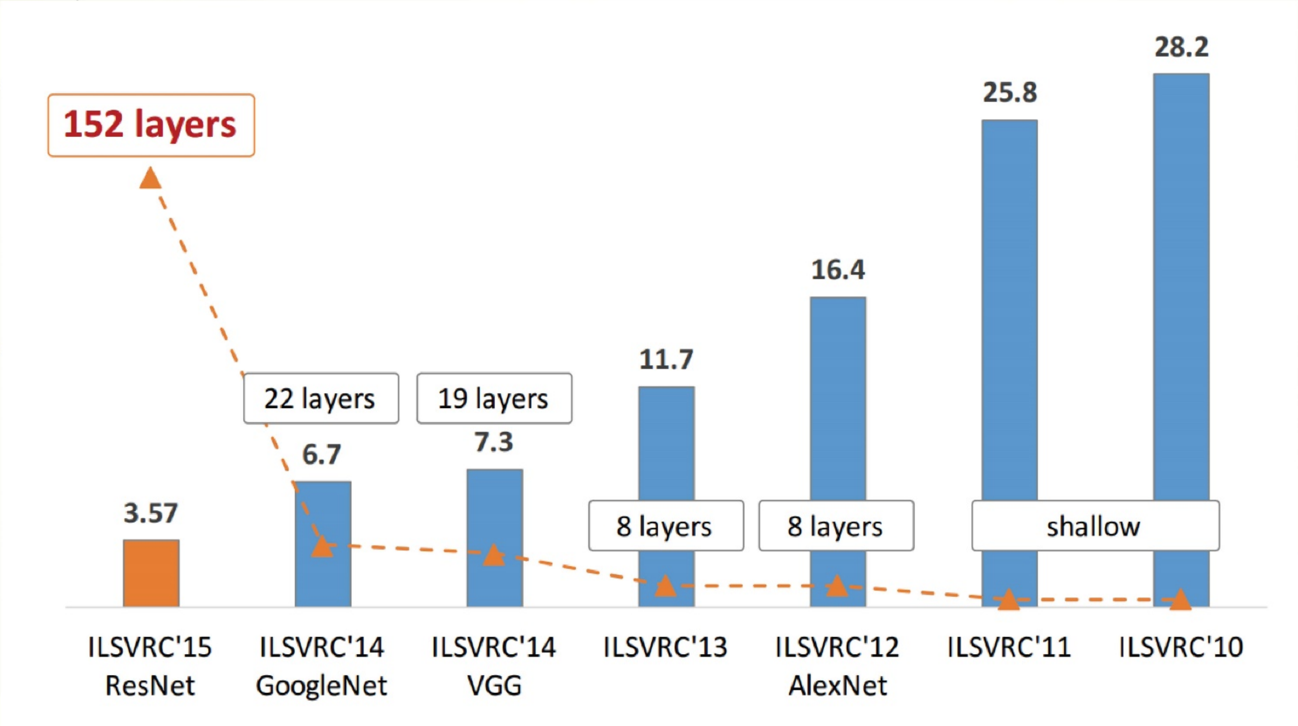
Speech Recognition: TIMIT



Computer Vision: ImageNet



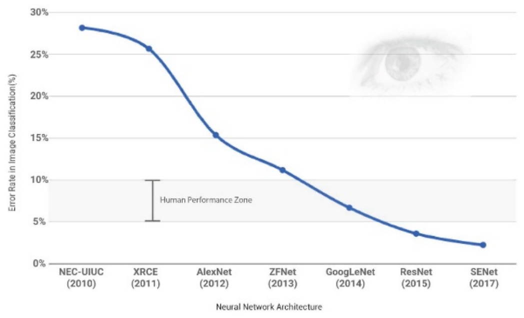
Depth as function of year



[He et al., 2016]

ILSVRC ImageNet Top 5 errors

- ImageNet (subset):
  - 1.2 million training images
  - 100,000 test images
  - 1000 classes
- ImageNet large-scale visual recognition Challenge

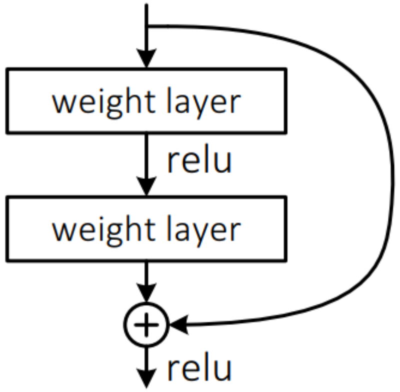


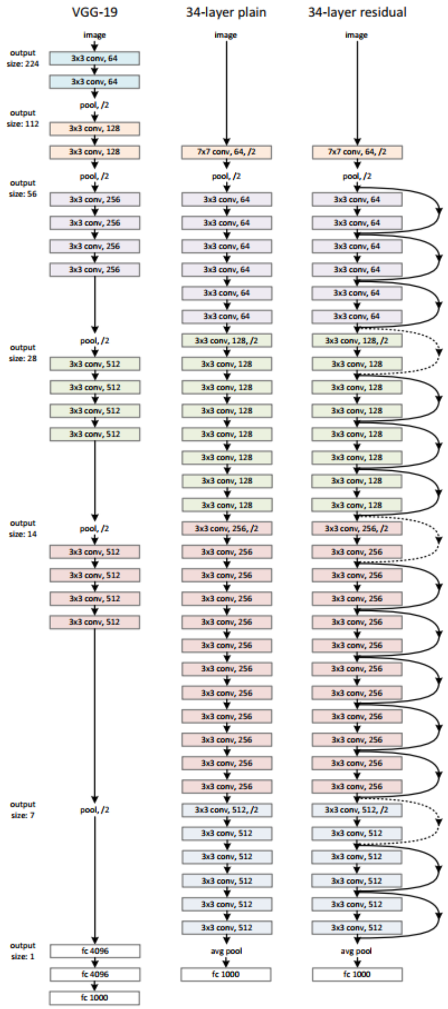
source: https://www.linkedin.com/pulse/must-read-path-breaking-papers-image-classification-muktabh-mayank

ResNet (2015)

[He-Zhang-Ren-Sun, 2015]

- Solves problem by adding skip connections
- Very deep: 152 layers
- No dropout
- Stride
- Batch normalization

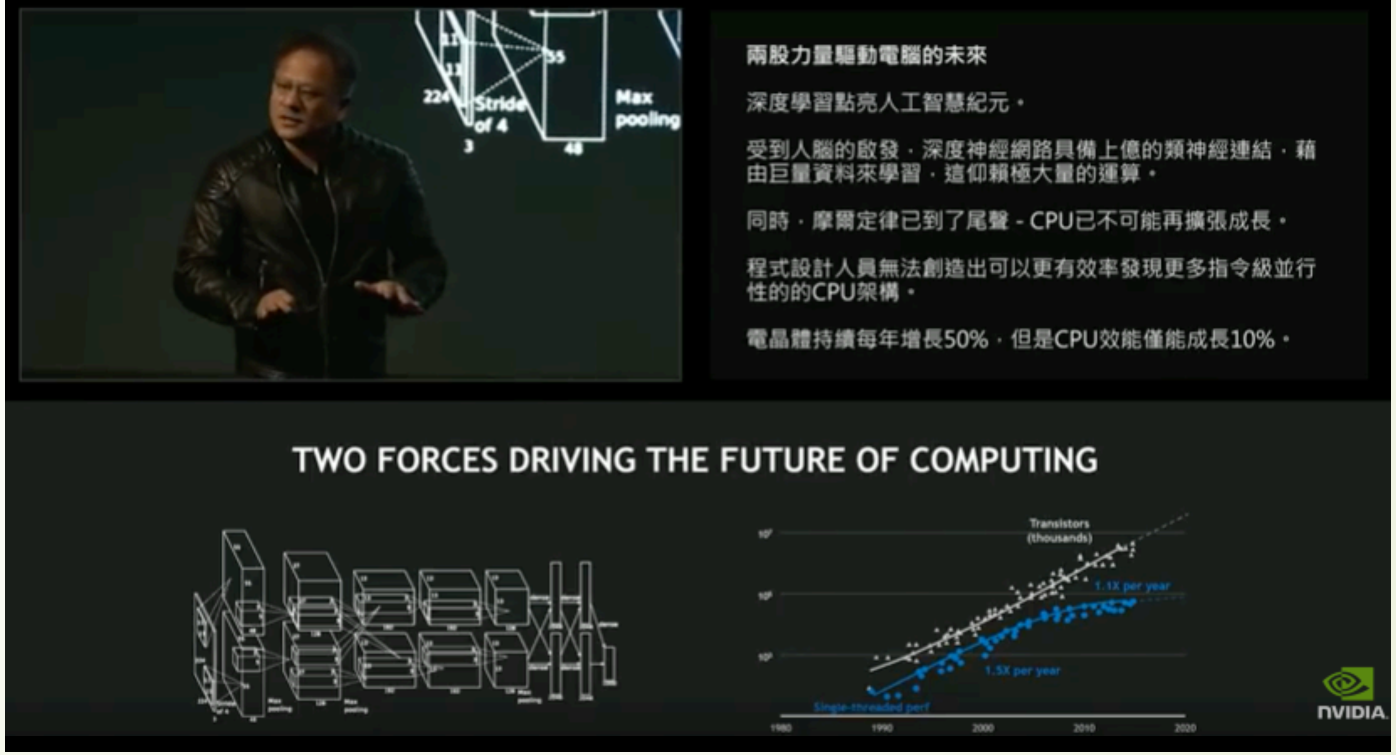




Source: Deep Residual Learning for Image Recognition

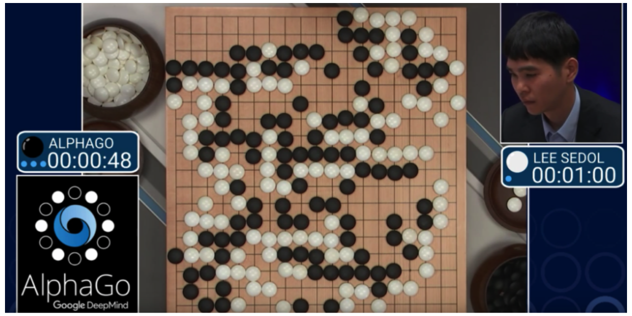
GPU + Big labeled data

"We're at the beginning of a new day…
This is the beginning of the AI revolution."
— Jensen Huang, GTC Taiwan 2017

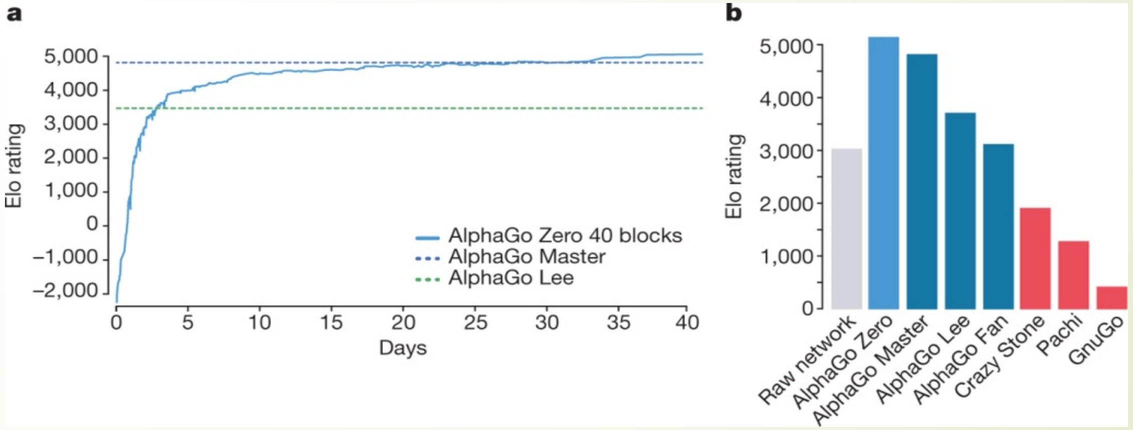


Reaching Human Performance Level in Games

Deep Blue in 1997



AlphaGo “LEE” 2016



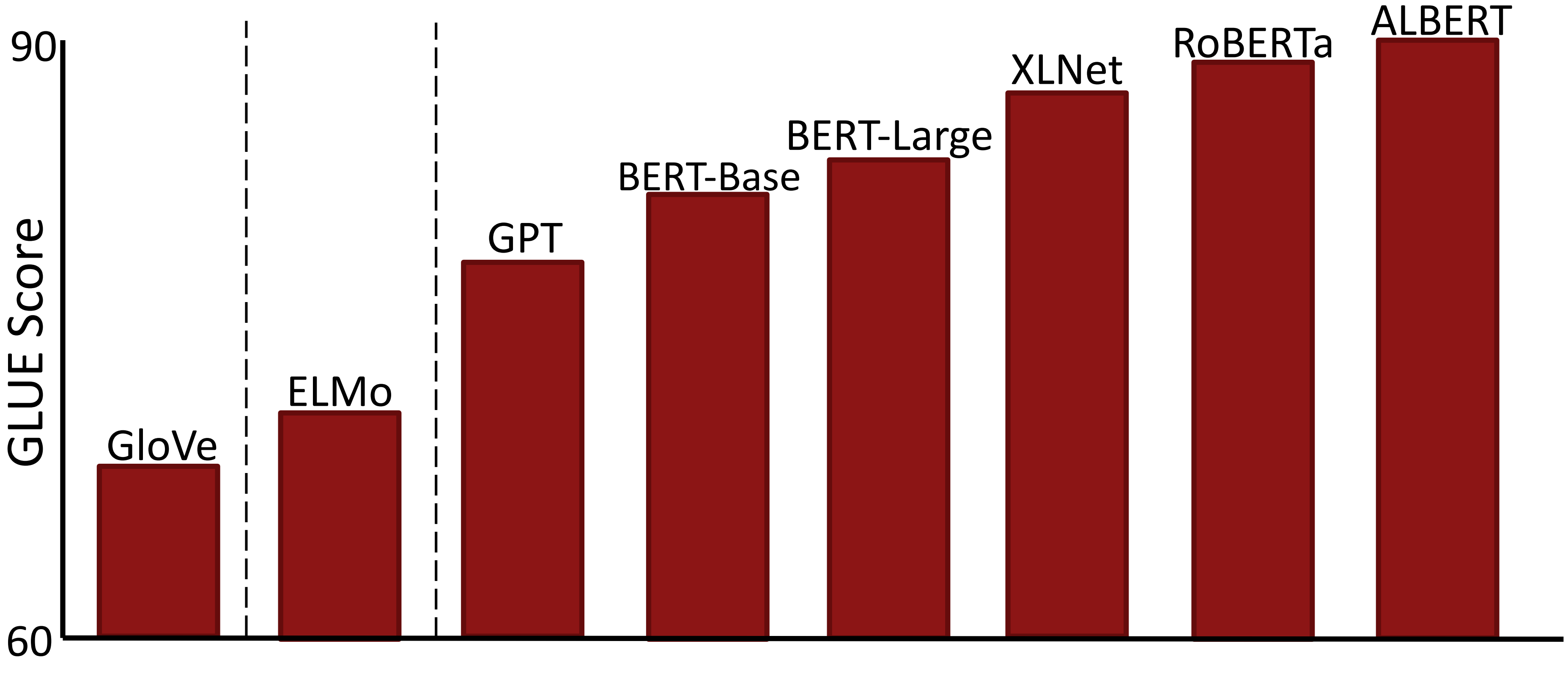
AlphaGo ”ZERO” D Silver *et al.* *Nature* **550,** 354–359 (2017) doi:10.1038/nature24270

Natural Language Processing (NLP) and Machine Translation

- In **2013-2015**, **LSTM**s started achieving state-of-the-art results
  - Successful tasks include: handwriting recognition, speech
  - recognition, machine translation, parsing, image captioning
  - LSTM became the dominant approach
- In **2019**, other approaches (e.g. **Transformers**) have become more dominant for certain tasks.
  - For example in **WMT** (a MT conference + competition):
  - In WMT 2016, the summary report contains "RNN" 44 times
  - In WMT 2018, the report contains "RNN" 9 times and "Transformer" 63 times

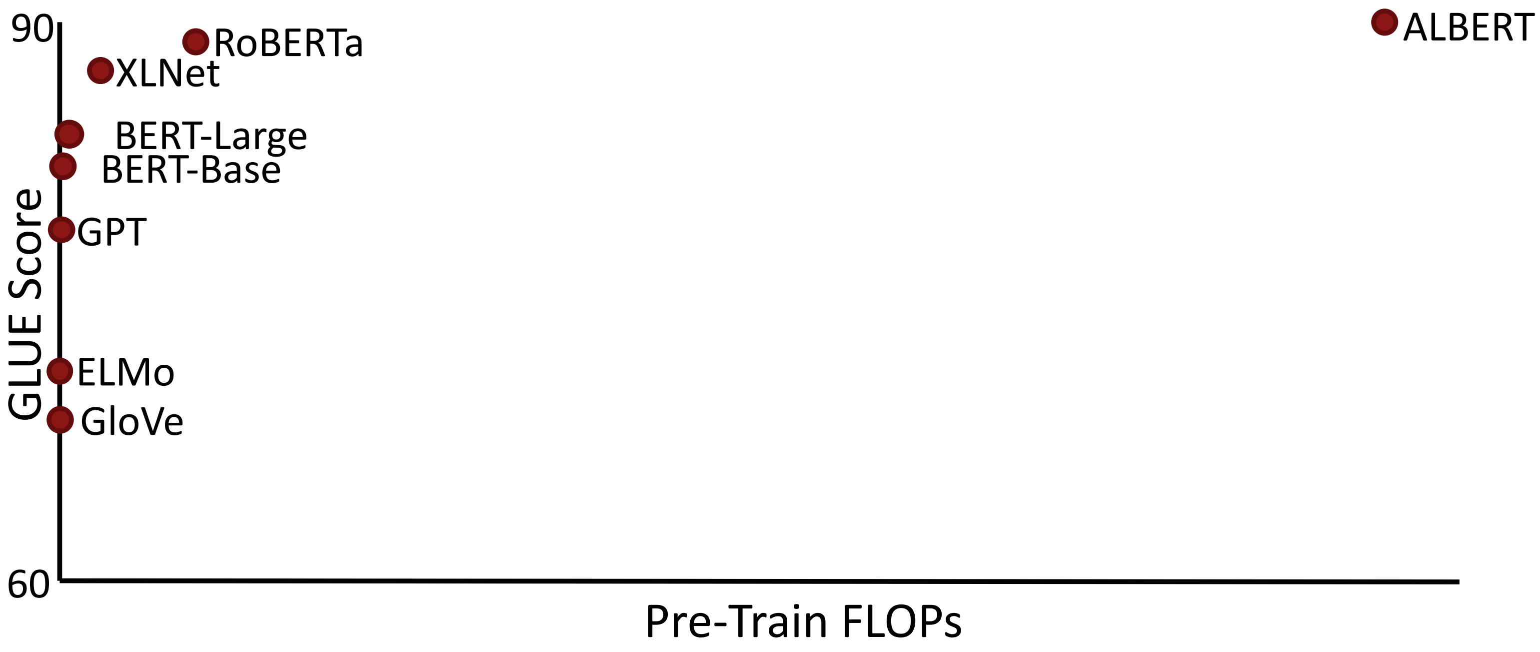
  - **Source:** "Findings of the 2016 Conference on Machine Translation (WMT16)", Bojar et al. 2016, http://www.statmt.org/wmt16/pdf/W16-2301.pdf
  - **Source:** "Findings of the 2018 Conference on Machine Translation (WMT18)", Bojar et al. 2018, http://www.statmt.org/wmt18/pdf/WMT028.pdf

Rapid Progress for NLP Pretraining (GLUE Benchmark)



Over 3x reduction in error in 2 years, “superhuman” performance

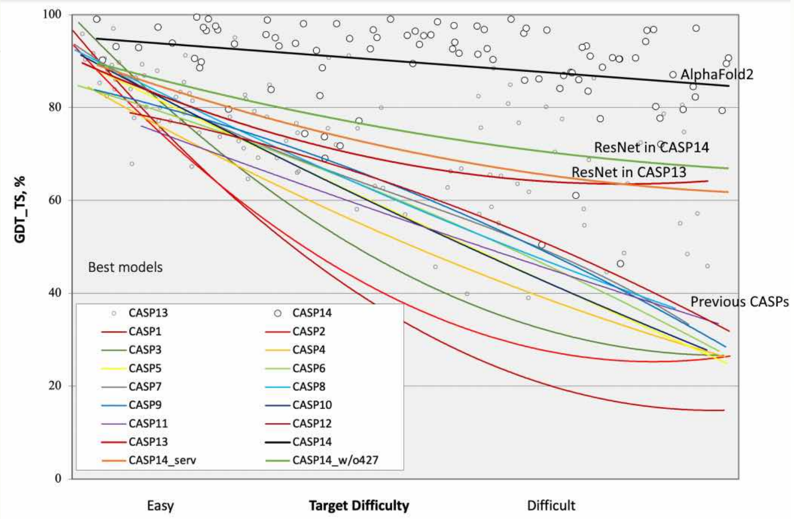
More compute, more better?



ALBERT uses 10x more compute than RoBERTa

Protein Folding Structure Prediction

AlphaFold



Article

Highly accurate protein structure prediction with AlphaFold

https://doi.org/10.1038/s41586-021-03819-2

Received: 11 May 2021

Accepted: 12 July 2021

Published online: 15 July 2021

Open access

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Proteins are essential to life, and understanding their structure can facilitate a mechanistic understanding of their function. Through an enormous experimental effort[1–4], the structures of around 100,000 unique proteins have been determined[5], but this represents a small fraction of the billions of known protein sequences[6,7]. Structural coverage is bottlenecked by the months to years of painstaking effort required to determine a single protein structure. Accurate computational approaches are needed to address this gap and to enable large-scale structural bioinformatics. Predicting the three-dimensional structure that a protein will adopt based solely on its amino acid sequence—the structure prediction component of the 'protein folding problem'[8]—has been an important open research problem for more than 50 years[9]. Despite recent progress[10–14], existing methods fall far short of atomic accuracy, especially when no homologous structure is available. Here we provide the first computational method that can regularly predict protein structures with atomic accuracy even in cases in which no similar structure is known. We validated an entirely redesigned version of our neural network-based model, AlphaFold, in the challenging 14th Critical Assessment of protein Structure Prediction (CASP14)[15], demonstrating accuracy competitive with experimental structures in a majority of cases and greatly outperforming other methods. Underpinning the latest version of AlphaFold is a novel machine learning approach that incorporates physical and biological knowledge about protein structure, leveraging multi-sequence alignments, into the design of the deep learning algorithm.

The development of computational methods to predict three-dimensional (3D) protein structures from the protein sequence has proceeded along two complementary paths that focus on either the physical interactions or the evolutionary history. The physical interaction programme heavily integrates our understanding of molecular driving forces into either thermodynamic or kinetic simulation of protein physics[16] or statistical approximations thereof[17]. Although theoretically very appealing, this approach has proved highly challenging for even moderate-sized proteins due to the computational intractability of molecular simulation, the context dependence of protein stability and the difficulty of producing sufficiently accurate models of protein physics. The evolutionary programme has provided an alternative in recent years, in which the constraints on protein structure are derived from bioinformatics analysis of the evolutionary history of proteins, homology to solved structures[18,19] and pairwise evolutionary correlations[20–24]. This bioinformatics approach has benefited greatly from the steady growth of experimental protein structures deposited in the Protein Data Bank (PDB)[5], the explosion of genomic sequencing and the rapid development of deep learning techniques to interpret these correlations. Despite these advances, contemporary physical and evolutionary-history-based approaches produce predictions that are far short of experimental accuracy in the majority of cases in which a close homologue has not been solved experimentally and this has limited their utility for many biological applications.

In this study, we develop the first, to our knowledge, computational approach capable of predicting protein structures to near experimental accuracy in a majority of cases. The neural network AlphaFold that we developed was entered into the CASP14 assessment (May–July 2020; entered under the team name 'AlphaFold2' and a completely different model from our CASP13 AlphaFold system[10]). The CASP assessment is carried out biennially using recently solved structures that have not been deposited in the PDB or publicly disclosed so that it is a blind test

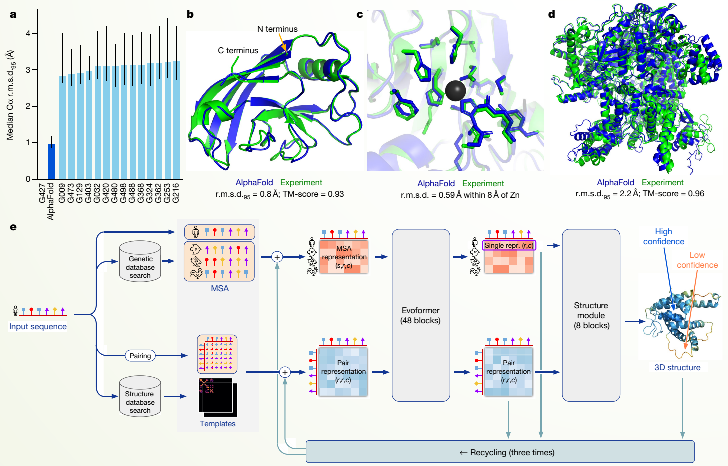

Fig. 1 | AlphaFold produces highly accurate structures. a, The performance of AlphaFold on the CASP14 dataset (n = 87 protein domains) relative to the top-15 entries (out of 146 entries), group numbers correspond to the numbers assigned to entrants by CASP. Data are median and the 95% confidence interval of the median, estimated from 10,000 bootstrap samples. **b**, Our prediction of CASP14 target T1049 (PDB 6Y4F, blue) compared with the true (experimental) structure (green). Four residues in the C terminus of the crystal structure are B-factor outliers and are not depicted. **c**, CASP14 target T1056 (PDB 6YJ1). An example of a well-predicted zinc-binding site (AlphaFold has accurate side chains even though it does not explicitly predict the zinc ion). **d**, CASP target T1044 (PDB 6VR4)—a 2,180-residue single chain—was predicted with correct domain packing (the prediction was made after CASP using AlphaFold without intervention). **e**, Model architecture. Arrows show the information flow among the various components described in this paper. Array shapes are shown in parentheses with s, number of sequences (N_{seq} in the main text); r, number of residues (N_{res} in the main text); c, number of channels.

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AI for Science

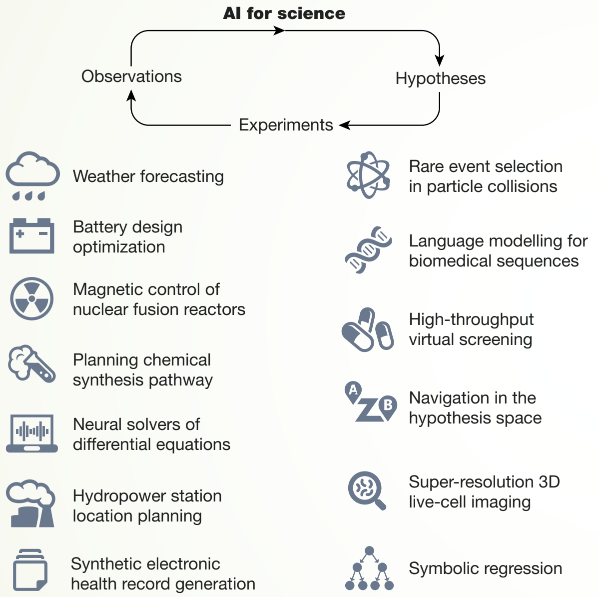

Fig. 1 | Science in the age of artificial intelligence. Scientific discovery is a multifaceted process that involves several interconnected stages, including hypothesis formation, experimental design, data collection and analysis. AI is poised to reshape scientific discovery by augmenting and accelerating research at each stage of this process. The principles and illustrative studies shown here highlight the contributions to enhance scientific understanding and discovery.

Scientific discovery in the age of artificial intelligence

https://doi.org/10.1038/s41586-023-06221-2

Received: 30 March 2022

Accepted: 16 May 2023

Published online: 2 August 2023

Check for updates

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Artificial intelligence (AI) is being increasingly integrated into scientific discovery to augment and accelerate research, helping scientists to generate hypotheses, design experiments, collect and interpret large datasets, and gain insights that might not have been possible using traditional scientific methods alone. Here we examine breakthroughs over the past decade that include self-supervised learning, which allows models to be trained on vast amounts of unlabelled data, and geometric deep learning, which leverages knowledge about the structure of scientific data to enhance model accuracy and efficiency. Generative AI methods can create designs, such as small-molecule drugs and proteins, by analysing diverse data modalities, including images and sequences. We discuss how these methods can help scientists throughout the scientific process and the central issues that remain despite such advances. Both developers and users of AI toolsneed a better understanding of when such approaches need improvement, and challenges posed by poor data quality and stewardship remain. These issues cut across scientific disciplines and require developing foundational algorithmic approaches that can contribute to scientific understanding or acquire it autonomously, making them critical areas of focus for AI innovation.

The foundation for forming scientific insights and theories is laid by how data are collected, transformed and understood. The rise of deep learning in the early 2010s has significantly expanded the scope and ambition of these scientific discovery processes[1]. Artificial intelligence (AI) is increasingly used across scientific disciplines to integrate massive datasets, refine measurements, guide experimentation, explore the space of theories compatible with the data, and provide actionable and reliable models integrated with scientific workflows for autonomous discovery.

Data collection and analysis are fundamental to scientific understanding and discovery, two of the central aims in science[2], and quantitative methods and emerging technologies, from physical instruments such as microscopes to research techniques such as bootstrapping, have long been used to reach these aims[3]. The introduction of digitization in the 1950s paved the way for the general use of computing in scientific research. The rise of data science since the 2010s has enabled AI to provide valuable guidance by identifying scientifically relevant patterns from large datasets.

Although scientific practices and procedures vary across stages of scientific research, the development of AI algorithms cuts across traditionally isolated disciplines (Fig. 1). Such algorithms can enhance the design and execution of scientific studies. They are becoming

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ChatGPT (GPT 3.5-4)

ChatGPT

94 languages

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From Wikipedia, the free encyclopedia

ChatGPT, which stands for **Chat Generative Pre-trained Transformer**, is a large language model-based chatbot developed by OpenAI and launched on November 30, 2022, notable for enabling users to refine and steer a conversation towards a desired length, format, style, level of detail, and language used. Successive prompts and replies, known as prompt engineering, are considered at each conversation stage as a context.[2]

ChatGPT is built upon GPT-3.5 and GPT-4 —members of OpenAI's proprietary series of generative pre-trained transformer (GPT) models, based on the transformer architecture developed by Google[3]—and it is fine-tuned for conversational applications using a combination of supervised and reinforcement learning techniques.[4] ChatGPT was released as a freely available research preview, but due to its popularity, OpenAI now operates the service on a freemium model. It allows users on its free tier to access the GPT-3.5-based version. In contrast, the more advanced GPT-4 based version and priority access to newer features are provided to paid subscribers under the commercial name "ChatGPT Plus".

By January 2023, it had become what was then the fastest-growing consumer software application in history, gaining over 100 million users and contributing to OpenAI's valuation growing to US$29 billion.[5][6] Within months, Google, Baidu, and Meta accelerated the development of their competing products: Bard, Ernie Bot, and LLaMA.[7] Microsoft launched its Bing Chat based on OpenAI's GPT-4. Some observers expressed concern over the potential of ChatGPT to displace or atrophy human intelligence and its potential to enable plagiarism or fuel misinformation.[4][8]

ChatGPT

Developer(s)	OpenAI
Initial release	November 30, 2022; 9 months ago
Stable release	August 3, 2023; 31 days ago[1]
Written in	Python
Engine	GPT-3.5 GPT-4
Platform	Cloud computing platforms
Type	Chatbot Large language model Generative text-to-image model Generative pre-trained transformer
License	Proprietary
Website	chat.openai.com/chat

Training

ChatGPT is based on particular GPT foundation models, namely GPT-3.5 and GPT-4, that were fine-tuned to target conversational usage.[9] The fine-tuning process leveraged both supervised learning as well as

- https://poe.com/

Number of AI papers on arXiv, 2010-2019

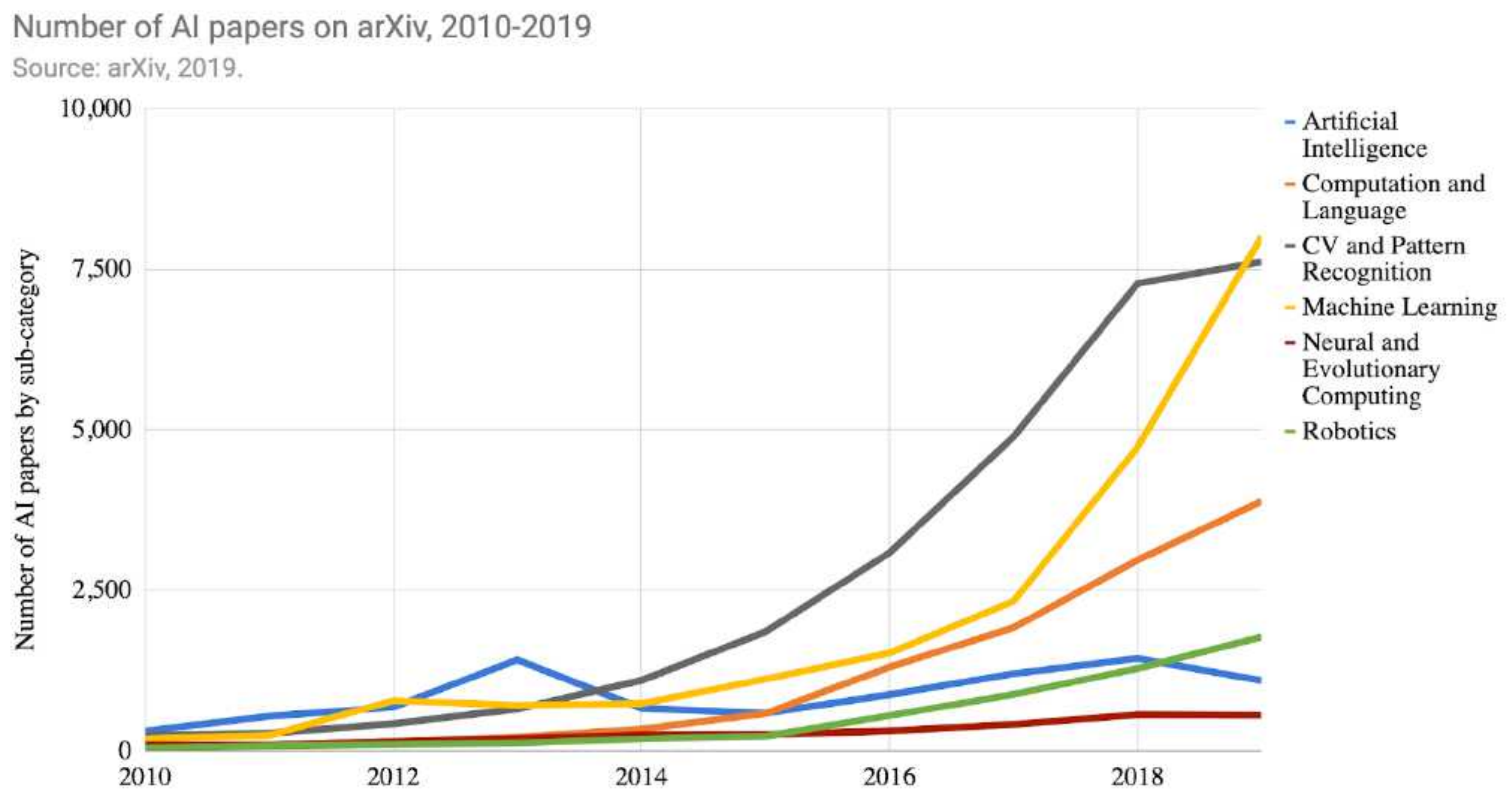
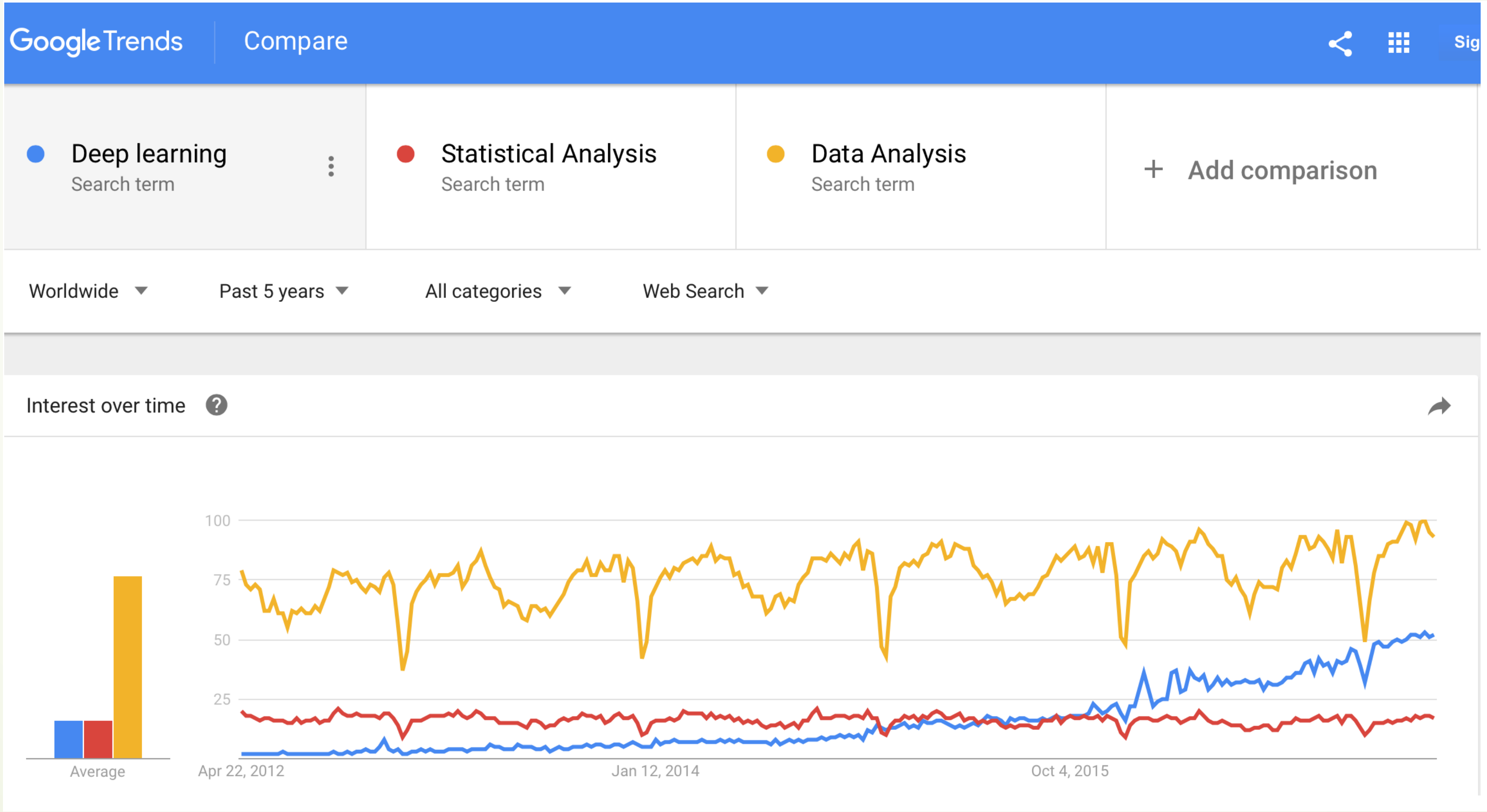


Fig. 1.6.

Growth of Deep Learning

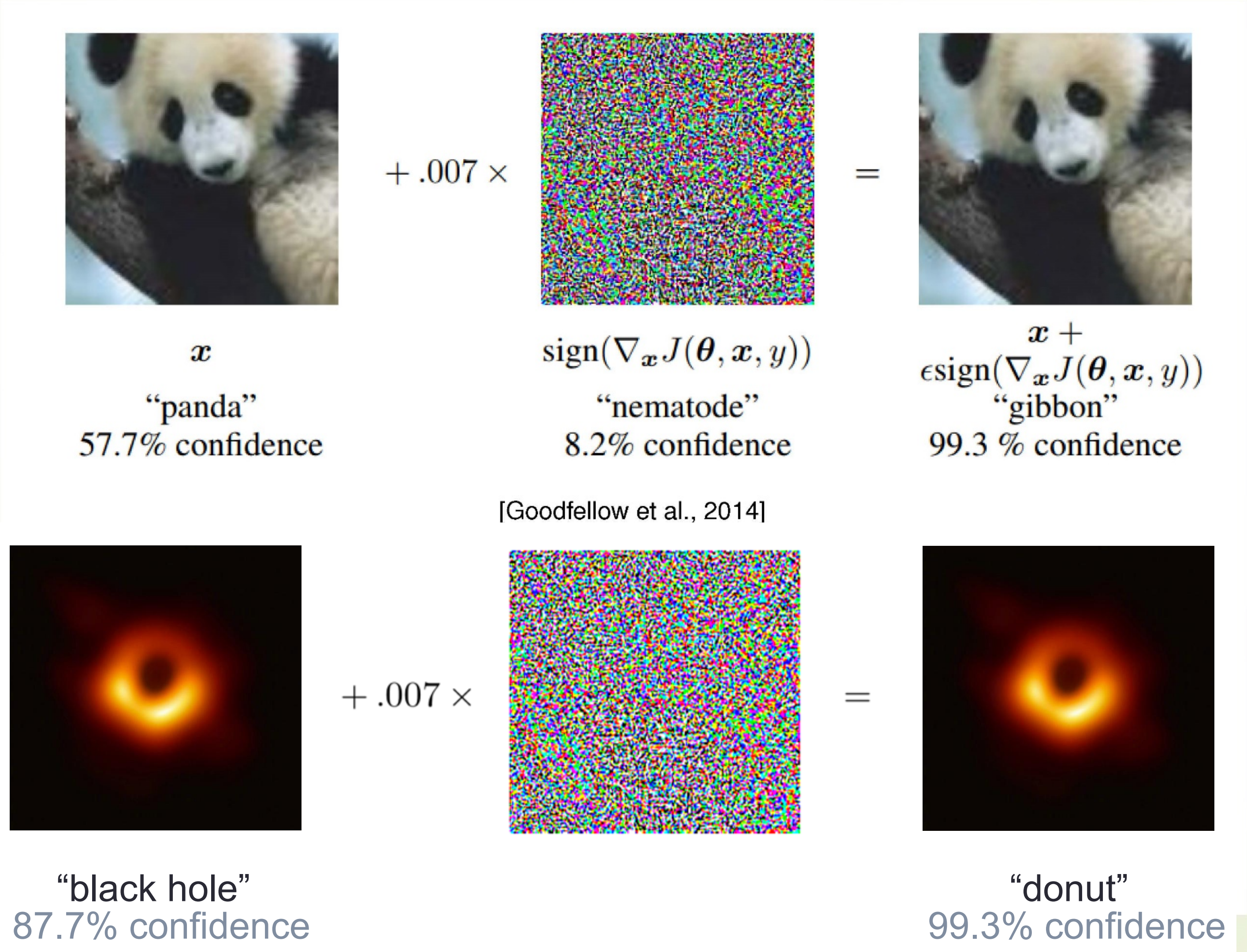
'Deep Learning' is coined by Hinton et al. in their Restricted Boltzman Machine paper, *Science* 2006, not yet popular until championing ImageNet competitions.



Some Cold Water: Tesla Autopilot Misclassifies Truck as Billboard

Problem: Why? How can you trust a blackbox?

Deep Learning may be fragile in generalization against noise!



CNN learns texture features, not shapes

(a) Texture image

81.4%	**Indian elephant**
10.3%	indri
8.2%	black swan

(b) Content image

71.1%	**tabby cat**
17.3%	grey fox
3.3%	Siamese cat

(c) Texture-shape cue conflict

63.9%	**Indian elephant**
26.4%	indri
9.6%	black swan

Geirhos et al. ICLR 2019

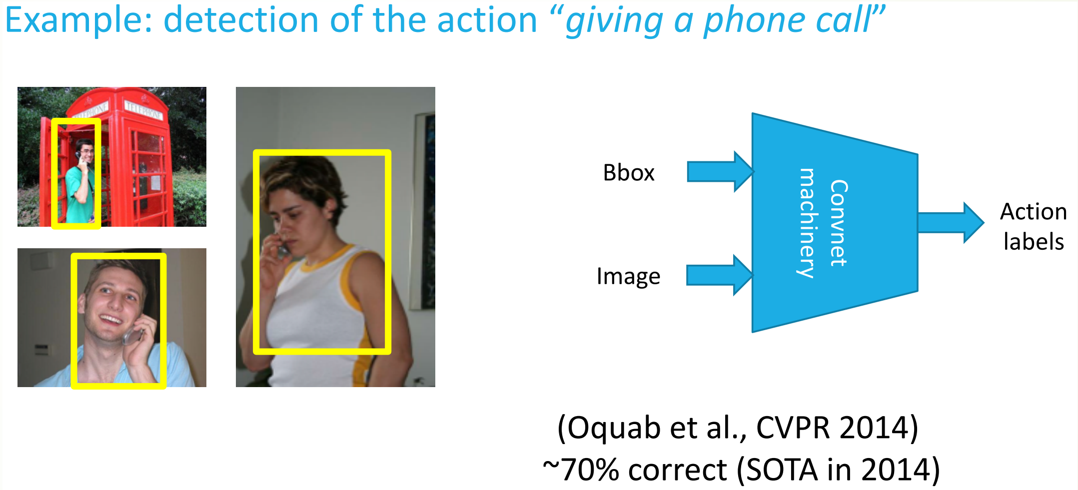
https://videoken.com/embed/W2HvLBMhCJQ?tocitem=46

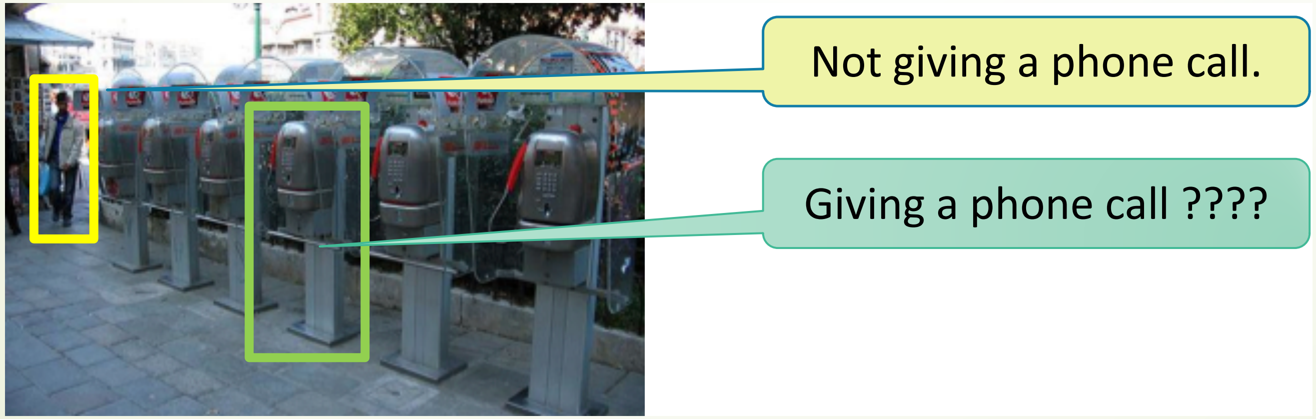
1:16:47

Capture spurious correlations and can't do causal inference on counterfactuals

https://videoken.com/embed/8UxS4ls6g1g?tocitem=2

Leon Bottou, ICLR 2019





Overfitting causes privacy leakage

- Model inversion attack leaks privacy

Figure: Recovered (Left), Original (Right)

Fredrikson et al. Proc. CCS, 2016

What's wrong with deep learning?

Ali Rahimi NIPS'17: Machine (deep) Learning has become **alchemy**.
https://www.youtube.com/watch?v=ORHFOnaEzPc

Yann LeCun CVPR'15, invited talk: **What's wrong with deep learning?**
One important piece: **missing some theory (clarity in understanding)**!

http://techtalks.tv/talks/whats-wrong-with-deep-learning/61639/

Being alchemy is certainly not a shame, not wanting to work on advancing to chemistry is a shame! -- **by Eric Xing**

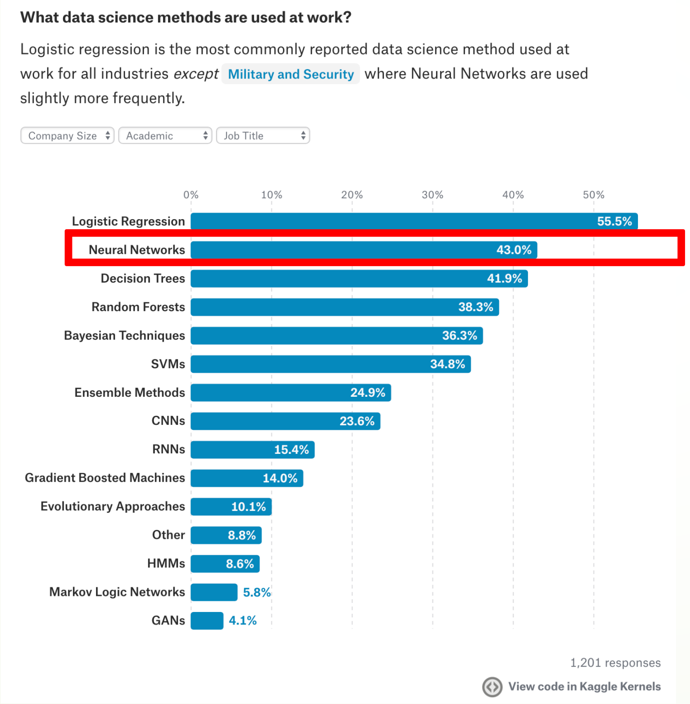
“Shall we see soon an emergence
from Alchemy to Science
in deep leaning?”

How can we teach our students in the next generation science rather than alchemy?

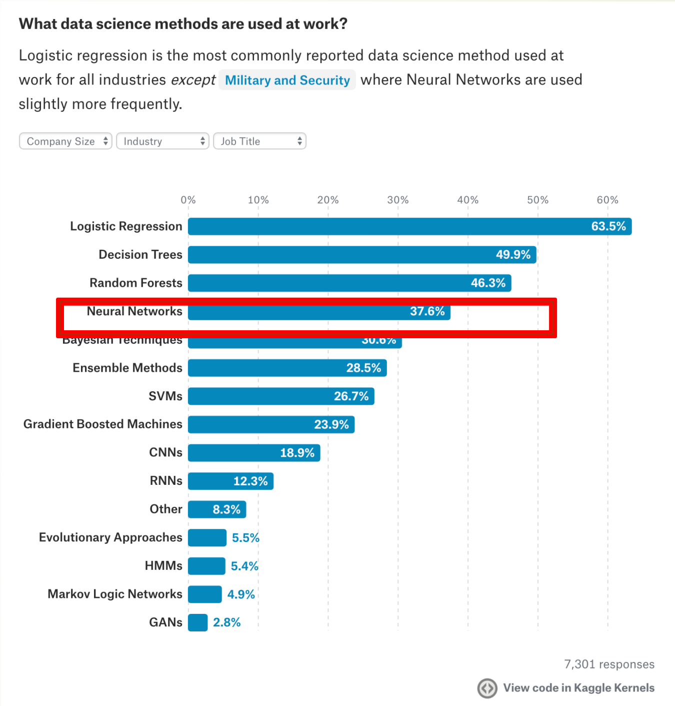
Kaggle survey: Top Data Science Methods

https://www.kaggle.com/surveys/2017

Academic



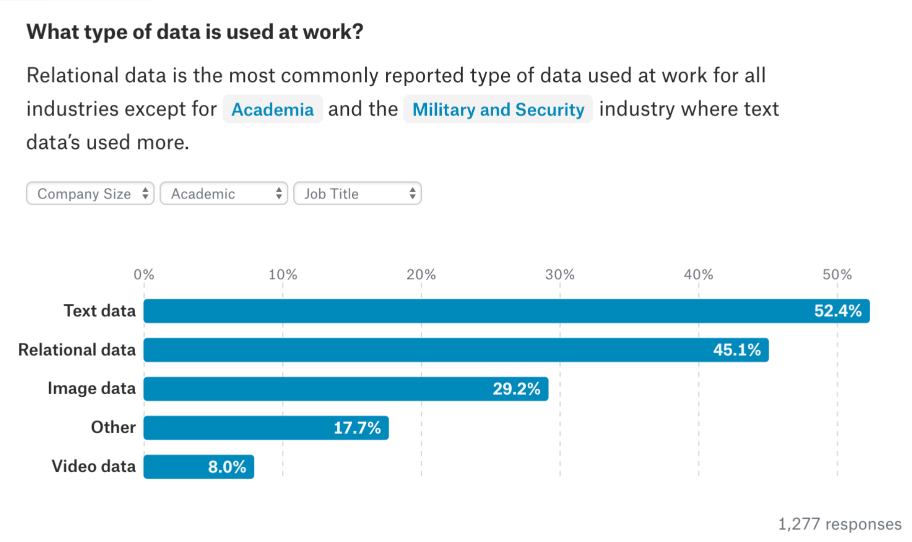
Industry



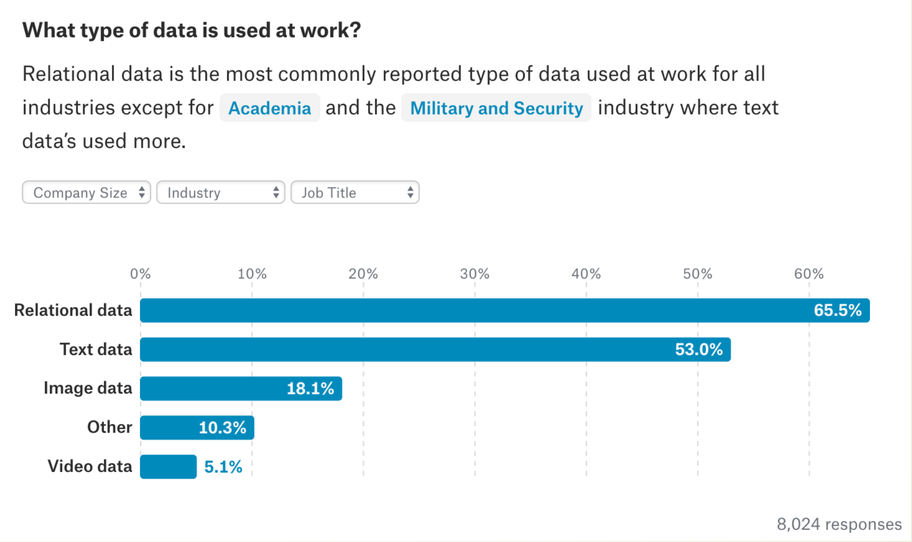
What type of data is used at work?

https://www.kaggle.com/surveys/2017

Academic



Industry



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

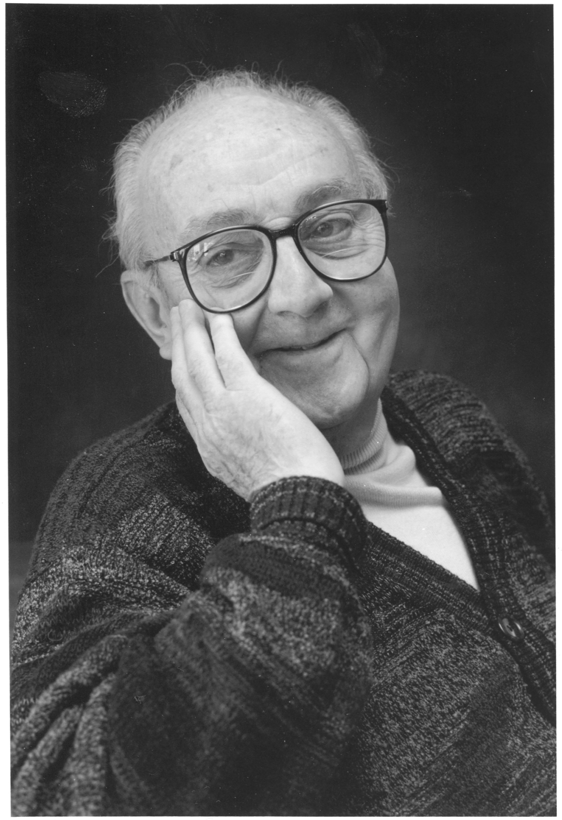


Figure 7: George Box: “Essentially, all models are wrong, but some are useful.”

In this class

- Understand its principles: statistics, optimization
- Analyze the real world data with the methods
- Team-work in projects

Thank you!