Biological systems, neuroscience and psychology have long served as inspiration and motivation for Artificial Intelligence.

There is no argument that current deep learning models and approaches are not biologically plausible.

But, throughout the development of neural networks and deep learning, biology has played a role…
The Brain

Biological Neurons
Late 1700’s - Early 1900’s
Advances in neuronal morphology

Santiago Ramón y Cajal
Jules Baillarger

Cell body
Axon
Telodendria
Synaptic terminals
Axon hillock
Golgi apparatus
Endoplasmic reticulum
Mitochondrion
Dendrite
Dendritic branches
Nucleus
• Biological Neurons “spike”
  • If sufficient spikes are received by the dendrites within a time period the neuron fires its “action potential”
  • Some inputs are inhibitory - they reduce the potential of the neuron to fire
  • Once it has fired there is a short refractory period which inhibits firing again
• There are also a number of other interesting dynamical properties
  • e.g. short-term synaptic depression

A Formalism for Approaching the Operation of a Single Neuron
1943
McCulloch-Pitts Artificial Neuron

\[ V_i = \begin{cases} 
1 & \text{: } \sum_j W_{ij} V_j \geq \theta \text{ AND no inhibition} \\
0 & \text{otherwise} 
\end{cases} \]

excitatory input

inhibitory input

\[ \text{all } W = 1, \theta = 2 \]

1958
Rosenblatt’s Perceptron

\[ y = \varphi(\sum_{i=1}^{n} w_i x_i + b) = \varphi(w^T x + b) \]

Frank Rosenblatt
Rosenblatt’s model captures many of the key points of a biological neuron:

- Output is a function of the sum of inputs
- Negative weights account for inhibitory connections
- The “activation function” can ensure that output is only produced once a threshold is exceeded (although we use many variants of these days)

\[ y = \varphi(\sum_{i=1}^{n} w_i x_i + b) = \varphi(w^T x + b) \]
Back to a real brain: The visual system
Circa AD 100 - 1000
Understanding of the visual system gross anatomy

Circa AD 1500
Foveal and peripheral vision

“The function of the human eye ... was described by a large number of authors in a certain way. But I found it to be completely different.”

– Leonardo Da Vinci
1930's
Gestalt Laws of Perceptual Grouping

(a) Symmetry

(b) Similarity

(c) Proximity

(d) Closure

(e) Smoothness

1959
Receptive Fields of Single Neurons in the Cat’s Striate Cortex

David Hubel
Torsten Wiesel
A modern understanding of the visual system
Gross Neuroanatomical Features

Neuroanatomy: the retina
Neuroanatomy: information flow along the optic nerve

Bandwidth of the optic nerve

- Estimated to be 8960kbps (https://www.newscientist.com/article/dn9633-calculating-the-speed-of-sight/)
  - ~1.1 megabytes per second
- An uncompressed 640*480 8-bit RGB image is 640*480*3 bytes = 0.92 megabytes
Neuroanatomy: the striate cortex (aka primary visual cortex or V1)

- Receives information from the LGN, with retinotopic mapping preserved
- Characterised by a layered structure of cells organised into “hypercolumns”
  - Small “receptive fields”
  - Neurons adapted to firing on relatively simple features like edges of specific orientations

Neuroanatomy: the extrastriate cortex (aka V2-V5)

- V2: local receptive fields, forward connections to V3, V4 and V5, backward connections to V1
  - Cells tuned to moderately complex patterns
- V3: lots of controversy to what the extent of this bit is & what it does!
- V4: attentional modulation; tuned to moderately complex object features
- V5/Middle Temporal: cells sensitive to movement and direction
- V6/Dorsomedial: processing of ego-motion
Neuroanatomy: the Inferior Temporal Cortex (IT)

- Cells sensitive to specific types of high-level features
  - For example, cells that fire when a face is present in the visual field

Functional Pathways
Nature or nurture... Do we “learn” to see?

1970
Is vision innate or acquired?

Colin Blakemore
Back to computational models: feature learning, local receptive fields and preserved spatial mappings

1979
Neocognitron

Kunihiko Fukushima
A word of warning from Marvin Minsky about learning features
Parting words

• Deep learning architectures are definitely not biologically plausible, but they do take ideas from our understanding of the brain.

• We haven’t talked about learning… is backprop biologically plausible?

• Does all learning need to involve gradients?