

Basic Architecture of the Visual Cortex

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The Retina and the Cortex. Basic Biology.

- With about 10 million retinal receptors, the human retina makes on the order of 10 to 100 million measurements per second. These measurements are processed by about a billion plus cortical neurons.
- How sensitive is the eye? What are the limits of vision?
- D.K. Kersten's slides.
- For a biophysics analysis – see handout from W. Bialek.

Purpose of the Retina

- The anatomy and electrophysiology of the retina has been studied extensively – far more deeply than the cortex.
- Their main functions are:
 - (i) Transduce image intensity patterns to patterns of neural activity.
 - (ii) To attenuate slow spatial and temporal changes through spatial and temporal filtering of the image.
 - (iii) Normalize responses – gain control -- to encode contrast and deal with the large range of luminance (intensity) from scene to scene. Ranging from faint starlight to bright sunlight (range of 1 to 10^7).
 - (iv) Encode the intensity so that it can be efficiently transmitted to the LGN and then on the visual cortex.

But is the human retina really that dumb?

- Does the retina of humans/monkeys just capture images and transmit them to the visual cortex? Or does it process them – e.g., by extracting edges. (like the retinas of simpler animals – frogs).
- Standard wisdom: “smart animals have dumb retinas and dumb animals have smart retinas.”
- This is questioned by M. Meister (handout). He argues that human/monkey retinas are more complex than current models suggest. That current models of retinal neurons are based on experimental findings using simple stimuli – and the neurons are more complicated when they see natural stimuli. (We will keep returning to this issue).
- Why use so many neurons if the retina is only a smart camera?

And the anatomy of the retina may not be so simple.

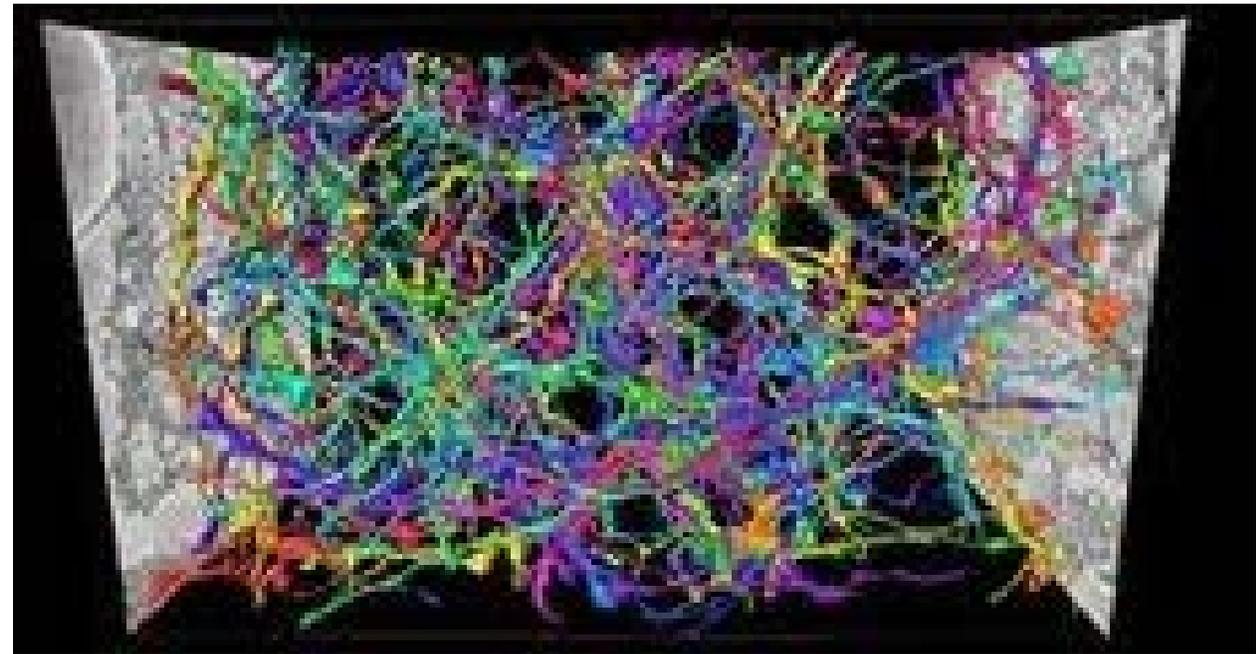
- The anatomical structure of the retina gets increasingly complex as scientists study it in detail. S. Seung. Connectonics. (YouTube).
- Many different types of neurons when you consider their detailed anatomy. Seung recruits volunteers to label the three-dimensional structure of neurons in the retina.
- 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).

Big Brain Initiatives

- The Allen Institute from Brain Sciences studies the structure of the Mouse Visual Cortex. Chief Research Scientist: C. Koch.
- <http://www.alleninstitute.org/>
- The EU has allocated \$1.3 billion to H. Markham to study the structure of mammalian brains and build a silicon retina.
- <http://www.wired.com/wiredscience/2013/05/neurologist-markam-human-brain/all/>
- Note: these studies suggest that the brain is not a connectionist network – as assumed by standard neural network models.

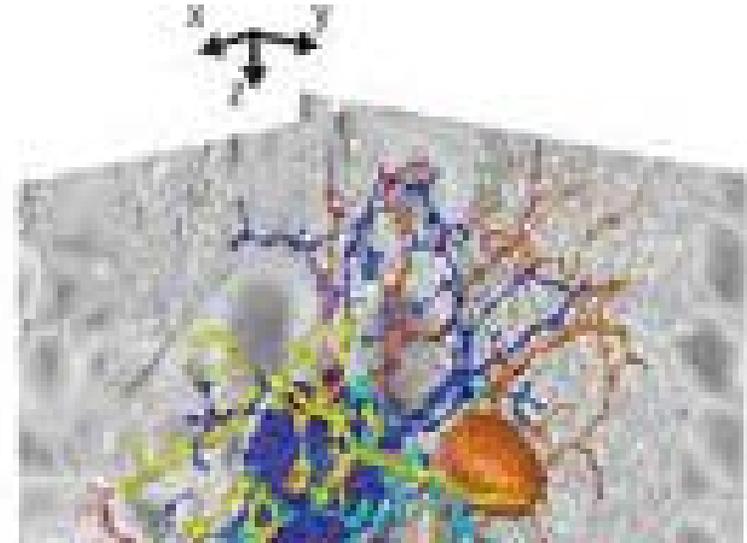
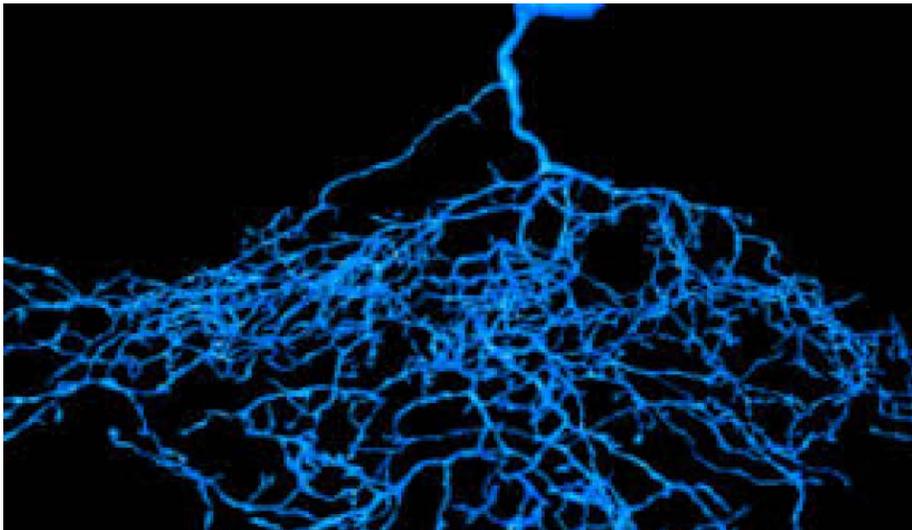
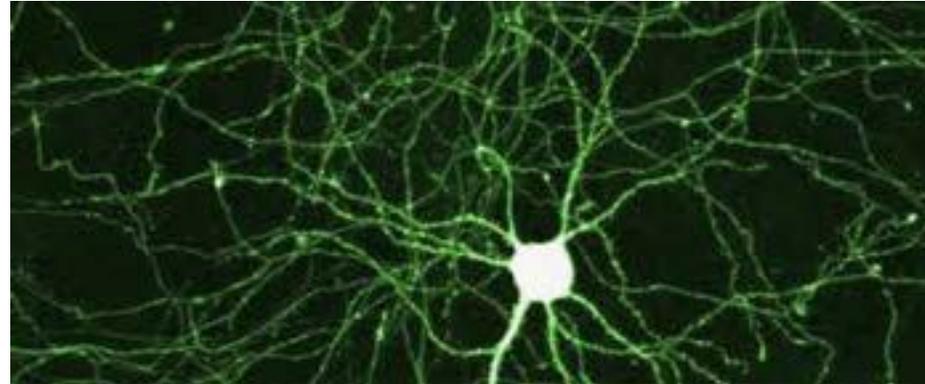
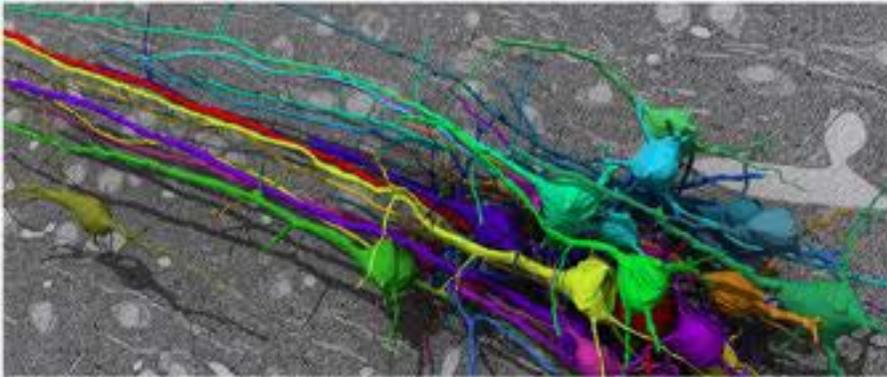
The Retina. Complex connections.

- Many different types of neurons – neurons have complex dendritic structure – and complex connections between neurons.



The Retina: Seung. Different types of neurons.

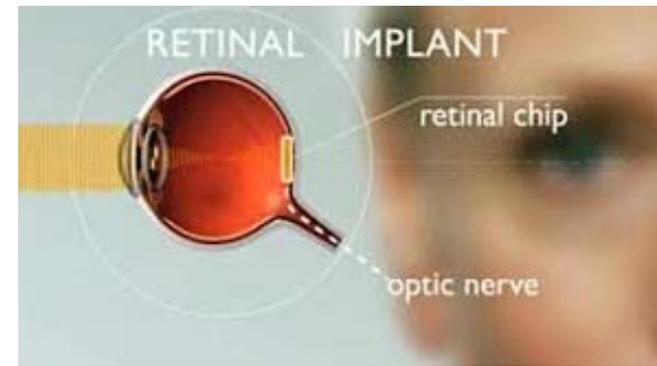
- Neurons: Dendrites, Axons, and Soma (cell body).



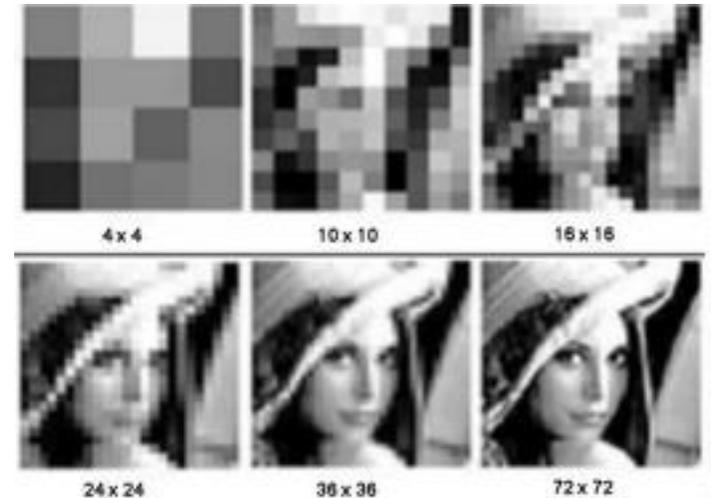
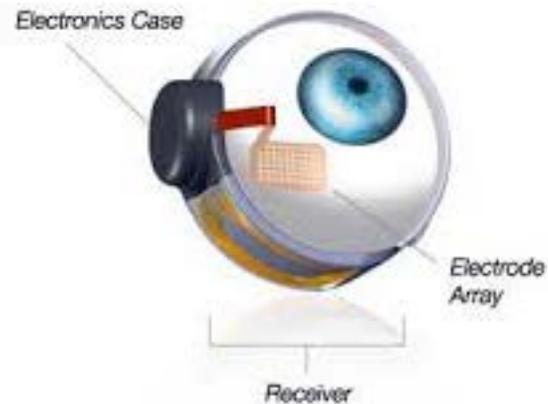
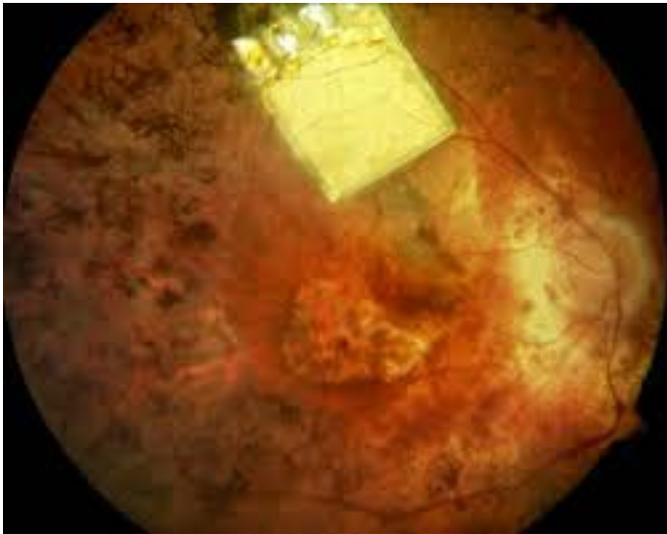
The Retina and Connectonics

- How much will wiring diagrams, or even detailed biophysical models, help understanding 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. And mice and human/monkey brains are more complicated by many orders of magnitude.
- Surely we have to 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.
- S. Seung and A. Movshon debate: <http://www.youtube.com/watch?v=fRHzkRqGf-g>
- But surely understanding the wiring diagrams and the biophysics is a pre-requisite.
- Show the Seung Video.

Retina Implants: Artificial Retinas.



- Retinal implants are intended to help blind people see.
- Current implants 10x10 arrays.
- But restoring input to the eye may not enable perception (Mike Mays)



From Retina to Cortex: The size of V1 and V2.

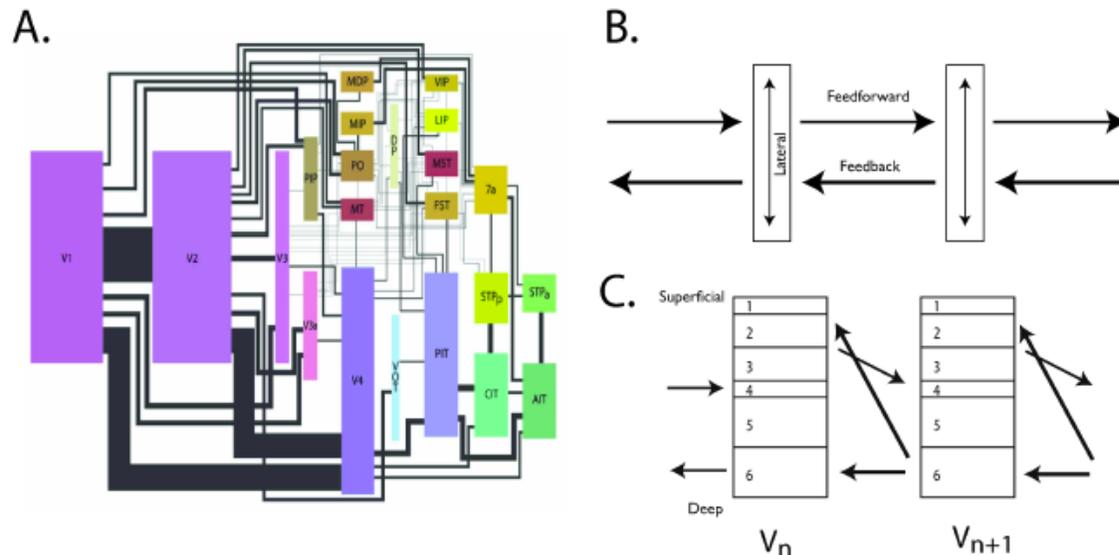
- Low-level vision (also called “early vision”) begins at the retina, continuing through the lateral geniculate nucleus (LGN), into the first visual cortical area, V1 and perhaps V2. V1 and V2 are both complex in terms of size and structure
- . V1 and V2, contain about seventy percent of the total number of neurons in the visual cortex, and hence roughly thirty percent of the neurons in the entire cortex. This is an enormous expansion compared to the LGN. Indeed it has been estimated that V1 is 400 times bigger than is needed to merely encode all the information it receives from the LGN
- It also follows that the rest of the visual cortex, which is believed to perform object recognition and scene understanding, is much smaller than V1 and V2.
- It has been possible to characterize these visual areas by probing the receptive fields of the neurons to determine their sensitivity to elementary stimuli in various “dimensions” (e.g, position, orientation, color, texture, shape, binocular stimuli, and so on) using single electrode recording, optical techniques, and non-invasive methods like fMRI.

The Cortex

Visual neuroscientists currently estimate that 40 to 50% of human visual cortex (your gray-matter) is closely involved in visual processing. The general structure of cortical layers and pattern of inter-connectivity is similar across the neocortex. Thus the hope that if we can understand visual computations in the cortex, this knowledge may generalize to other cognitive domains.

Figure, panel A, below shows a subset of the visual areas of the monkey, together with their interconnections. The areas of the rectangles represents the relative proportions of neurons in each, and the thickness of the lines the proportion of feedforward neural fibers connecting them.

- Feedforward and Feedback.
- 6 Layers of the Cortex. Input to Layer 4.



The Visual Cortex.

- The early visual cortex consists of visual areas – V1, V2, V4, MT (V3, MST) – which are determined by anatomical and electrophysiological measurements [159]. All these areas have a rough retinotopic organization, and are organized hierarchically. There are two main pathways:
- (I) The ventral stream consisting of V1, V2, V4, and then to the infero-temporal areas of extrastriate cortex which performs object detection and scene understanding.
- (II) The second pathway goes from V1, MT to the parietal cortex and is used for analysis of movements and positions
- of objects. The ventral stream puts most emphasis on the central visual field while the motion analysis concentrates more on the periphery. Lennie argues that these two visual streams need never be brought together because they support different perceptions and behaviors. (But others disagree).

Cortical Structure and Function

- For convenience the visual system's hierarchy can be divided into low-, intermediate-, and high-level visual processing functions.
- Functionally, it is useful to think of low-level vision as processing that can be done without explicit knowledge that images come from surfaces in depth.
- Intermediate-level visual processing can be done without explicit knowledge of objects. High-level vision makes explicit inferences about objects, and their action-dependent relations to the viewer.
- Anatomically, these functional divisions can be roughly mapped onto a hierarchical organization of cortical areas.
- There is general understanding about the basic structure of the visual cortical hierarchy. Anatomical and electrophysiological studies show that it is divided into distinct visual areas (e.g., V1, V2, V3, V4, MT, MST, PIT, AIT).
- Each visual area, like all the cerebral cortex consists of six layers (numbered 1 to 6, from superficial to deep) with input primarily in deep layers. The connectivity within [122] and between these visual areas has been mapped. Input to each area enters in to layer 4, and with feedback originating outside of 4, and projecting back to superficial and deep layers.

Overview

- (I) The retina. What are the fundamental limits of perception?
- (II) Connectonics. Neurons and Neural Circuits.
- (III) The broad structure of the Visual Cortex.