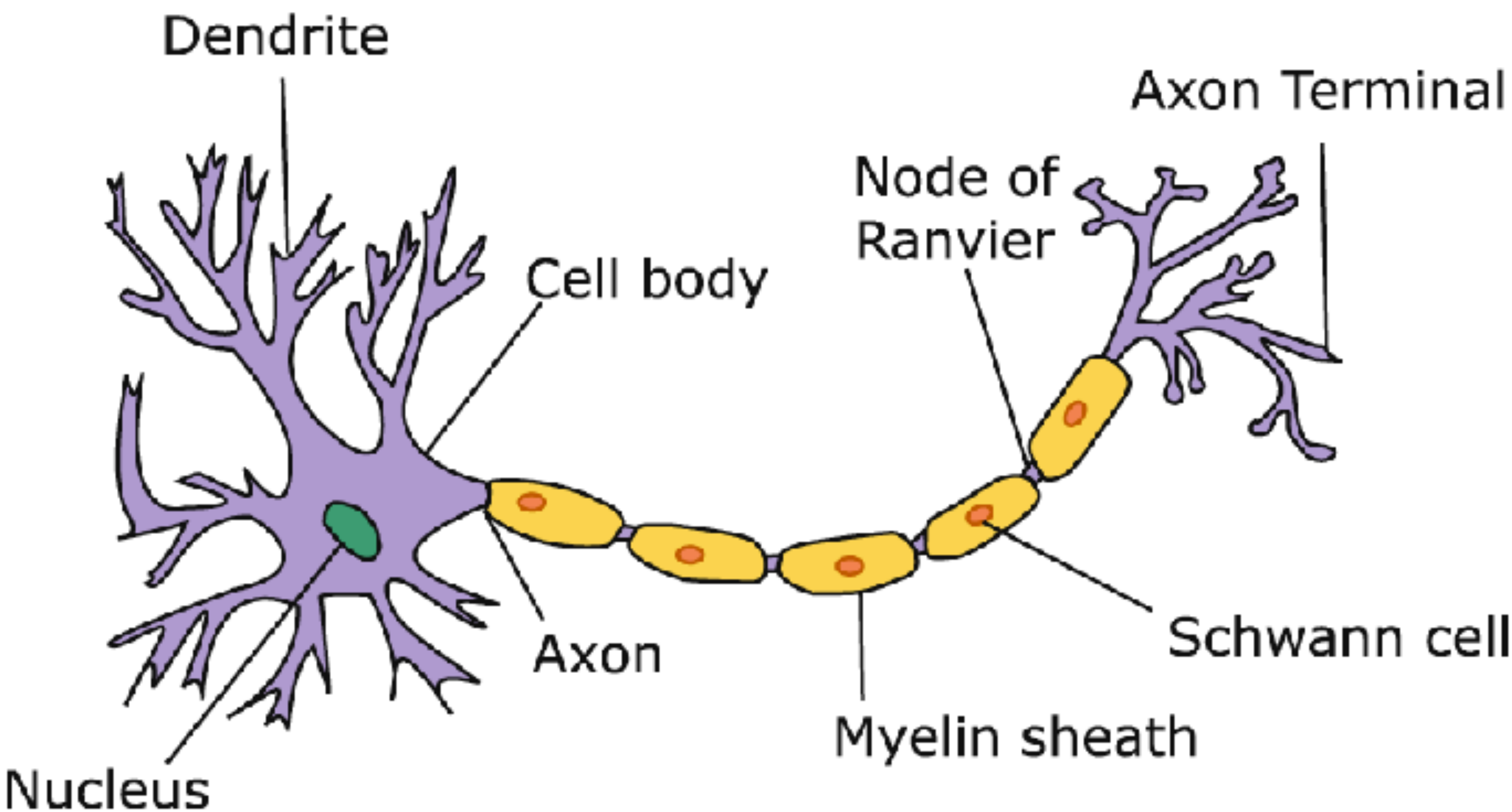
BIOENG-456

Controlling Behavior in Animals and Robots

Week 4: Visual motion and tracking

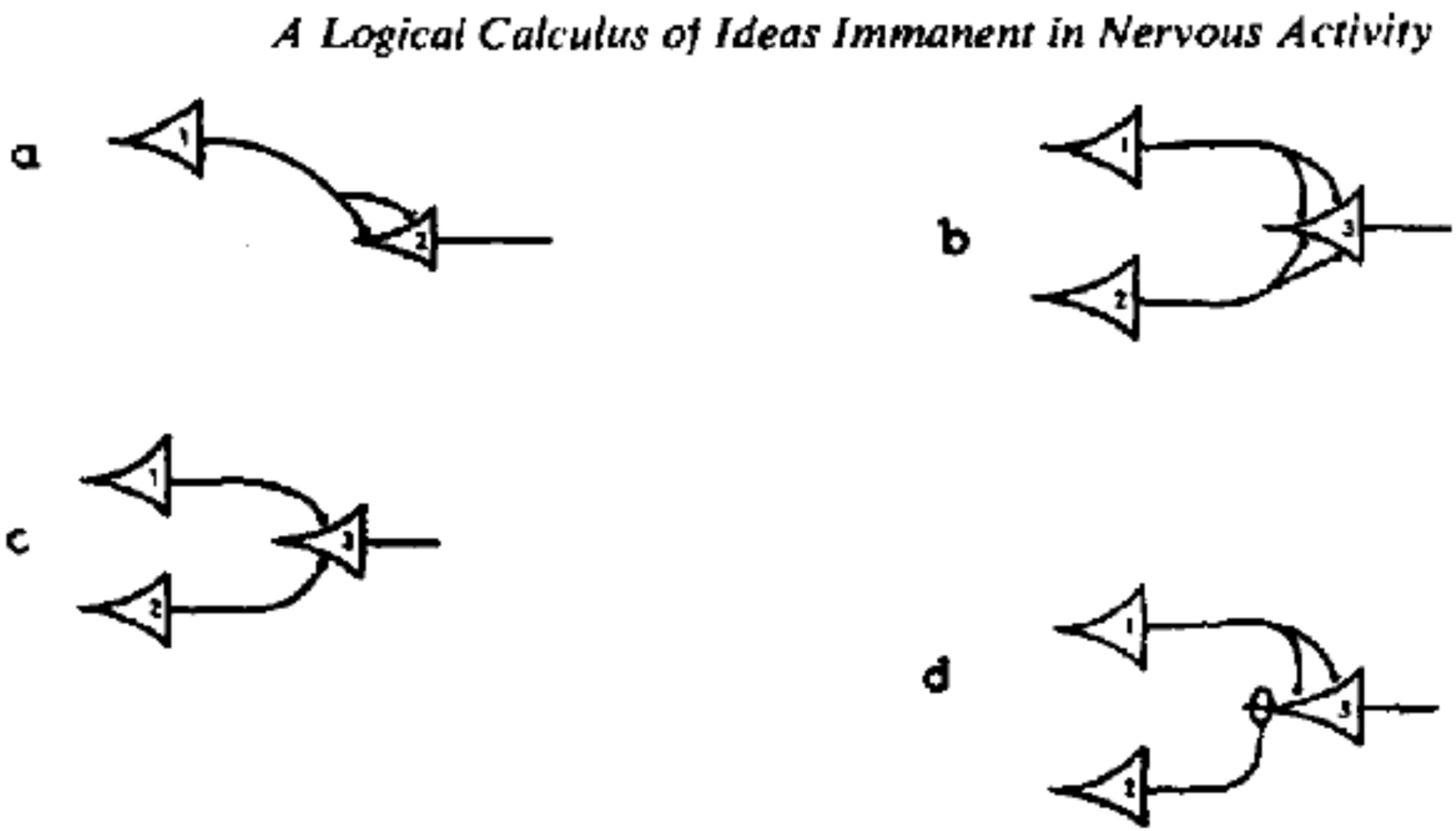
Neural networks…

The neuron



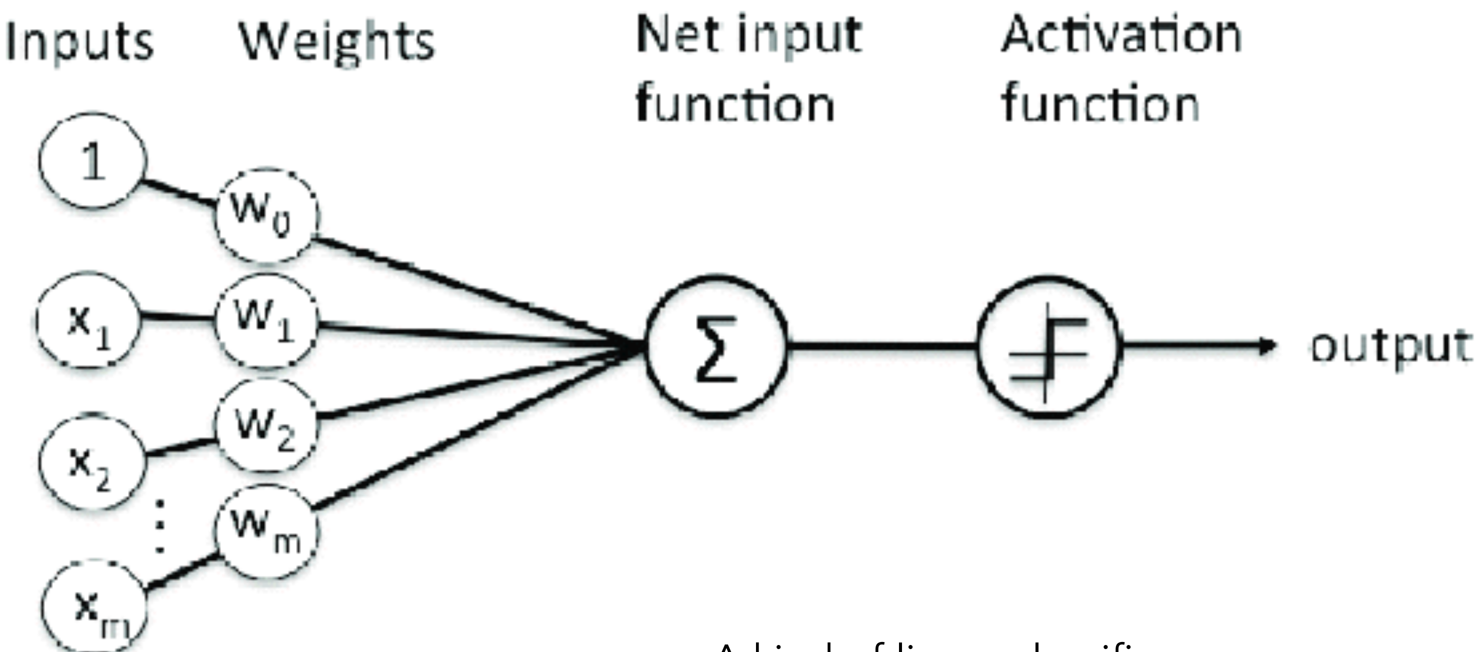
https://commons.wikimedia.org/wiki/File:Neuron.svg

The logic of neuronal calculation



McCulloch & Pitts, *Bulletin of Mathematical Biophysics*, 1943

The perceptron, an abstraction of neuronal calculation

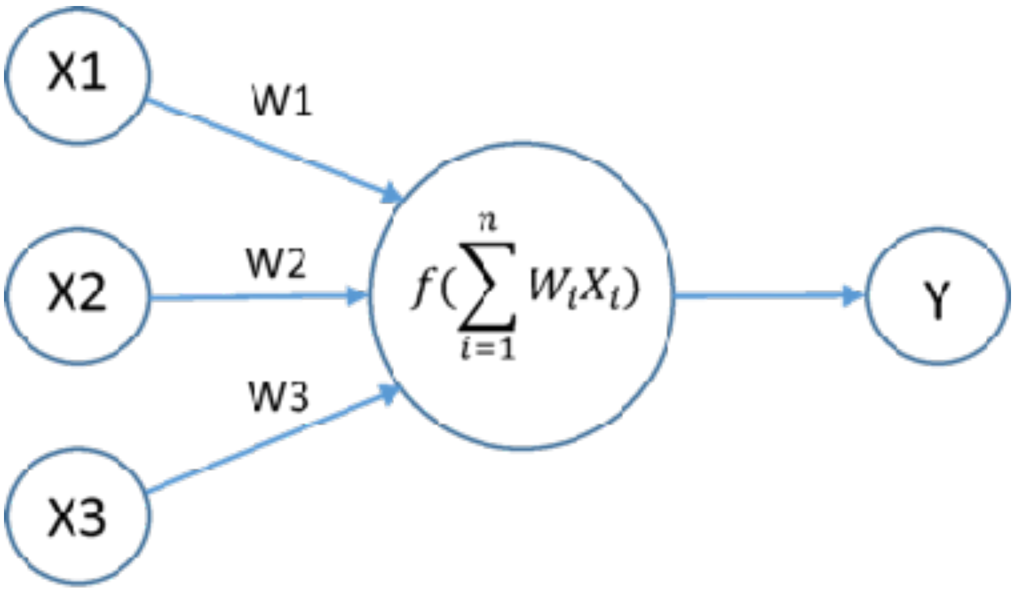


A kind of linear classifier

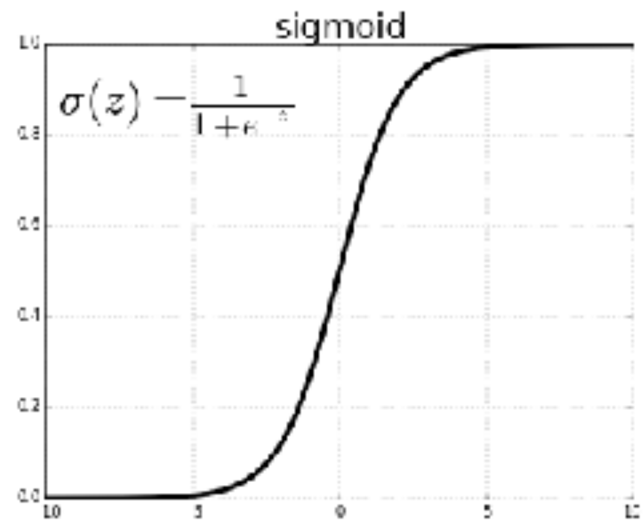
Rosenblatt, *Psychological Review*, 1958

A (mathematical) description of the perceptron

Neural network



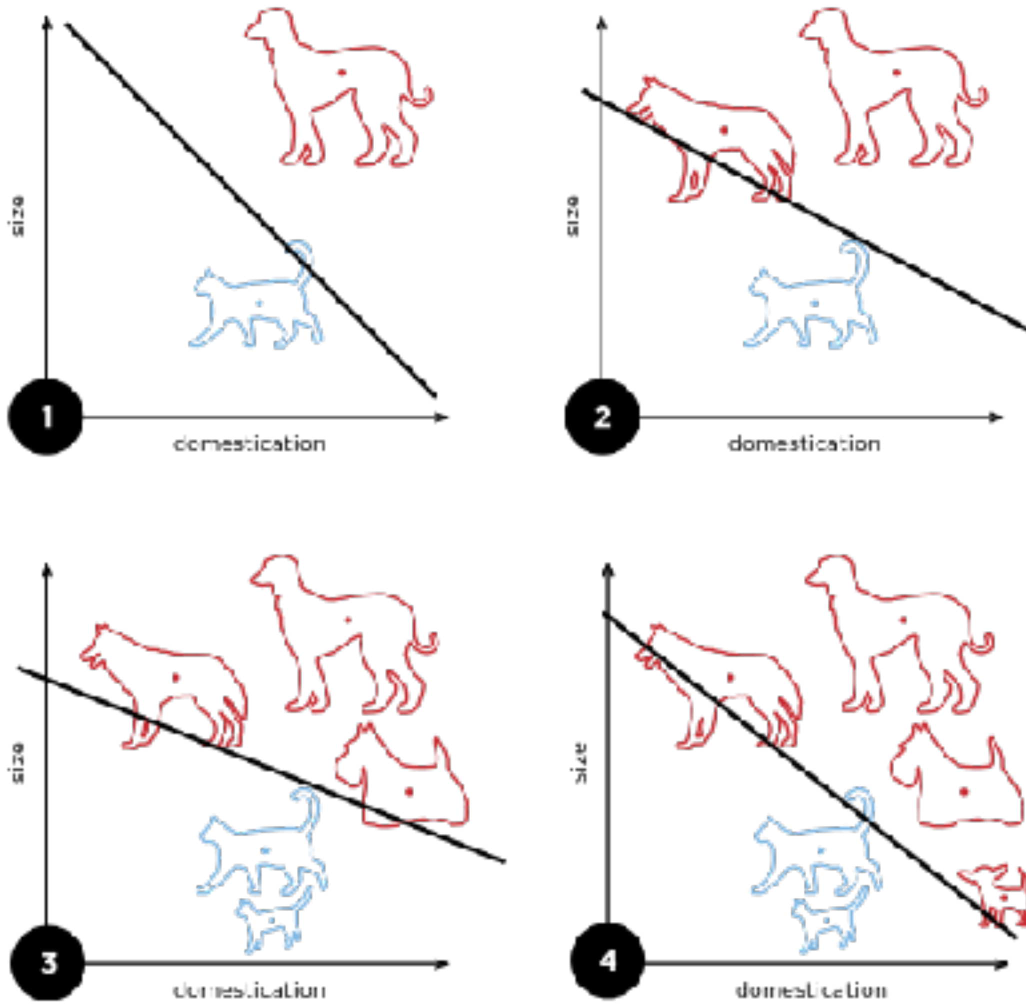
Activation function



A kind of linear classifier

https://medium.com/@UdacityINDIA/how-to-build-your-first-neural-network-with-python-6819c7f65dbf

Shallow networks perform linear classification

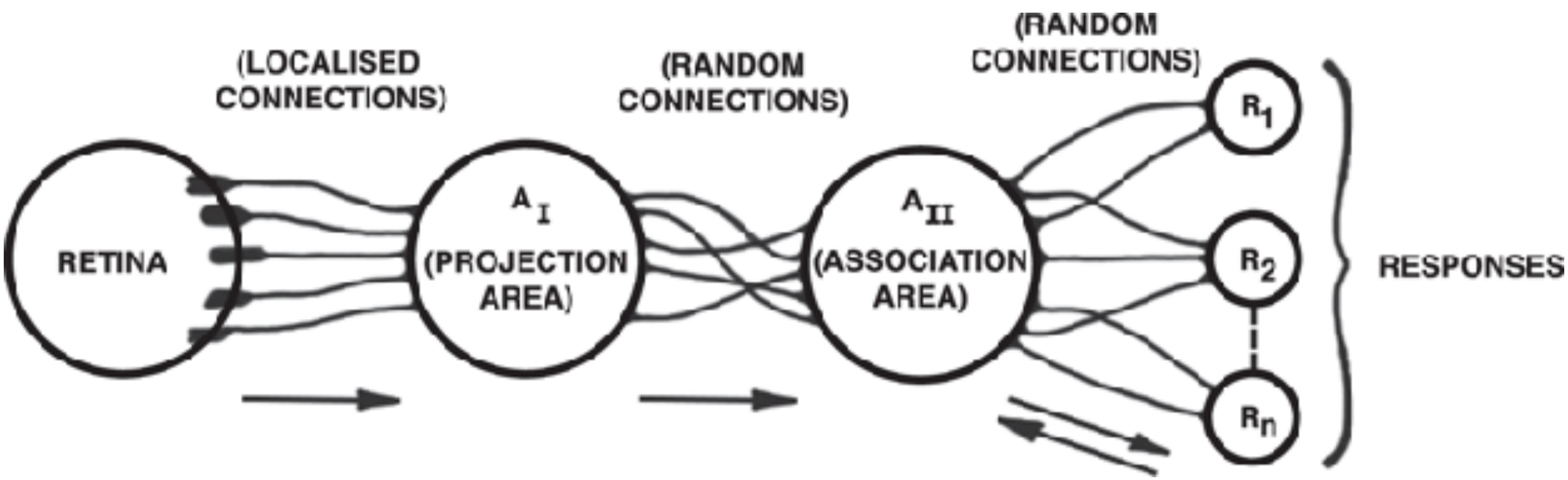


https://en.wikipedia.org/wiki/Perceptron

Inspiration by the visual system

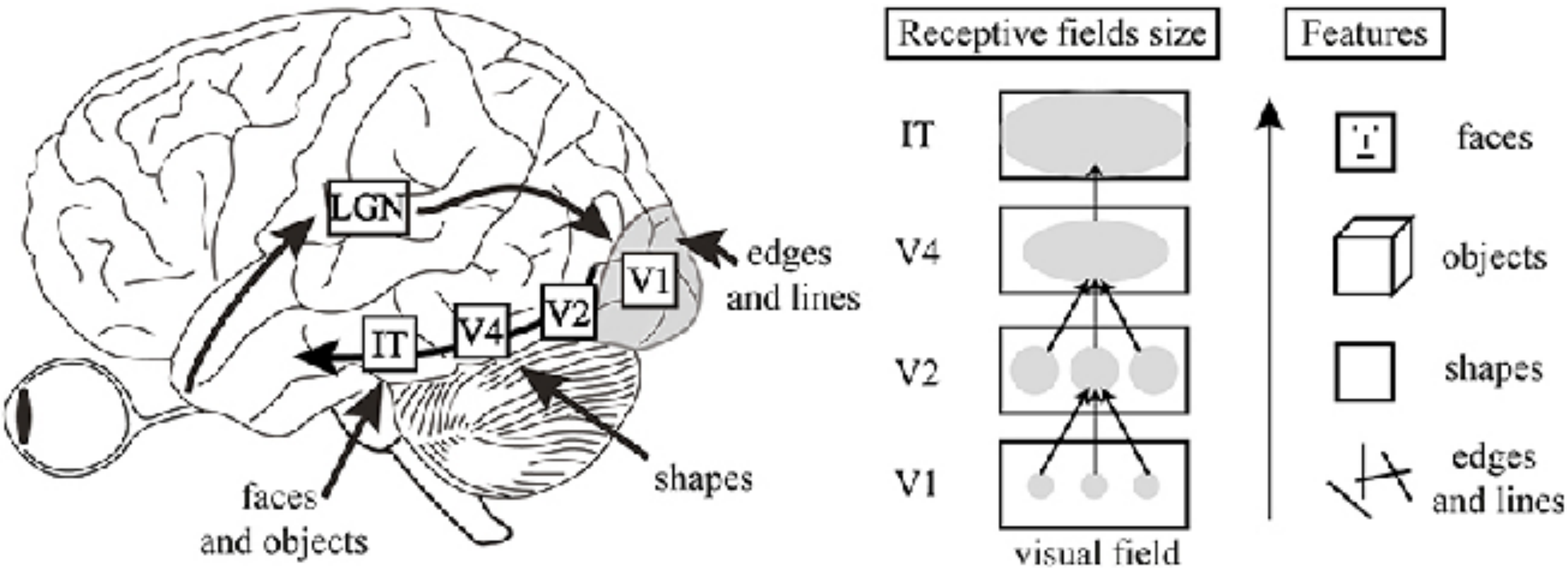
THE PERCEPTRON: A PROBABILISTIC MODEL FOR INFORMATION STORAGE AND ORGANIZATION IN THE BRAIN[1]

F. ROSENBLATT



Rosenblatt, *Psychological Review*, 1958

Neural layers transform visual information

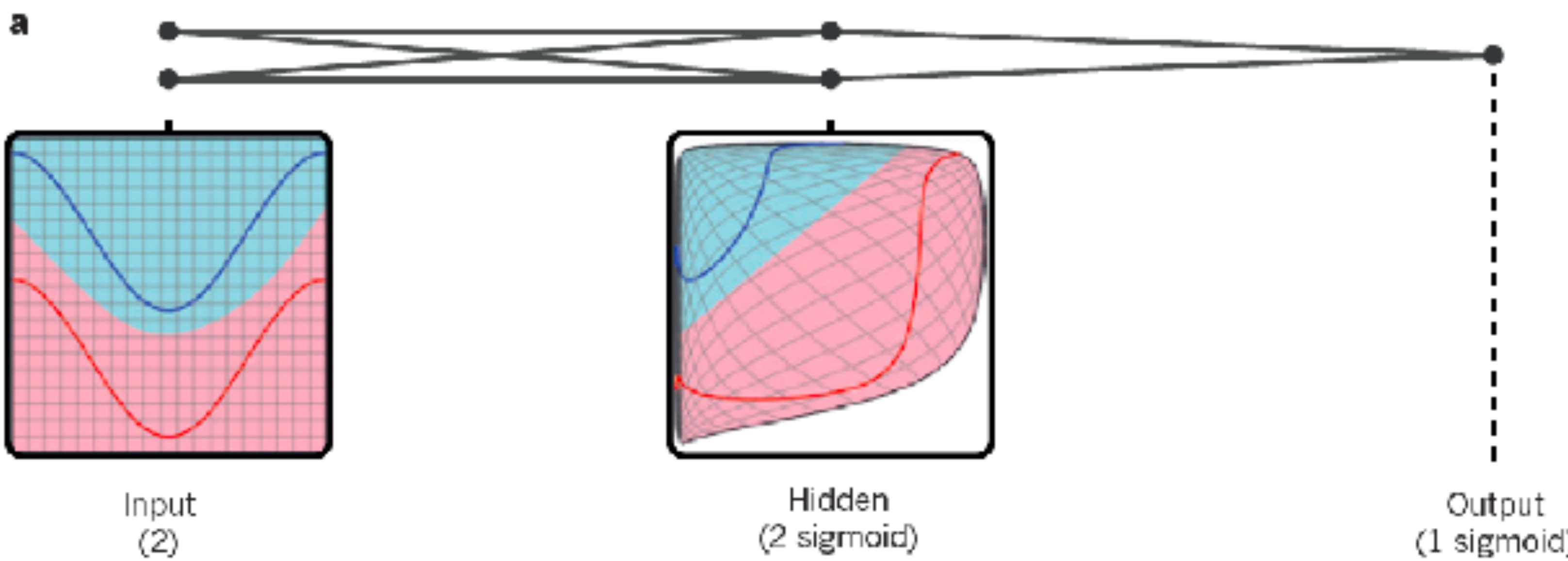


Herzog & Clarke, *Frontiers in Computational Neuroscience*, 2014

Deep networks perform nonlinear classification

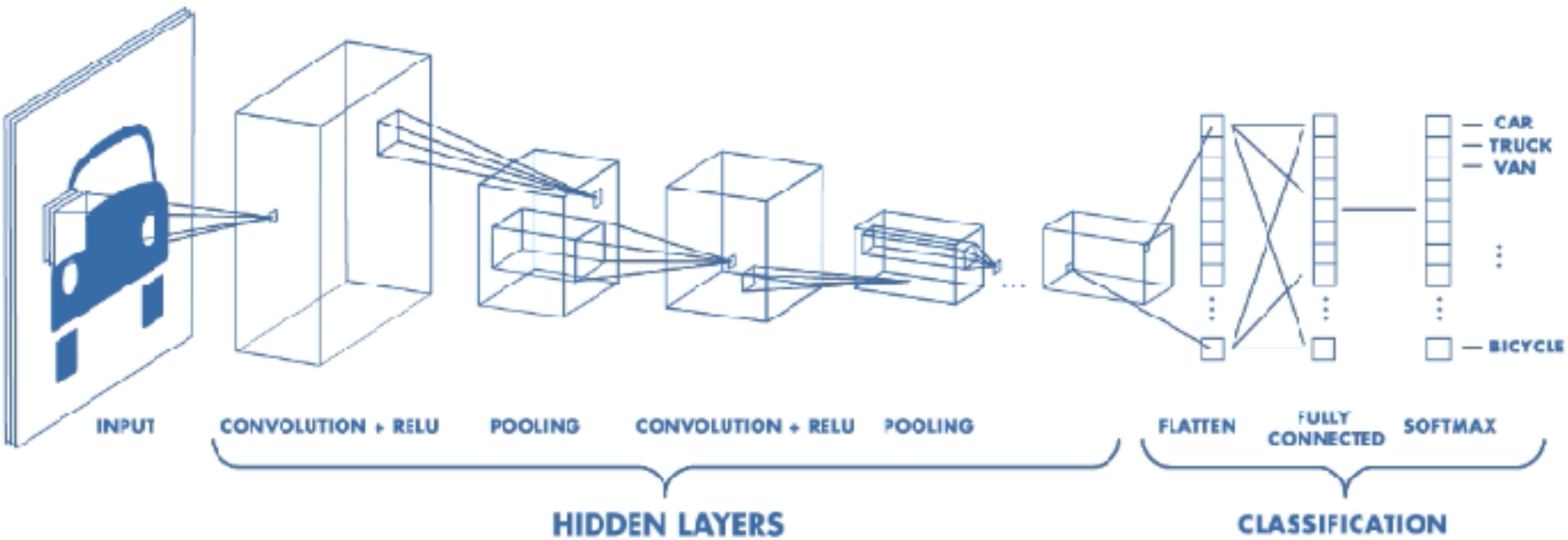
Deep learning

Yann LeCun[1,2], Yoshua Bengio[3] & Geoffrey Hinton[4,5]



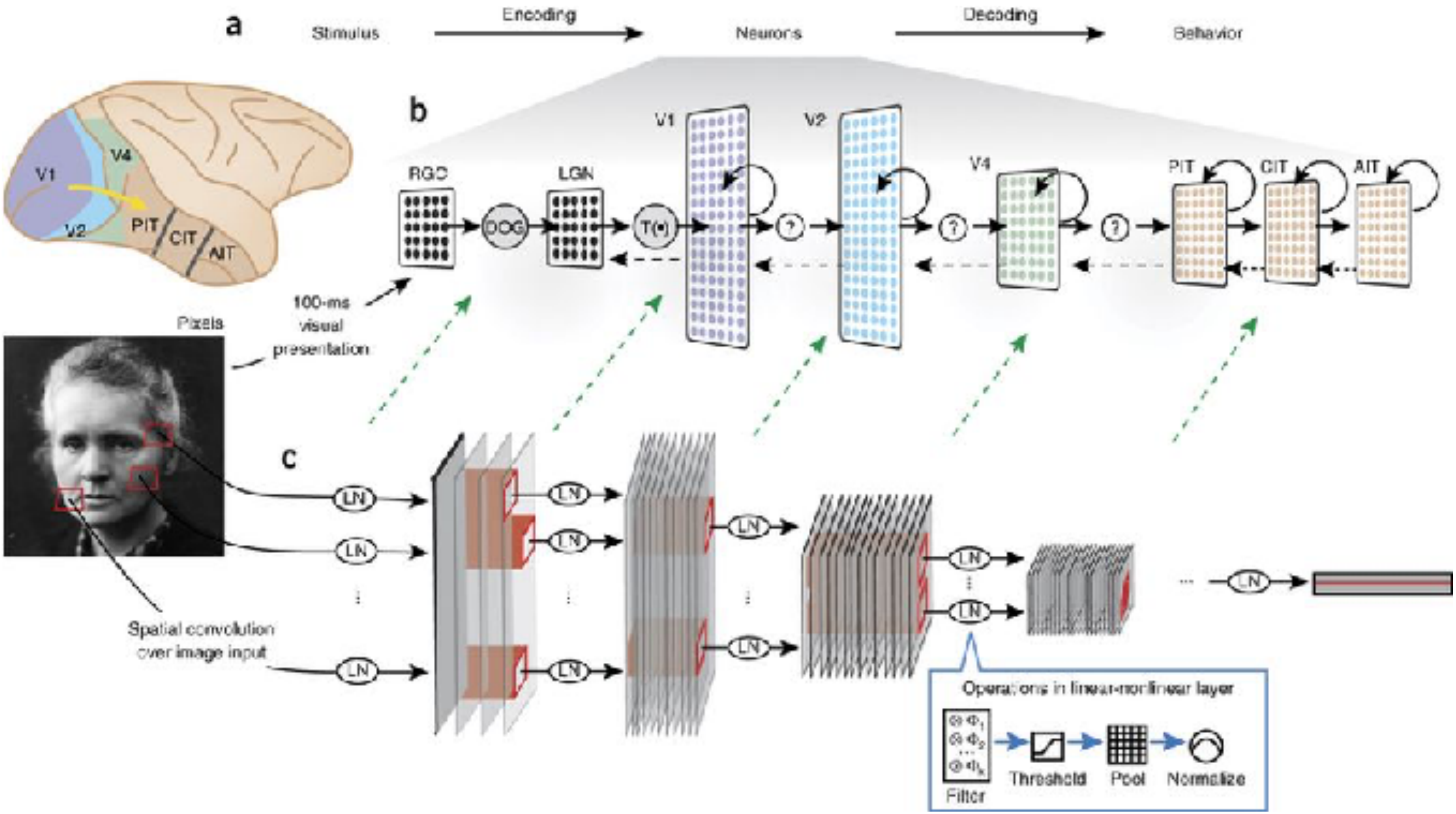
LeCun, Bengio, & Hinton, *Nature* 2015

Deep convolutional networks perform classification



https://medium.freecodecamp.org/an-intuitive-guide-to-convolutional-neural-networks-260c2de0a050

Using deep networks to understand the brain

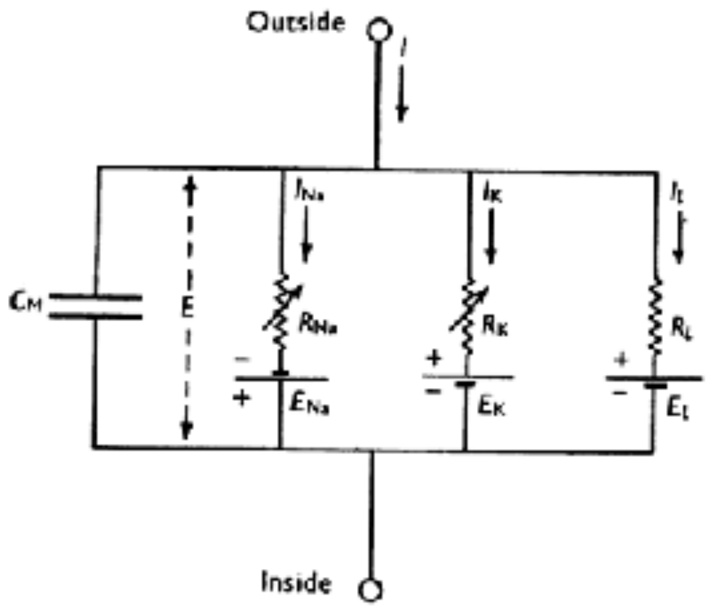


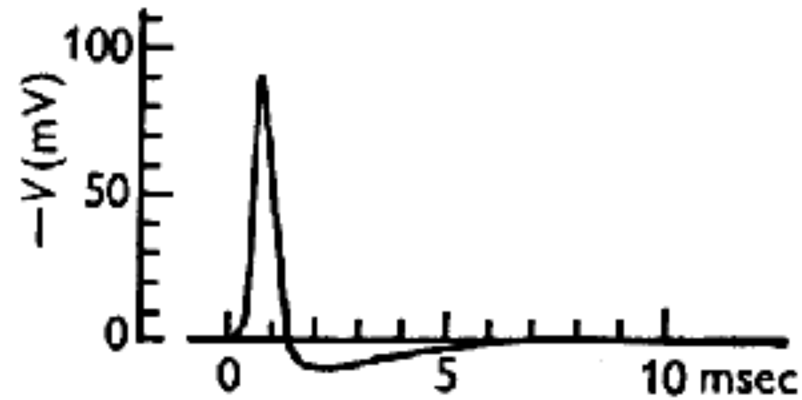
Yamins & DiCarlo, *Nature Neuroscience*, 2016

More realistic biophysical models of the neuron

A QUANTITATIVE DESCRIPTION OF MEMBRANE CURRENT AND ITS APPLICATION TO CONDUCTION AND EXCITATION IN NERVE

By A. L. HODGKIN and A. F. HUXLEY



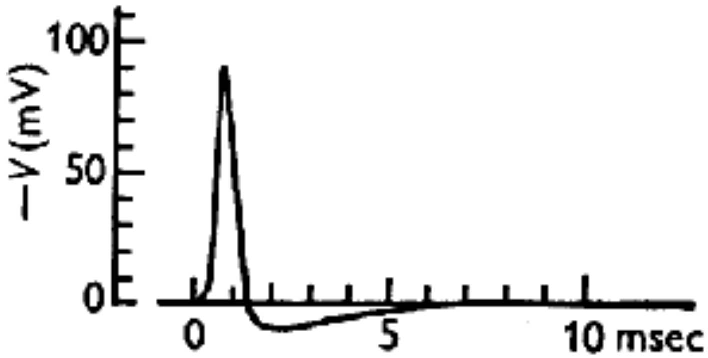


$$I = C_M \frac{dV}{dt} + \bar{g}_K n^4 (V - V_K) + \bar{g}_{Na} m^3 h (V - V_{Na}) + \bar{g}_l (V - V_l),$$

Hodgkin & Huxley, *Journal of Physiology*, 1952

Levels of abstraction in neural networks

Detailed models



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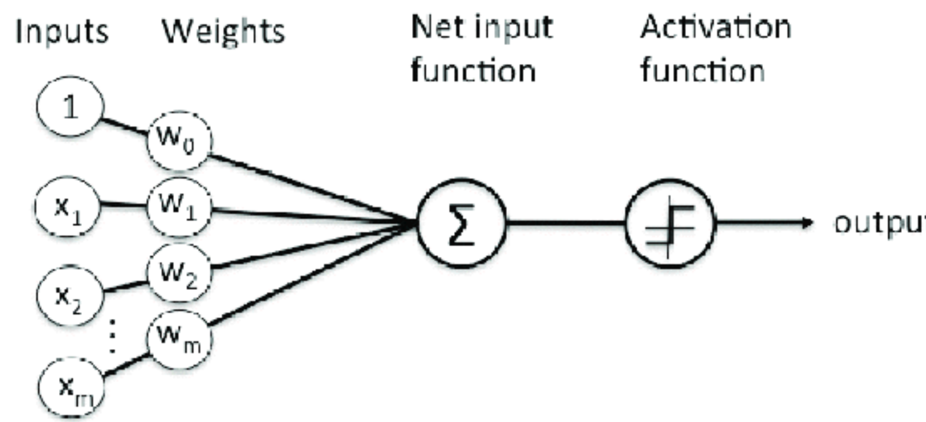
Abstracted models



Pros:

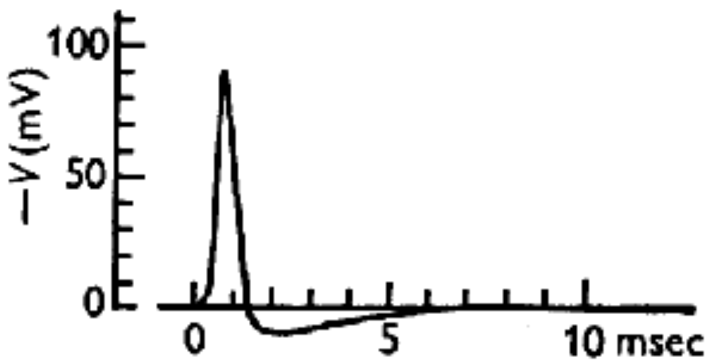
Cons:

Pros:

Cons:

Levels of abstraction in neural networks

Detailed models



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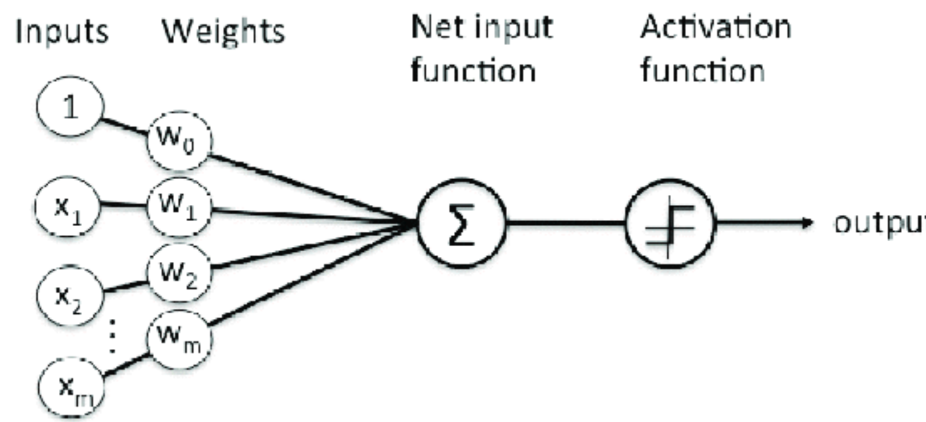
Abstracted models



Pros: Fine-grained biological insight

Cons: Computationally intensive

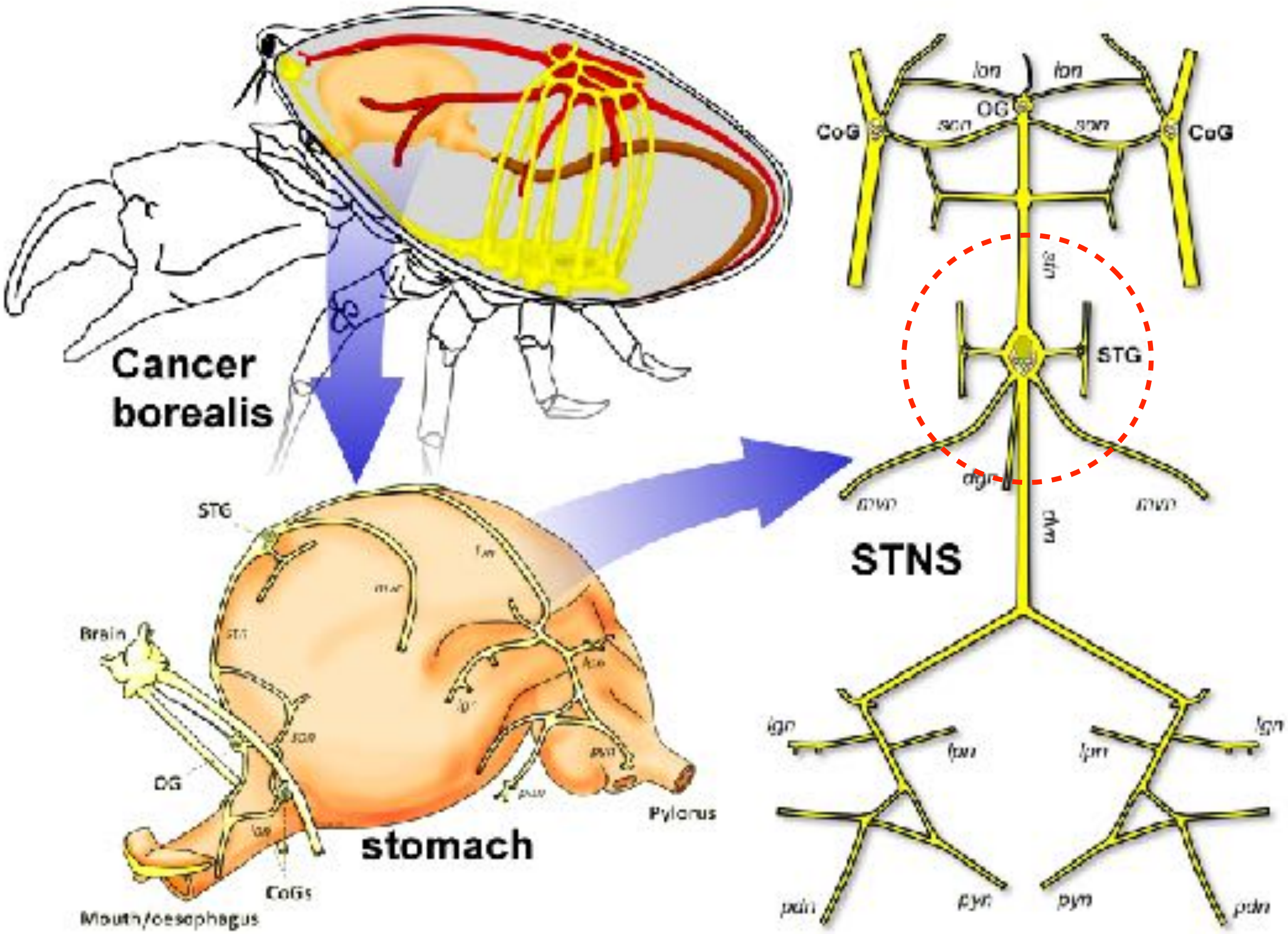
Pros: Real-world applications

Cons: Limited biological insight

Any questions?

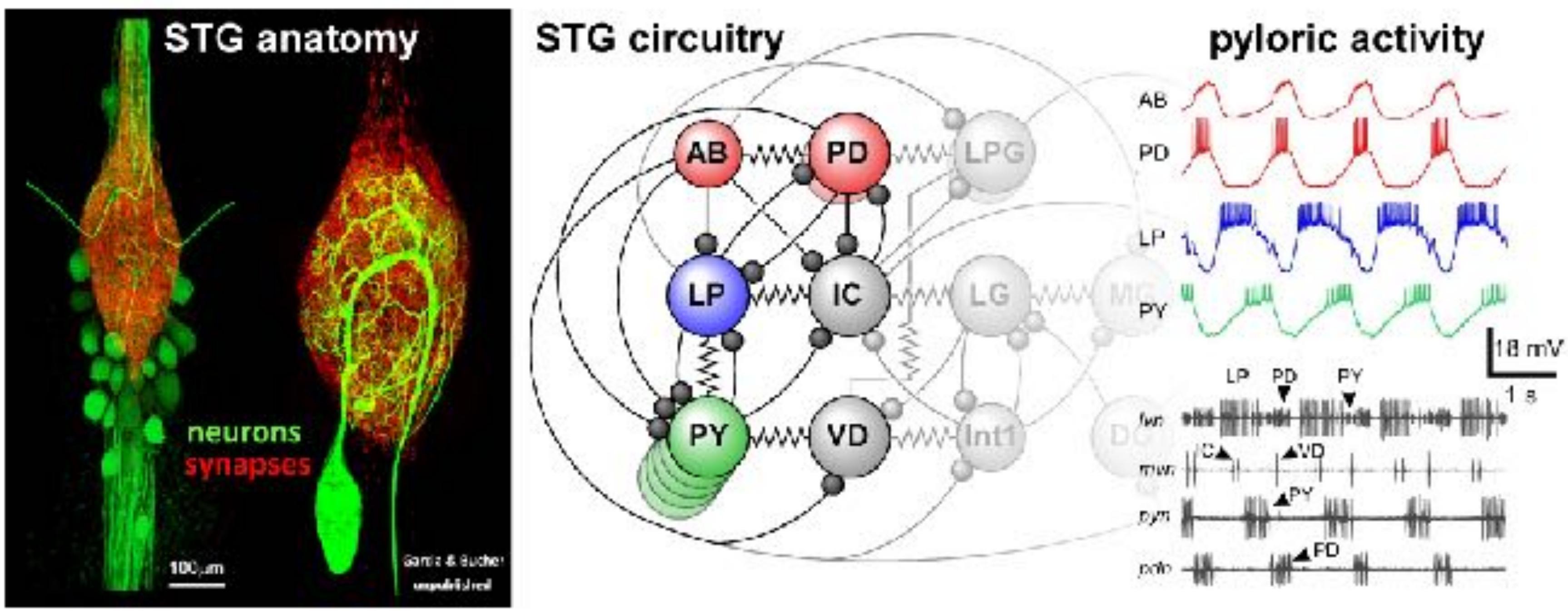
A cautionary tale about networks…

The crustacean stomatogastric ganglion (STG)



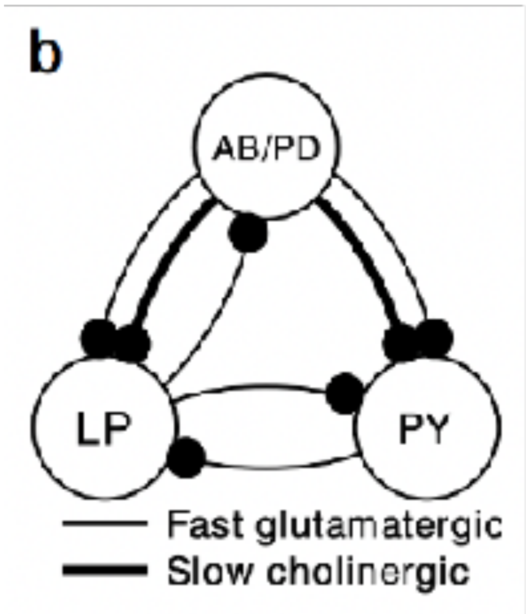
STG Lab (Nadim, Golowasch, & Bucher)

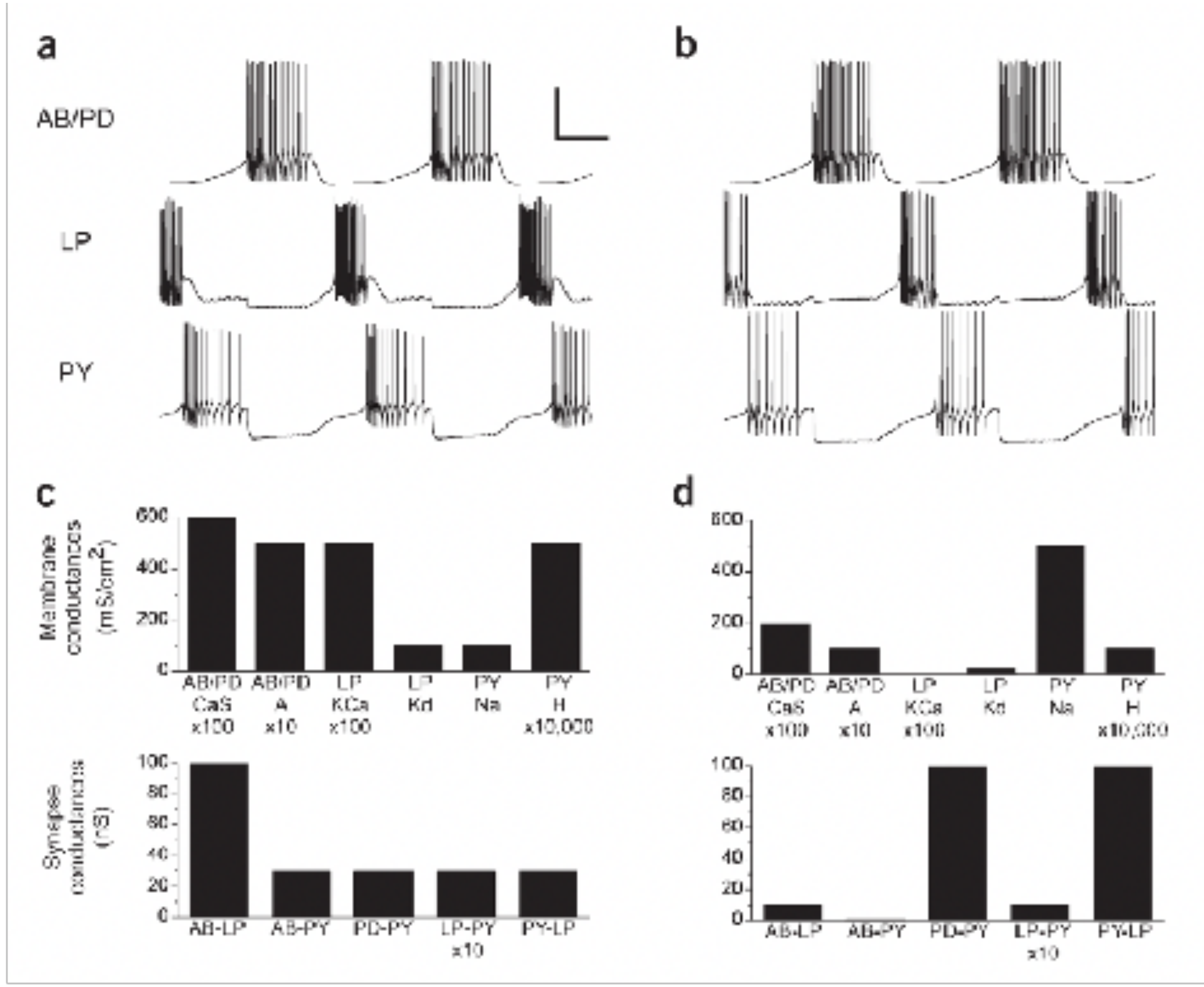
The crustacean stomatogastric ganglion (STG)



STG Lab (Nadim, Golowasch, & Bucher)

Different networks generate **similar** pyloric rhythms





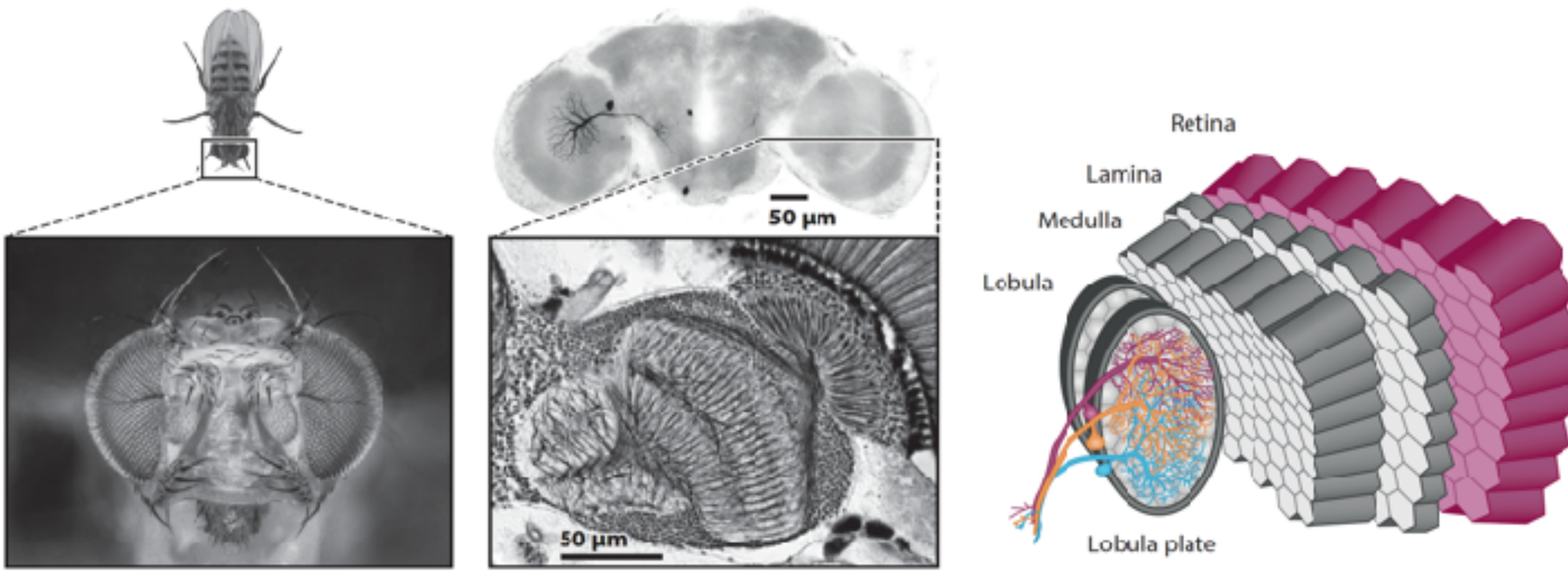
See also the **Universal Approximation Theorem** for neural networks

Prinz et al., *Nature Neuroscience* 2006

Any questions?

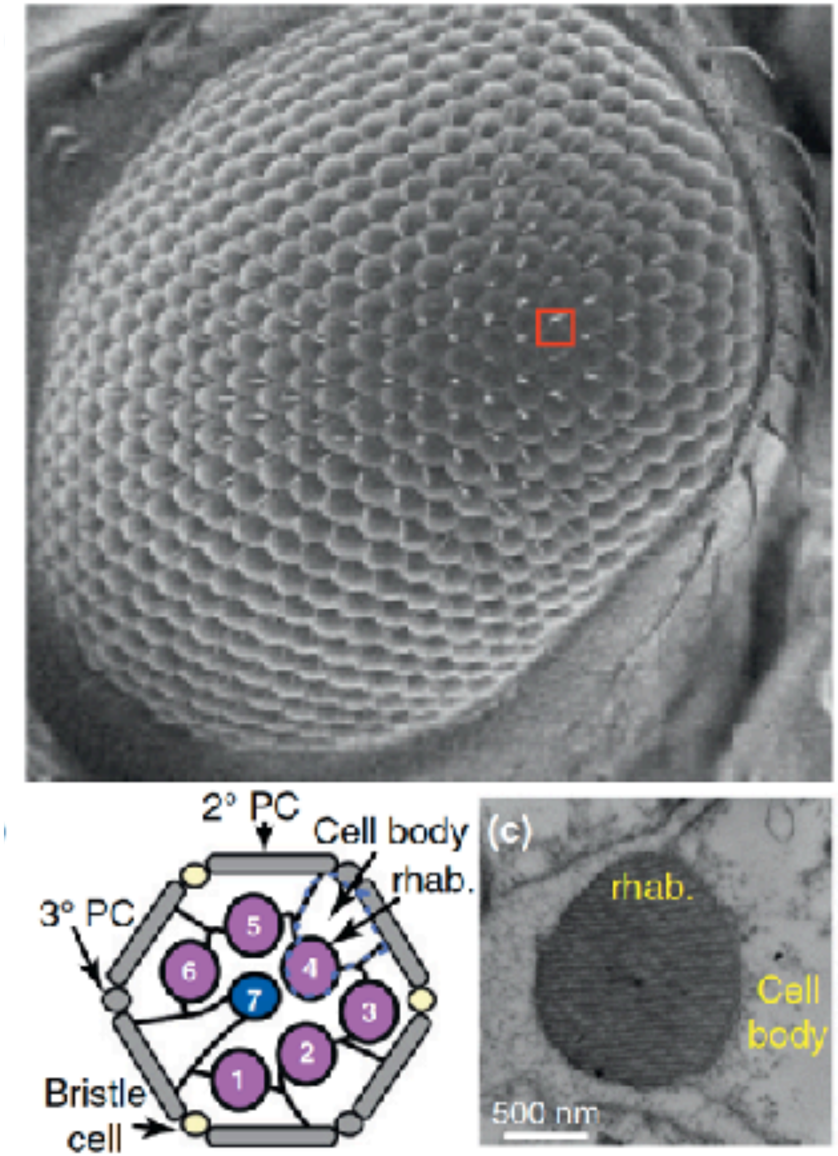
Fly vision…

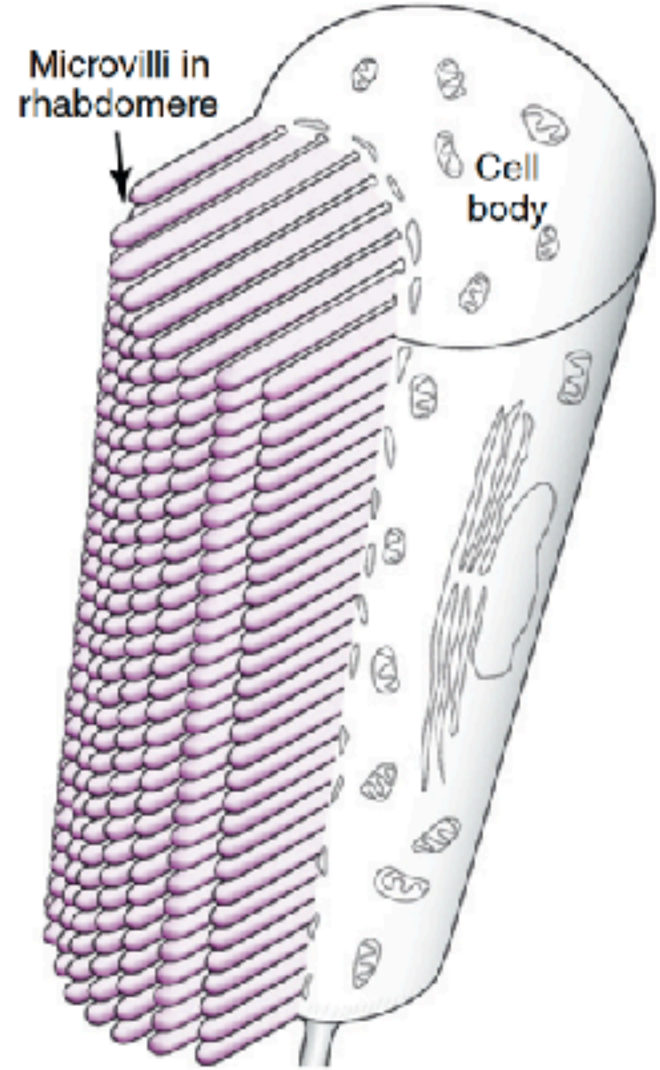
The compound eye



Borst & Groschner, *Annual Review of Neuro.* 2023

Phototransduction in the retina and ommatidia

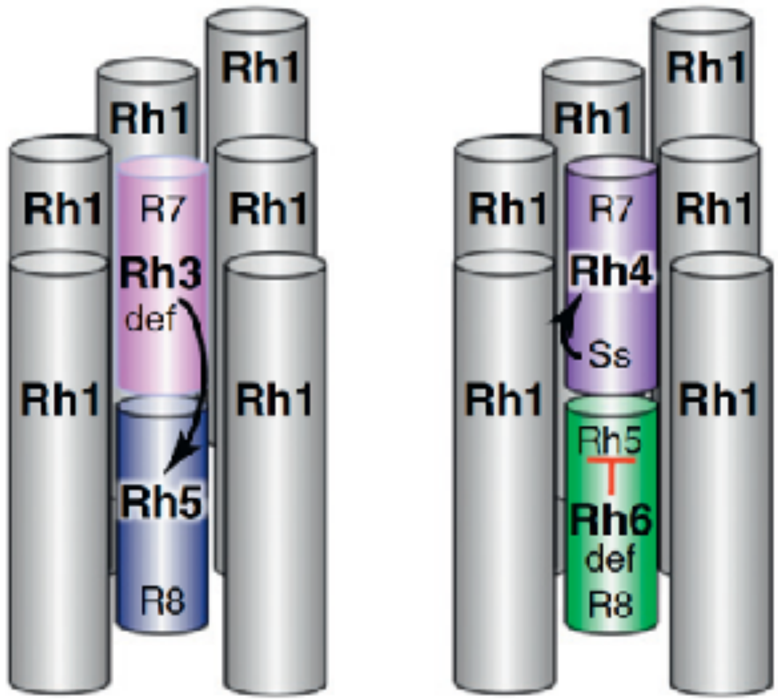




Montell, *Trends in Neuro.* 2012

Phototransduction in the retina and ommatidia

Rhodopsin	Expression pattern	Peak sensitivity rhodopsin (nm)	Peak sensitivity metarhodopsin (nm)
Rh1	R1–R6	~486	~566
Rh2	Ocelli	~418	~506
Rh3	R7 (~30%)	~331	~468
Rh4	R7 (~70%)	~355	~470
Rh5	R8 (~30%)	~442	~494
Rh6	R8 (~70%)	~515	~468
Rh7	?	?	?

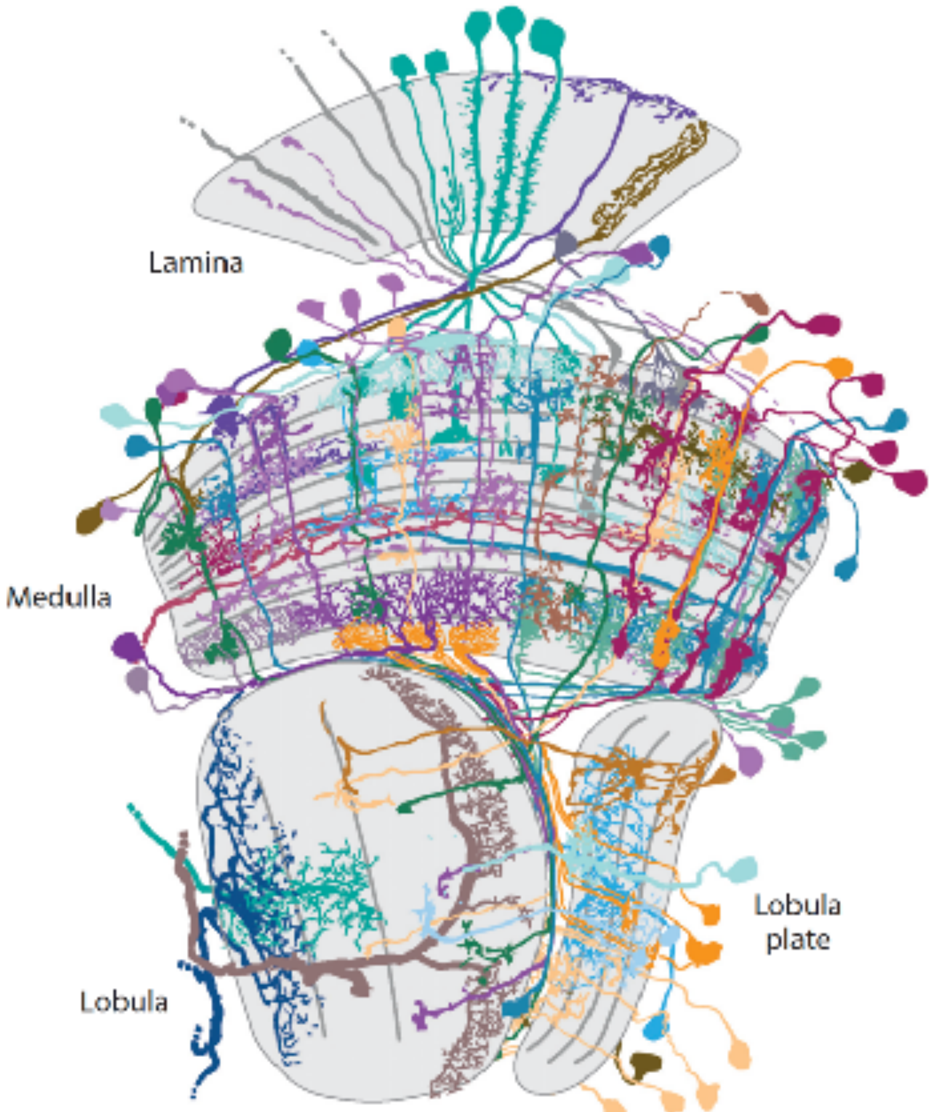


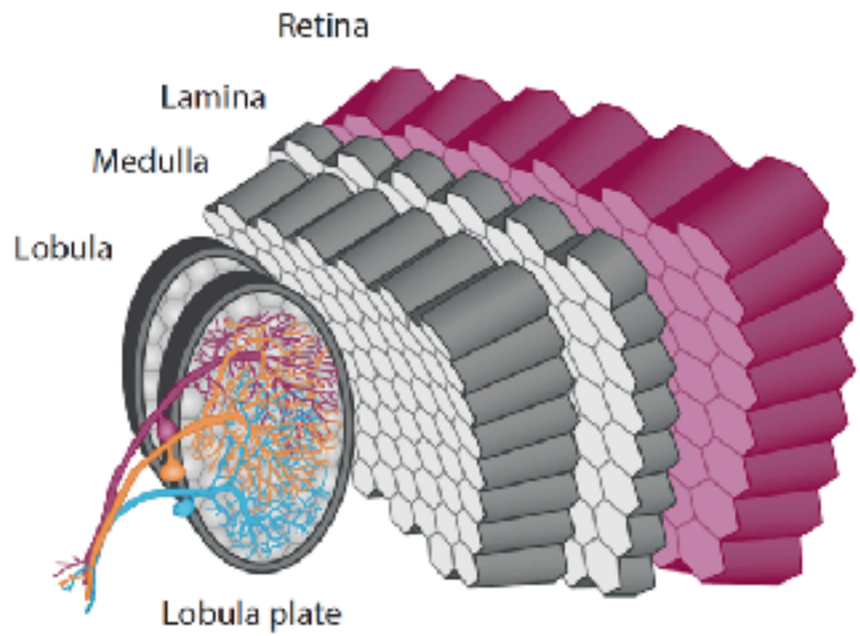
Pale ommatidia
~30%

Yellow ommatidia
~70%

Montell *Trends in Neuro.* 2012

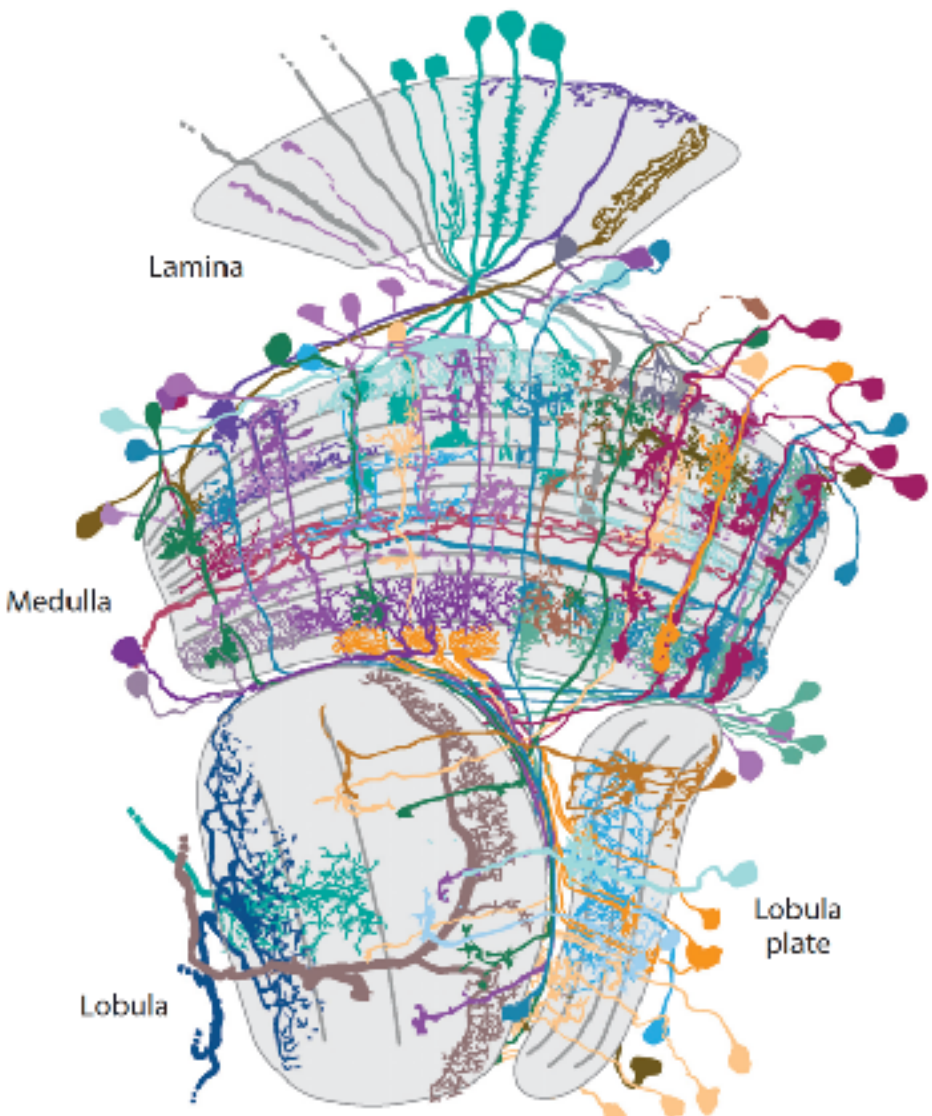
The optic lobe

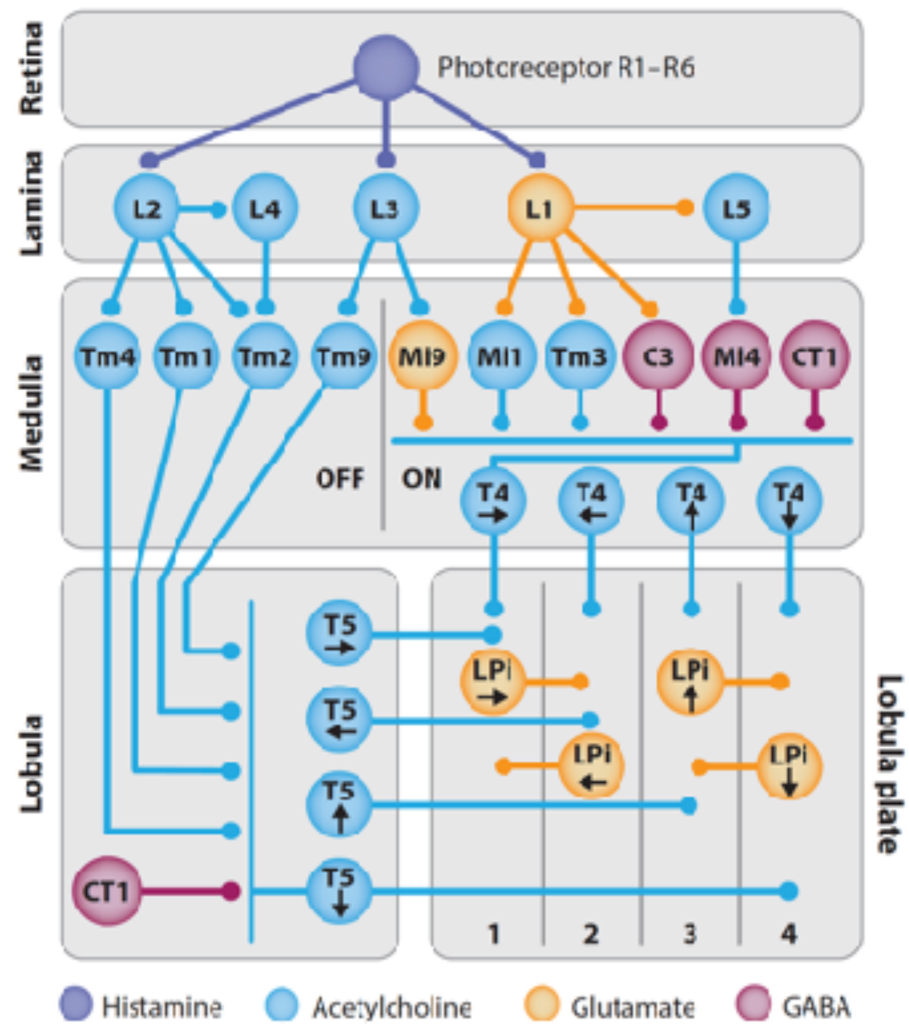




Borst & Groschner, *Annual Review of Neuro.* 2023

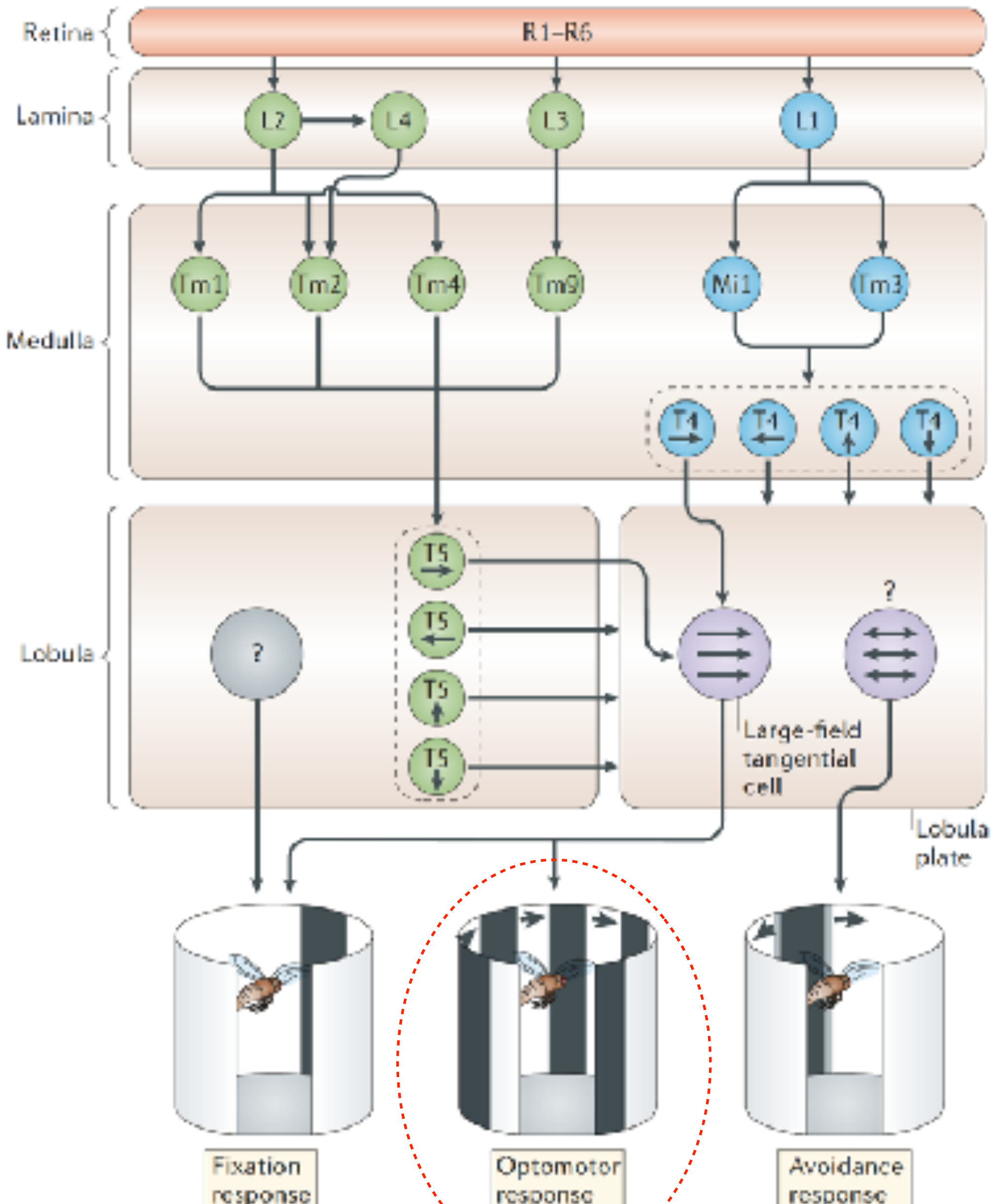
The optic lobe





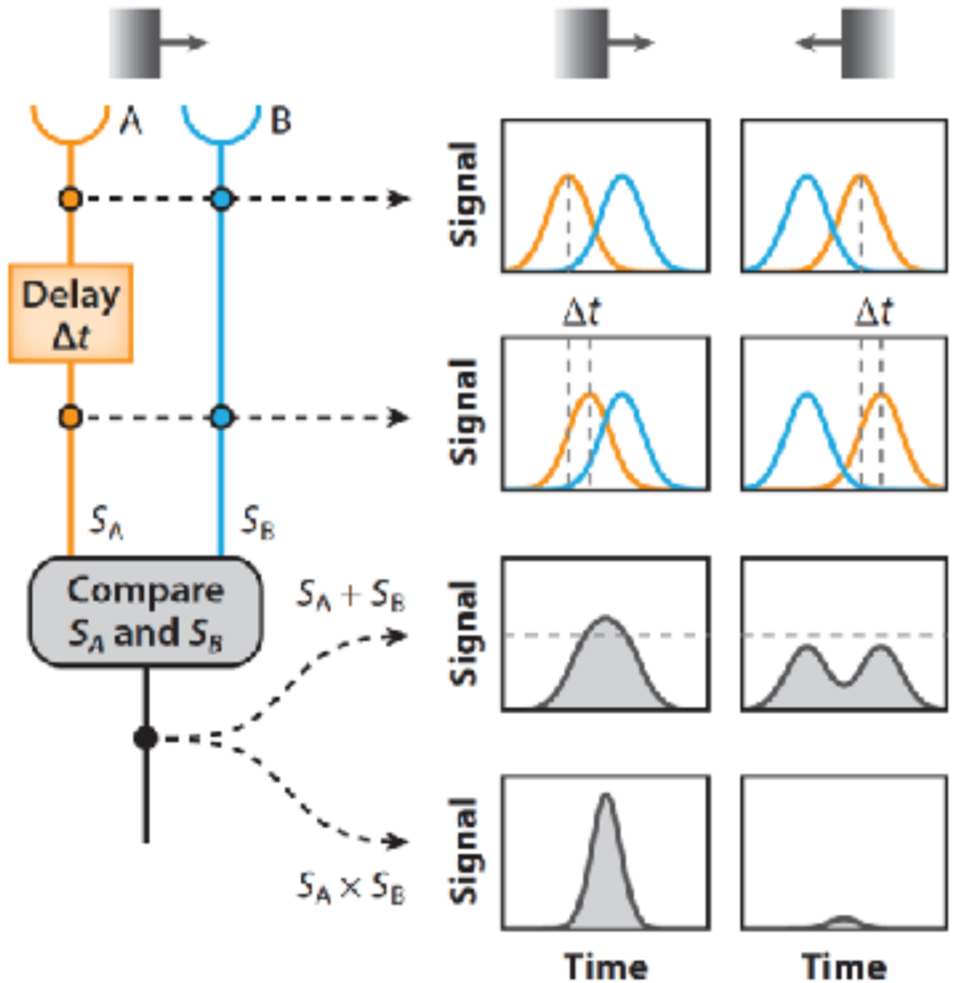
Borst & Groschner, *Annual Review of Neuro.* 2023

Vision in action: the optomotor response



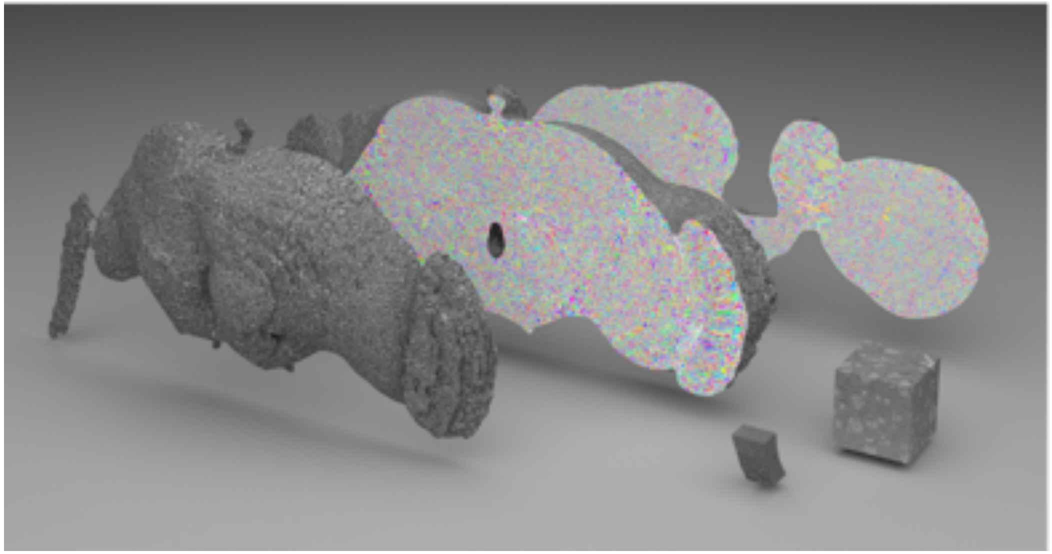
Borst, *Nature Reviews Neuro.* 2014

The HRC: an abstract visual motion detector

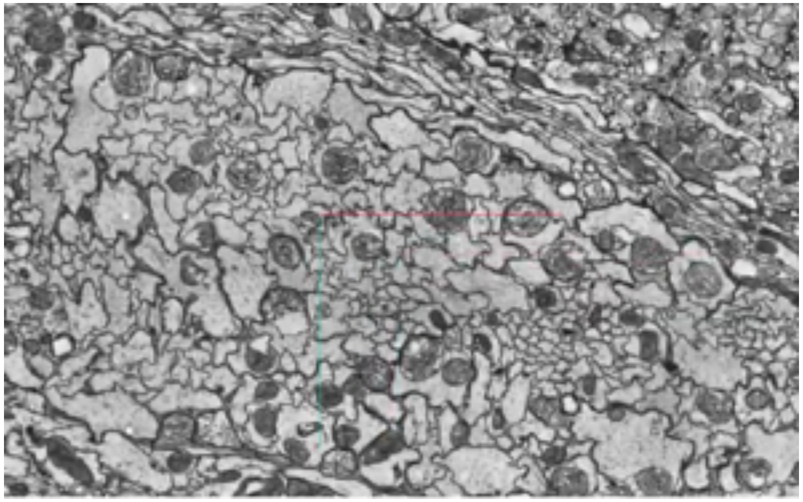


Borst & Groschner, *Annual Review of Neuro*. 2023

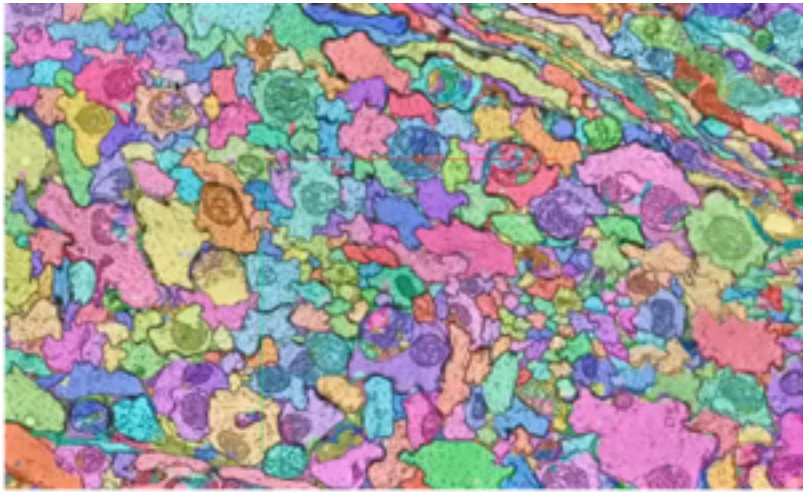
Connectomics



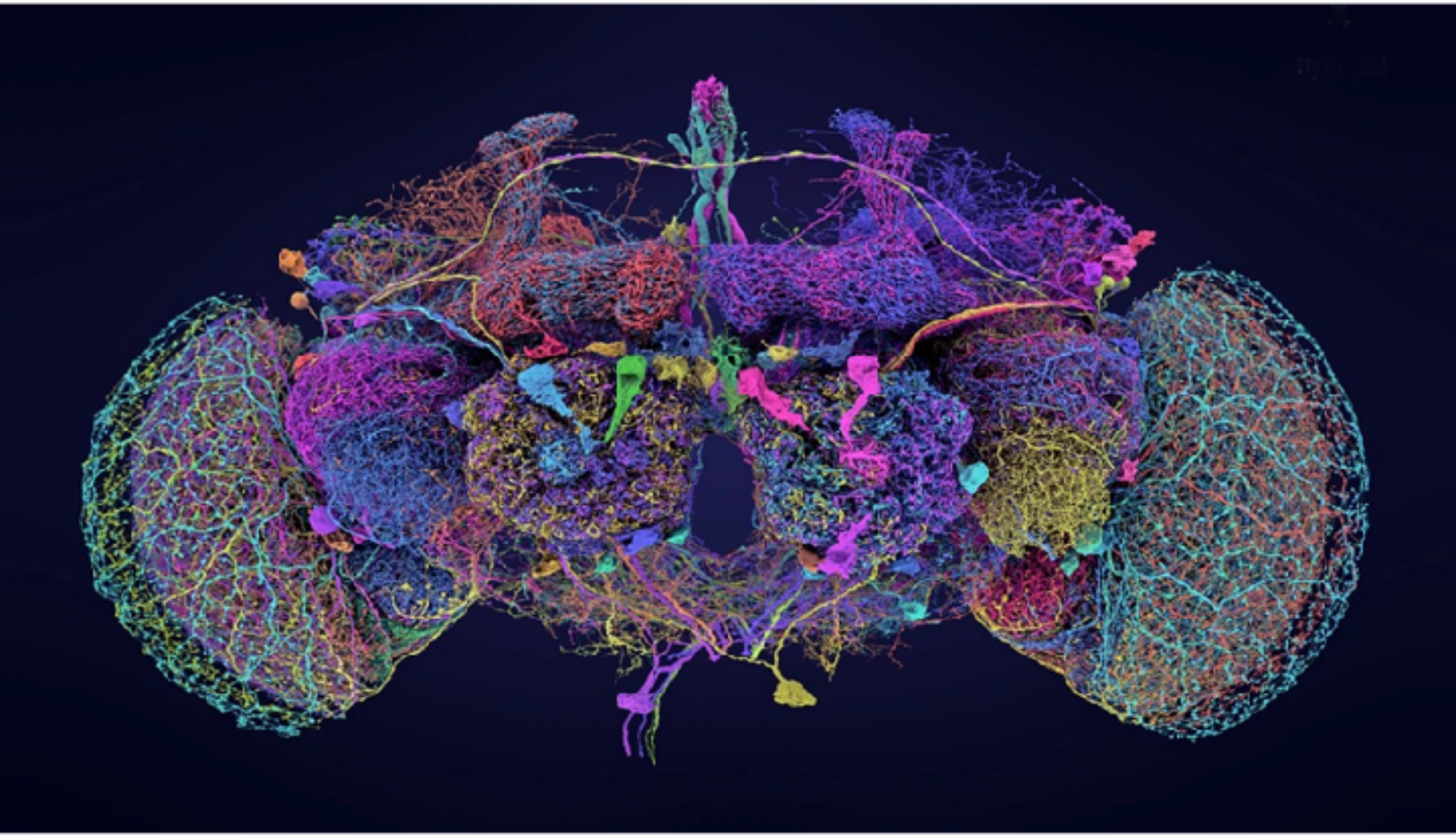
-High-throughput electron microscopy
-Automated neural tracing using human annotations and trained neural networks



Machine learning

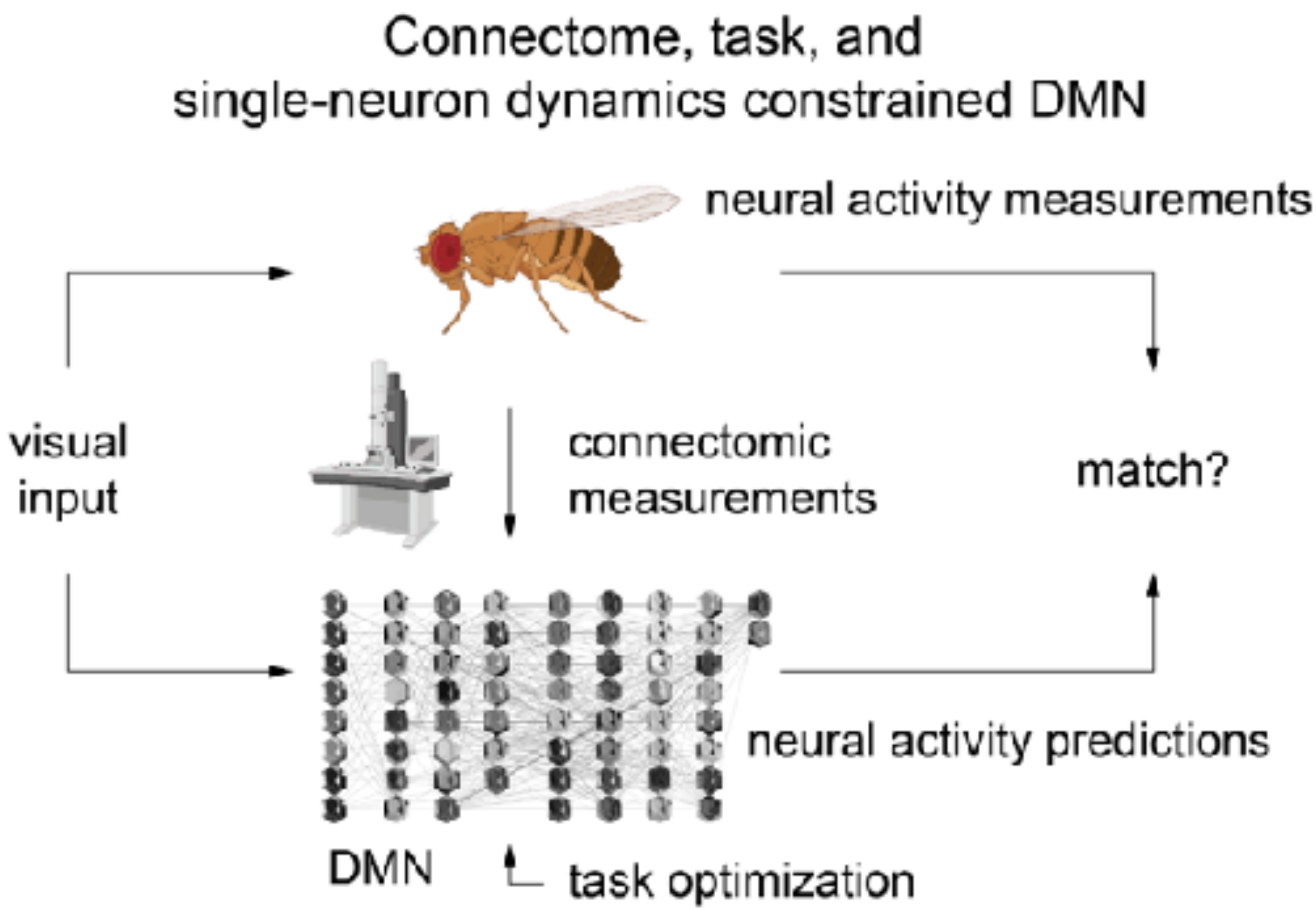


A complete connectome of the fly brain



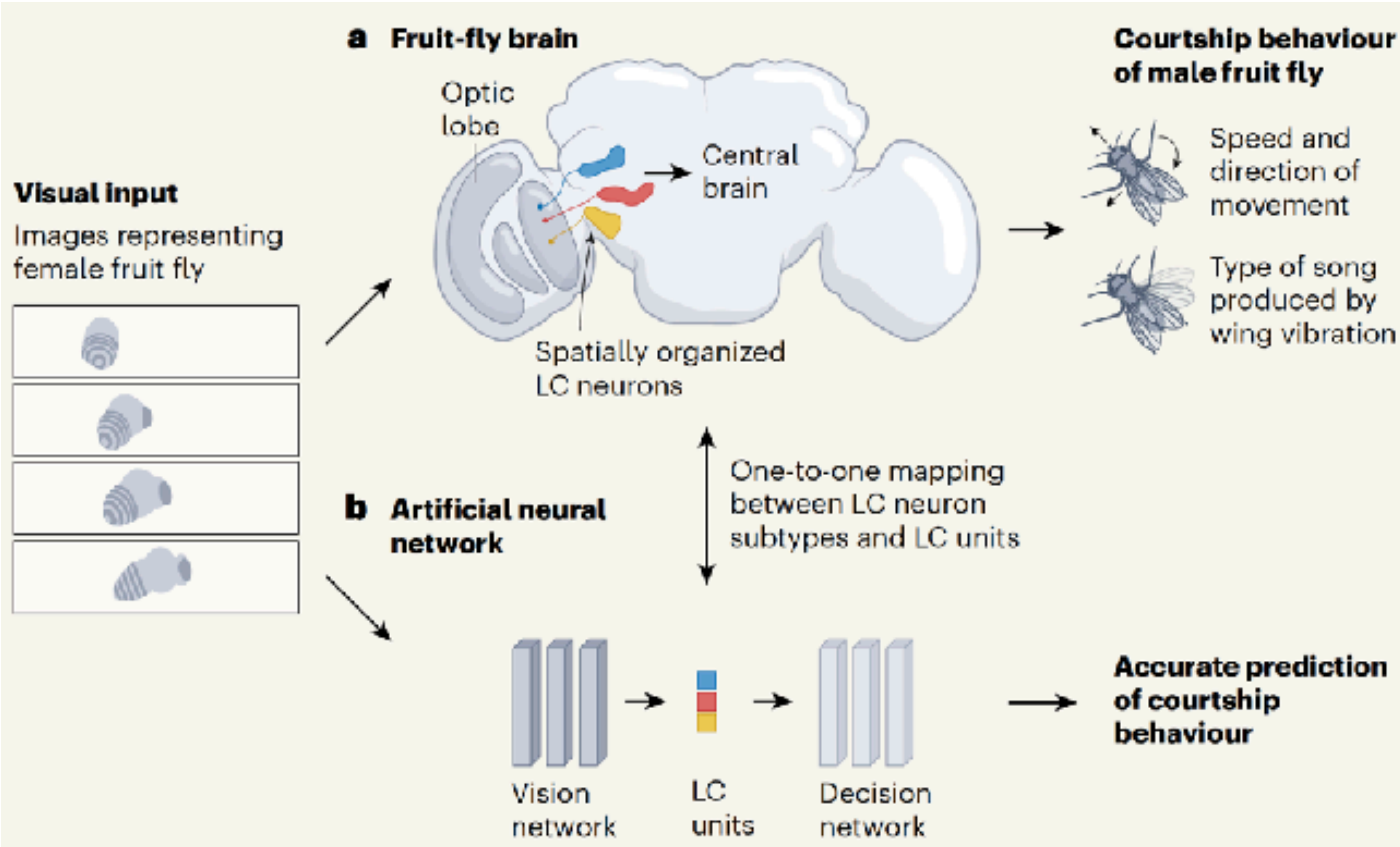
Dorkenwald et al., *Nature* 2024; Schlegel et al., *Nature* 2024

Paper 1: Connectome-constrained models of motion detection



Lappalainen, *Nature* 2024

Paper 2: One to one mapping between neuron types and artificial neurons



New and Views from Ramdya, *Nature* 2024

Any questions?

Journal Club papers