Things we know, and don’t know, about biological vision

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The Unknown

As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don't know
We don't know.

Feb. 12, 2002, Department of Defense news briefing

From: The Poetry of Donald Rumsfeld
Hart Seeley, Slate Magazine
The evolution of eyes
Land & Fernald (1992)
Figure 4: The fly’s eyes. At left a photograph taken by B. Pijpker at the Rijksuniversiteit Groningen showing venetian blinds. The other six receptors look out through hexagonal micro lenses but these are not used for motion sensing. The other six receptors look out through hexagonal micro lenses but these are not used for motion sensing. The fly’s eye has about 8,000 ocelli and about 7,000 single-lens eyes. Each eye is a single-lens eye. The fly’s eye has about 8,000 ocelli and about 7,000 single-lens eyes. Each eye is a single-lens eye.
Fly H1 neuron - dynamic range of speed sensitivity
Lewen, Bialek & de Ruyter van Steveninck (2001)

![Graph showing the average rate (spikes/s) of fly H1 neuron responses to naturalistic motion stimuli. The graph compare the responses outside and inside the laboratory.](image)
Philanthus triangulum
Jumping spiders
Jumping spiders
Jumping spider retina

horizontal section

photoreceptor array

Layer 1

Layer 2

(●) Layer 3
(●) Layer 4
Jumping spider eye movements

(i) Spontaneous activity

(ii) Saccades

(iii) Tracking

(iv) Scanning
Jumping spiders do ‘object recognition’

Text-fig. 12. Stimuli found by Drees to evoke courtship (a) and prey capture (b) in male jumping spiders (*Epiblemum scenicum*). The numbers beneath each figure in (a) are the percentage of trials on which courtship was evoked. After Drees (1952).
Mantis shrimp
Mantis shrimp - photoreceptor spectral sensitivities
Human - photoreceptor spectral sensitivities
Human retina - cone mosaic
Fixational eye movements

head/space  eye/head  eye/space

sitting 0.5°
Human fixational eye movements
(Austin Roorda, UCB)
HI horizontal cell
HI horizontal cells connected via gap junctions

HI horizontal cells labeled following injection of one HI cell (⋆)

after Dacey, Lee, and Stafford, 1996
Bipolar cells

diffuse
midget
“S-cone”
rod
bipolar cells
On vs. off cone bipolar cells
Rod bipolar cell is of on-type only

Net convergence of rods to bipolar cells
All amacrine cell links rod bipolar cells to ganglion cells
Ganglion cells
ganglion cells in peripheral retina
Midget ganglion cells receive input from midget bipolar cells.

Ratio is 1:1 in fovea.
Smoothing and subsampling by retinal ganglion cells
Retinal ganglion cell spacing as a function of eccentricity

$$\Delta E \approx 0.01(|E| + 1)$$
Dendritic field size as a function of eccentricity
Letter size vs. eccentricity
(Anstis, 1974)
Fig. 2. All letters should lie at threshold when centre of this chart is fixated. Threshold letter size increases linearly with increasing distance from fixation point.
Fig. 3. All letters should be equally readable when centre of this chart is fixated, since each letter is ten times its threshold height.
Lateral geniculate nucleus (LGN)
Space-time tiling by parvo- and magno-cells
Receptive fields of monosynaptically connected cells in retina (a) and LGN (b) (from Marty Usrey)
Color opponency in LGN
(Derrington, Krauskopf & Lennie, 1984)
VI - topographic representation
Orientation columns
V1 receptive fields - ‘simple cells’

Jones & Palmer (1987)
VI space-time receptive field
(Courtesy of Dario Ringach, UCLA)
The “standard model” of VI

Image $I(x,y,t)$ → Receptive field $K(x,y,t)$ → linear response → Response normalization → Pointwise non-linearity → Response $r(t)$
Cat V1 - natural movies (J. Baker, S.C. Yen, C.M. Gray, MSU Bozeman)
Responses of V1 neurons are not well predicted by RF models.

Receptive field:
Responses of neighboring cells are heterogeneous
Five problems with the current view of V1

- Biased sampling (single unit recording)
- Biased stimuli (bars, spots, gratings)
- Biased theories (data-driven vs. functional theories)
- Interdependence and context (effect of intra-cortical inputs)
- Ecological deviance

1 mm$^2$ of cortex analyzes ca. 14 x 14 array of retinal sample nodes and contains 100,000 neurons.
Figure 3: it may be in the case of a highly precise neuron that the outputs of the thin branch subunits depend on the inputs.

(a) Thin branch subunits
(b) 2-Layer model
(c) 3-Layer model

Distal apical thin branches
Perisomatic thin branches

Hausser & Mel (2003)

Current Opinion in Neurobiology
Single unit recording is blind to neuronal interactions

...their (neurons') apparently erratic behavior was caused by our ignorance, not the neuron's incompetence. -- H.B. Barlow (1972)
What is the other 85% doing?

~85% of V1 function not understood

Proportion of cells studied
Variance explained

0.3-0.4

~0.4
There’s hope.
Silicon polytrodes