Biological Neural Networks

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A Reality Check about Biological Neurons.

- Biological Neural Networks differ enormously from Neural Networks. They are complex and poorly understood.
- Biological Neurons may be orders of magnitude more complex than AI Neurons. There have been speculations for over forty years.
- There is no biological neural system – even C Elegans with only 150 neurons – where we can successfully model the activity of neural circuits.
- We do not know the neural code and how neurons transmit information.
- We do not know the wiring diagrams of the neurons.
- This is am extremely important research area and progress is being made, but it is extremely difficult.

The anatomy of the retina is not simple.

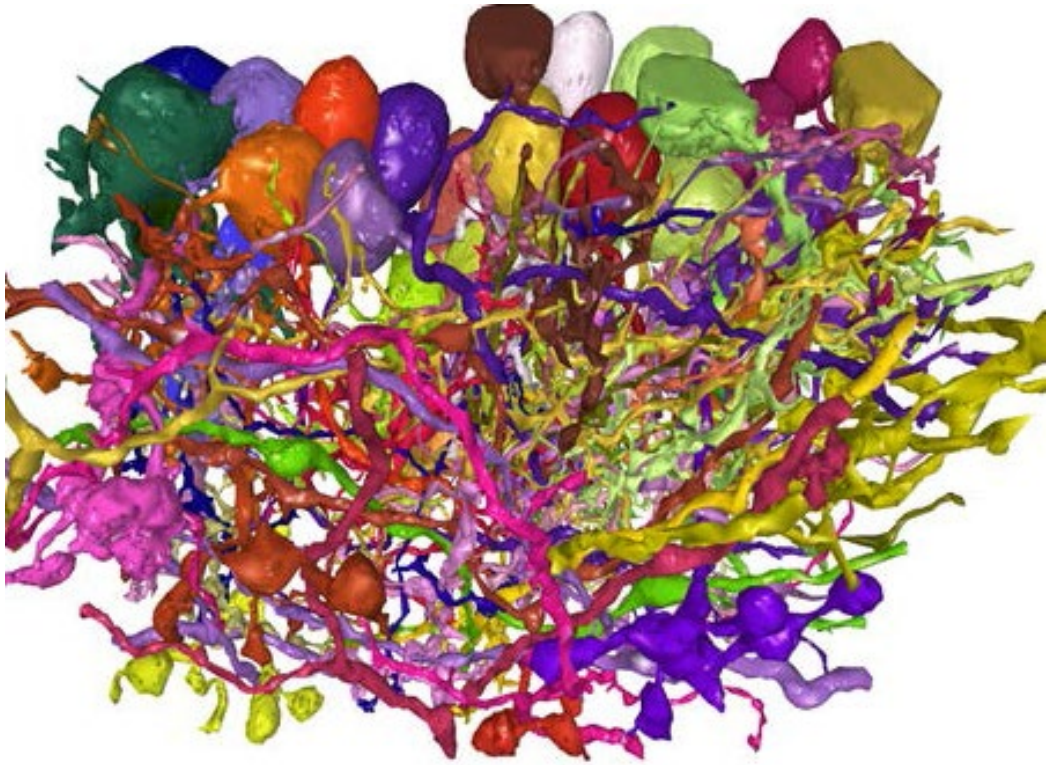
- The anatomical structure of the retina gets increasingly complex the more scientists study it in detail. (S. Seung. Connectonics).
- There are many different types of neurons when you consider their detailed anatomy (R. Masland). Seung recruited volunteers to label the three-dimensional structure of neurons in the retina.

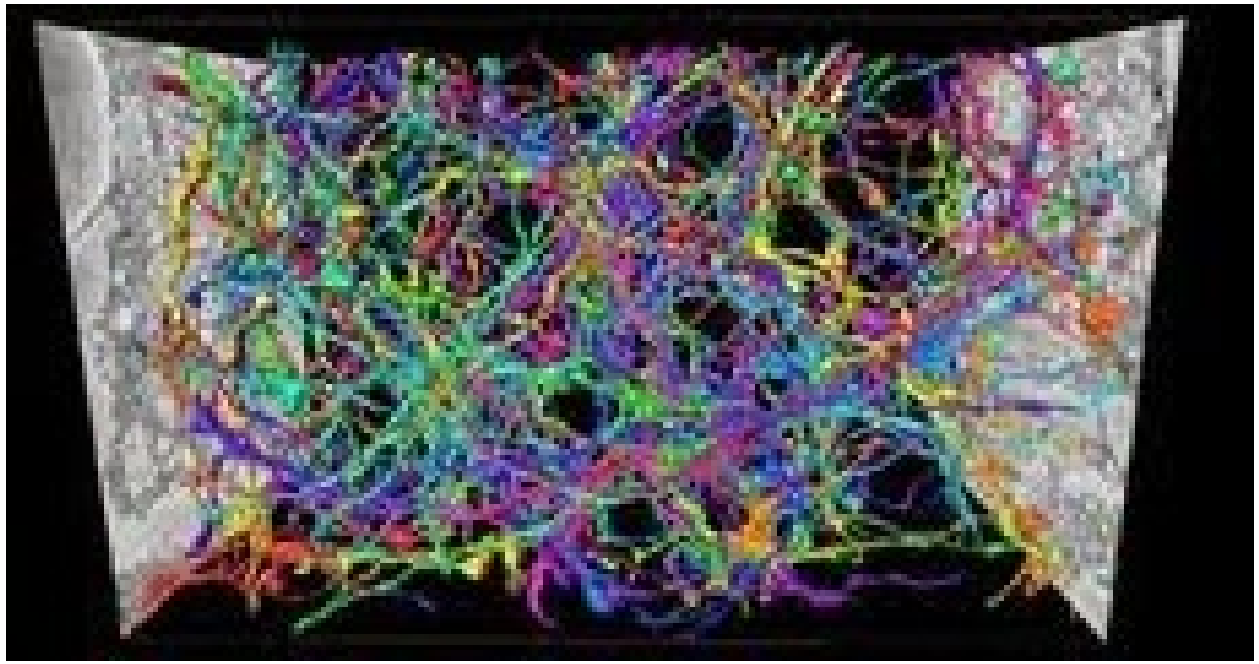
Anatomy of the Visual Cortex is more complex

- Scientists who study the visual cortex also find many different types of neurons (hundreds) the more they look into the details. Although many are pyramidal neurons.
- Labeling the 3D structure of neurons in brains is a fascinating research field which is becoming big science (Allen Institute, Kalvi Neuroscience Discovery Institute JHU, Janelia Research Campus).
- Watching videos of fly thoughs of the brain is like watching a simulation of galaxies with billions and billions of stars. *But the interactions between biological neurons is enormously more complex than interactions between stars.*

Biological Neurons and their Connections.

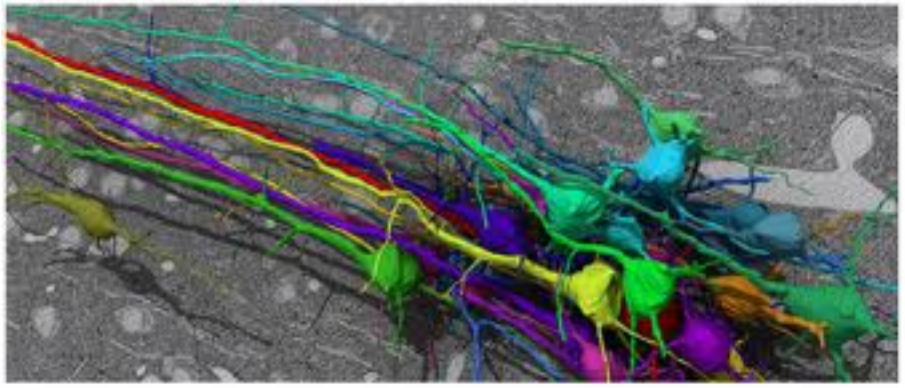
- There are many different types of neurons – neurons have complex dendritic structure – and complex connections between them.

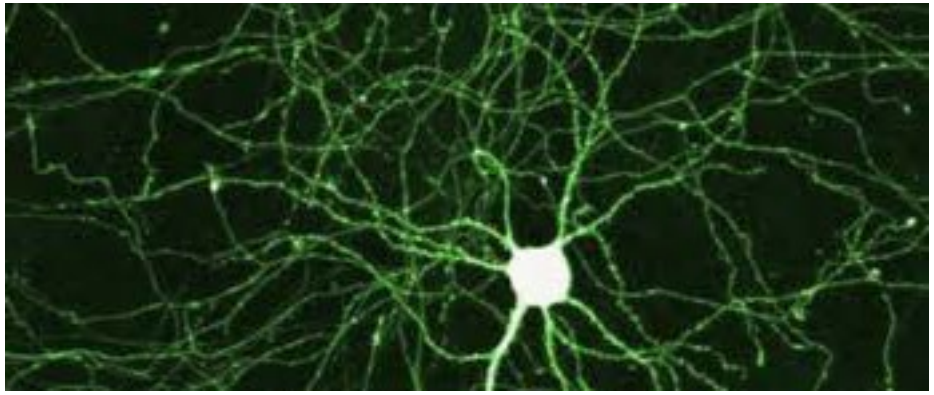


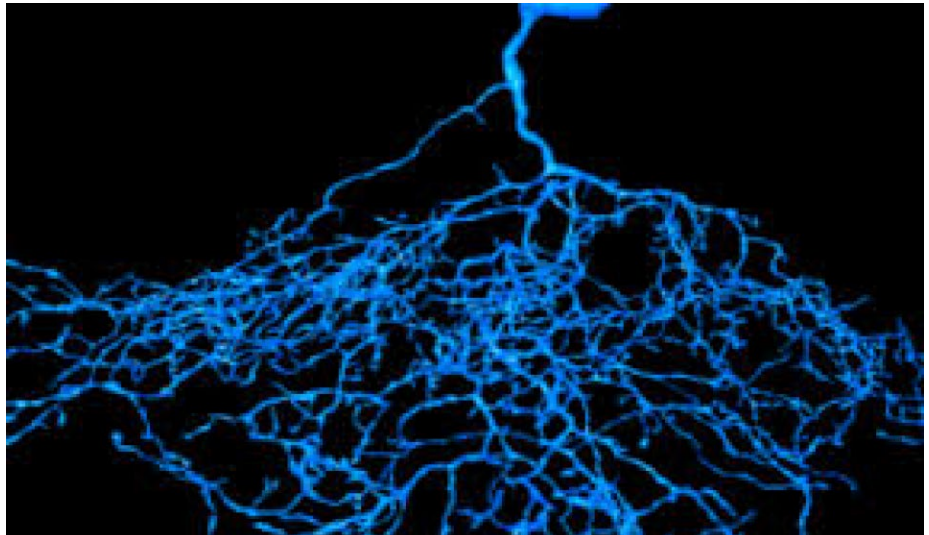


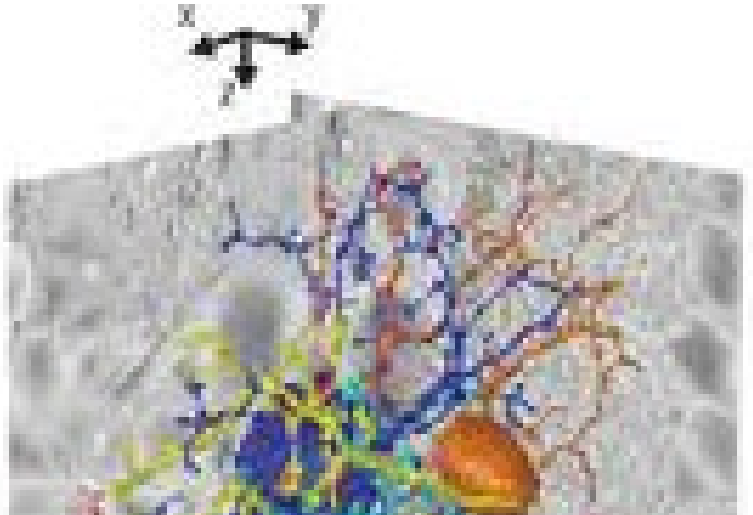
Neurons have Complex Structures.

- Neurons: Dendrites, Axons, and Soma (cell body).









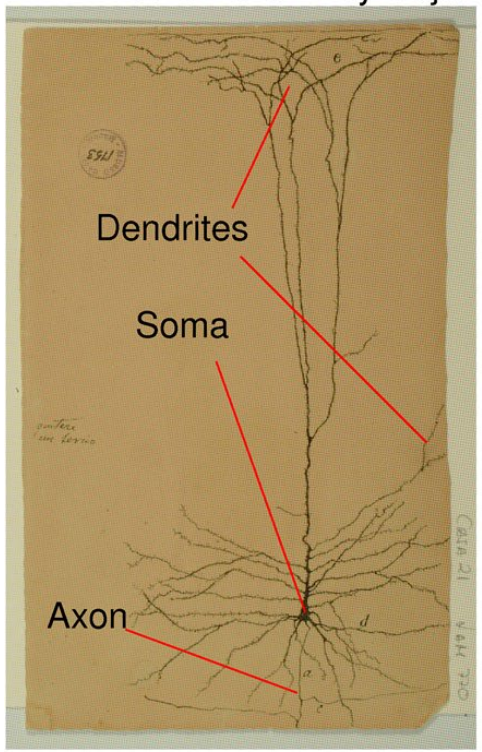
Connectonics: The Seung Movshon Debate.

- How much will wiring diagrams, or even detailed biophysical models, help understand the brain?
- *Scientists understood the wiring and biophysics of C. Elegans (150 neurons) but this failed to give much insight into the computations performed in its brain (after thirty years).* And mice and human/monkey brains are more complicated by many orders of magnitude.
- *Surely we must understand the types of computations being performed as well – it would be hard to understand the function of a TV by just analyzing its electrical circuits – and you certainly could not understand what program it was showing.*
- "Could a neuroscientist understand a microprocessor". Eric Jonas and Konrad Kording. PLOS.
- S. Seung and A. Movshon debate: http://www.youtube.com/watch?v=fRHzkRqGf-g

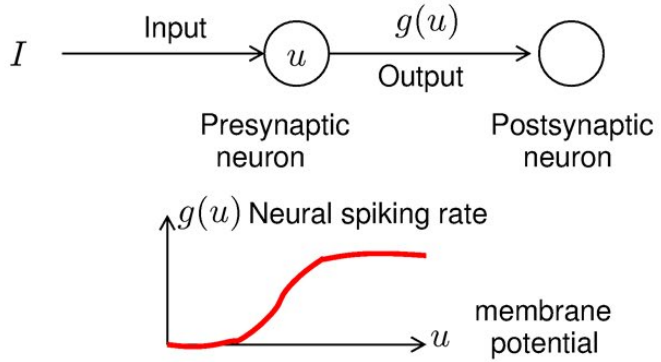
Artificial Neurons and Neural Circuits

- Real neurons and neural circuits. B. Mel handout.

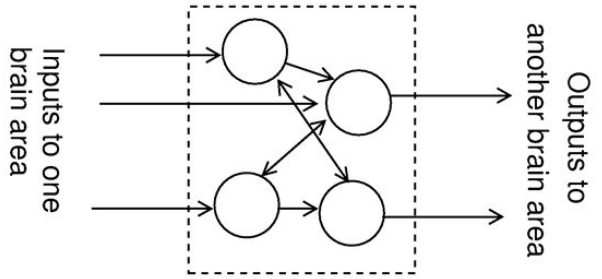
A: A neuron drawn by Cajal



B: Two model neurons linked by a synaptic connection



C: A model neural circuit for a brain area



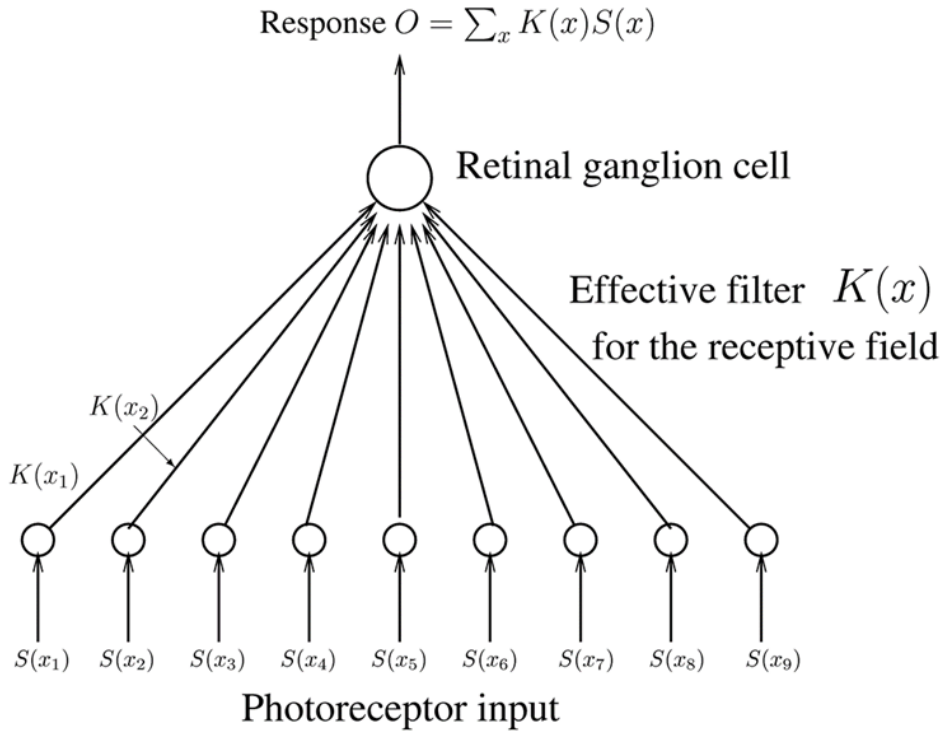


Figure from "Understanding Vision: theory, models, and data", by Li Zhaoping, Oxford University Press, 2014

Classic Conjectures

- Neurons perform computations on their dendrites (T. Poggio, V. Torre, C. Koch 1980's). Studies of in vitro neurons suggest that a neuron may be best modeled by multi-layer perceptrons (B. Mel).
- Neurons may have synaptic connections that can change very rapidly (F. Crick proposed a mechanism 1980s).
- Neurons may store memories in the Soma (cell body). The internal structure of the Soma (and all cells) is very complex.
- Neurons may exploit their morphological structures.

Complexity and the Brain

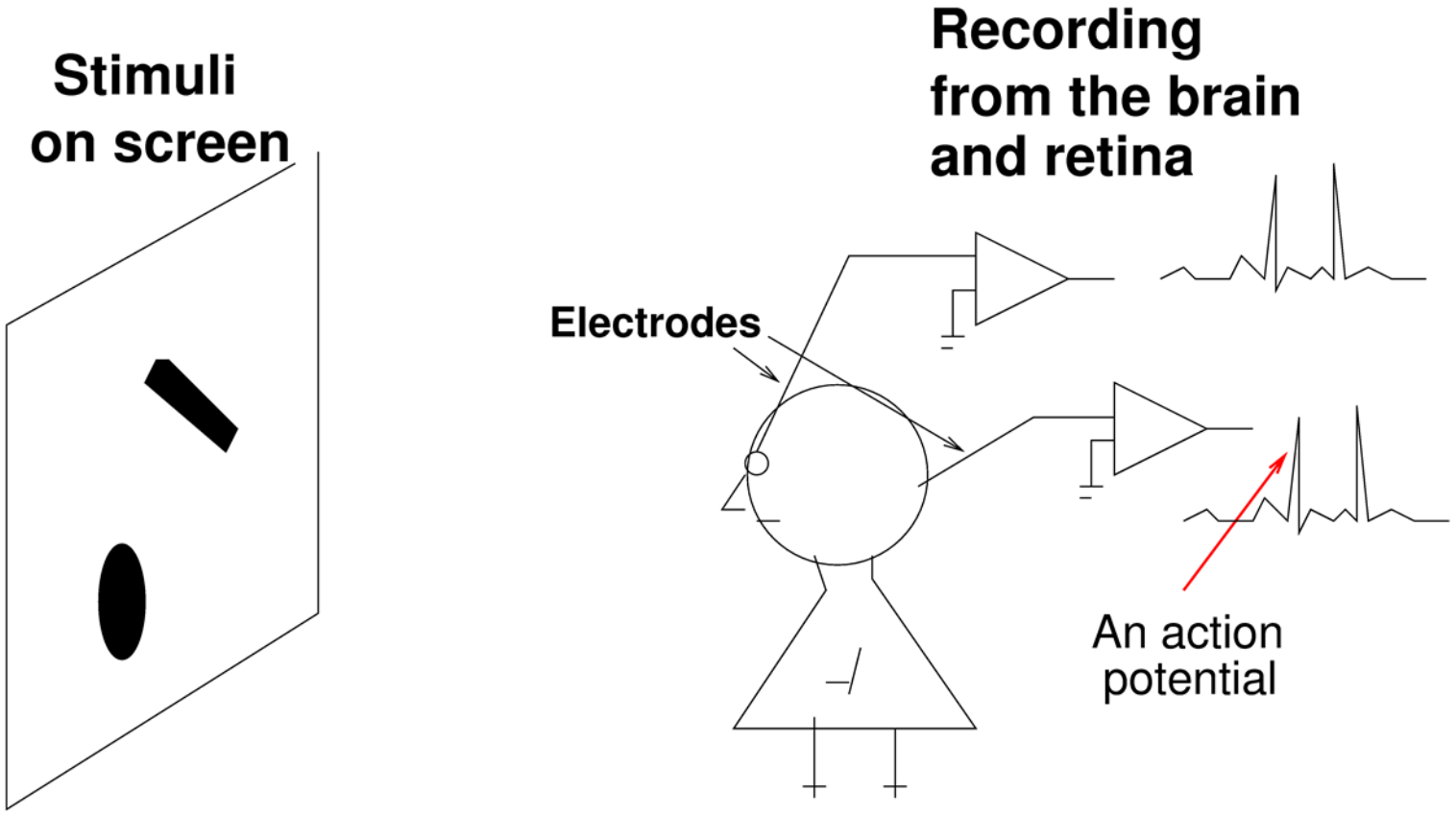
- The brain is the most complex physical system in the universe. The number of neurons in the cortex is similar to the number of trees in the Amazon rainforest. The number of connections between neurons is similar to the number of leaves in the Amazon.
- Neurons and Neural Circuits are complex and poorly understood.
- Dreams of a cortical microcircuit – the cortex has expanded extremely rapidly (evolutionary time) and is fairly homogeneous. So if we can understand this microcircuit we can scale up.
- Coarse understanding. We can predict coarse activity (fMRI) which may serve as a starting point.

How to Measure Neural Activity?

- The standard way to measure neural activity, of individual neurons and neural circuits is electrophysiology which records electrical activity using electrodes. Electrodes can now record for over a year (used to be a few days). But we can only record from a limited number of neurons at the same time.
- There are other methods, such as optical techniques. This is fairly non-invasive so possible to record for a long period of time (but can only record from limited parts of the cortex).
- There are cruder methods – fMRI – which measure blood flow activity.

Measuring Receptive Fields

- Electrophysiology: Move and vary stimulus until neuron fires.



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How to Stimulate Neurons?

- We can stimulate neurons by injecting electrical current. But for vision, it is most common to show visual stimuli.
- ***Huge Problem: what visual stimuli to show? There are so many. And recording techniques mean that we can only show a limited number of stimuli.***
- ***This is a major challenge for Vision (AI and Biological Vision). The set of possible stimuli is infinite. So how can we test vision if we can only show a limited number of stimuli?***
- Later I will sketch a (radical) strategy for addressing this issue for AI but challenging to adapt this to Biological Vision.

Testing with a Restricted Set of Stimuli

- Neuroscientists have tested neurons using restricted sets of stimuli. Oriented bars. Sine wave gratings. Random Noise.
- But experimental studies (C. Baker handout) shows that finding on these stimuli do not make accurate predictions of neural responses on real world stimuli.
- *Finding on simple stimuli – for AI and Biological Vision – often fail to generalize to complex realistic stimuli. They can be suggestive, and helpful for diagnosis, but only tell part of the story and can be extremely misleading. (The six blind men and the elephant).*

Biological Neurons Summary

- Neuroscience is extremely difficult. Neuroscience findings depend strongly on the stimulus set and may not generalize to complex realistic stimuli. Coarse findings are more likely to generalize.
- There are many innovative techniques which may help (E. Boyden. Ted talk) but the complexity of neuroscience is daunting. And testing them is even more so.
- An alternative strategy is to create computational theories that perform very well (at human level) on complex real world stimuli and then try to map these theories back onto neuroscience.