Neural Networks

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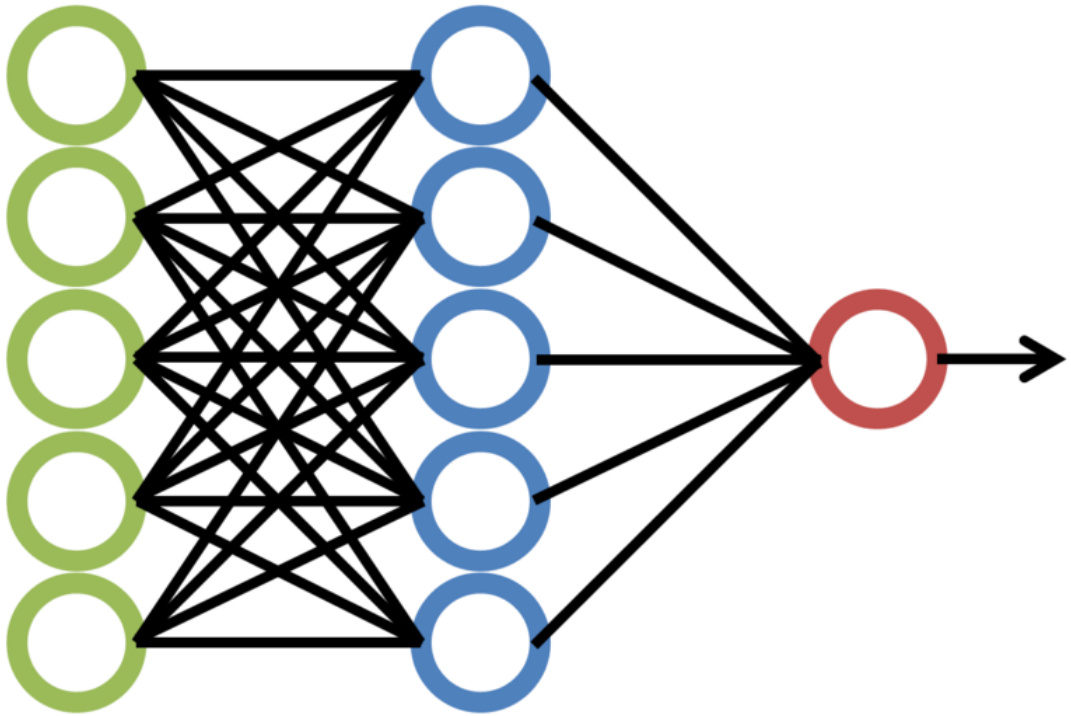
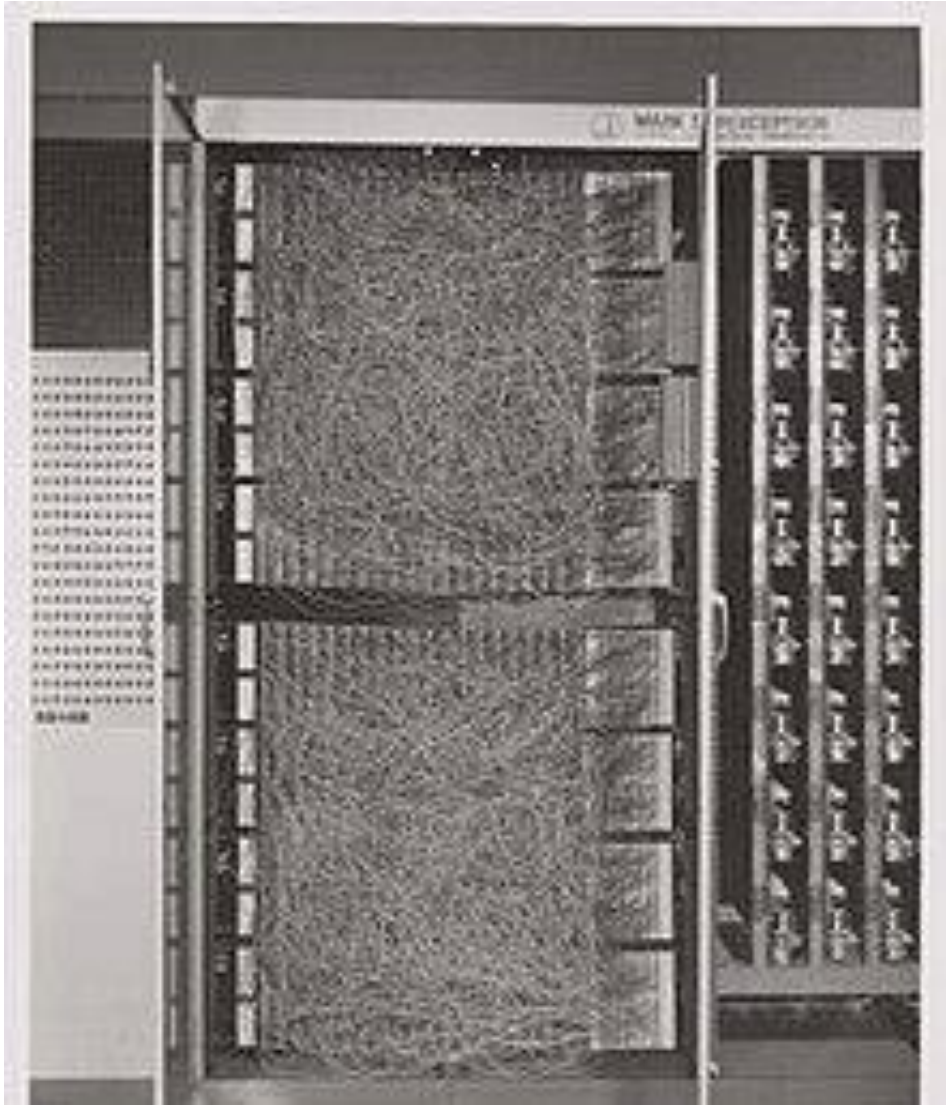
What is a neural network?

- Complex structure of interconnected computing nodes (neurons)
- Can identify patterns and trends in complex data
- NNs operate on the principle of “learning” from data, using a process that mimics how biological brains learn



History of NNs

- 1940s – Early Beginnings
  - Concept of a neural network is first proposed: “A Logical Calculus of Ideas Immanent in Nervous Activity”
- 1950s – The Perceptron
  - With funding from the US Navy, Cornell builds the Mark 1 Perceptron, a physical neural network
  - The New York Times reported the perceptron to be "the embryo of an electronic computer that [the Navy] expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence.”



History of NNs

- 1960s – The First AI Winter
  - Despite the excitement of the 50s, NN research stalled
  - A highly influential book – *Perceptrons (1969)* – showed that these early neural networks were severely limited
- 1980s – Backpropagation
  - The discovery of backpropagation allowed for the first time the creation of multi-layer neural networks that could efficiently learn from examples
- 1990s – Support Vector Machines and the Second AI Winter
  - NN research stalled again due to the rising popularity of SVMs, which provided a better theoretical framework and outperformed the NNs of the day

History of NNs

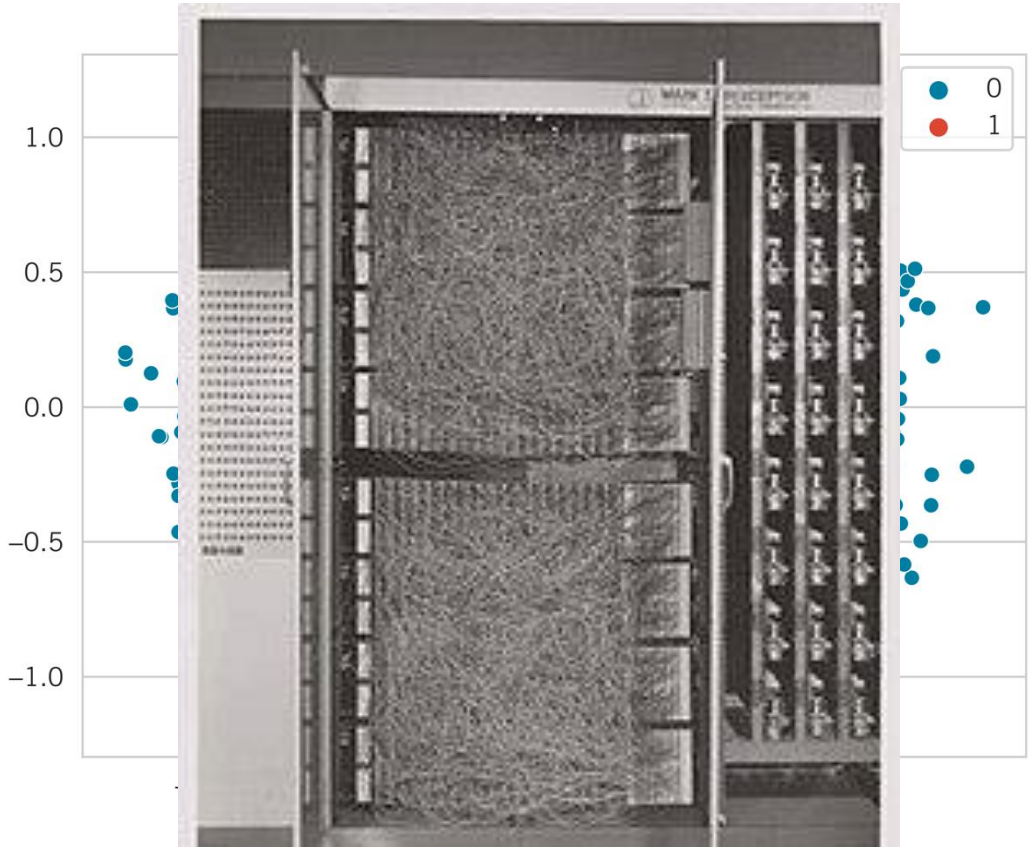
- 2000s – Dawn of the Deep Learning Era
  - The term “deep learning” began to circulate, reflecting a new focus on deeper, multi-layered neural networks
  - Advances in hardware, datasets, and training techniques allowed the development of much more sophisticated networks
- 2010s – Breakthroughs and Wide Adoption
  - With the success of AlexNet, Convolutional Neural Networks gained prominence and became a go-to method for image tasks
  - Recurrent Neural Networks show impressive results in natural langauge understanding
  - Tech giants begin to heavily invest in deep learning technology

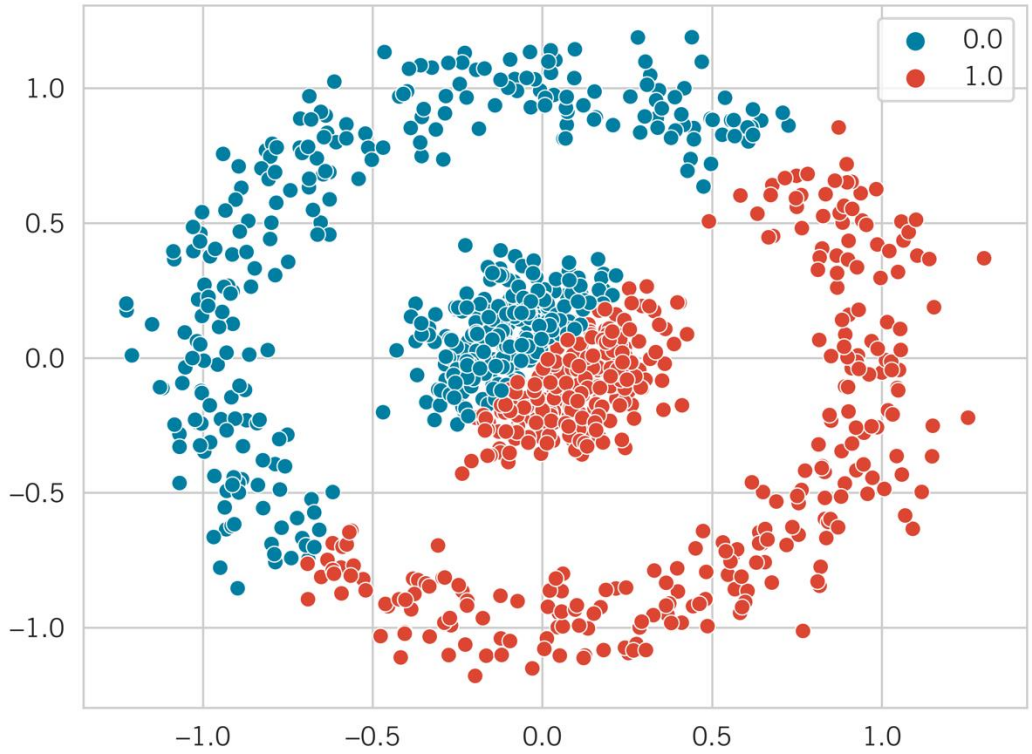
History of NNs

- 2020s – Transformers and the Era of Large Language Models
  - The Transformer model, introduced in the paper “Attention is All You Need”, starts demonstrating state-of-the-art performance in language tasks
  - An increasing focus on large-scale models with billions, or even trillions, of parameters begins, leading to unprecedented performance…
  - …but also raising questions about computational efficiency, environmental impact, and accessibility.

How do Neural Networks actually work?

Why do we want non-linearity?

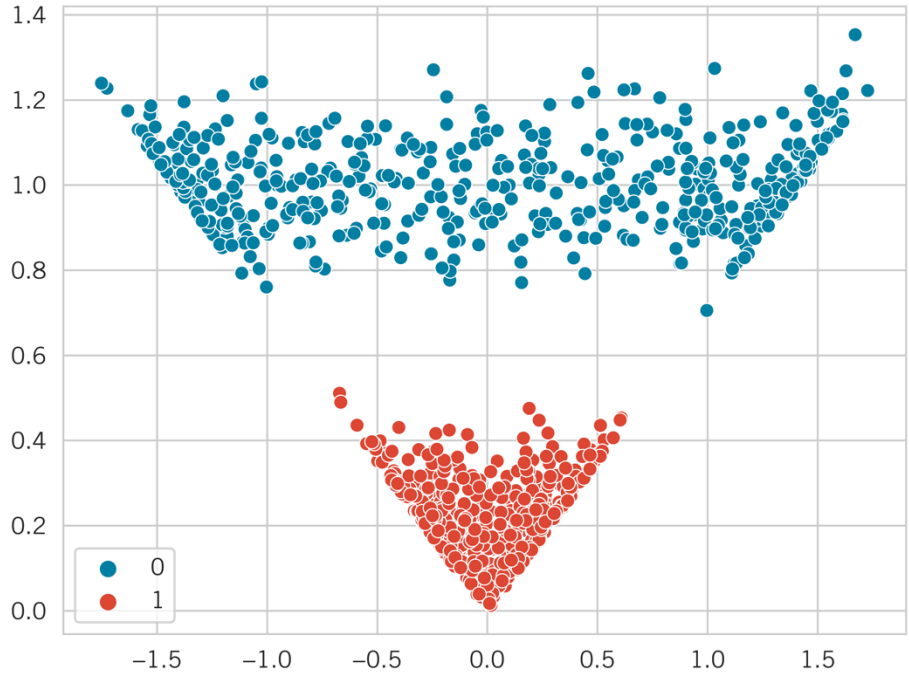




Cannot apply a linear classifier!

Why do we want non-linearity?

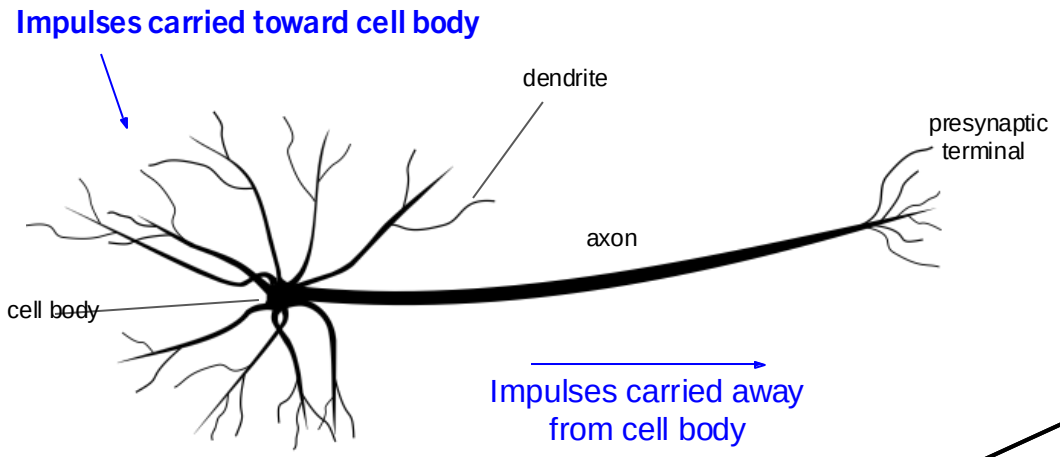
- After applying feature transformation, points become linearly separable

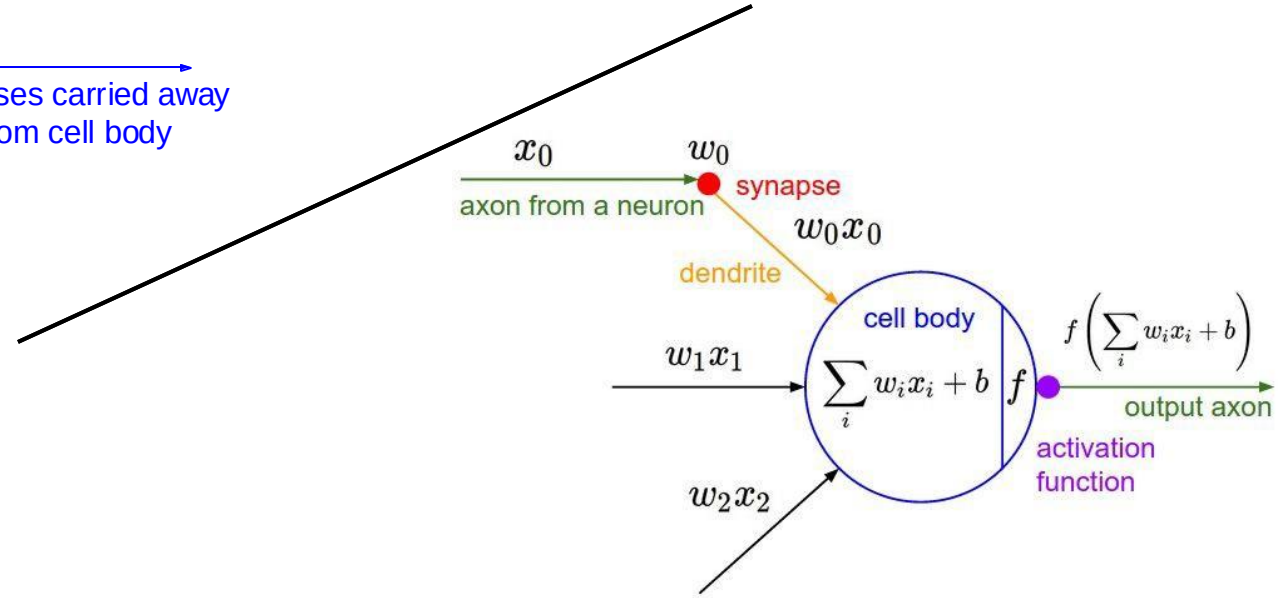


The Neuron Metaphor

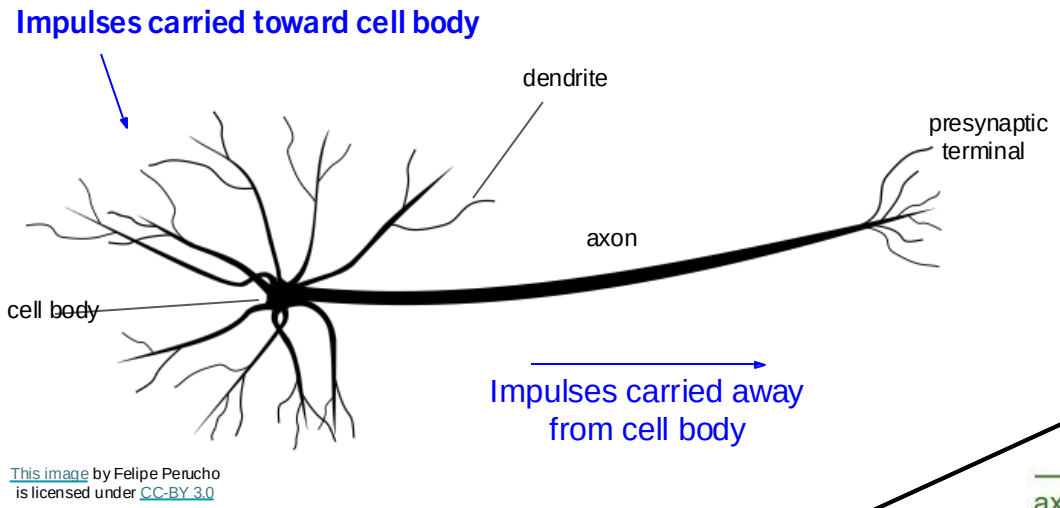
- Neural networks were inspired by our understanding of the brain and how neurons interact.
- An artificial neuron in a neural network takes in multiple inputs, applies a function to them, and generates an output – mirroring the basic functionality of a biological neuron.
- This analogy has been extremely useful for explaining and visualizing how these artificial structures work.

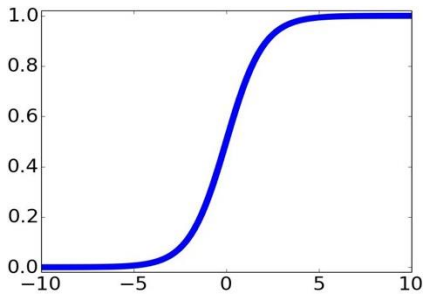
The Neuron Metaphor





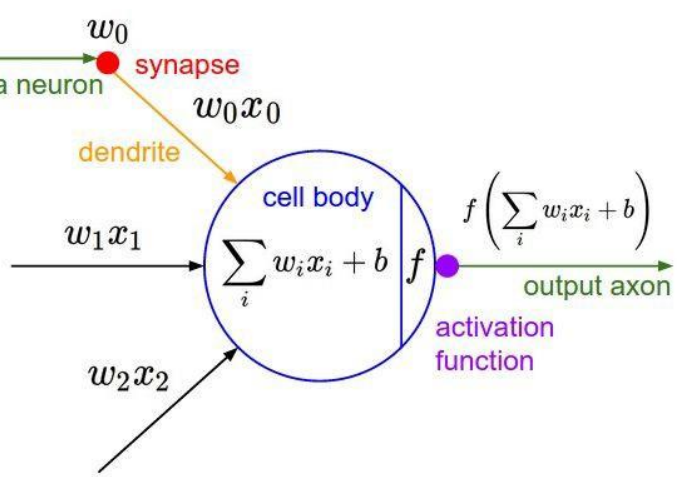
The Neuron Metaphor





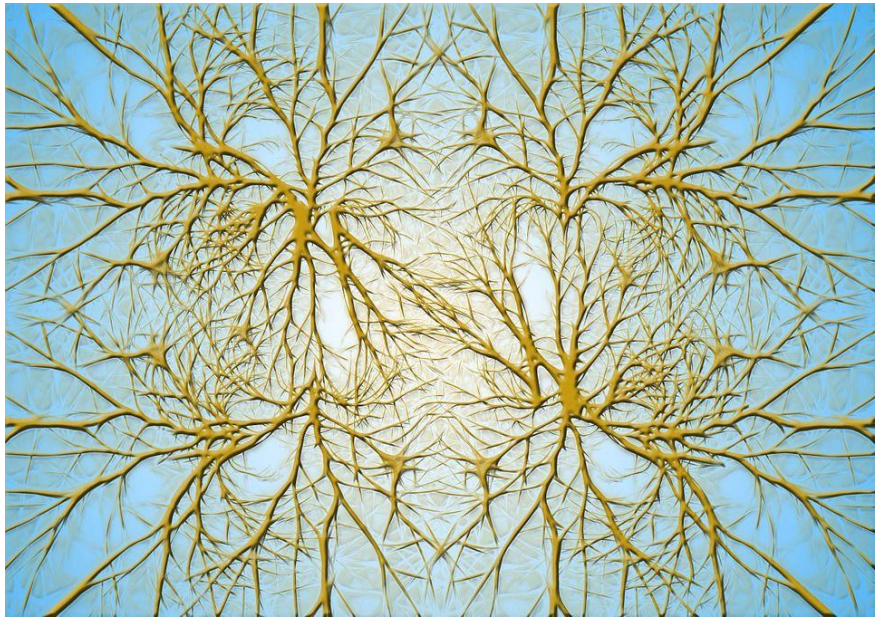
sigmoid activation function

$$\frac{1}{1+e^{-x}}$$

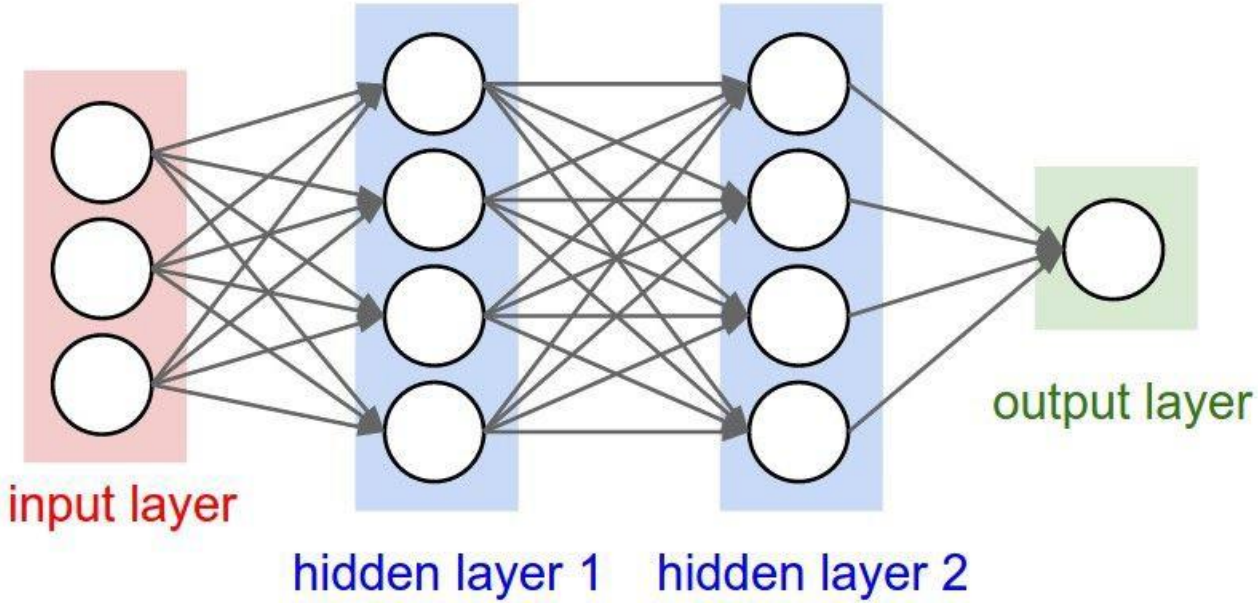


The Metaphor Breaks Down

Biological Neurons:
Complex connectivity patterns



Neurons in a neural network:
Organized into regular layers for computational efficiency



The Metaphor Breaks Down

- Biological neurons are vastly more complex: they use a mixture of electrical and chemical signals, have complex temporal dynamics, and can restructure their own connections.
- The brain is not just a feed-forward network: it has many complex feedback loops, which are not typically found in artificial neural networks.
- The brain isn't easily divided into distinct layers, as we do in artificial neural networks.

The Metaphor Breaks Down

- Over-reliance on the analogy can lead to misunderstandings about how neural networks function and their capabilities.
- This can lead to unrealistic expectations about what neural networks can do, or to overgeneralizations about their functioning.
- For instance, claiming a neural network "thinks" or "understands" like a human brain is misleading.
- To further progress, it's important to view artificial neural networks as mathematical/statistical tools, and not overstate the comparison to the human brain.

Neural Network Playground

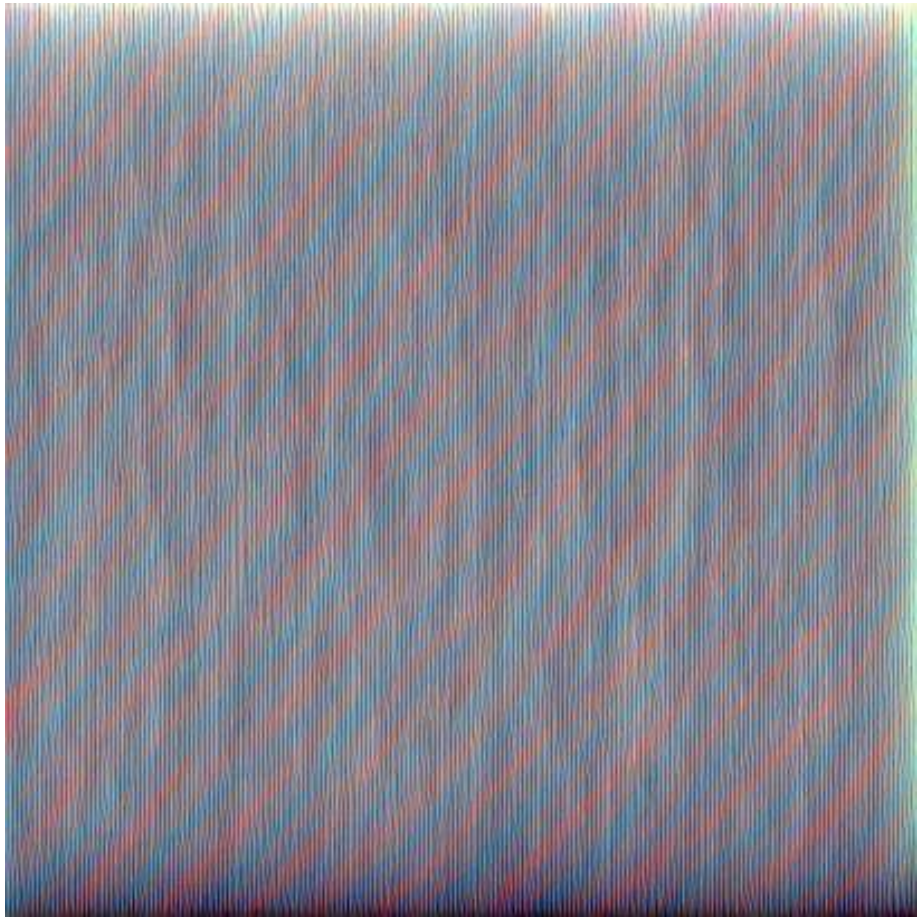
https://playground.tensorflow.org

Going past the fully connected network

- In many image tasks, we want to be able to recognize something regardless of where it is in the image
- For fully-connected networks, the order of the inputs is fixed
- No “shift invariance”

Going past the fully connected network

- In the 1950s and 60s, researchers showed that the brain contains neurons which respond to specific patterns, regardless of where they appear
- Combinations of very basic patterns can then be recognized as a more complicated one!



VGG-16, neuron in layer 7

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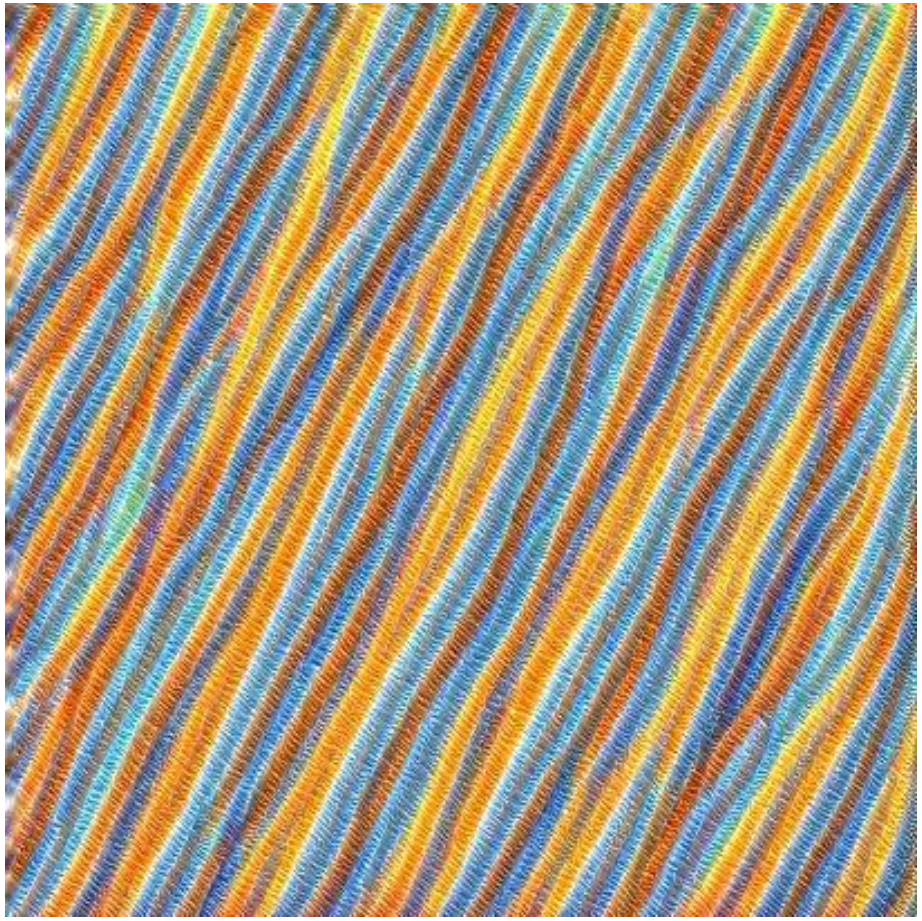

VGG-16, neuron in layer 14

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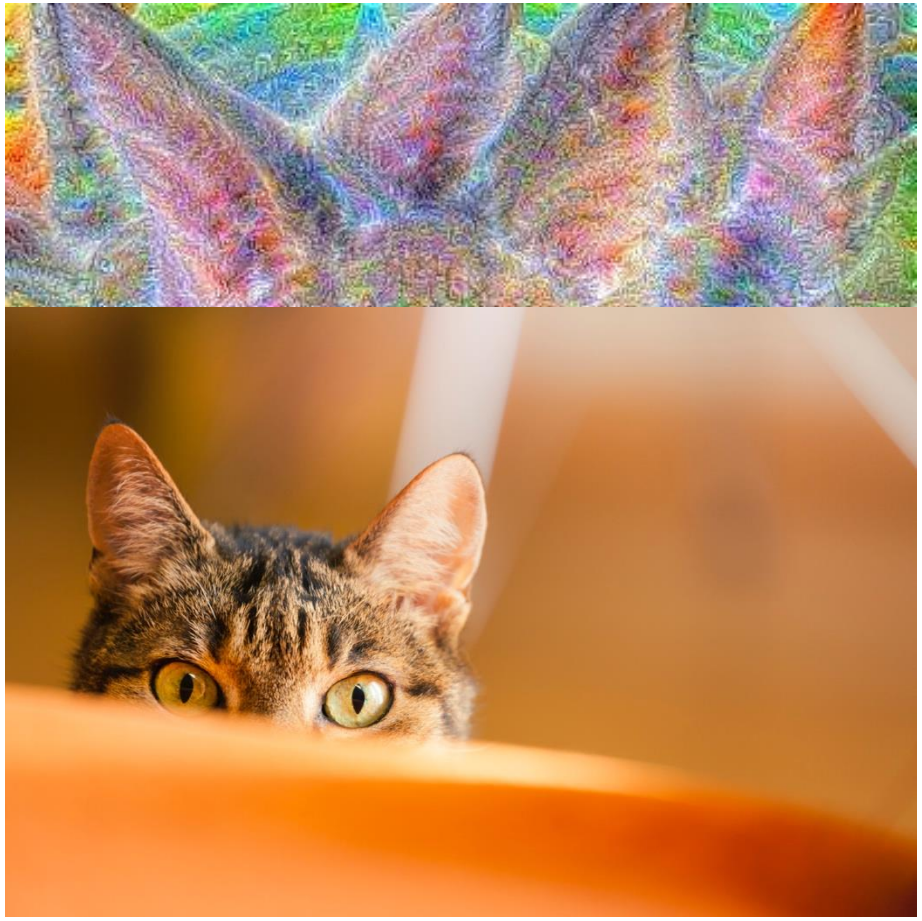

VGG-16, neuron in layer 40

Interactive CNNs

https://adamharley.com/nn_vis/cnn/2d.html