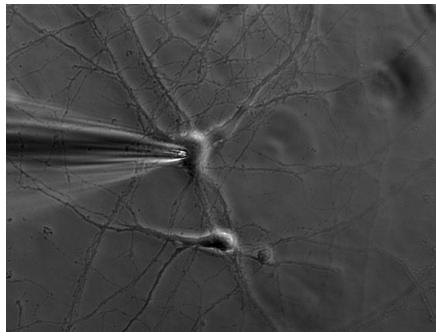
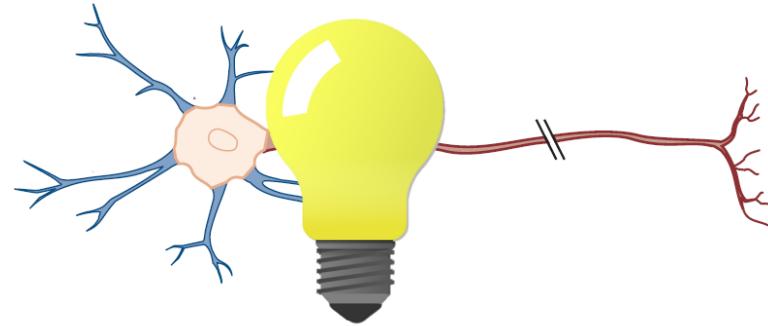
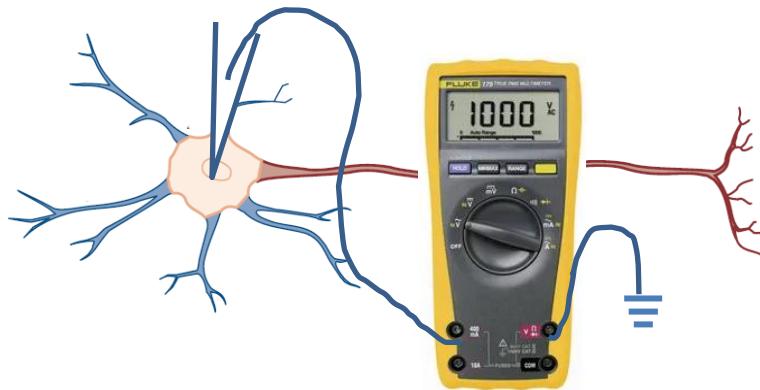


Cognitive Neuroscience for AI Developers

Week 10-ish – Measuring neural activity and connectivity, and vision

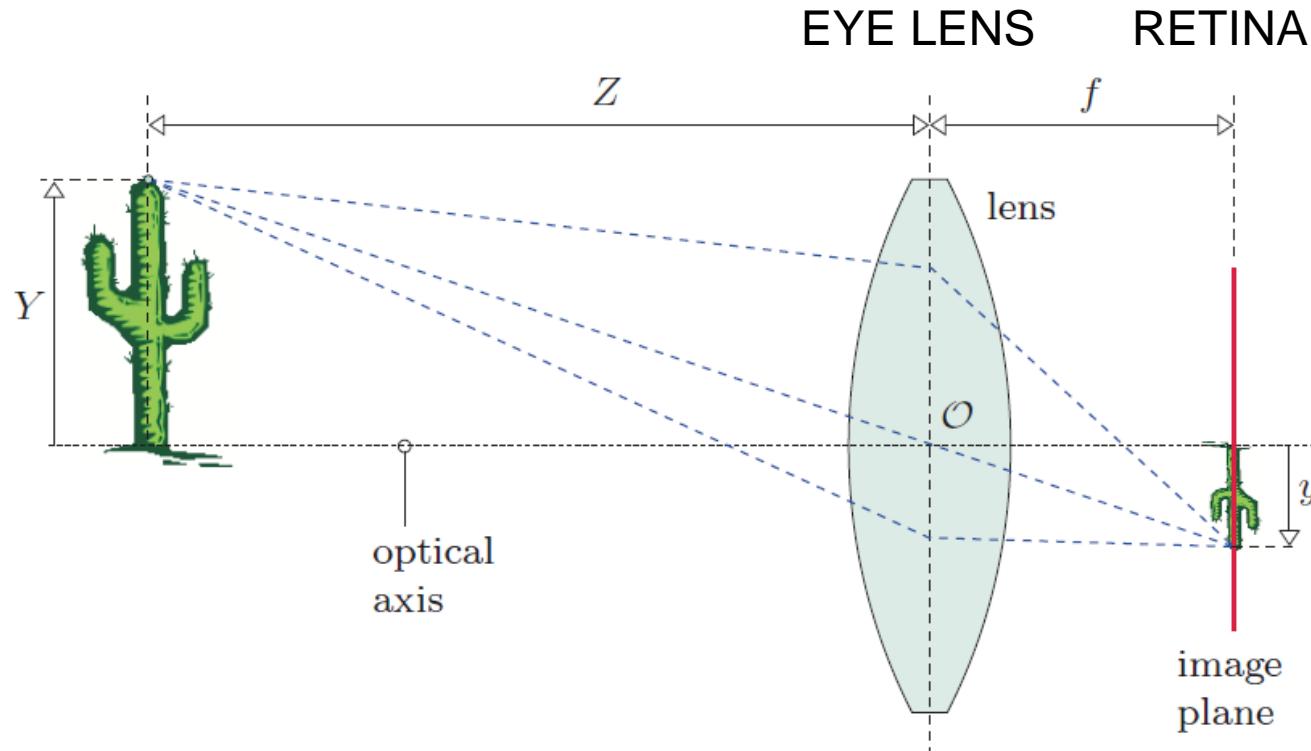


Measuring neural activity

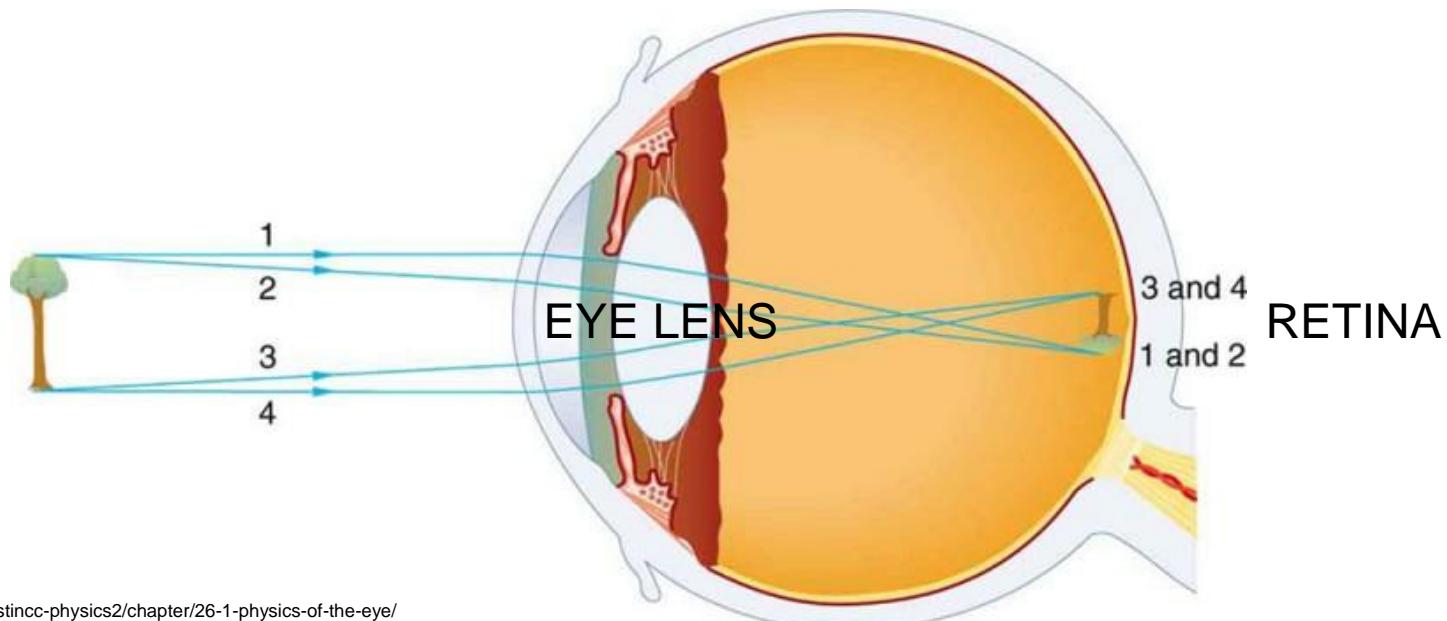
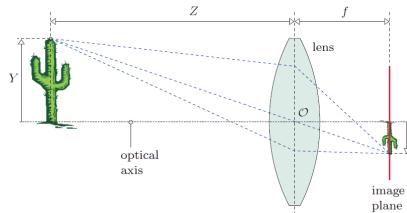


Optical approaches to measure
neural activity

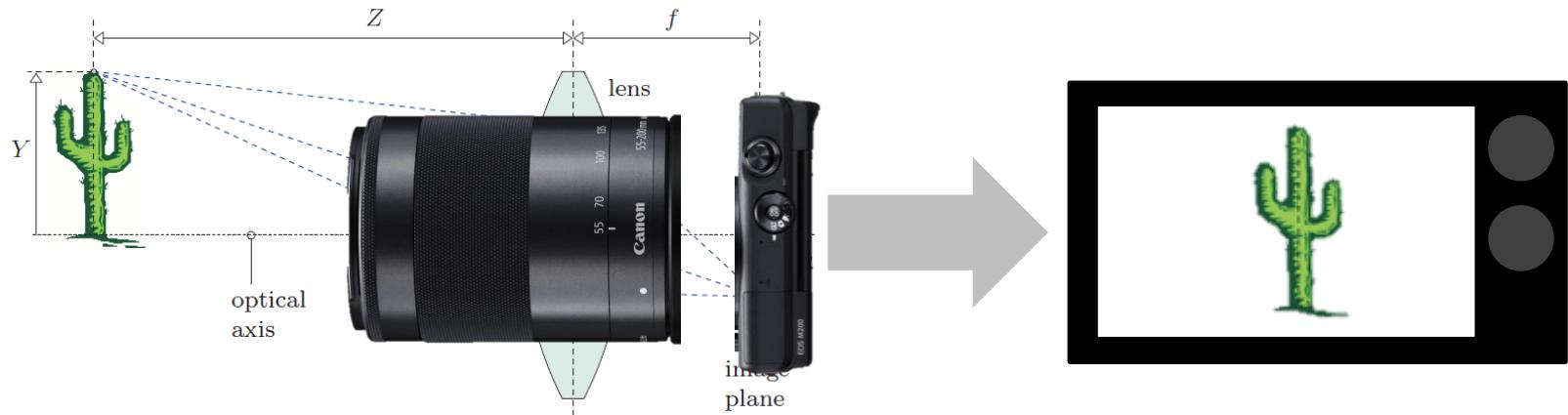
How does imaging work?

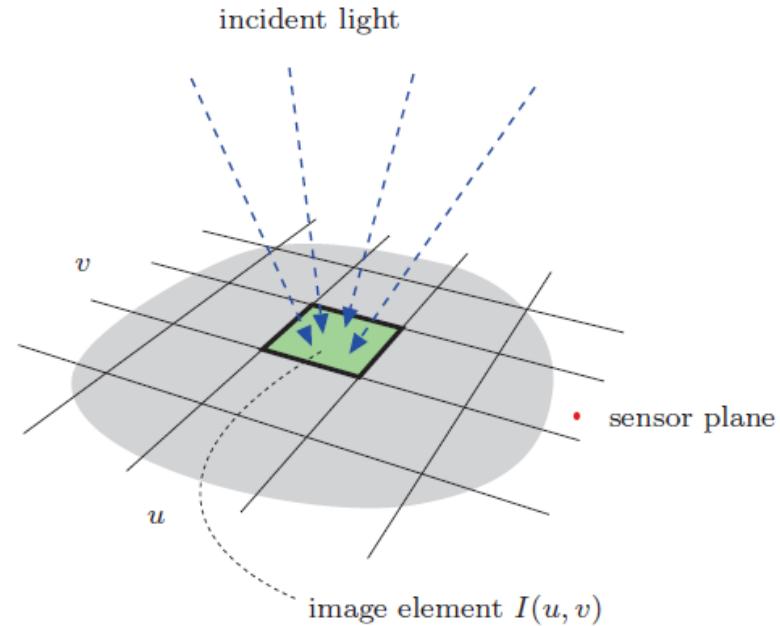
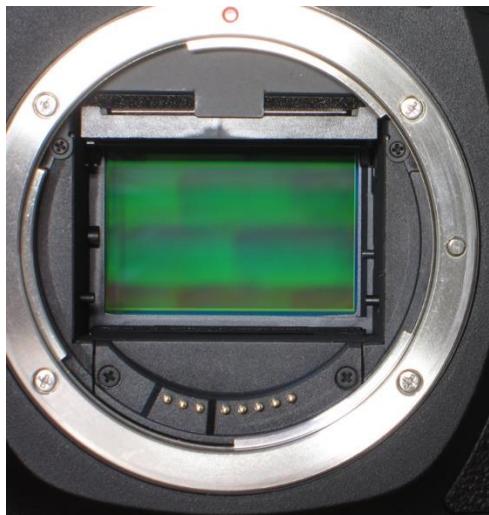


How does imaging work?

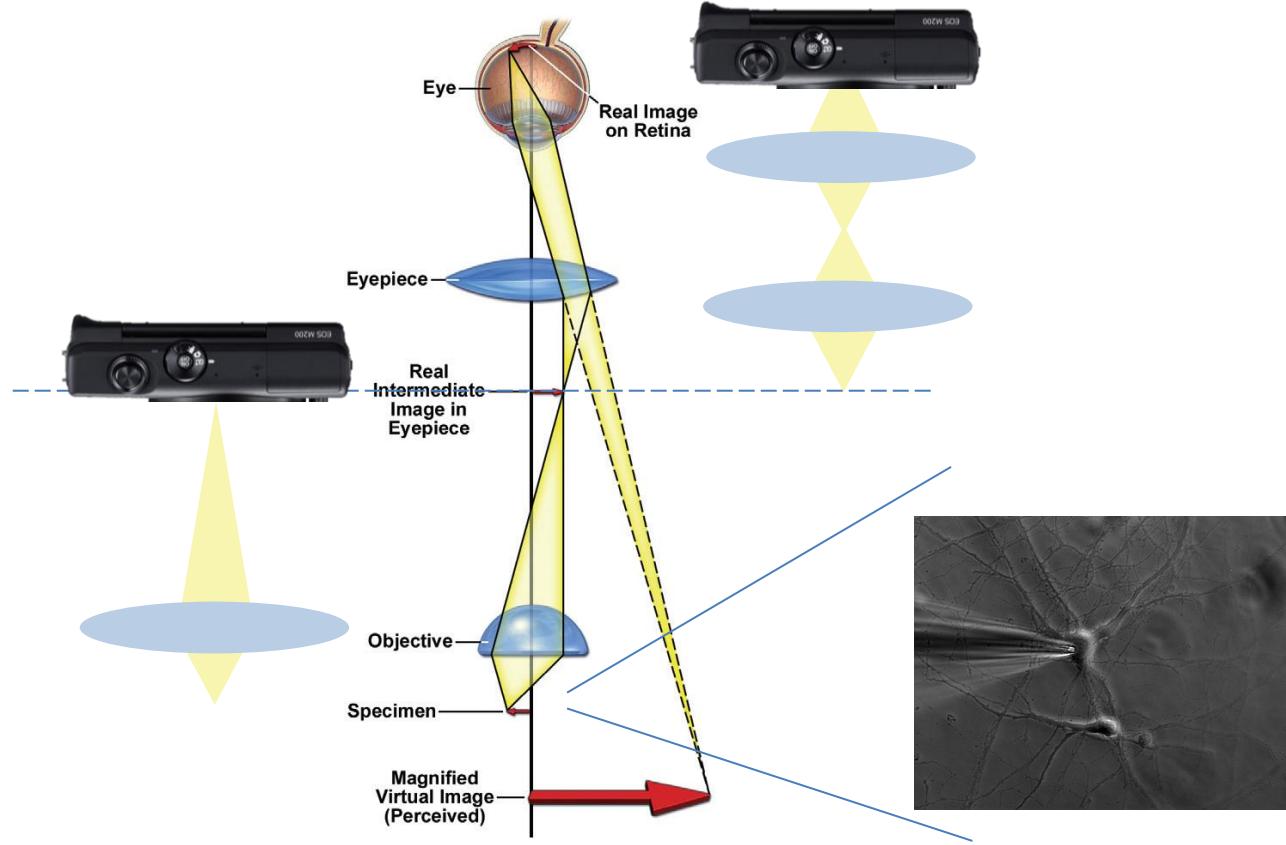


How does imaging work?

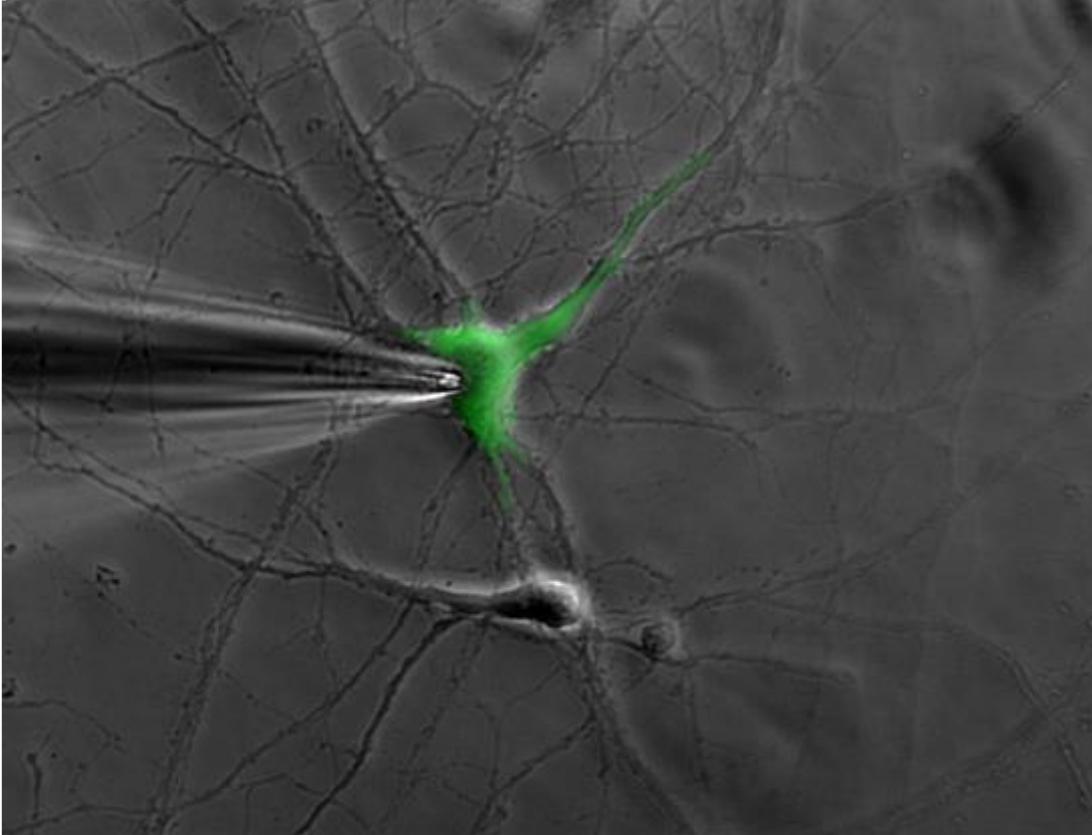




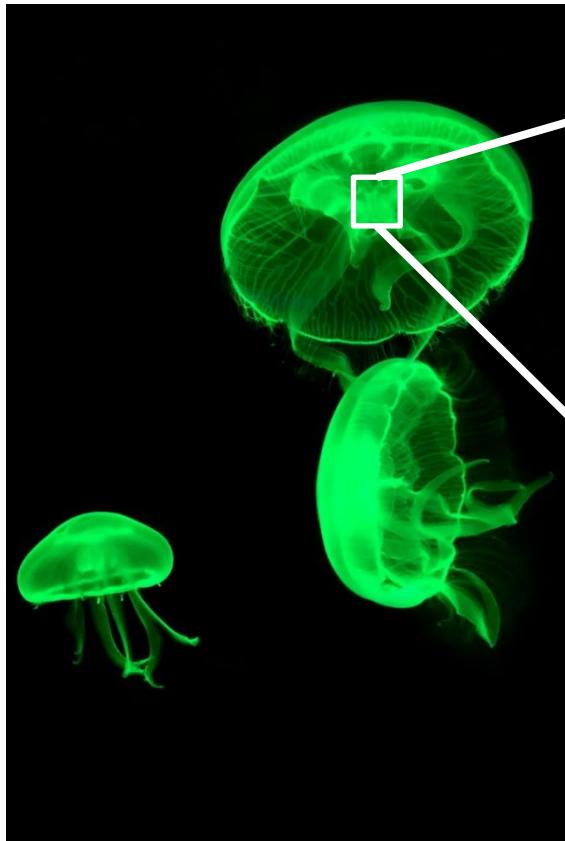
A basic microscopy setup



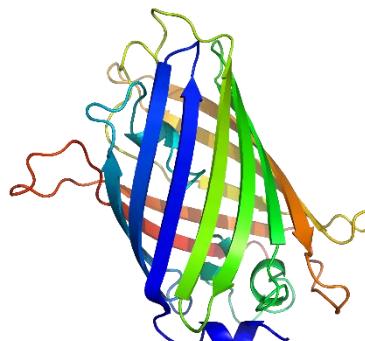
Making cells shine



Glowing jellyfish



Green fluorescent protein (GFP)



The Nobel Prize in Chemistry 2008



© The Nobel Foundation. Photo: U. Montan
Osamu Shimomura
Prize share: 1/3



© The Nobel Foundation. Photo: U. Montan
Martin Chalfie
Prize share: 1/3



© The Nobel Foundation. Photo: U. Montan
Roger Y. Tsien
Prize share: 1/3

The Nobel Prize in Chemistry 2008 was awarded jointly to Osamu Shimomura, Martin Chalfie and Roger Y. Tsien "for the discovery and development of the green fluorescent protein, GFP."

A protein that fluoresces

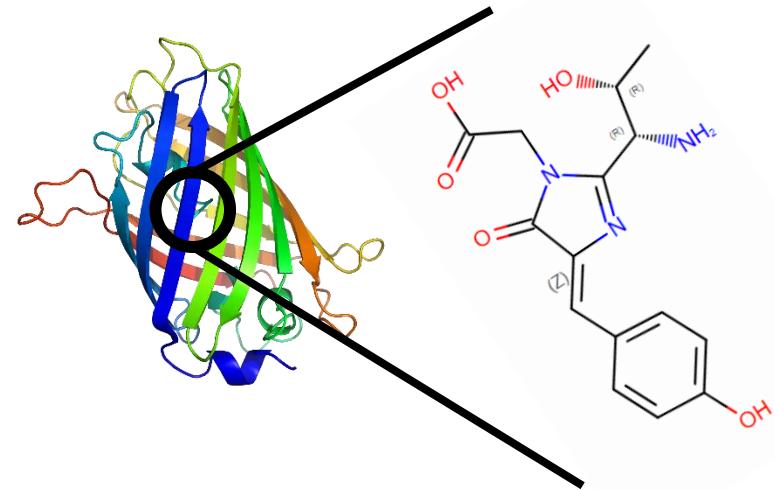
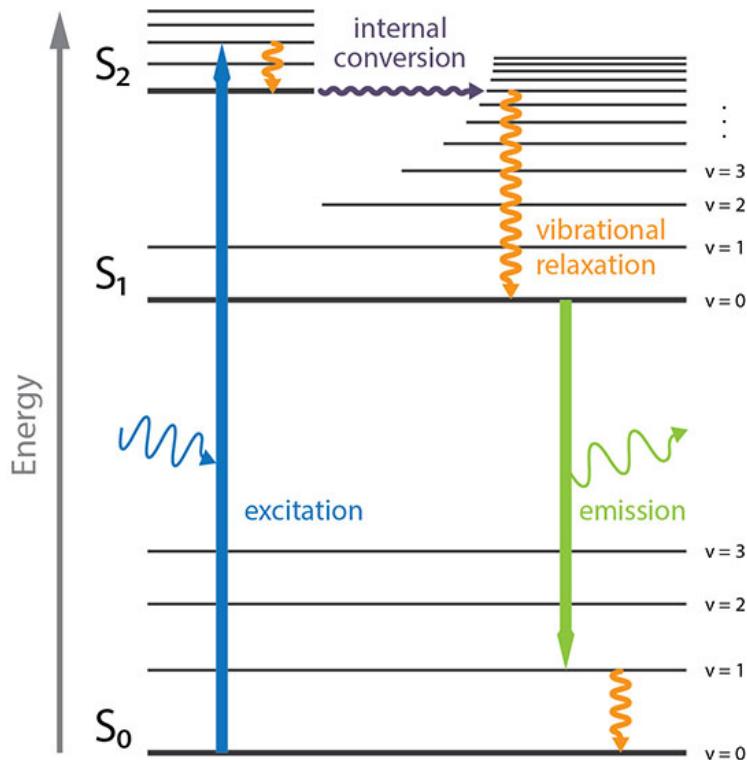
Bacteria expressing GFP



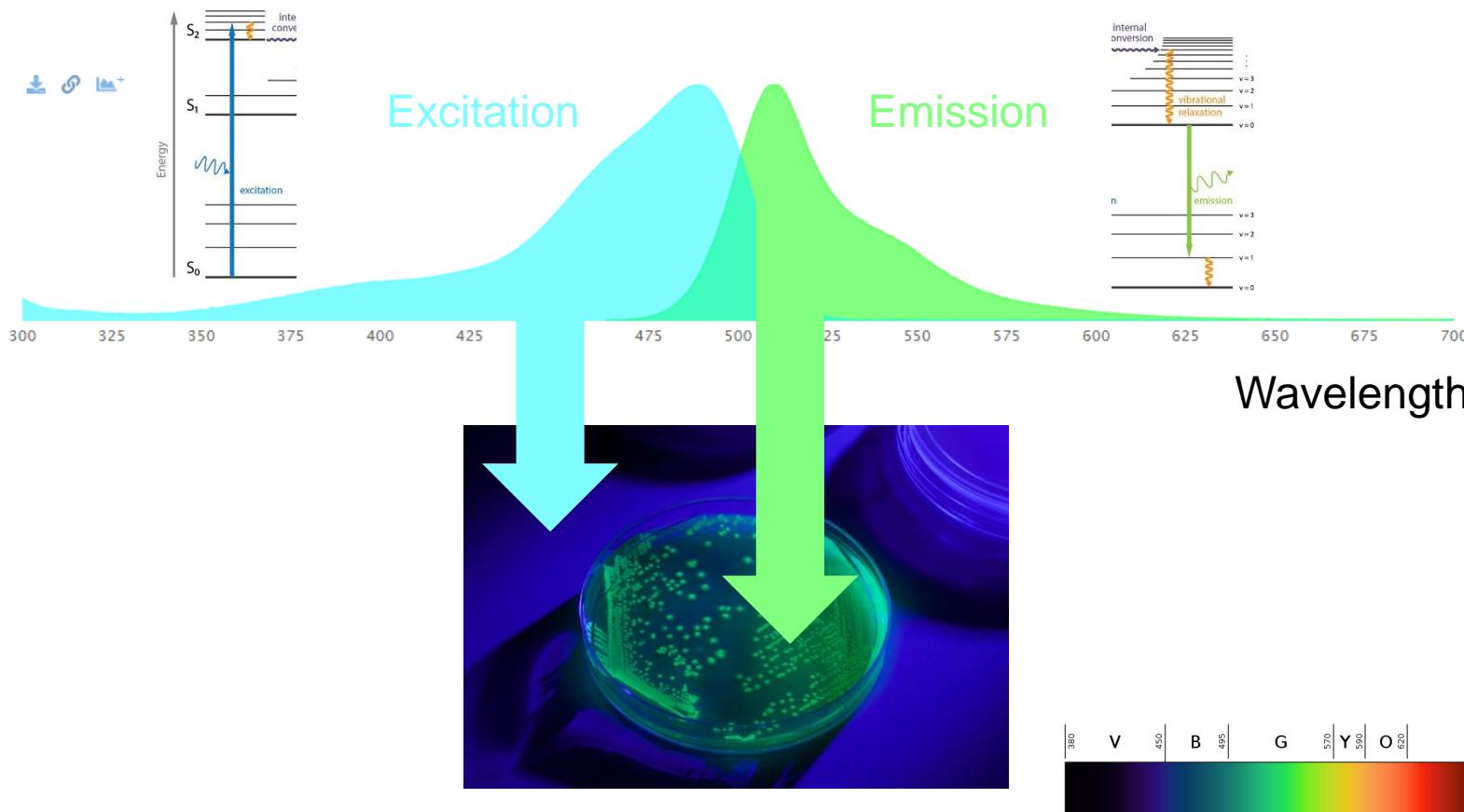
What is fluorescence?

Why is it useful?

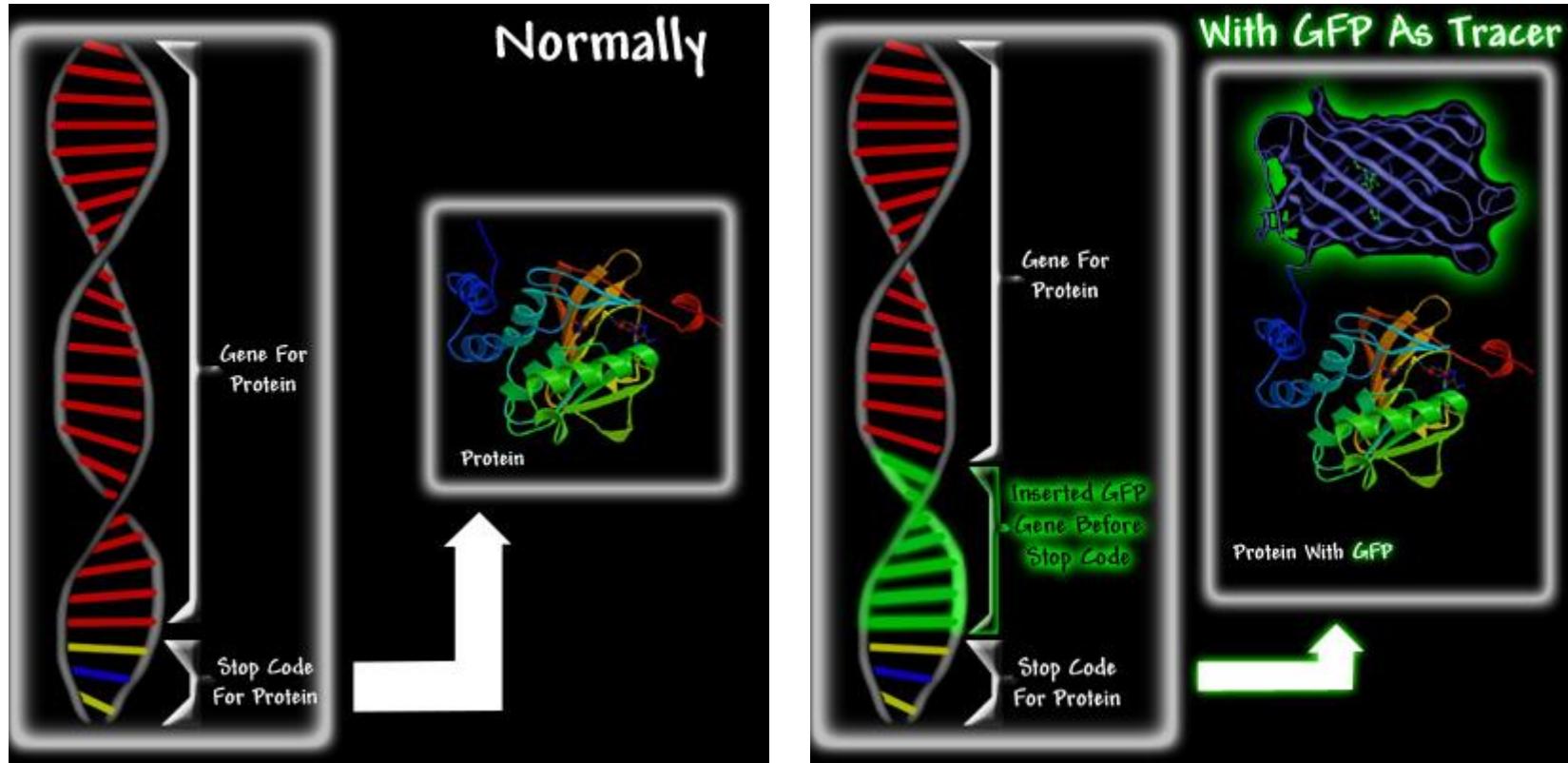
Fluorescence in essence



Spectral properties of GFP

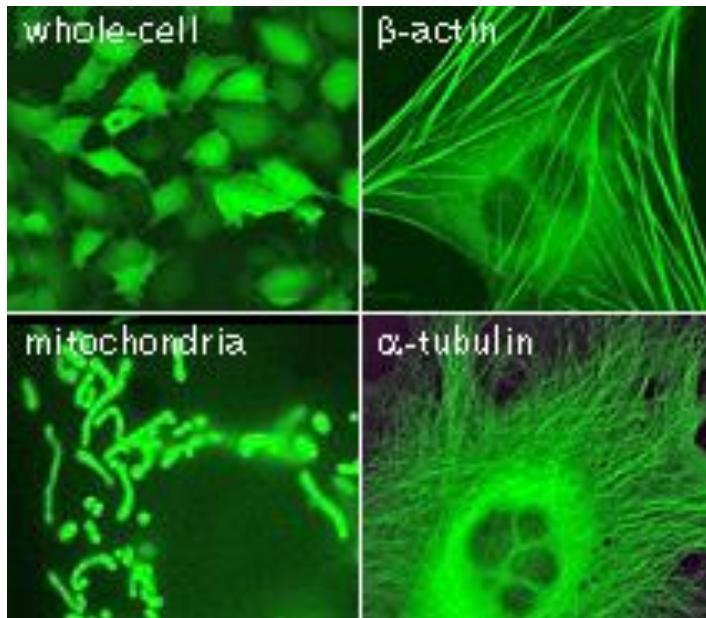


Why is it useful

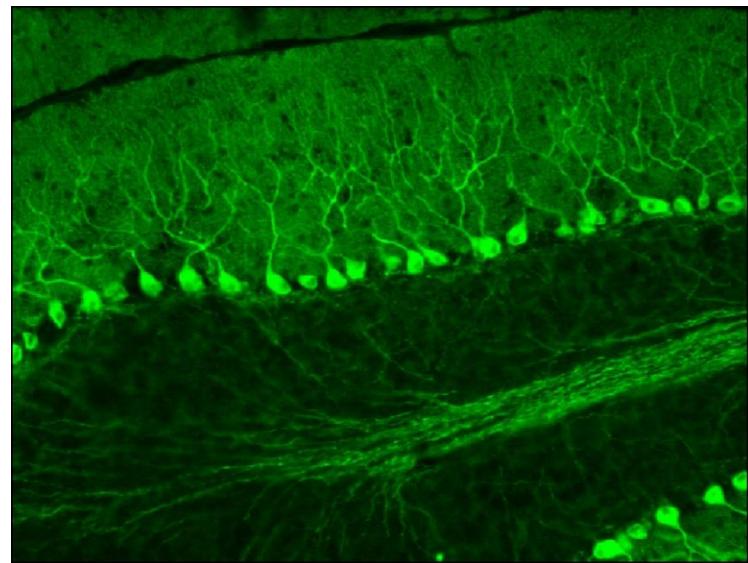


GFP tagging

GFP allows the visualization of cell structures,
when CELLS ARE ALIVE!

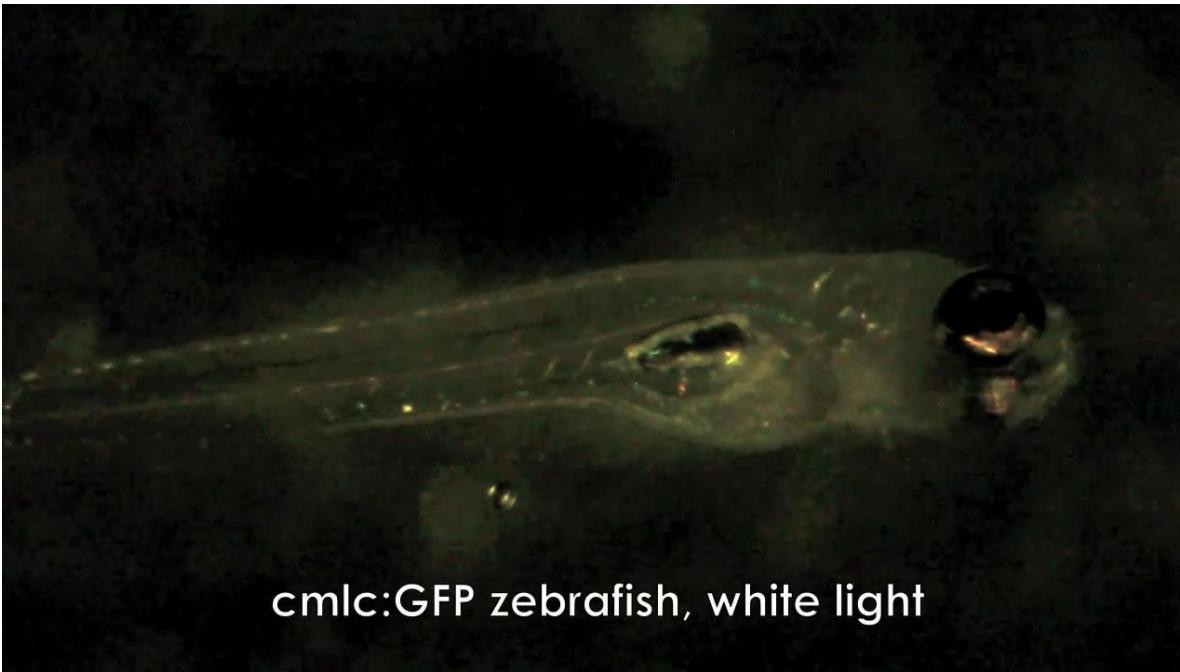


<https://www.biocat.com/proteomics/green-fluorescent-proteins-gfp-s>



https://www2.tmic.or.jp/Mn_B/English/GFP_in_Purkinje_cell.html

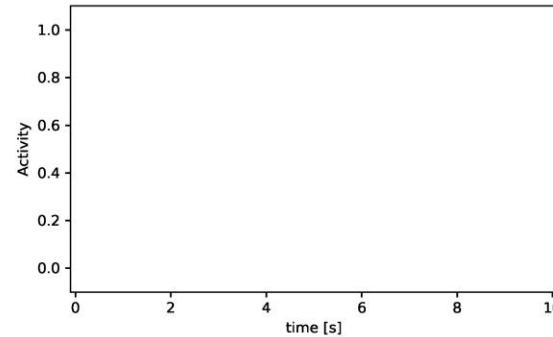
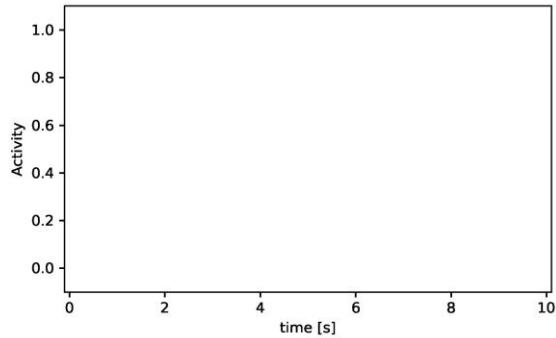
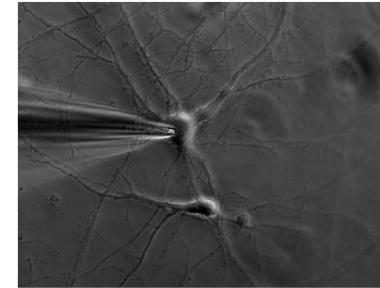
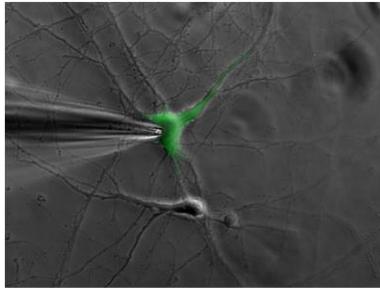
Larval zebrafish (ca. 5 days old)



cmlc:GFP zebrafish, white light

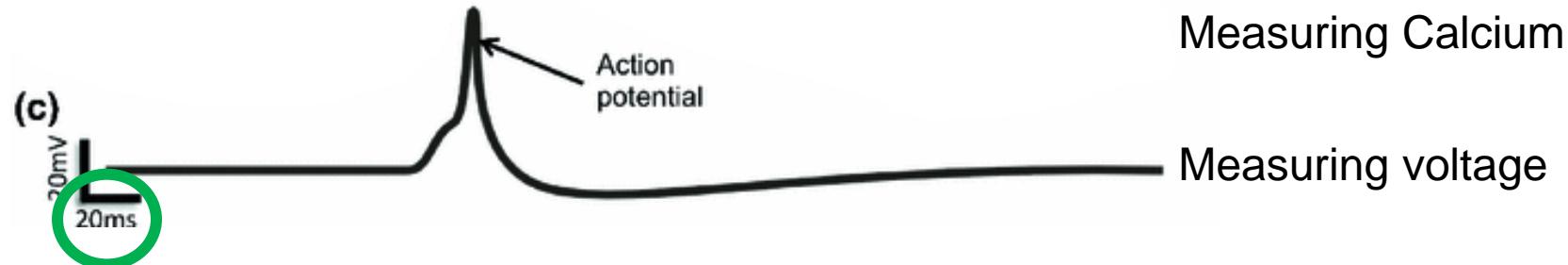
© Nightsea, <https://www.youtube.com/watch?v=fYMOEN7ANM>

How to track neural activity?

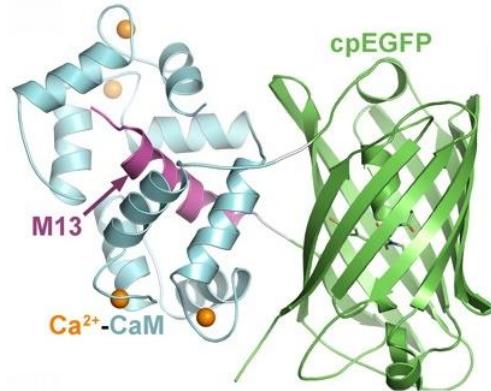


Activity-dependent fluorescence!

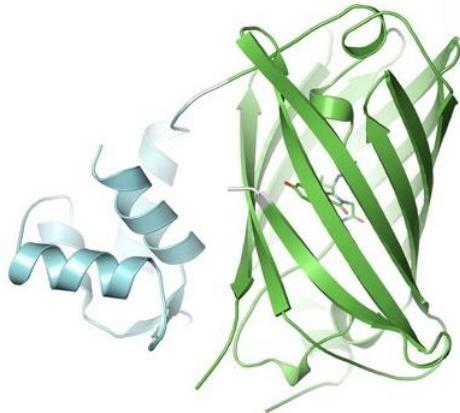
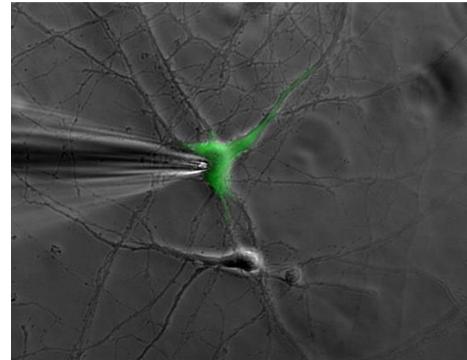
Activity dependent fluorescence



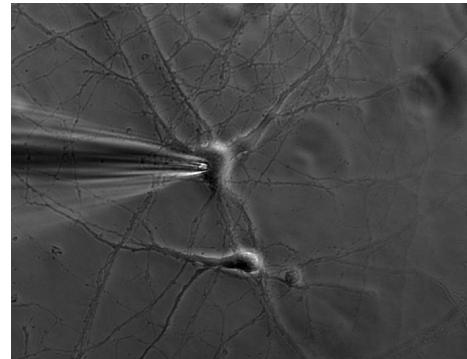
Calcium imaging



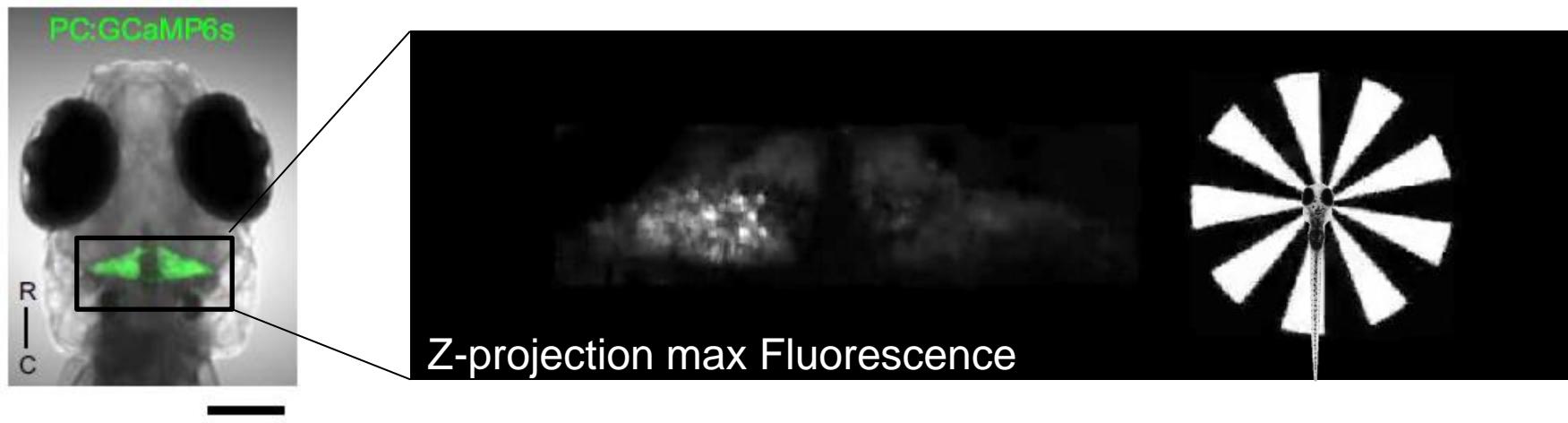
with Ca^{2+}



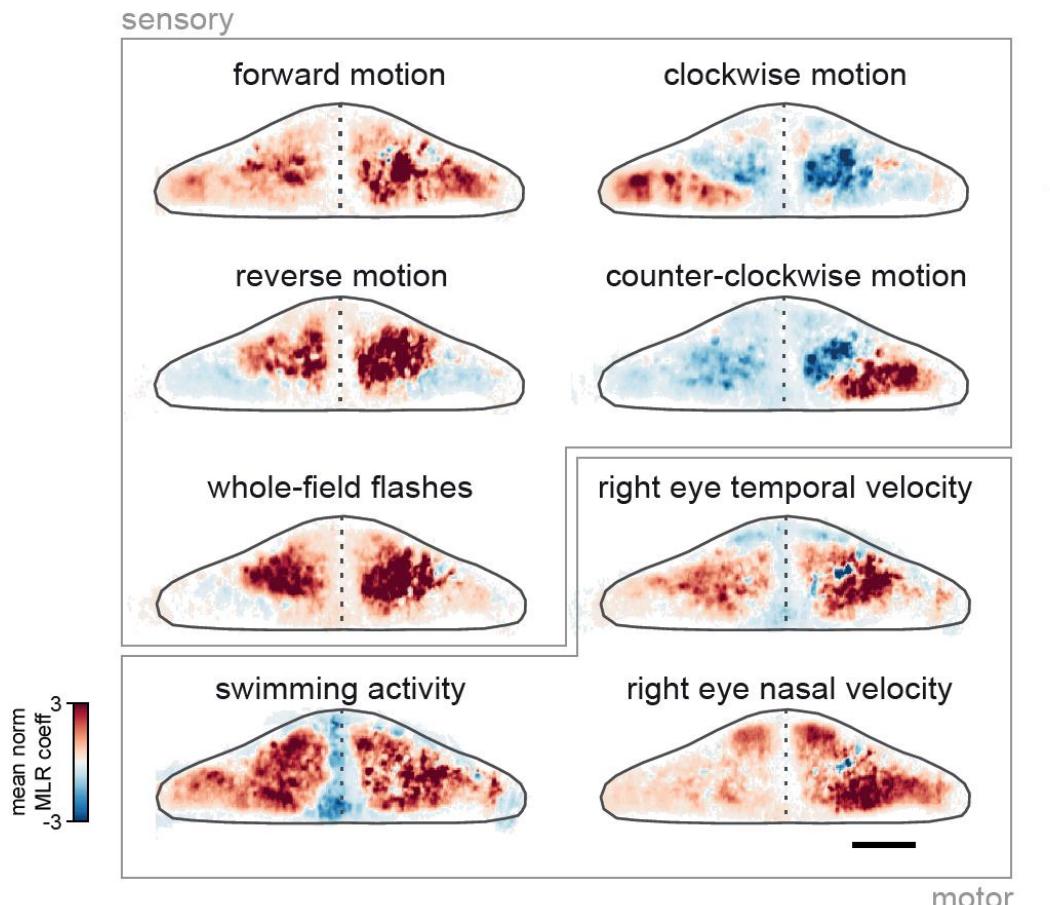
w/o Ca^{2+}



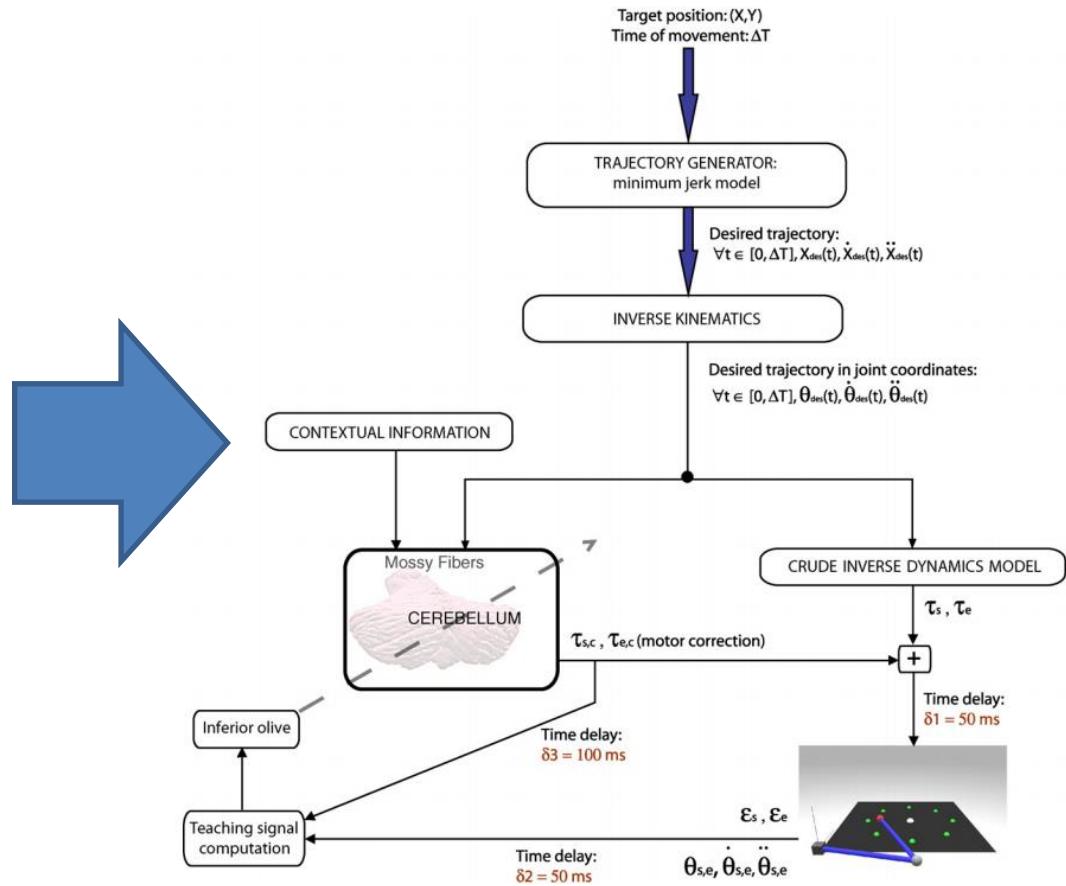
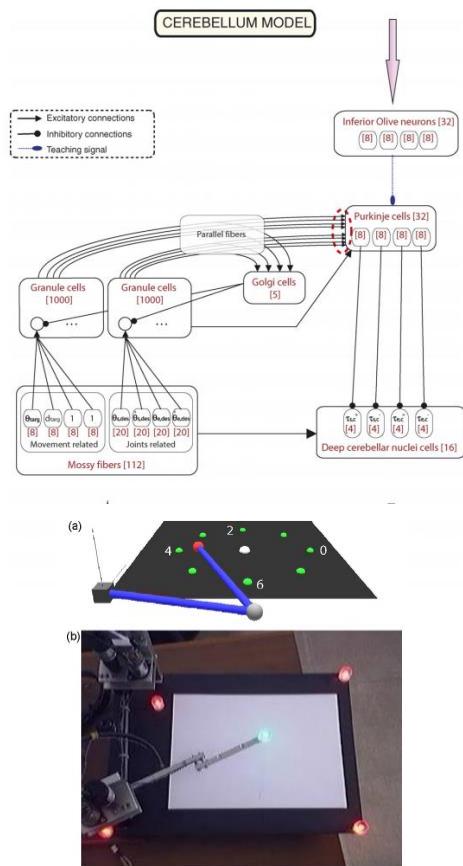
Imaging Purkinje cells in larval zebrafish



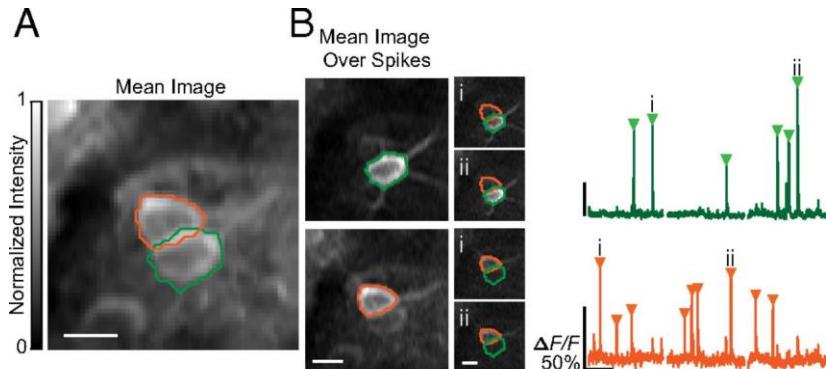
Calcium imaging reveals activity dependent on sensory stimuli



Why is this important to AI Developers?



Application of AI in life sciences



CalciumGAN: A Generative Adversarial Network Model for Synthesising Realistic Calcium Imaging Data of Neuronal Populations

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Nathalie Rochefort^{2,3}
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Arno Onken¹
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¹School of Informatics, University of Edinburgh

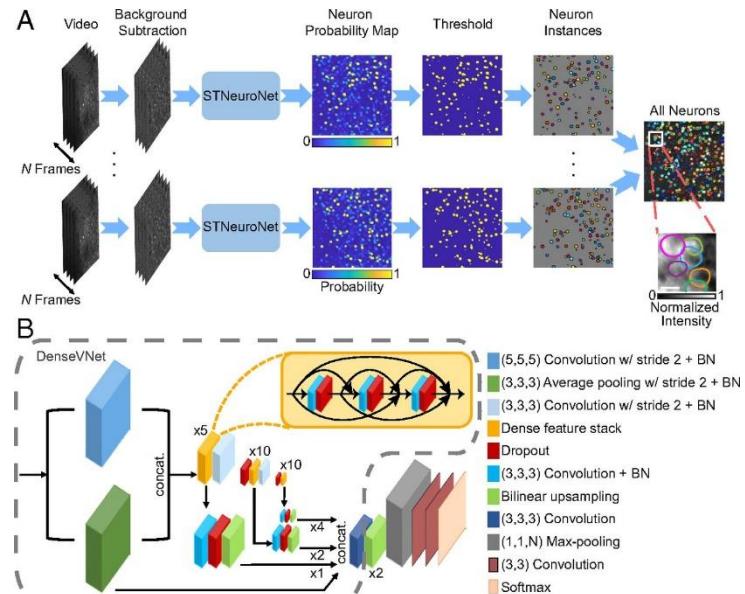
²Centre for Discovery Brain Sciences, University of Edinburgh

³Simons Initiative for the Developing Brain, University of Edinburgh

Fast and robust active neuron segmentation in two-photon calcium imaging using spatiotemporal deep learning

• Somayeh Soltanian-Zadeh, Kaan Sahingur, Sarah Blau, Yiyang Gong, and Sina Farsiu
+ See all authors and affiliations

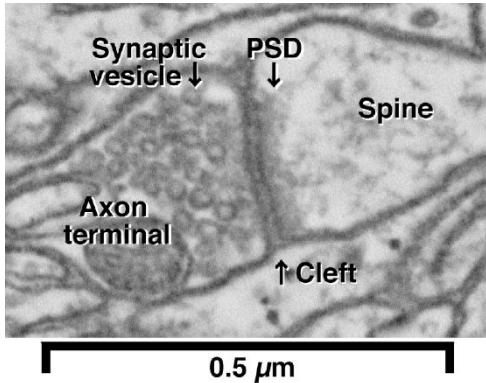
PNAS April 23, 2019 116 (17) 8554-8563; first published April 11, 2019; <https://doi.org/10.1073/pnas.1812995116>



Connectivity

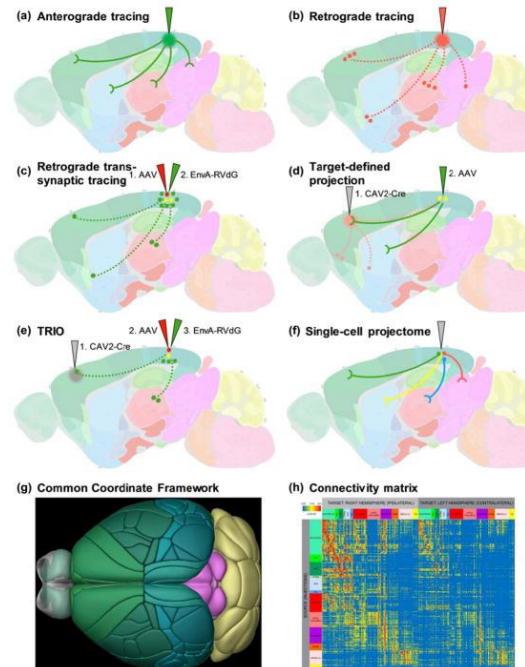
Connectivity analysis

Micro [μ ms]



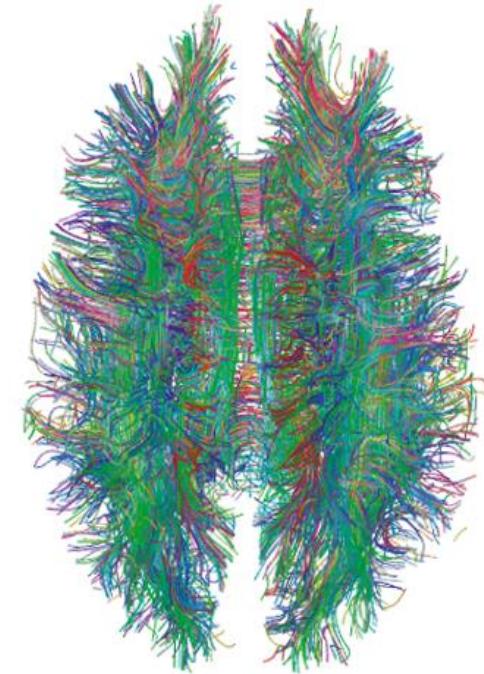
<https://blogs.zeiss.com/microscopy/en/brain-circuits/>

Meso [100 μ ms]



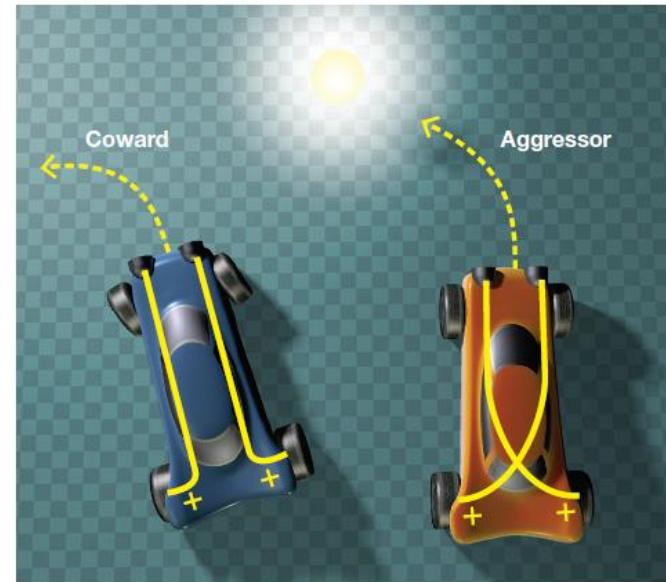
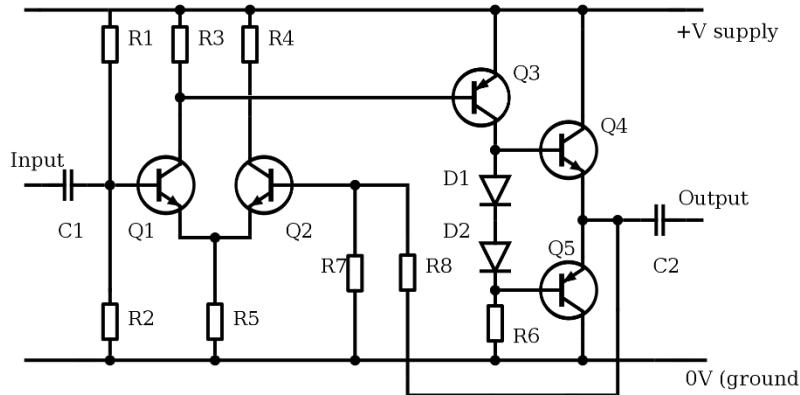
Zeng, Curr Opin Neurobiol 2018

Macro [mms]



Xavier Gigandet
et al., 2008

Why is it important?



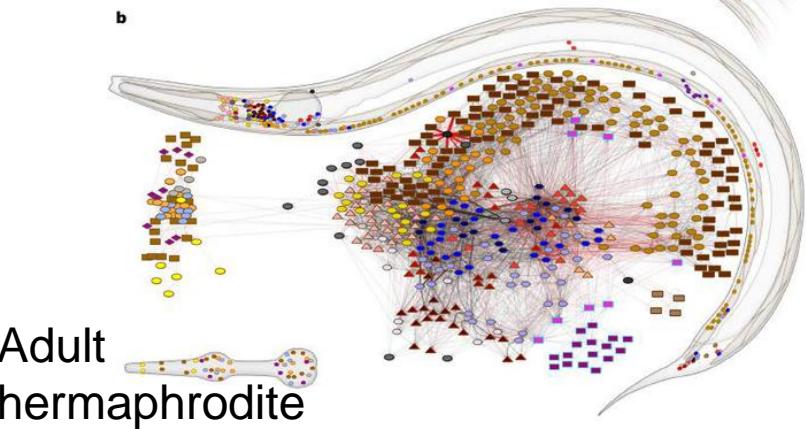
Knowing the circuitry helps in identifying the purpose

https://en.wikipedia.org/wiki/Amplifier#/media/File:Amplifier_Circuit_Small.svg

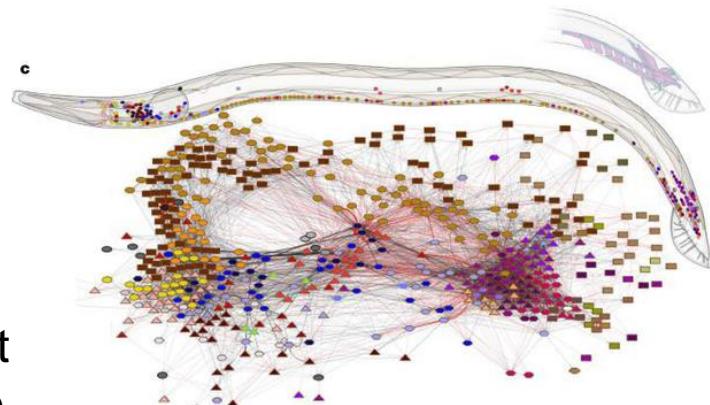
C. elegans connectome



© Bob Goldstein



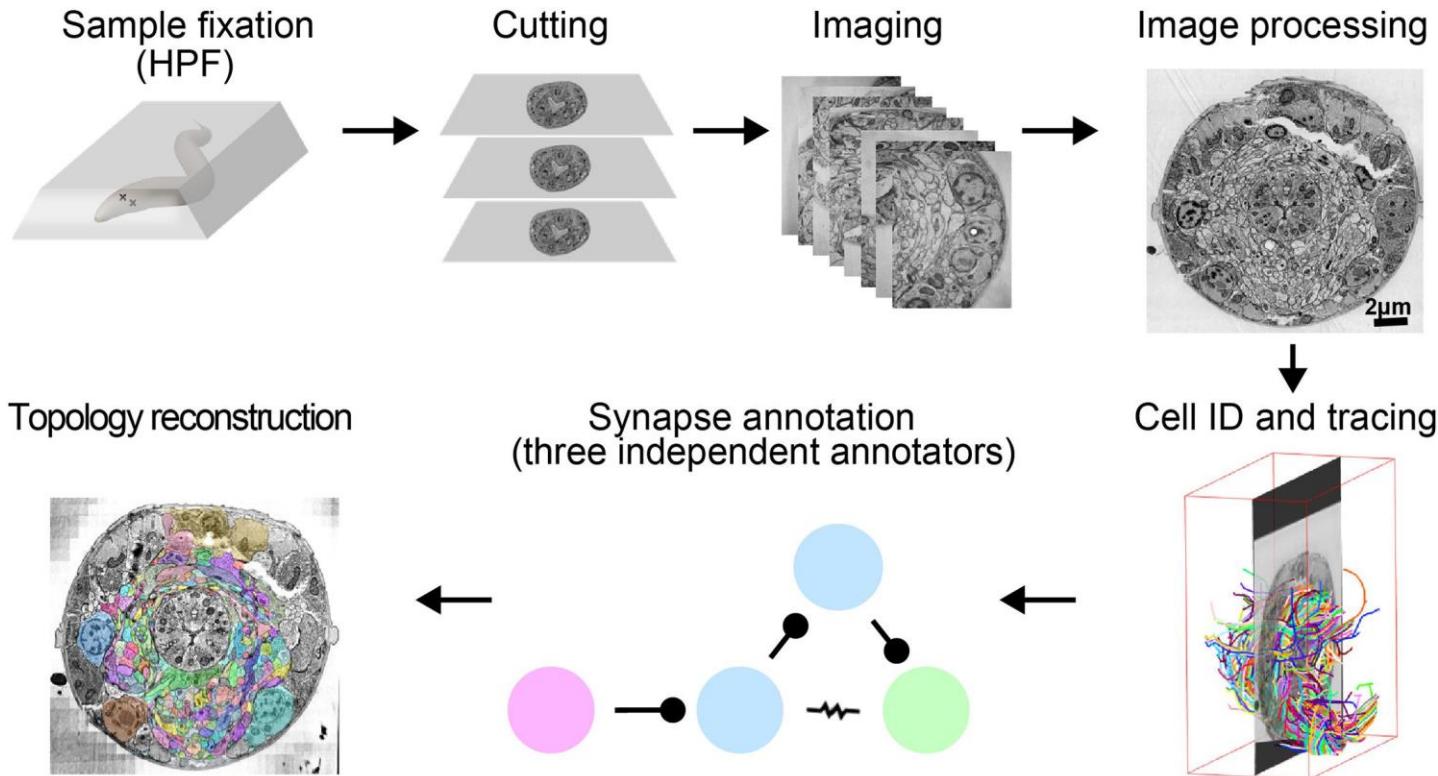
Adult
hermaphrodite



Adult
male

Cook et al., Nature 2019

Electron microscopy



Gamification of tasks



Using AI for connectomics analysis

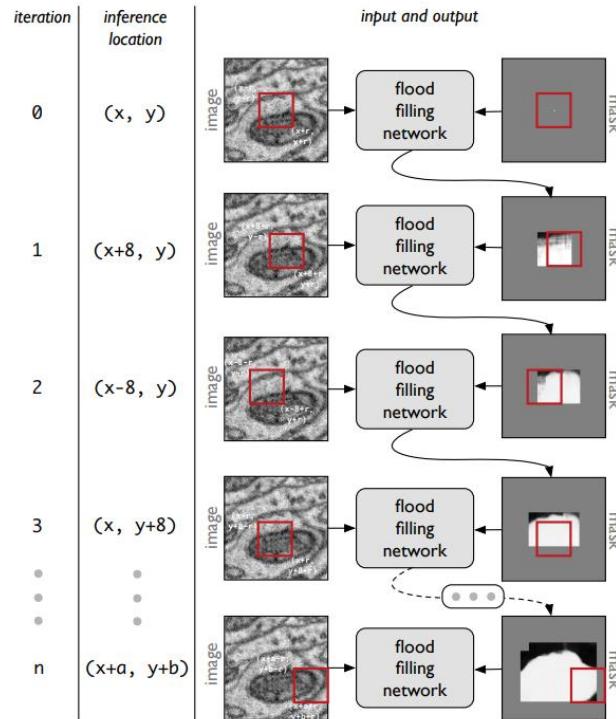
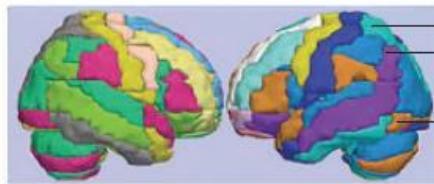
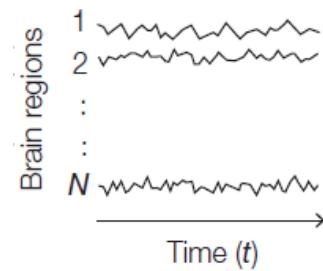


Figure 2: Schematic of multiple-field-of-view inference of a flood-filling network.

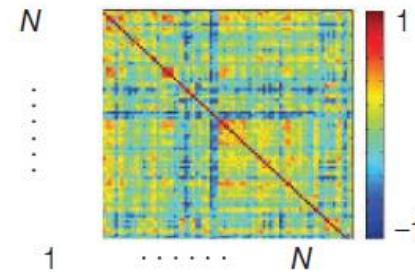
Construction a human brain network



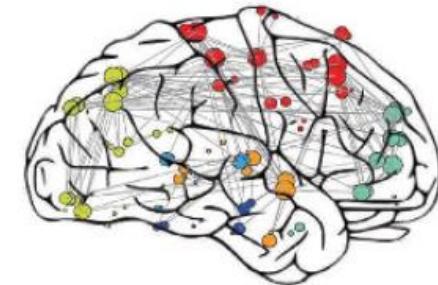
① Anatomical nodes



② fMRI time series



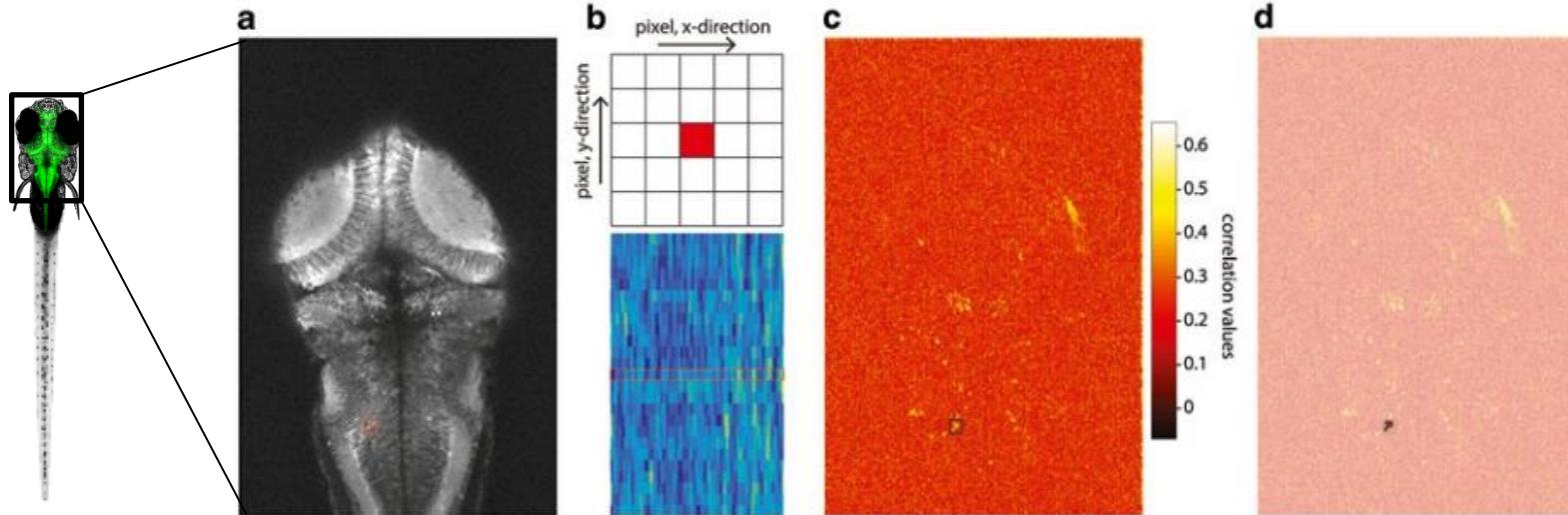
③ Association matrix



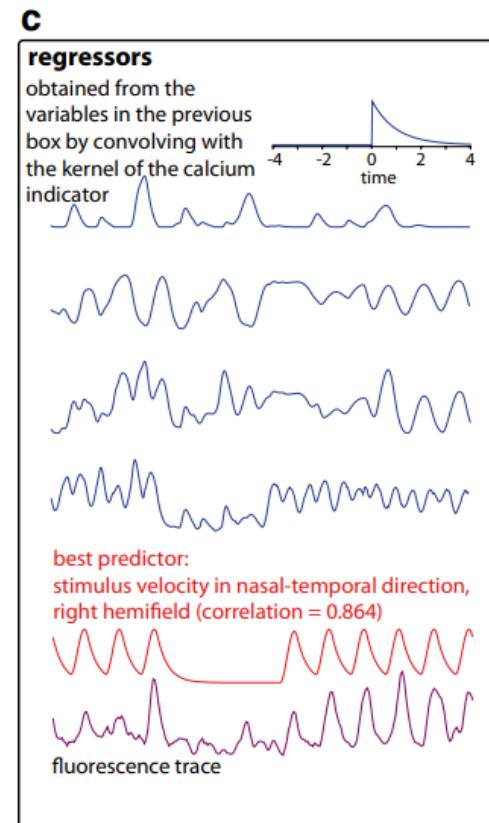
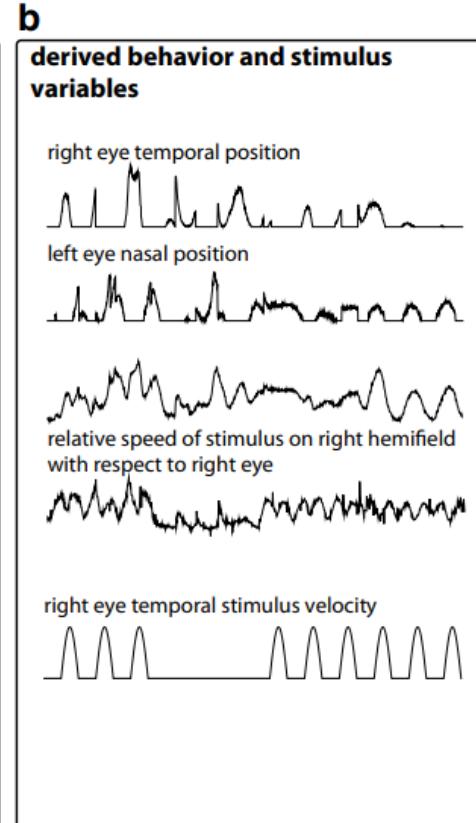
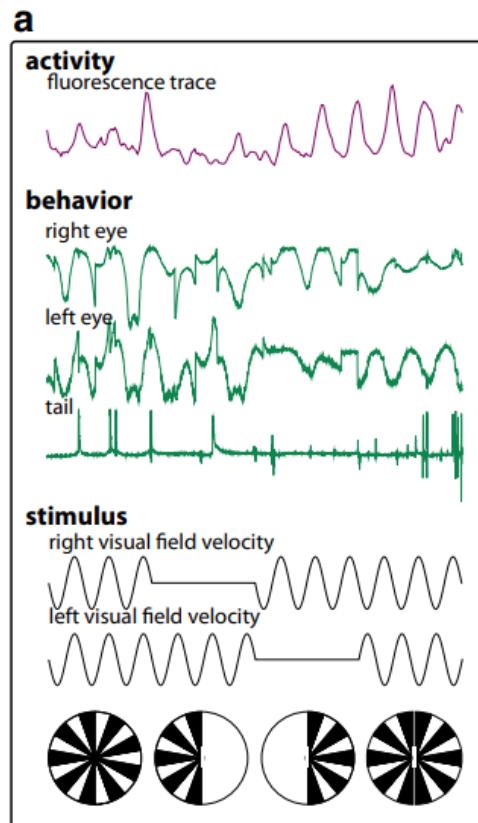
④ Connectivity map

Voxel-based correlation map

Unbiased voxel-based self-correlation

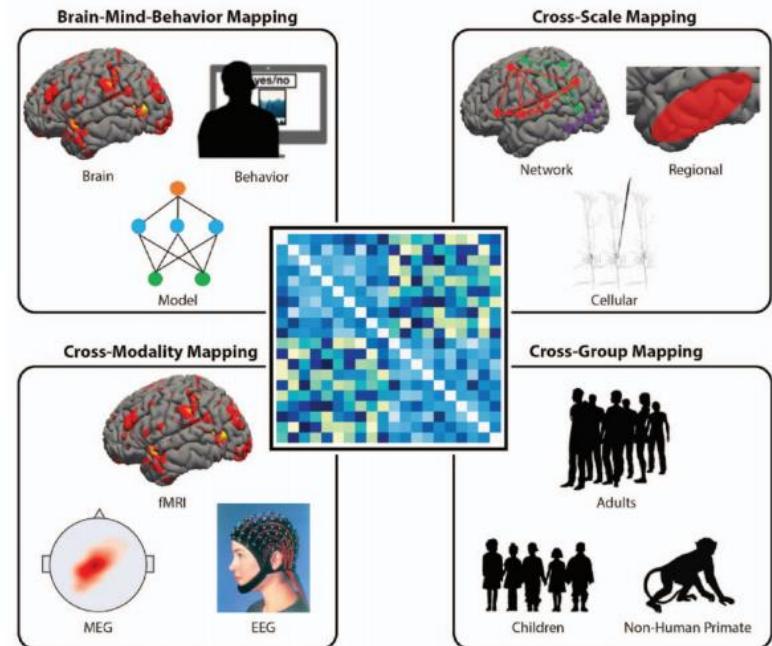


Voxel-based correlation maps

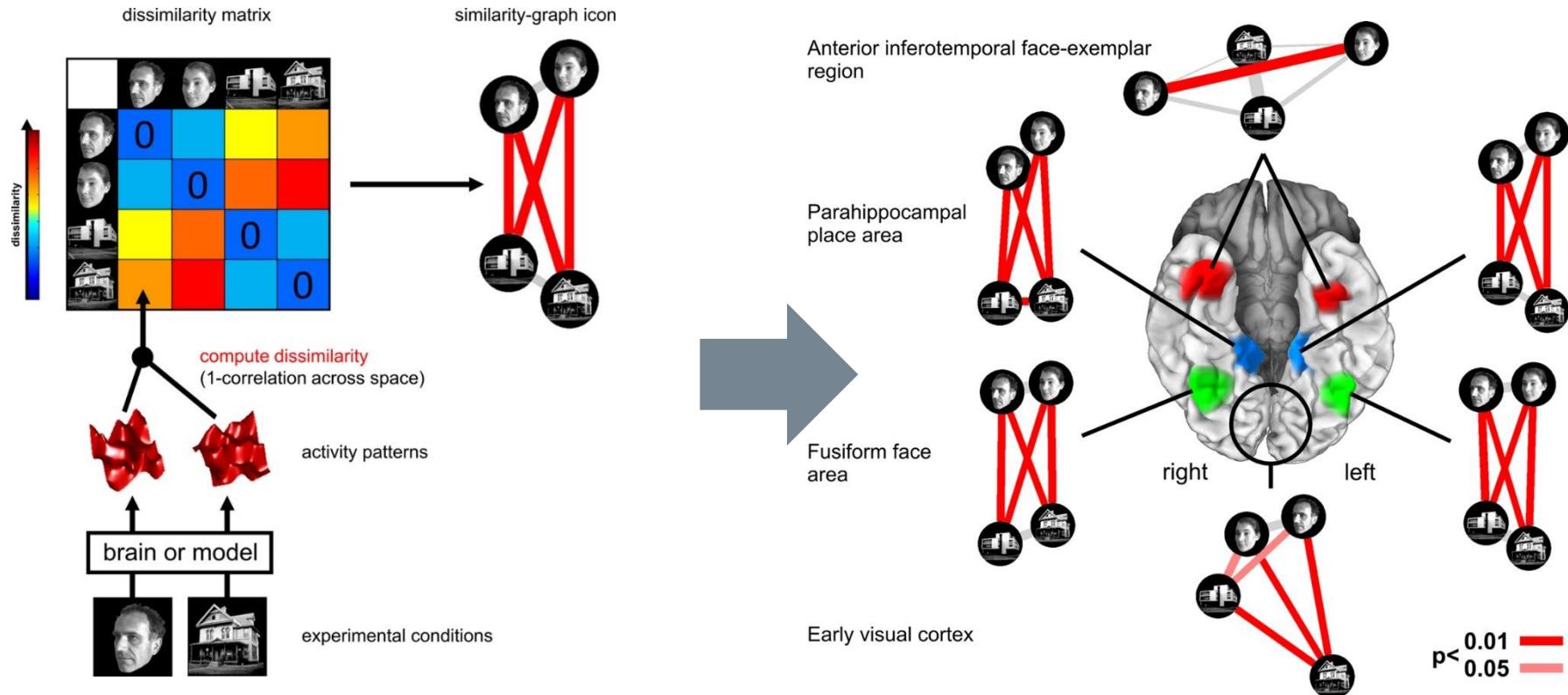


representational similarity analysis - RSA

- RSA combines data from different sources by using a common representational space.
- RSA is unique in its ability to incorporate data from a variety of sources

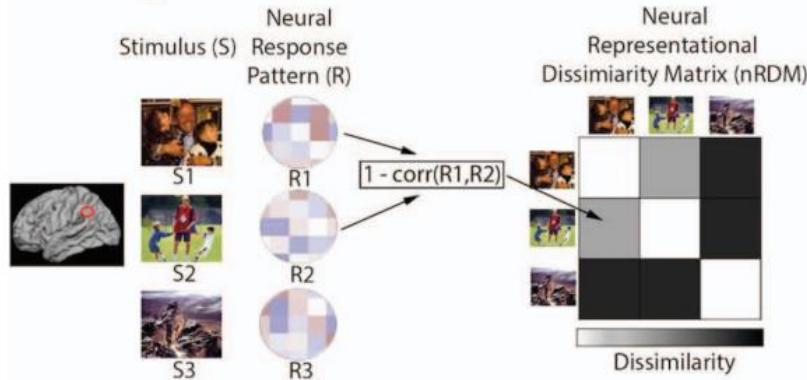


Representational Dissimilarity Matrices (RDMs)

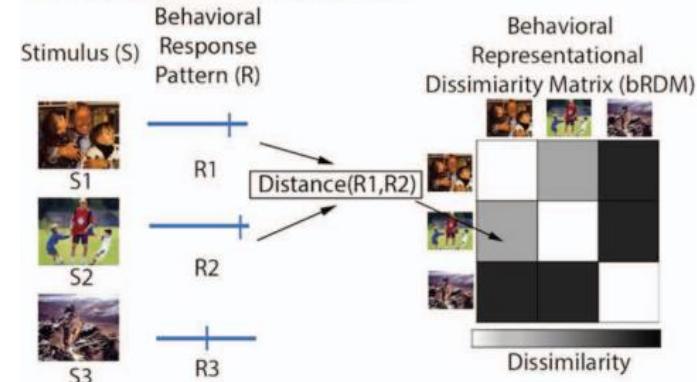


Creating RDMs

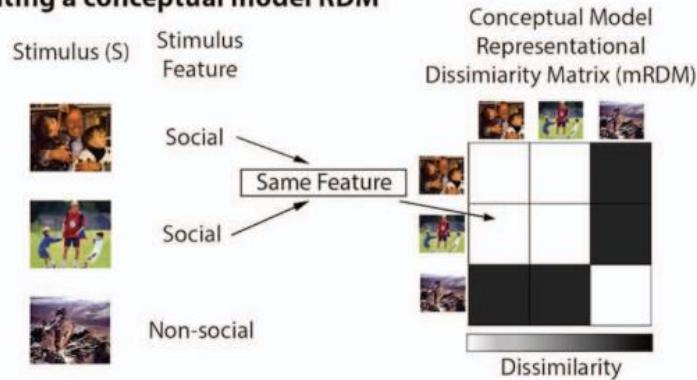
A. Creating a neural RDM



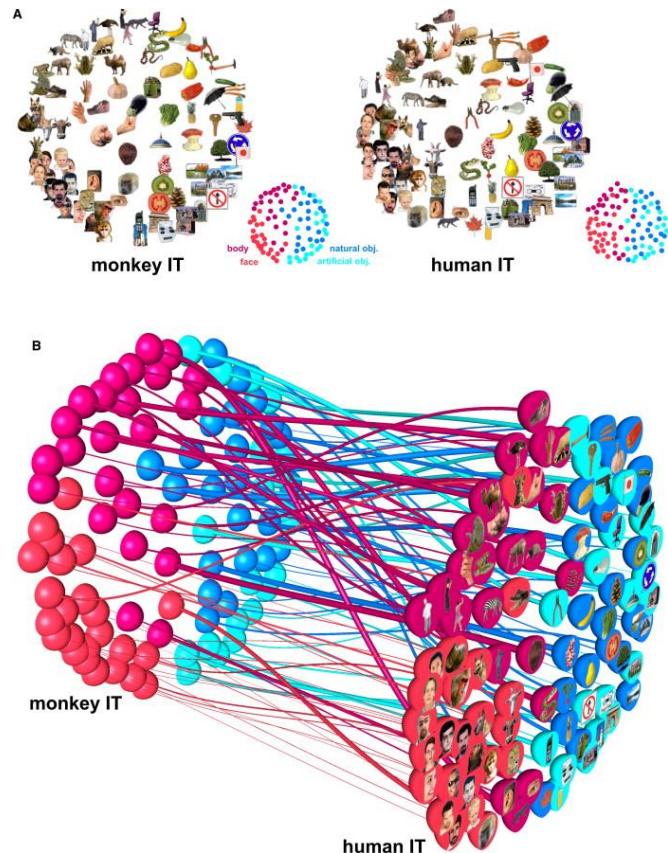
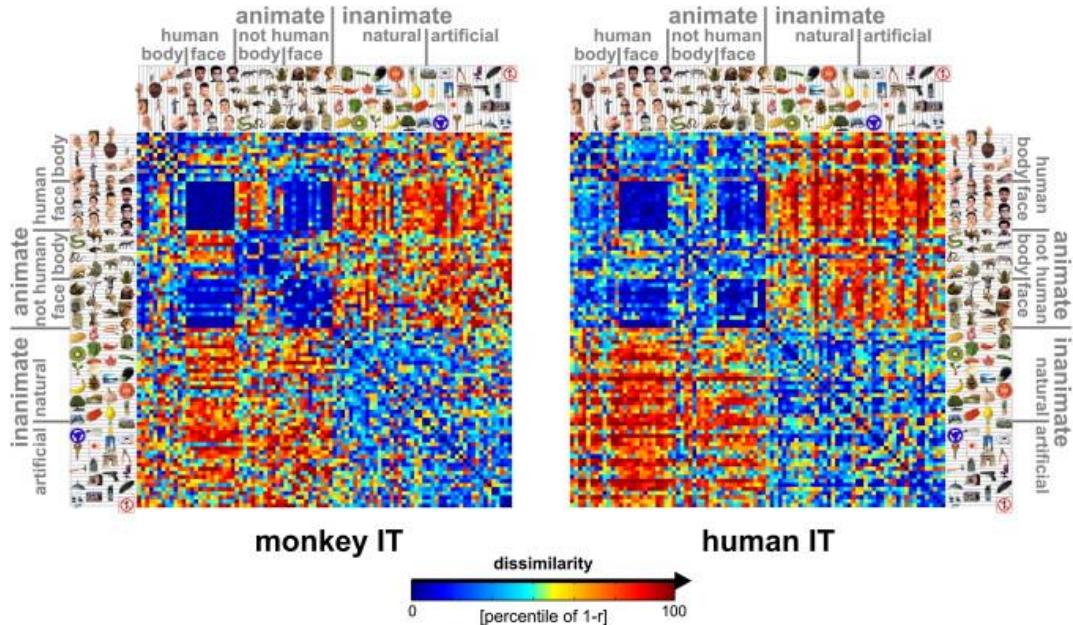
B. Creating a behavioral RDM



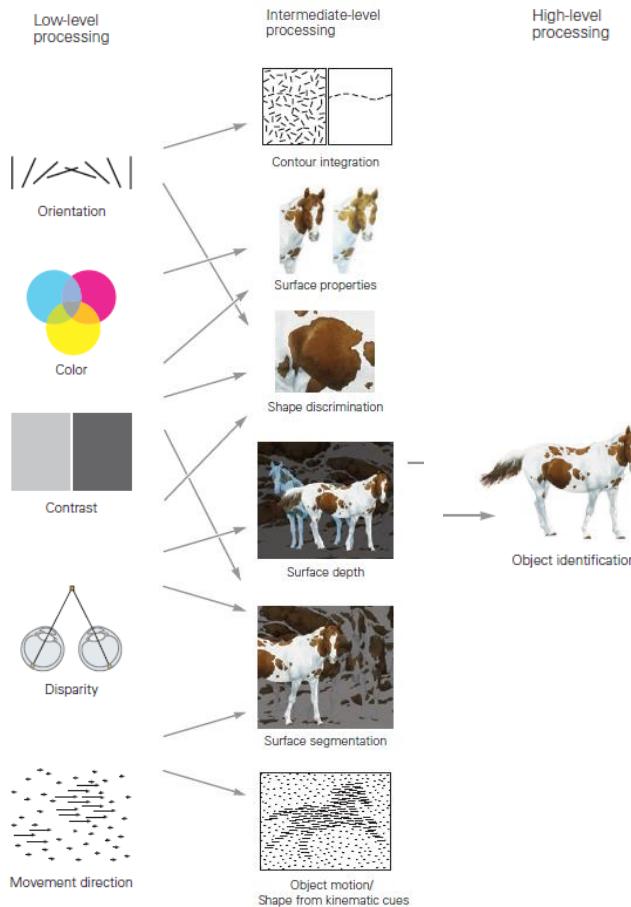
C. Creating a conceptual model RDM



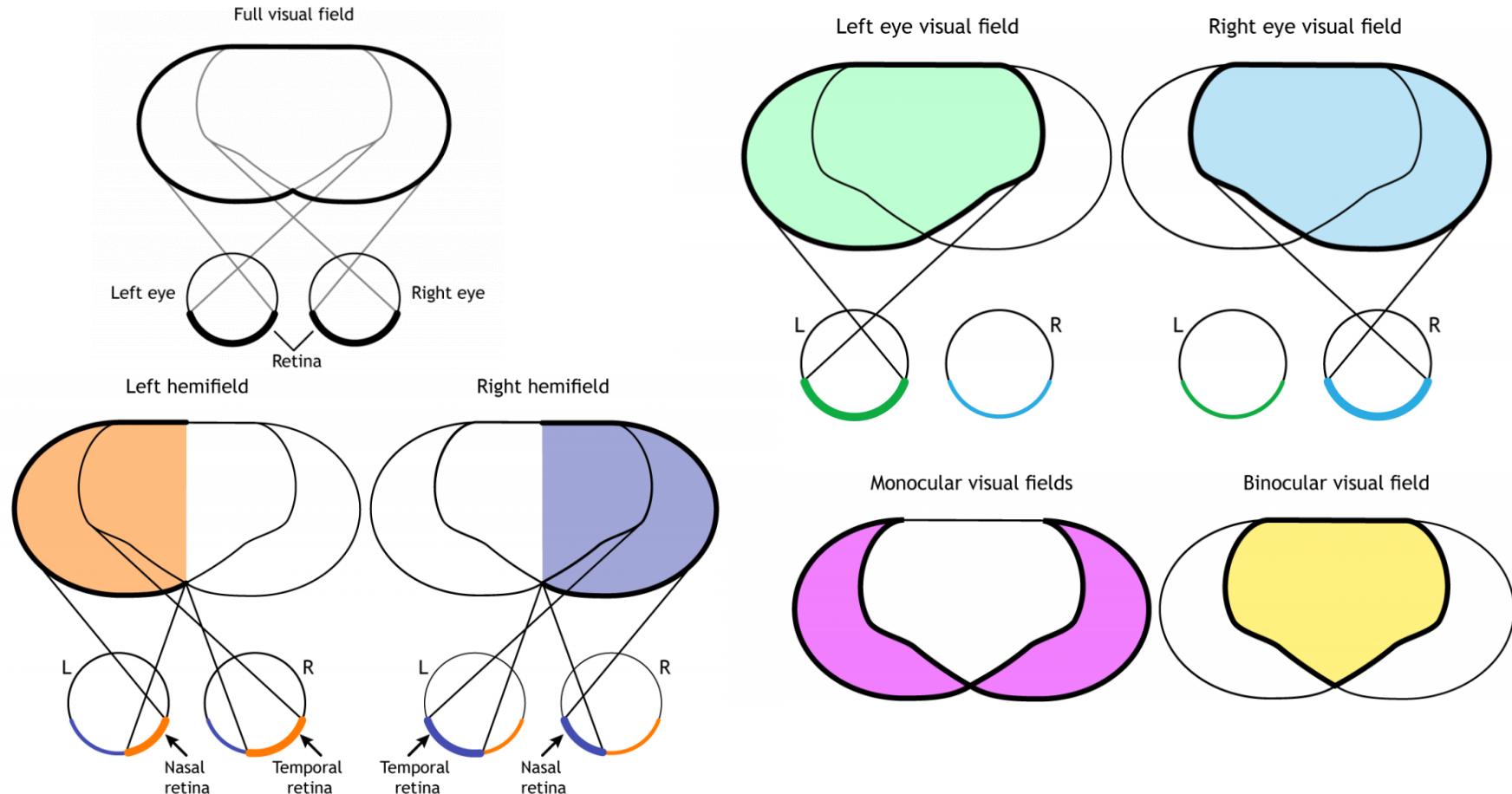
RSA to uncover brain coding in humans and monkeys



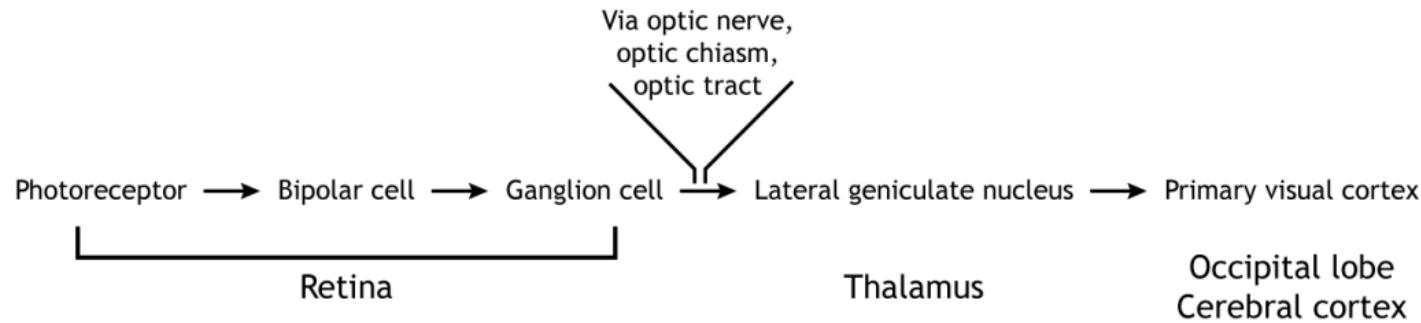
A visual scene is analyzed in 3 levels



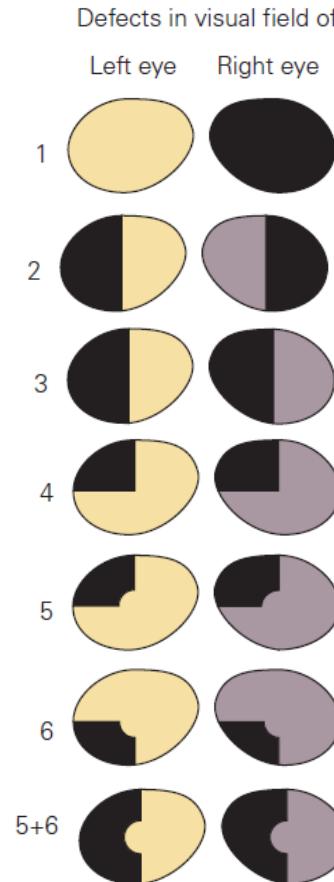
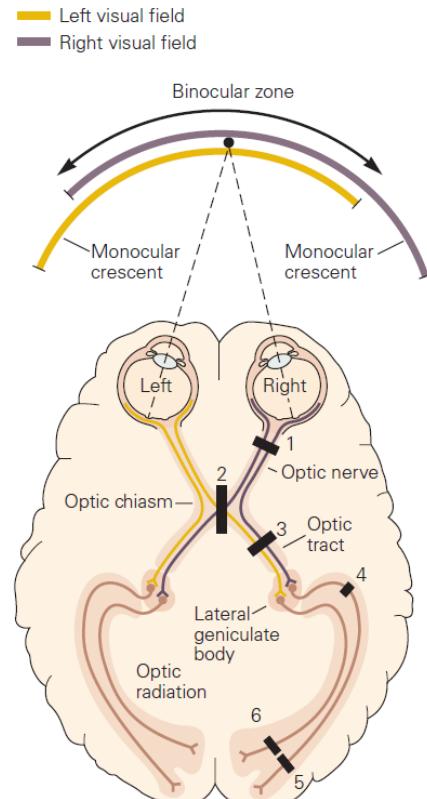
What can we see?



Visual pathway

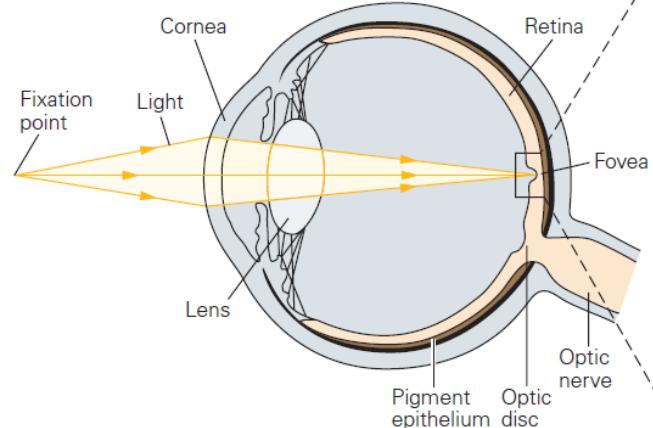


Visual field along the visual pathway

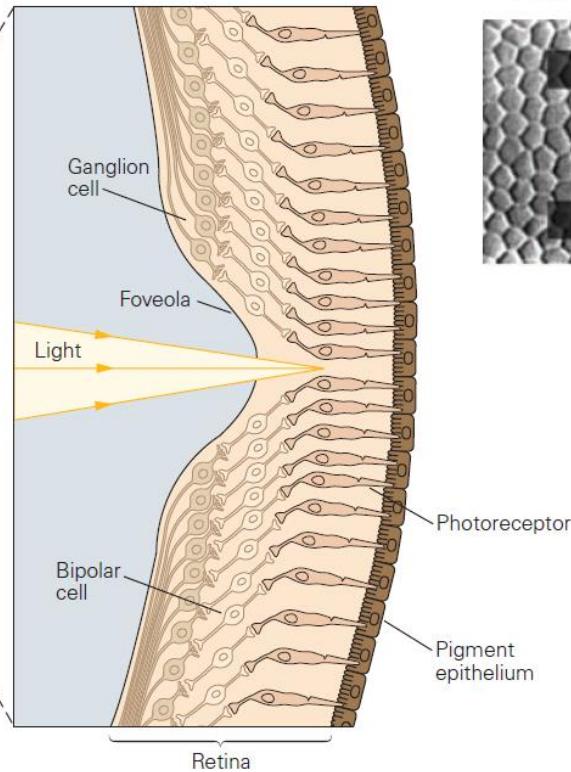


Low-level visual processing

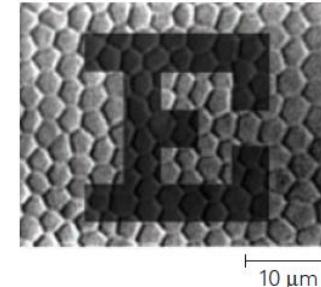
A Refraction of light onto the retina



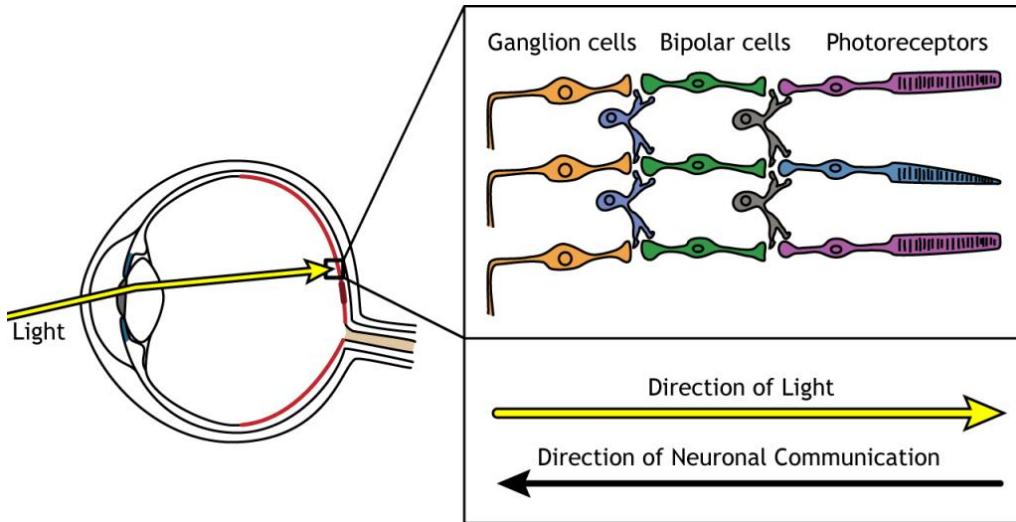
B Focusing of light in the fovea



C Packing of photoreceptors in the fovea



Neural communication is against direction of light

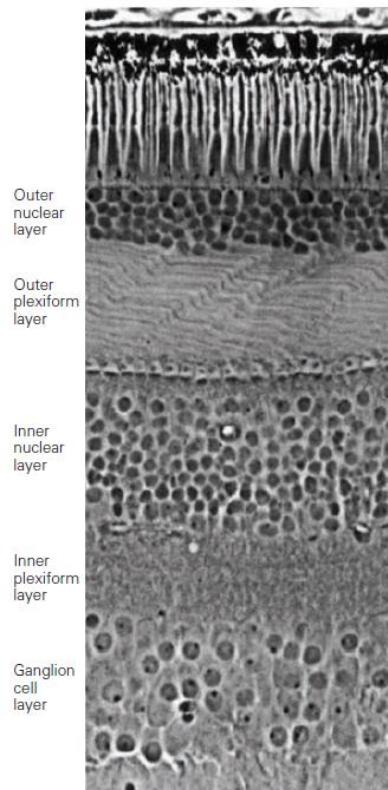


Why inverted in vertebrates?

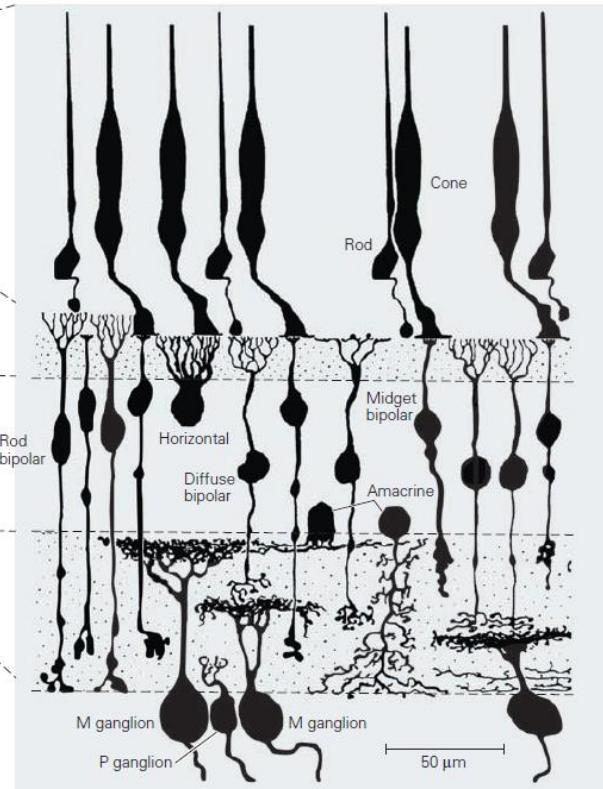
- Save-spacing in inverted eyes against everted eyes (Kröger & Biehlmaier, 2009)
- Existing Retinal Pigment Epithelium (RPE) containing melanin absorbing light and avoiding back reflections
- Better maintenance of photoreceptors
- Light guides by ganglion cells

Retina components

A Section of retina



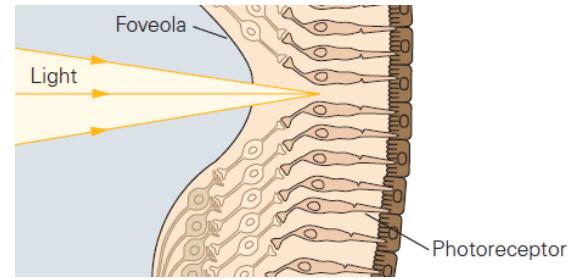
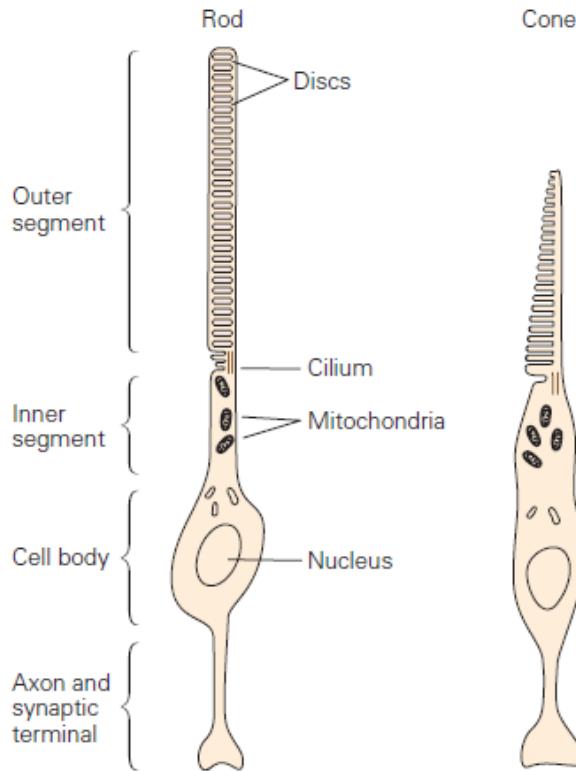
B Neurons in the retina



Rods and cones

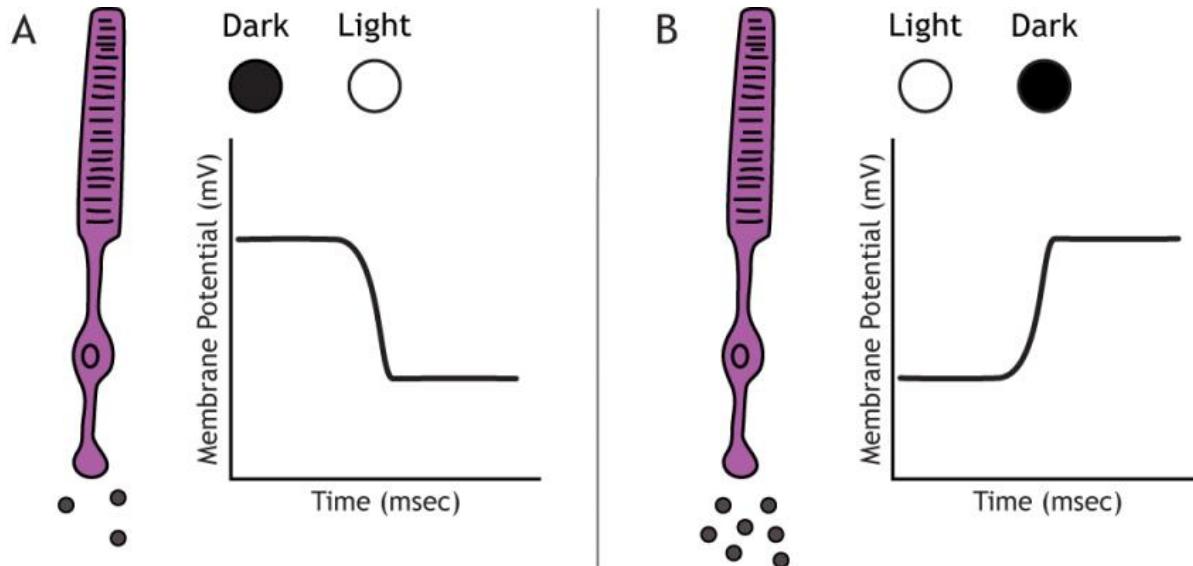
Black&white

A Morphology of photoreceptors

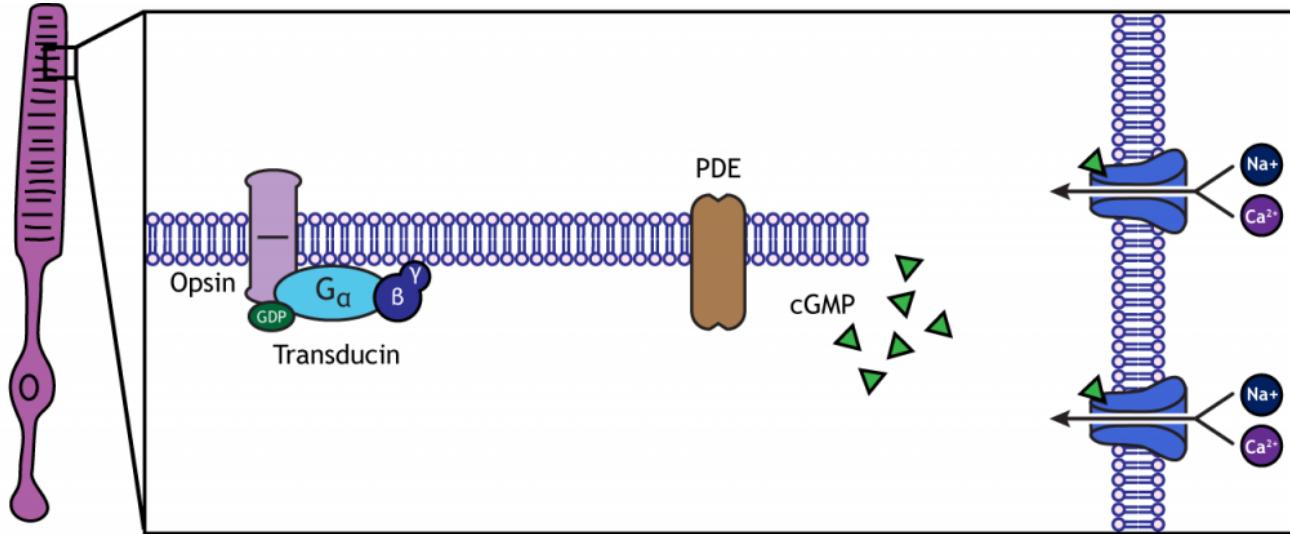


Color

How does our „Analog-Digital-Converter“ work?



The light sensing cascade

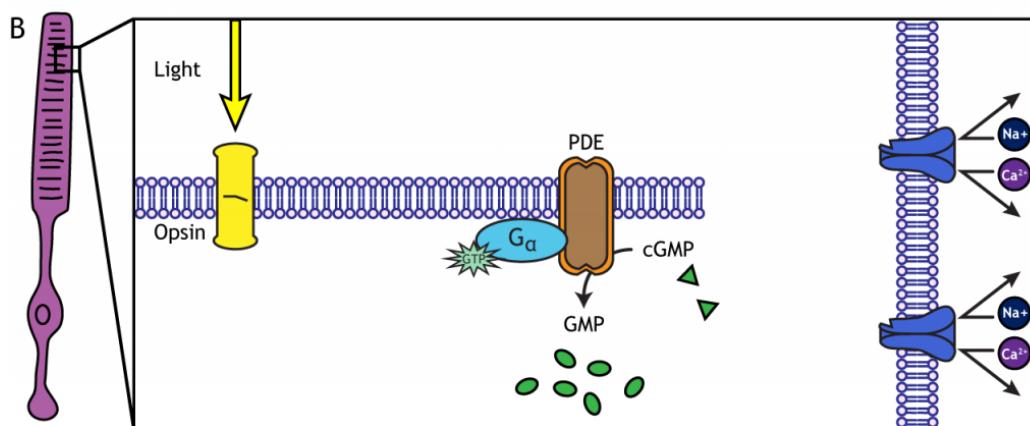
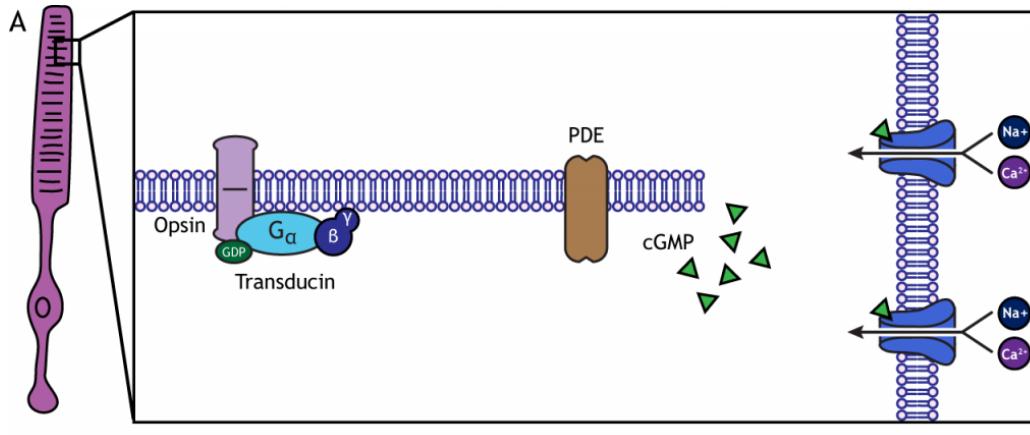


Opsin: The light-sensing channel

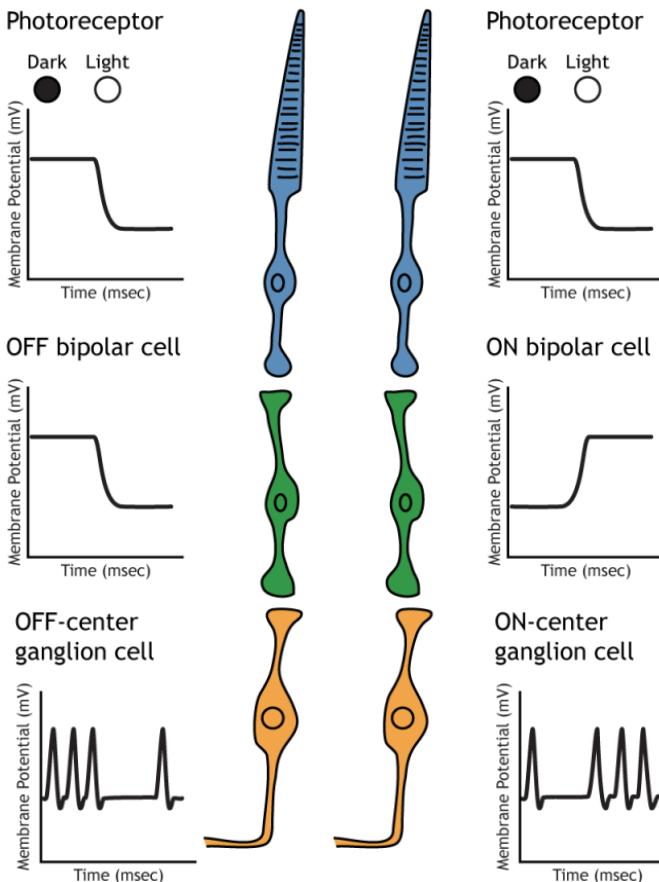
PDE: Phosphodiesterase

cGMP: circular Guanosine monophosphate

Darkness vs Light



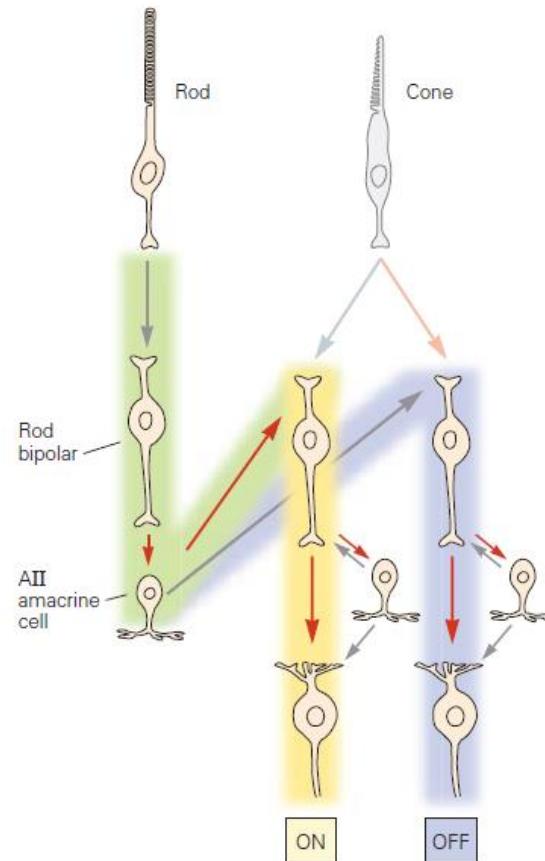
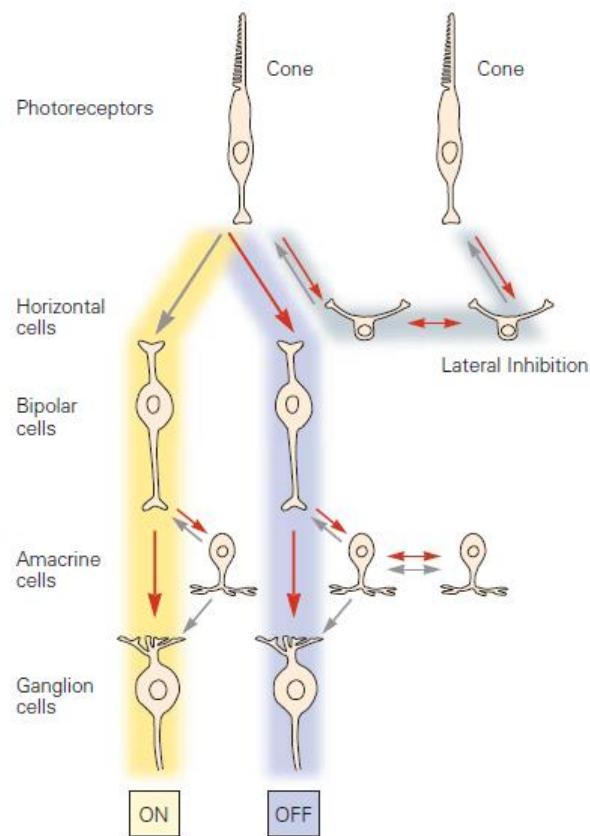
Ganglion cell activity



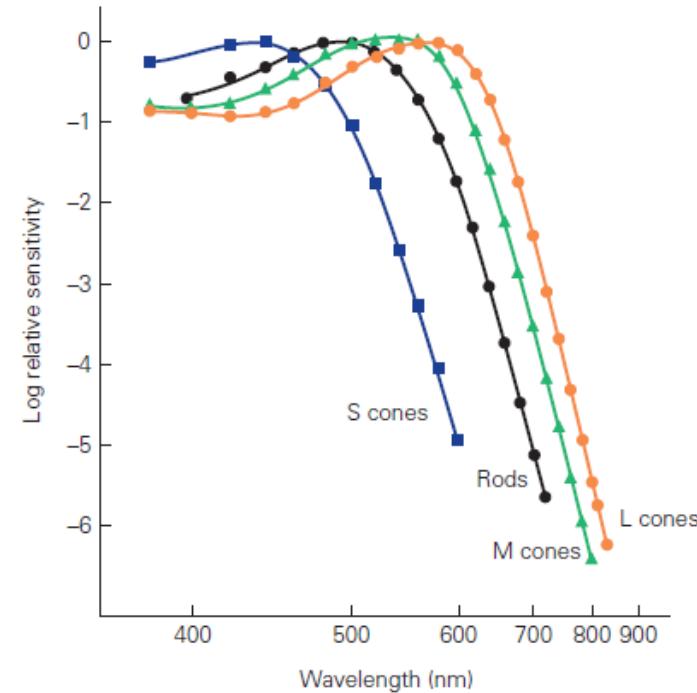
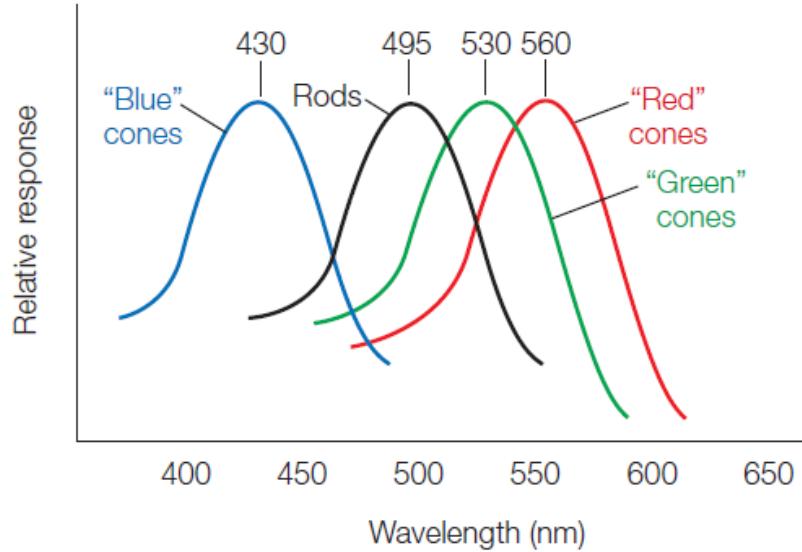
Bipolar cells can bypass signal or invert signal, can amplify signal

Ganglion cells encode signal using action potentials

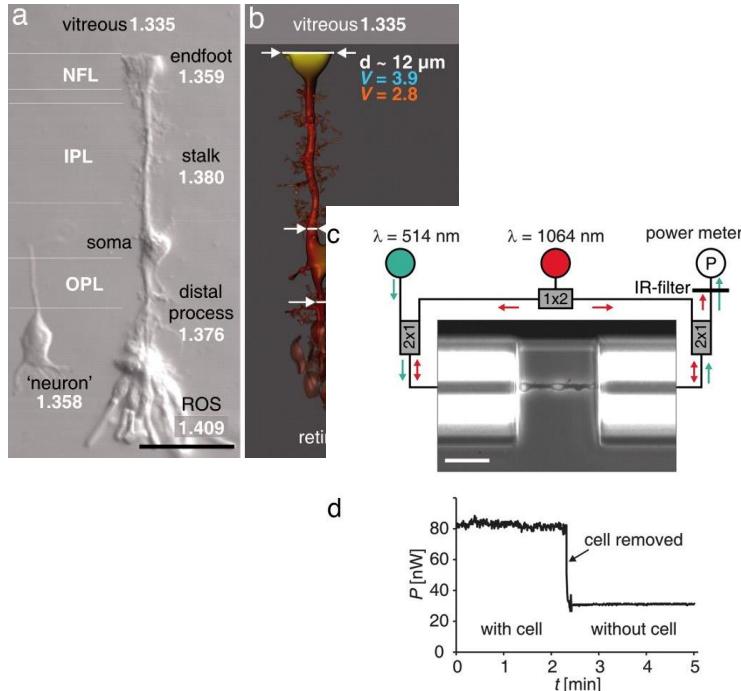
Retinal circuitry



Rod and cone spectral sensitivity

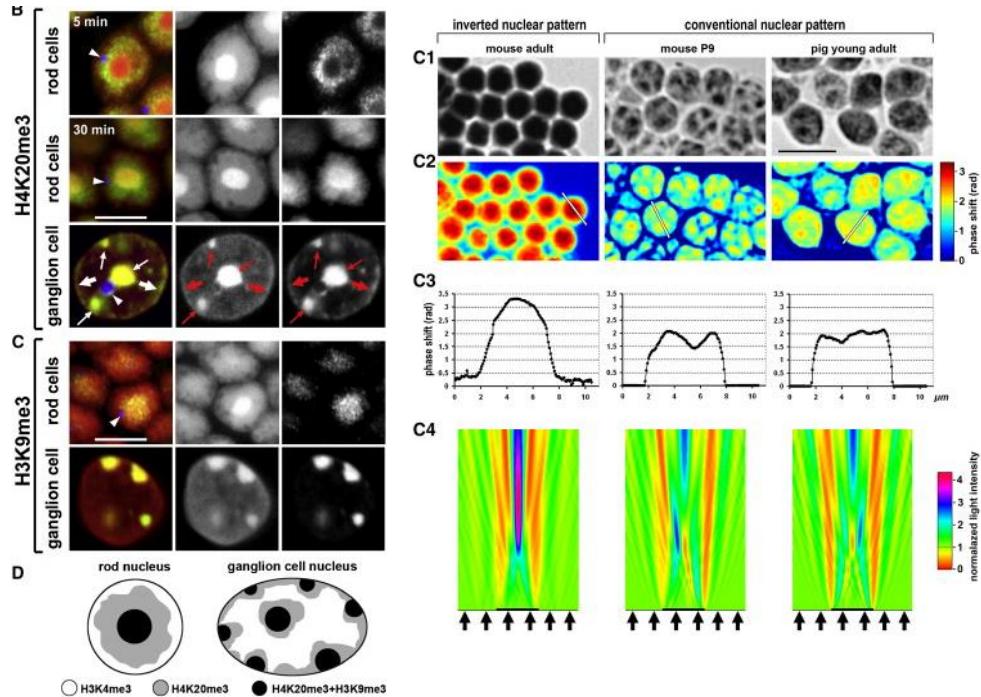


Retina physiology is fascinating

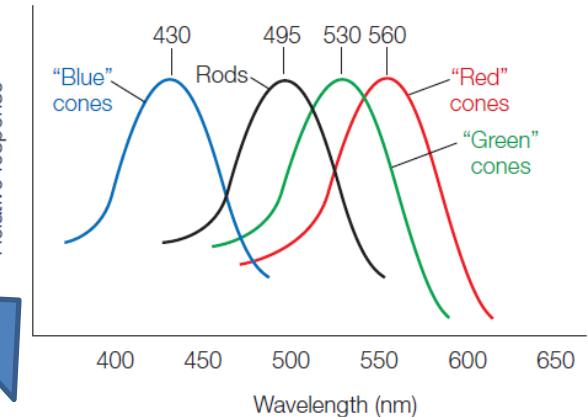
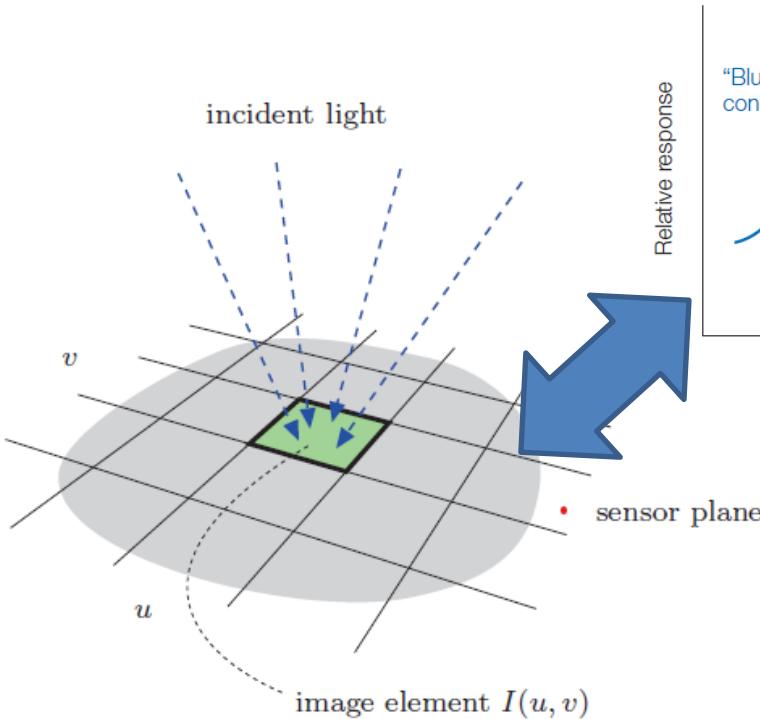
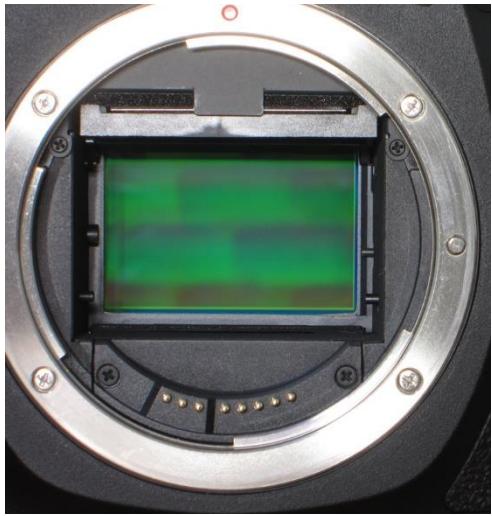


Müller cells are light guides

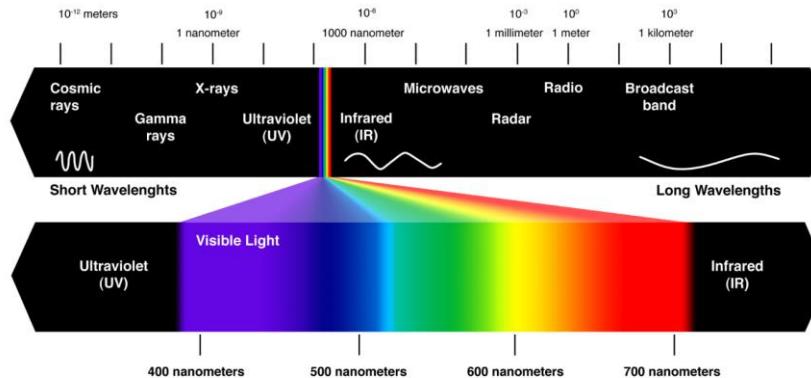
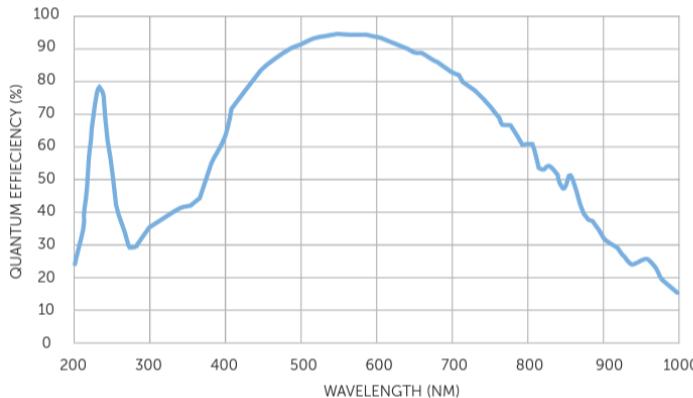
Inverted cell nucleus organization acts as a focusing lens



Generating color images for image processing tasks

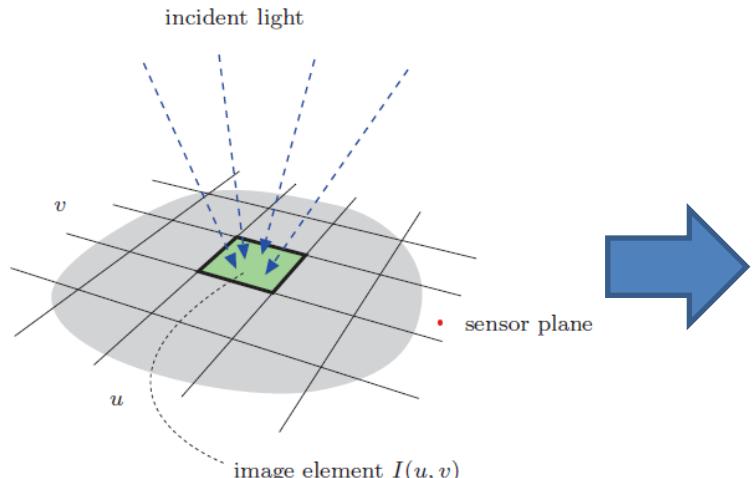


Spectral properties of a sCMOS camera

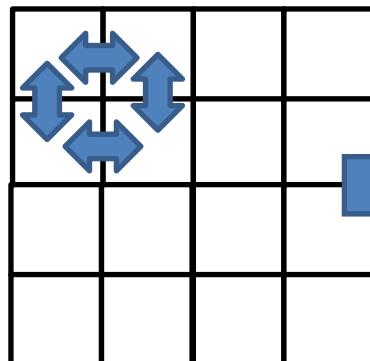


Frame Rate (PCIe interface)		
Array Size	16-bit	12-bit
1200 x 1200	40	80
1200 x 512	94	188
1200 x 256	188	374
1200 x 128	374	737

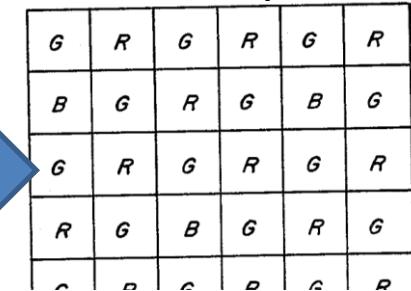
The Bayer pattern



Adjacent pixels have high correlation!



Can we just put
Small bandpass filter
Over the pixels?!



United States Patent [19] 3,971,065
Bayer [11] July 20, 1976
[45]

[54] COLOR IMAGING ARRAY

[75] Inventor: Bryce E. Bayer, Rochester, N.Y.
[73] Assignee: Eastman Kodak Company,
Rochester, N.Y.

[22] Filed: Mar. 5, 1975
[21] Appl. No.: 558,477

[52] U.S. CL 358/41; 350/162 SP;
350/137; 358/44
[51] Int. Cl. H04N 9/24
[58] Field of Search 358/44, 45, 46, 47,
358/48; 350/317, 162 SP; 315/169 TV

[56] References Cited

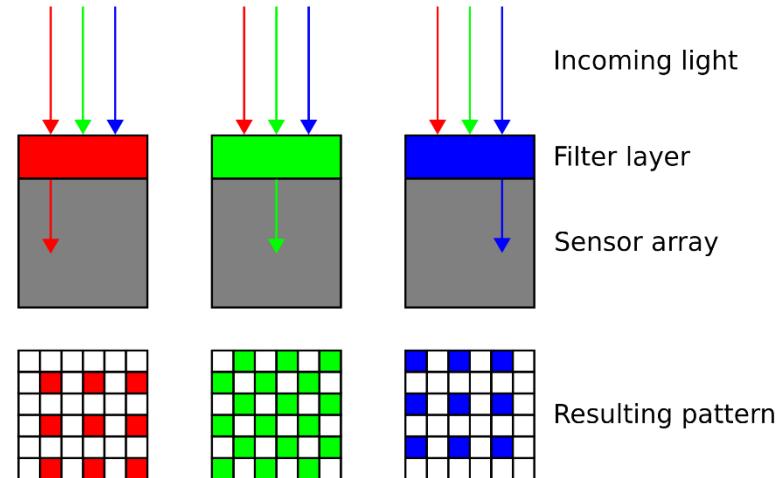
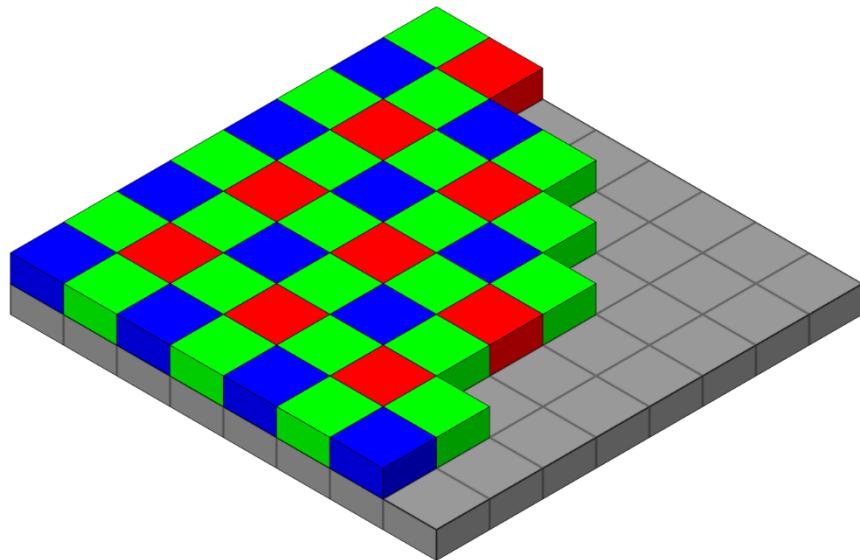
UNITED STATES PATENTS
2,446,791 8/1949 Schroeder..... 358/44
2,508,267 5/1950 Kasperowicz..... 358/44
2,884,483 4/1959 Ehrenhaft et al..... 358/44
3,725,572 4/1973 Kurokawa et al..... 358/46

Primary Examiner—George H. Libman
Attorney, Agent, or Firm—George E. Grosser

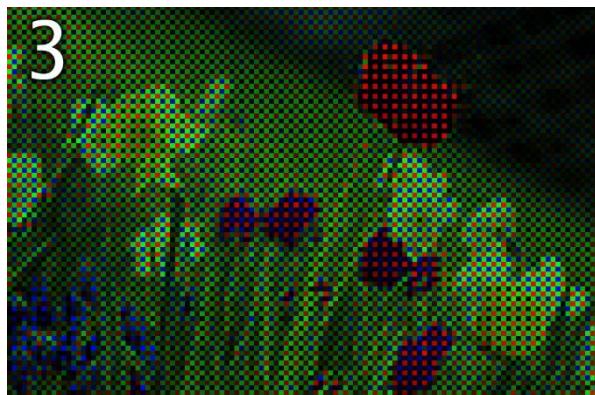
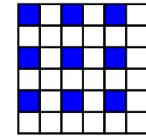
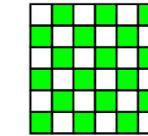
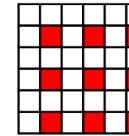
[57] ABSTRACT
A sensing array for color imaging includes individual luminance- and chrominance-sensitive elements that are so intermixed that each type of element (i.e., according to sensing characteristics) occurs in a repeating pattern with luminance elements occurring in every other element position to provide a relatively high frequency sampling pattern which is uniform in two dimensions (e.g., horizontal and vertical). The chrominance patterns are interlaced therewith and fill the remaining element positions to provide relatively lower frequencies of sampling.
In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad spectral range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.

11 Claims, 10 Drawing Figures

Bayer pattern image generation



Generate a color image



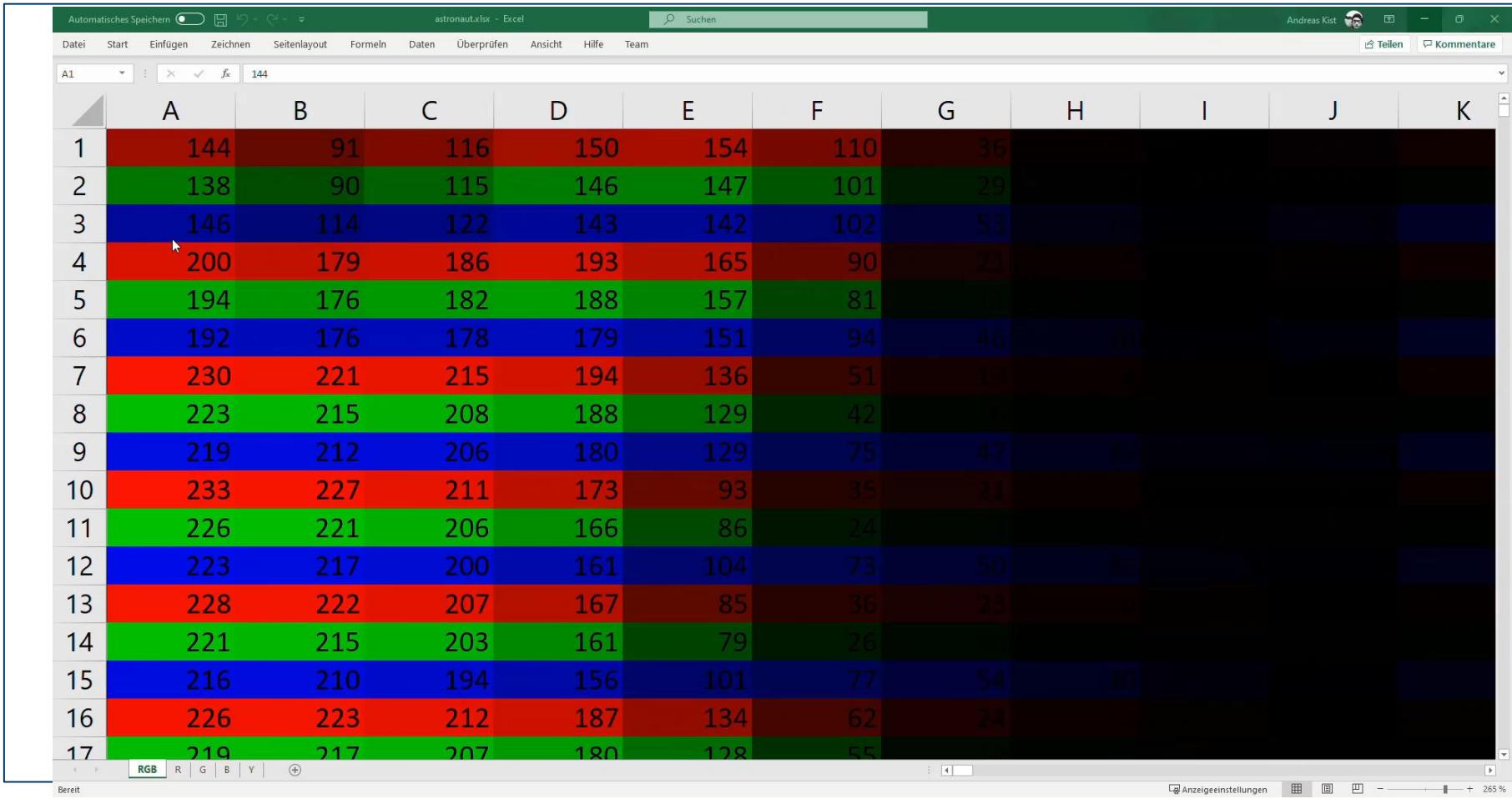
Demosaicing

Most frequent
artifact: Moiré
patterns

Images are Excel sheets

Automatisches Speichern Datei Start Einfügen Zeichnen Seitenlayout Formeln Daten Überprüfen Ansicht Hilfe Team

A1 :x: fx 144 Suchen [Andreas Kist] Teilen Kommentare

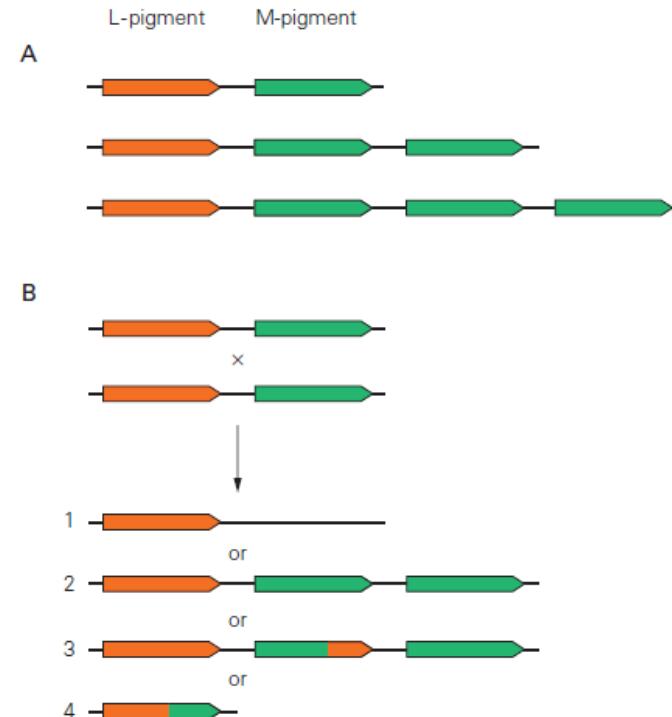
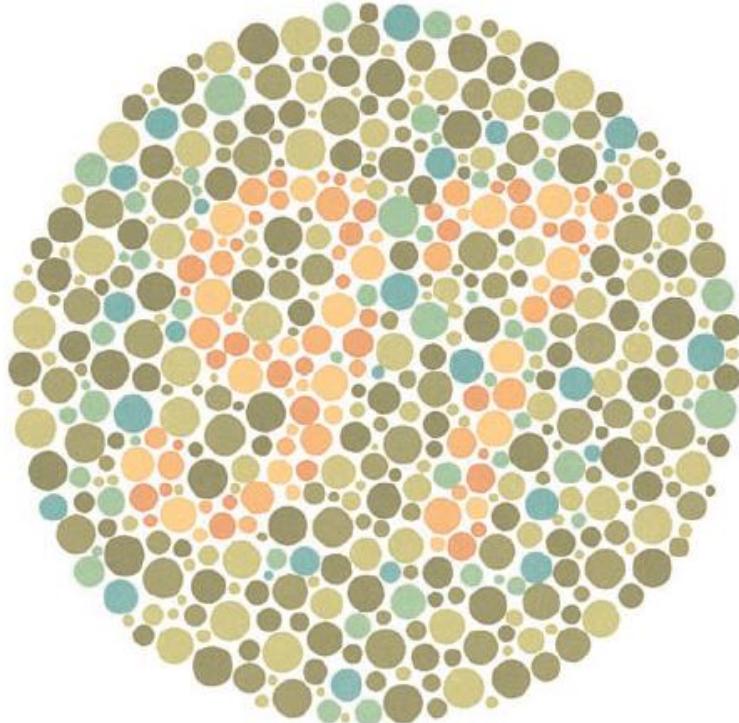


The following table represents the data from the Excel sheet:

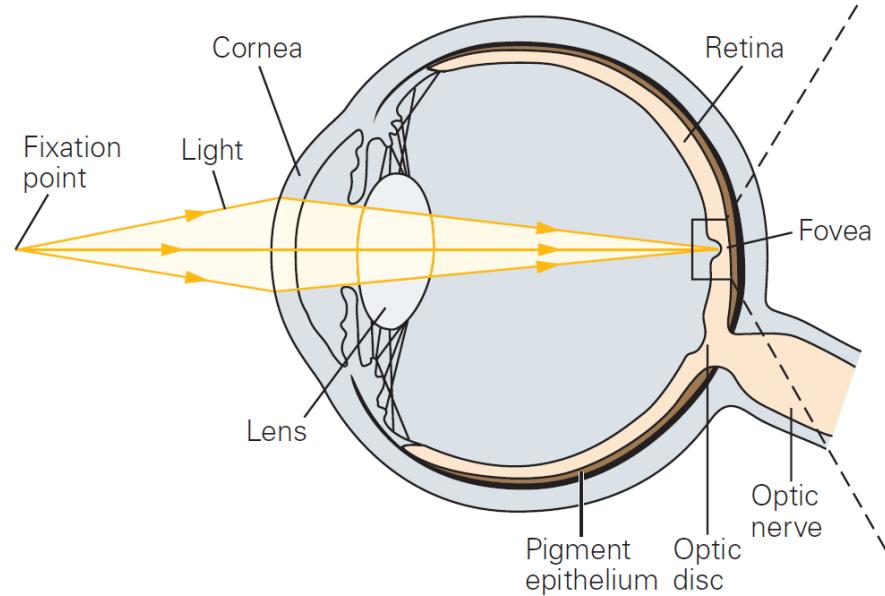
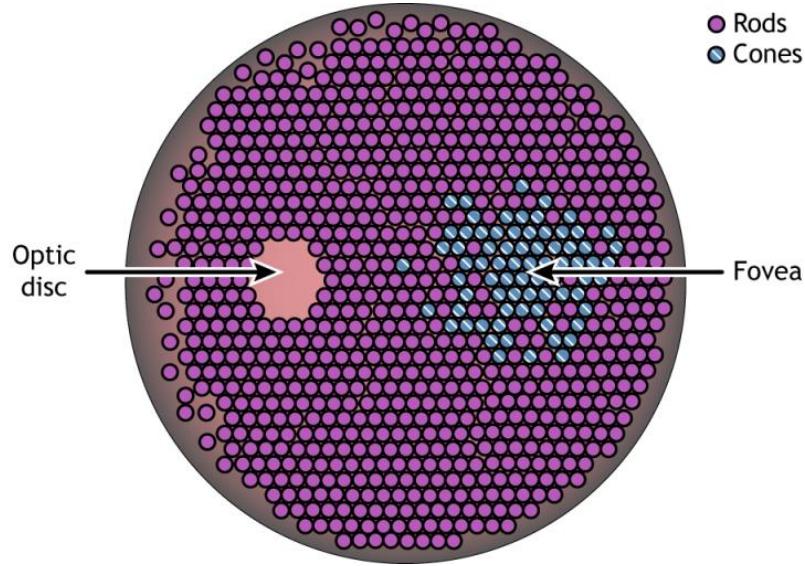
1	144	91	116	150	154	110	36			
2	138	90	115	146	147	101	29			
3	146	114	122	143	142	102	53			
4	200	179	186	193	165	90	21			
5	194	176	182	188	157	81	11			
6	192	176	178	179	151	94	46			
7	230	221	215	194	136	51	13			
8	223	215	208	188	129	42	11			
9	219	212	206	180	129	75	47			
10	233	227	211	173	93	35	21			
11	226	221	206	166	86	24	11			
12	223	217	200	161	104	73	50			
13	228	222	207	167	85	36	23			
14	221	215	203	161	79	26	11			
15	216	210	194	156	101	77	54	10		
16	226	223	212	187	134	62	24			
17	219	217	207	180	128	55	11			

Bereit Anzeigeeinstellungen 265% 57

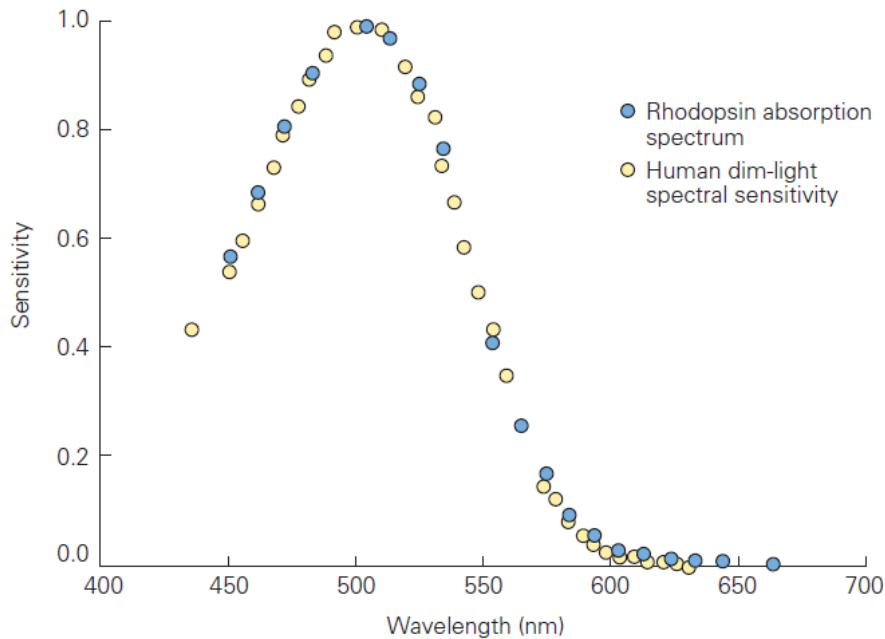
Color weak- and blindness



Our communication channel: the optic nerve

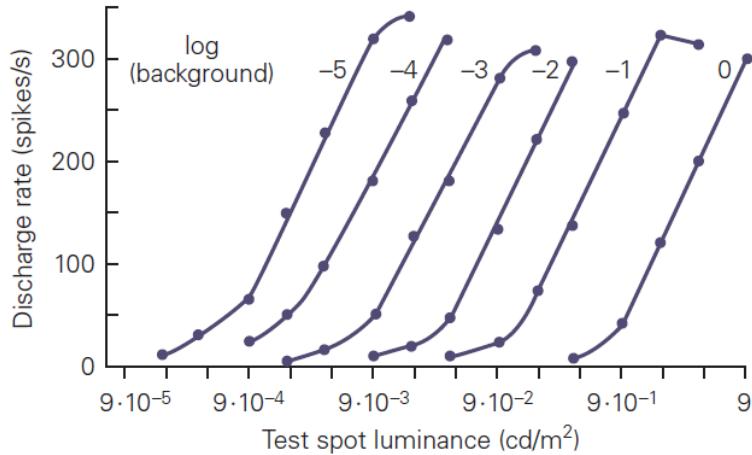


Our night vision

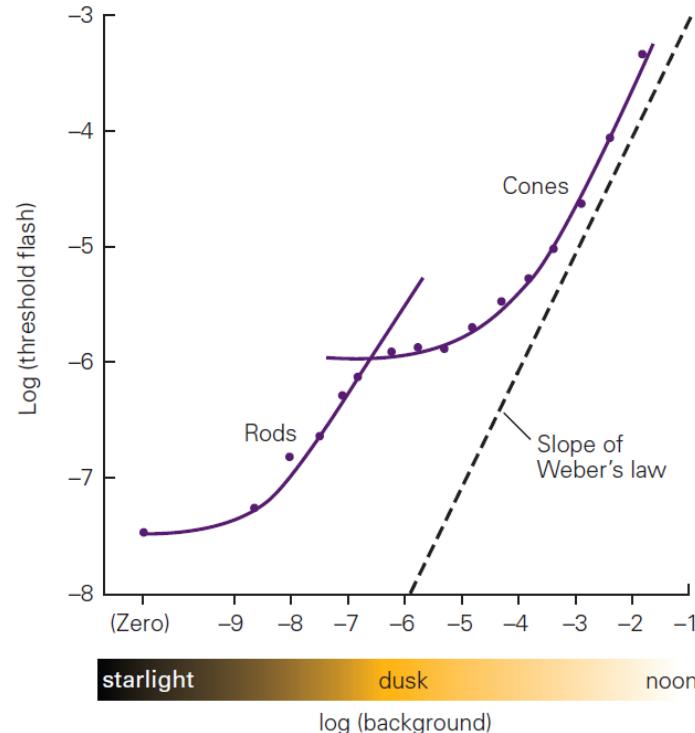


Light adaptation

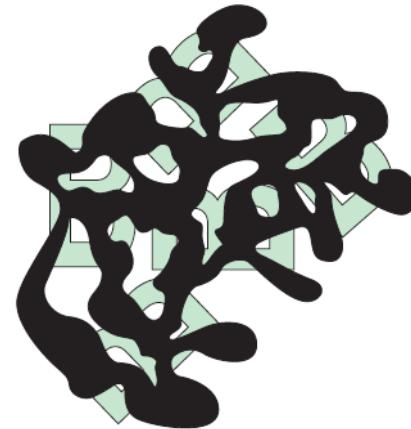
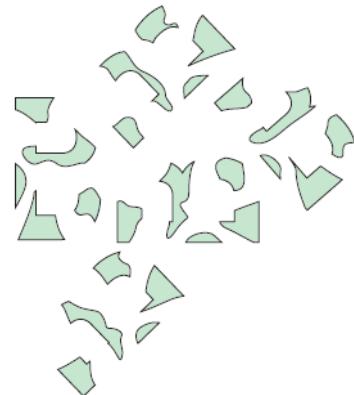
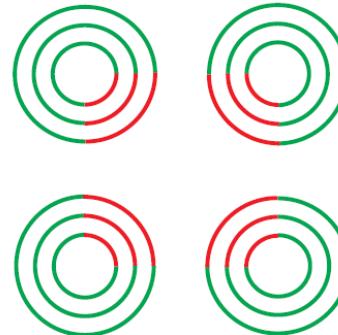
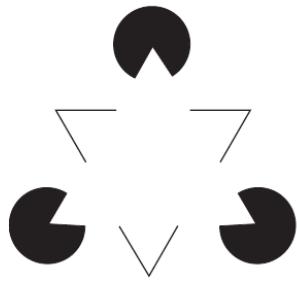
A Cat ganglion cell



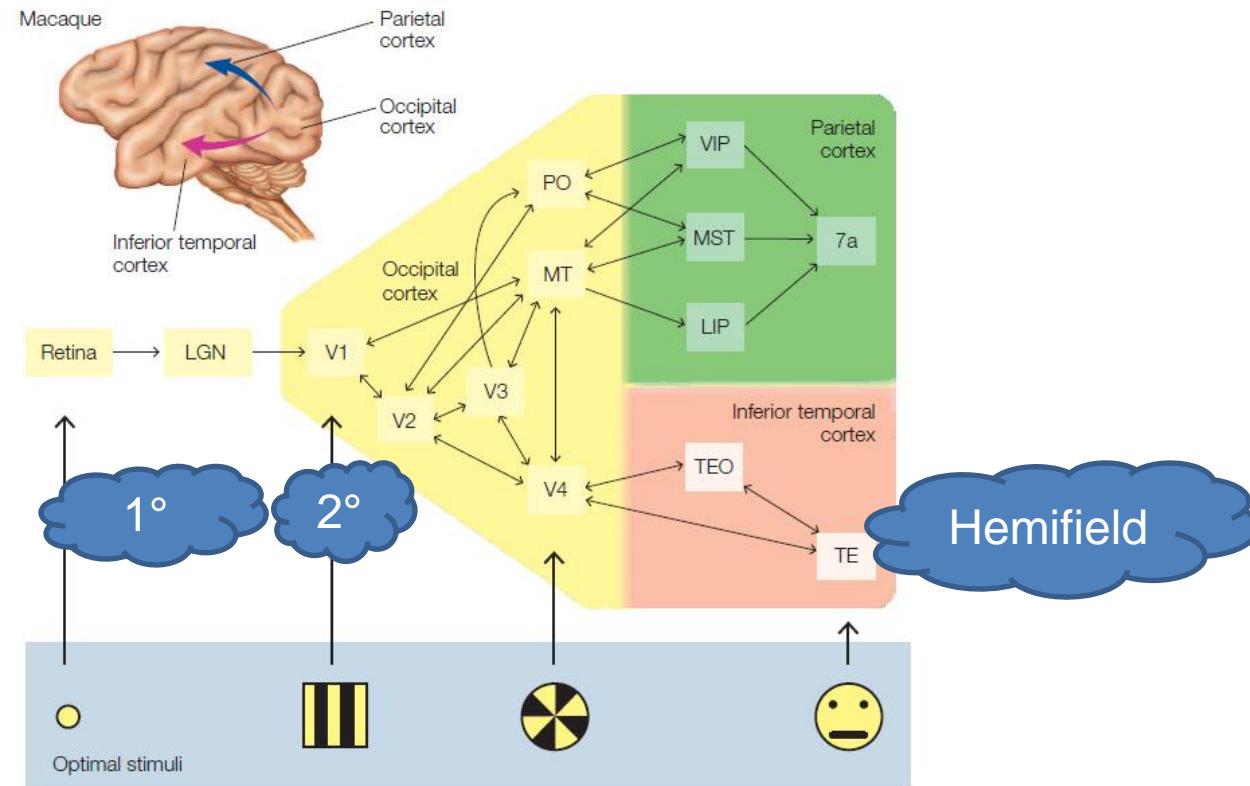
B Human subjects



Visual perception

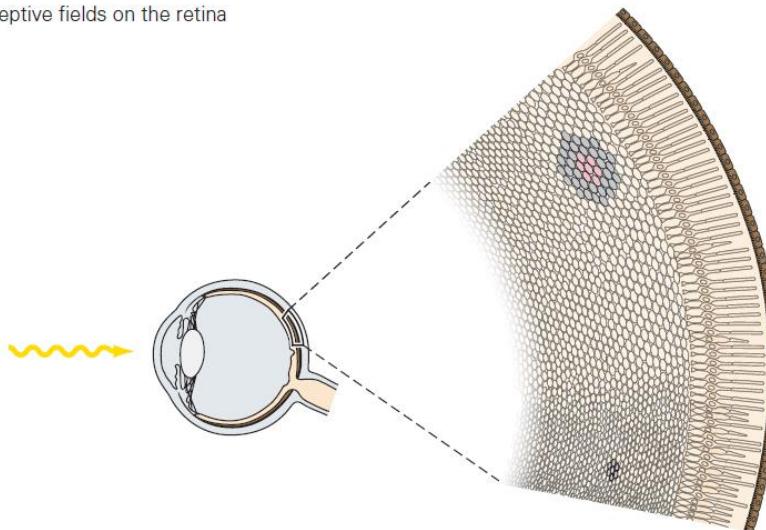


Layers of abstraction

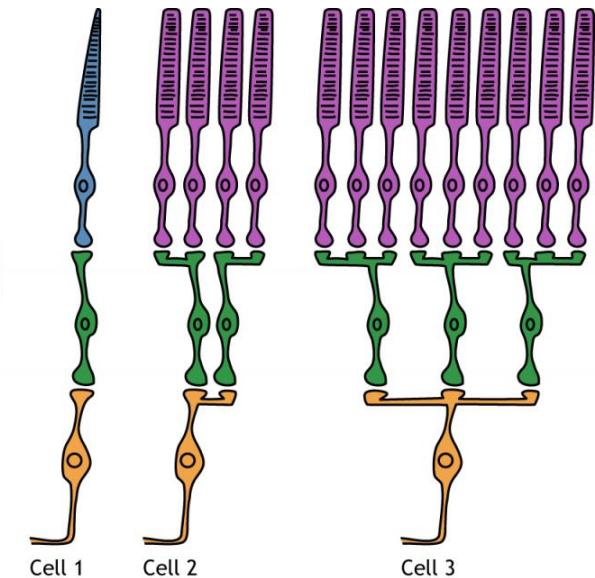
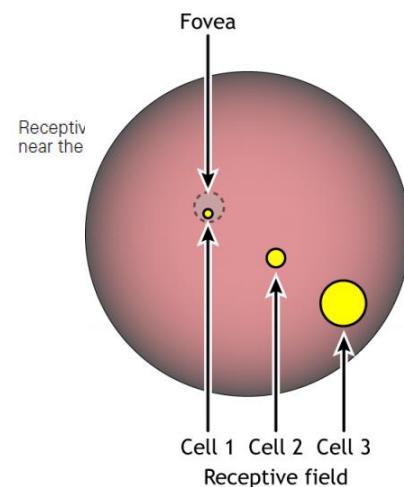


Generating a receptive field

Receptive fields on the retina

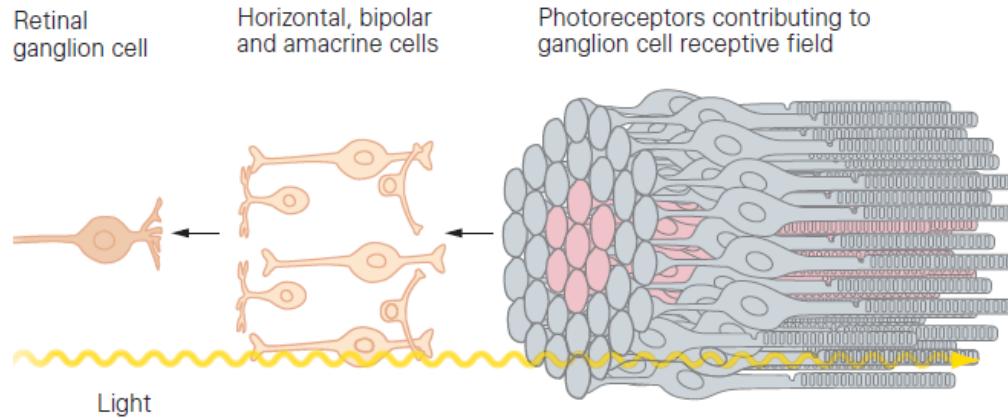


Receptive field
in the periphery

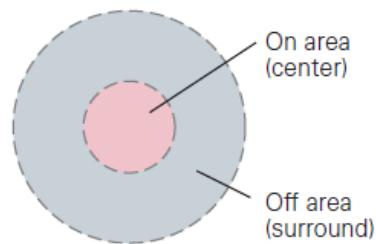


Generating a receptive field

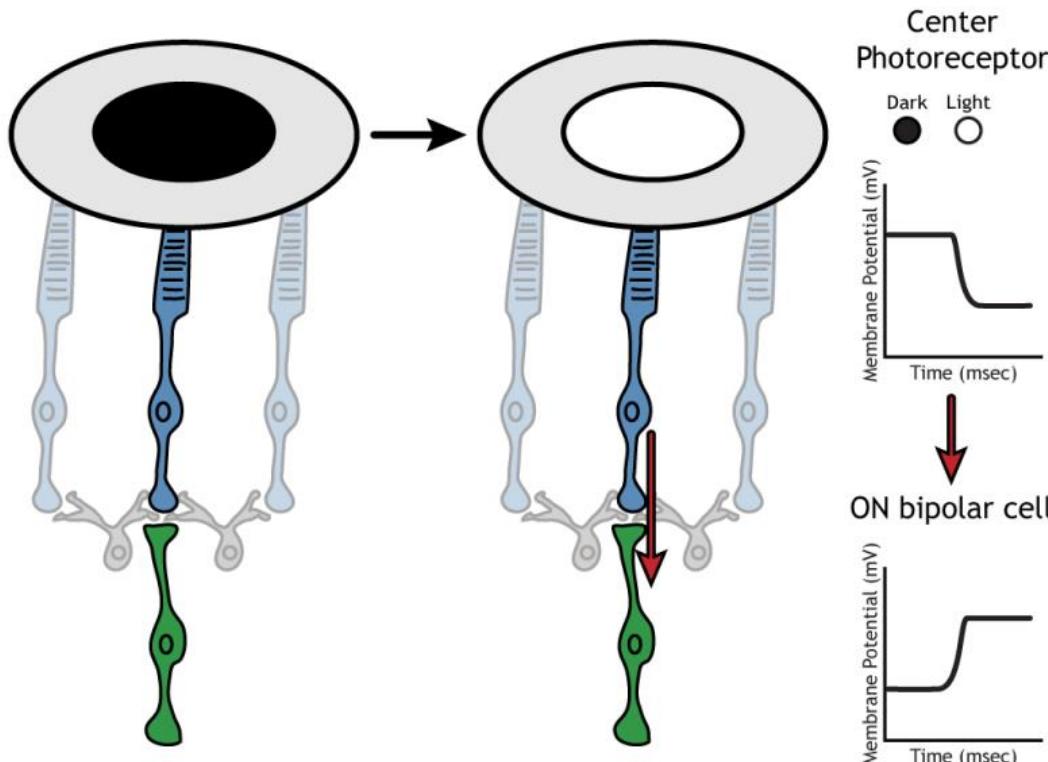
Receptive field of a retinal ganglion cell



Center-surround structure of ganglion cell receptive field

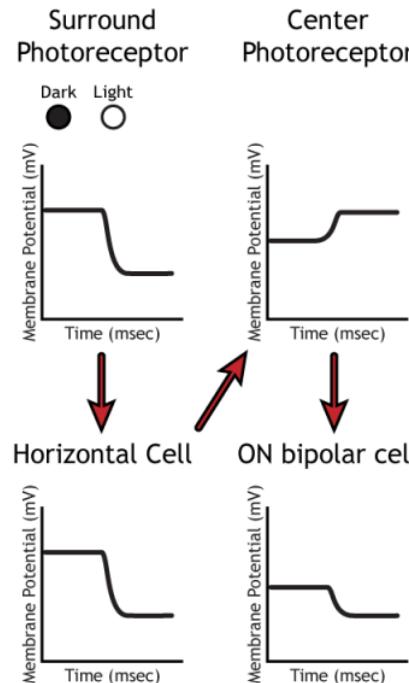
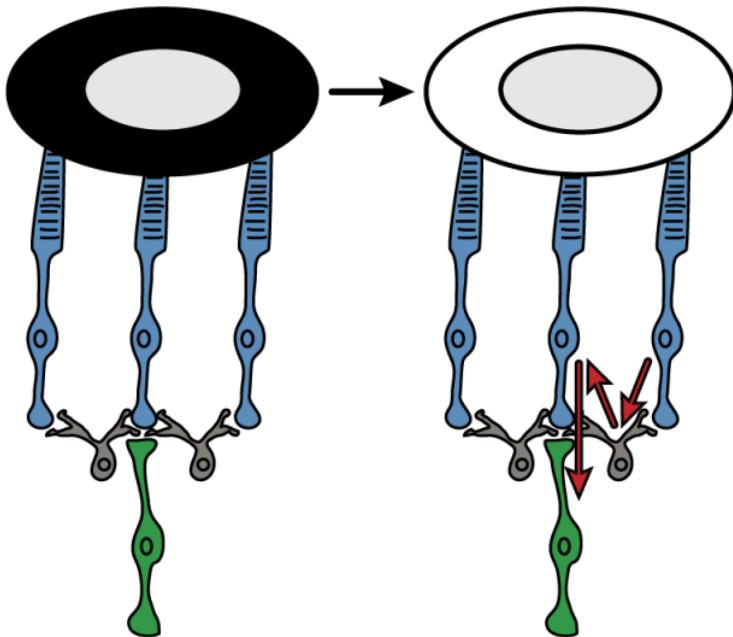


Examples for receptive field



The ON bipolar cell depolarizes upon hyperpolarization of the center photoreceptor

Examples for receptive fields

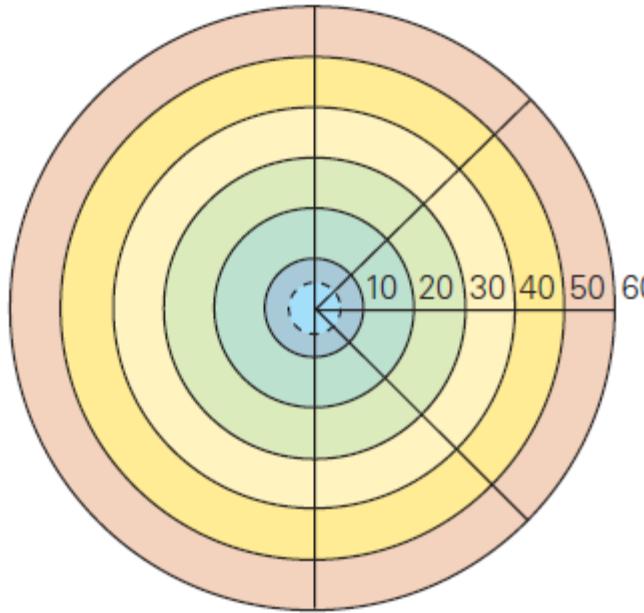


- (i) the surrounding photoreceptor will hyperpolarize
- (ii) The postsynaptic horizontal cell will hyperpolarize
- (iii) The center photoreceptor depolarizes
- (iv) The ON bipolar cell to hyperpolarize.

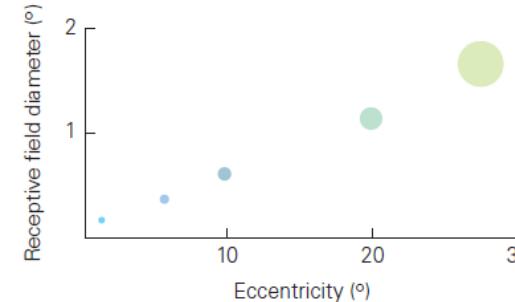
→ Same as if the center photoreceptor experiences dark

Receptive field changes with eccentricity

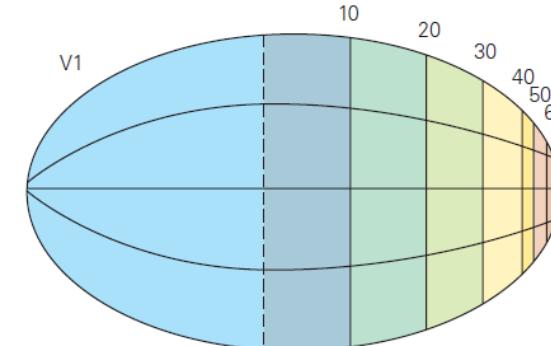
Map of retinal eccentricity



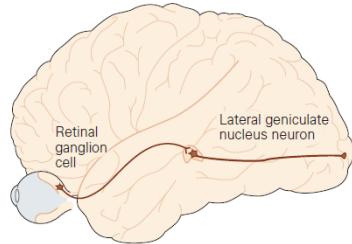
B Receptive field size varies systematically with eccentricity



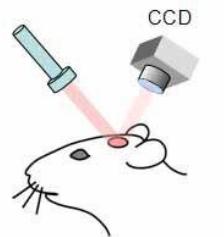
C Cortical magnification varies with eccentricity



Retina produces visuotopic maps in V1

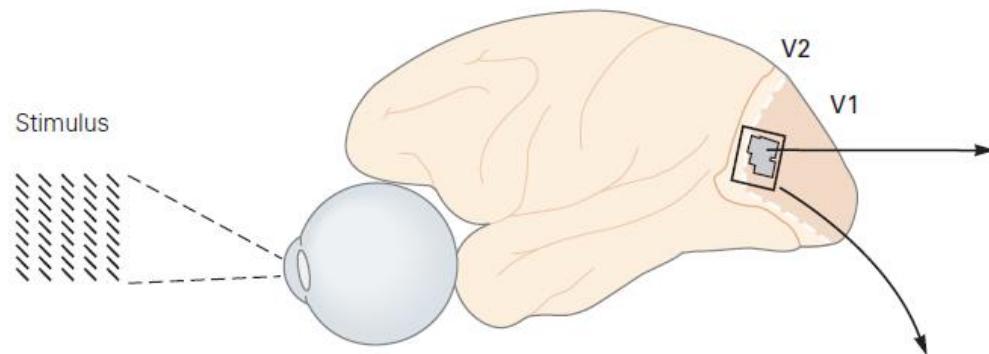


Visuotopic map



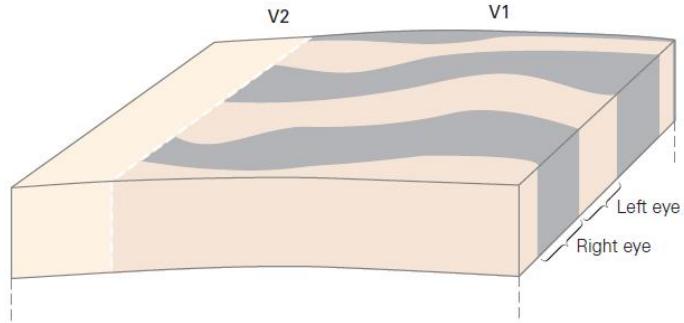
Intrinsic optical imaging

© Uniklinik Jena

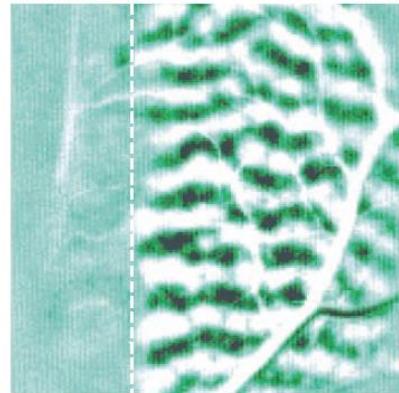


Pattern of
excitation
in response
to striped
stimulus

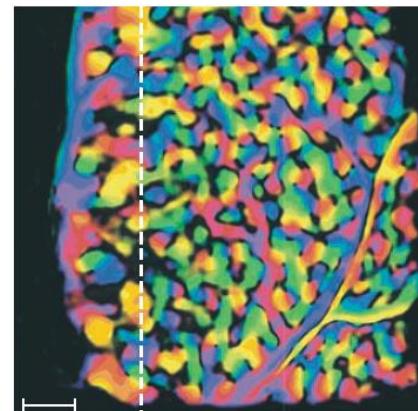
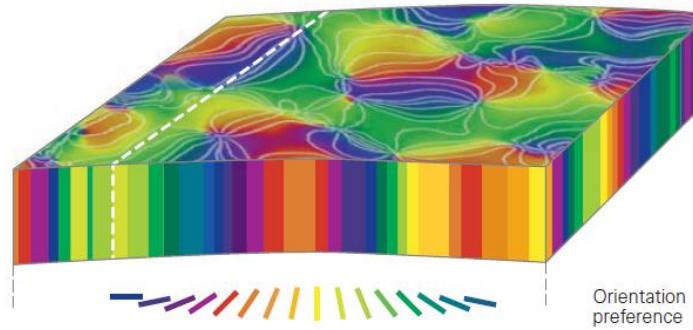
B Ocular dominance columns

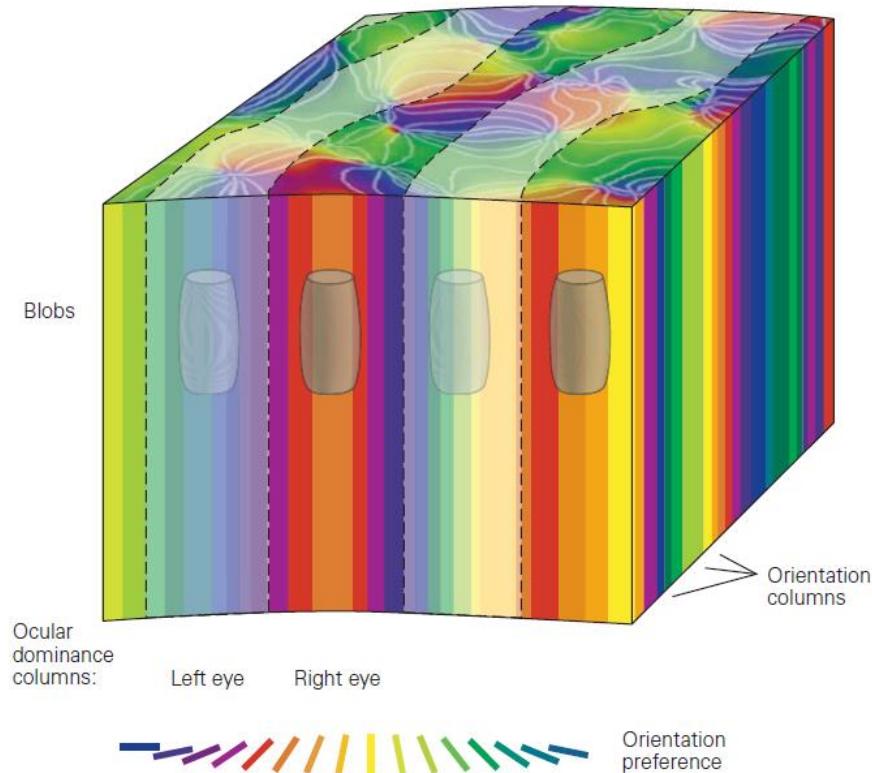


V2 V1

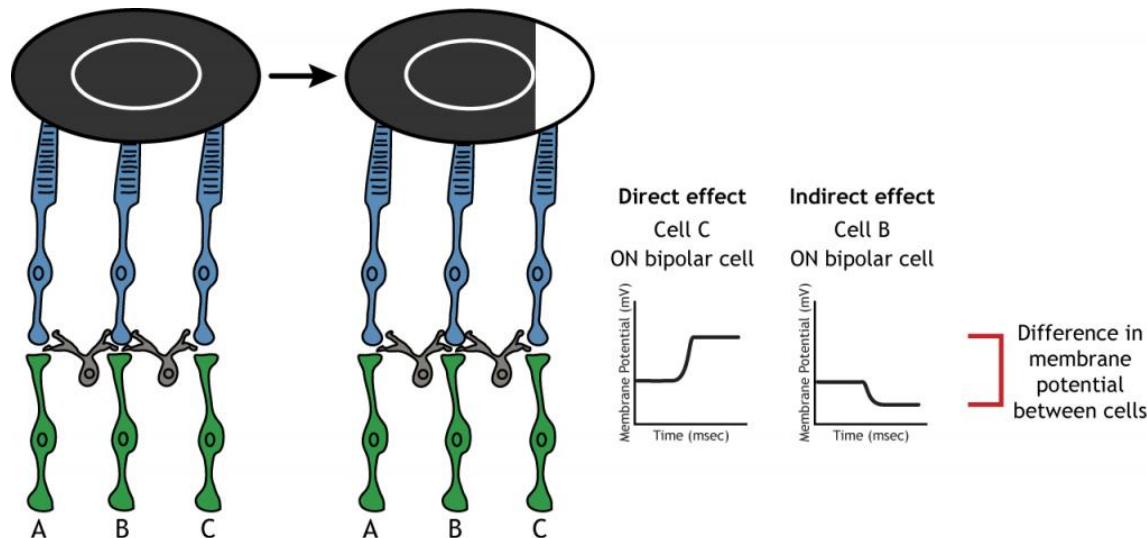


C Orientation columns





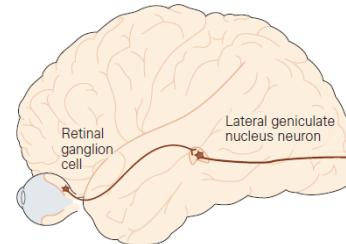
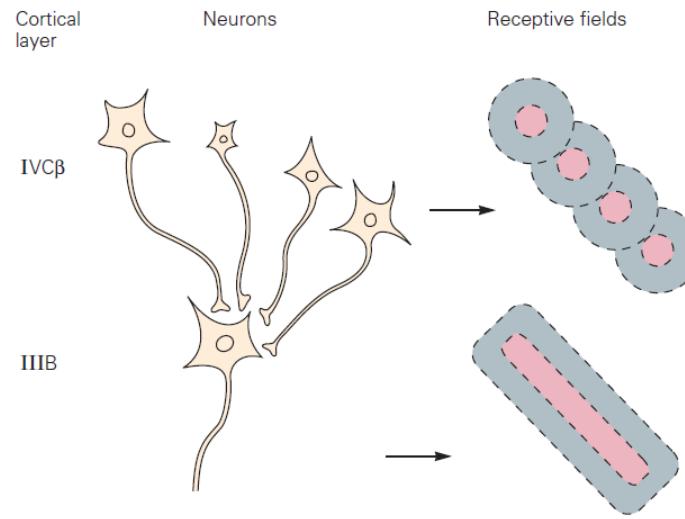
Edge detection using lateral inhibition



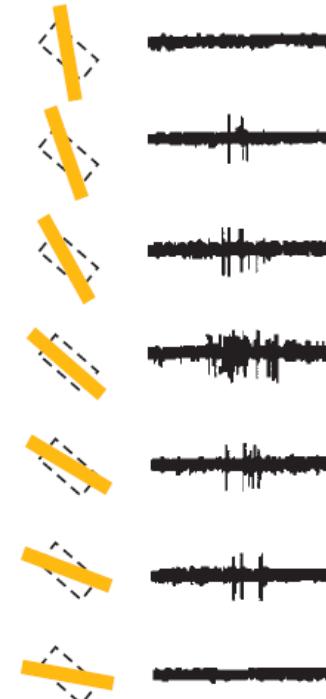
(i) The light will cause bipolar cell C to depolarize because of the direct synapse with the photoreceptor. (ii) The light will also cause bipolar cell B to hyperpolarize because of the indirect synapses through the horizontal cell. → This hyperpolarization causes **a larger membrane potential difference** between cells B and C that would occur if the horizontal cells were absent. → The larger membrane potential difference between the cells will enhance the perception between the dark and light side of the edge.

Direction selectivity

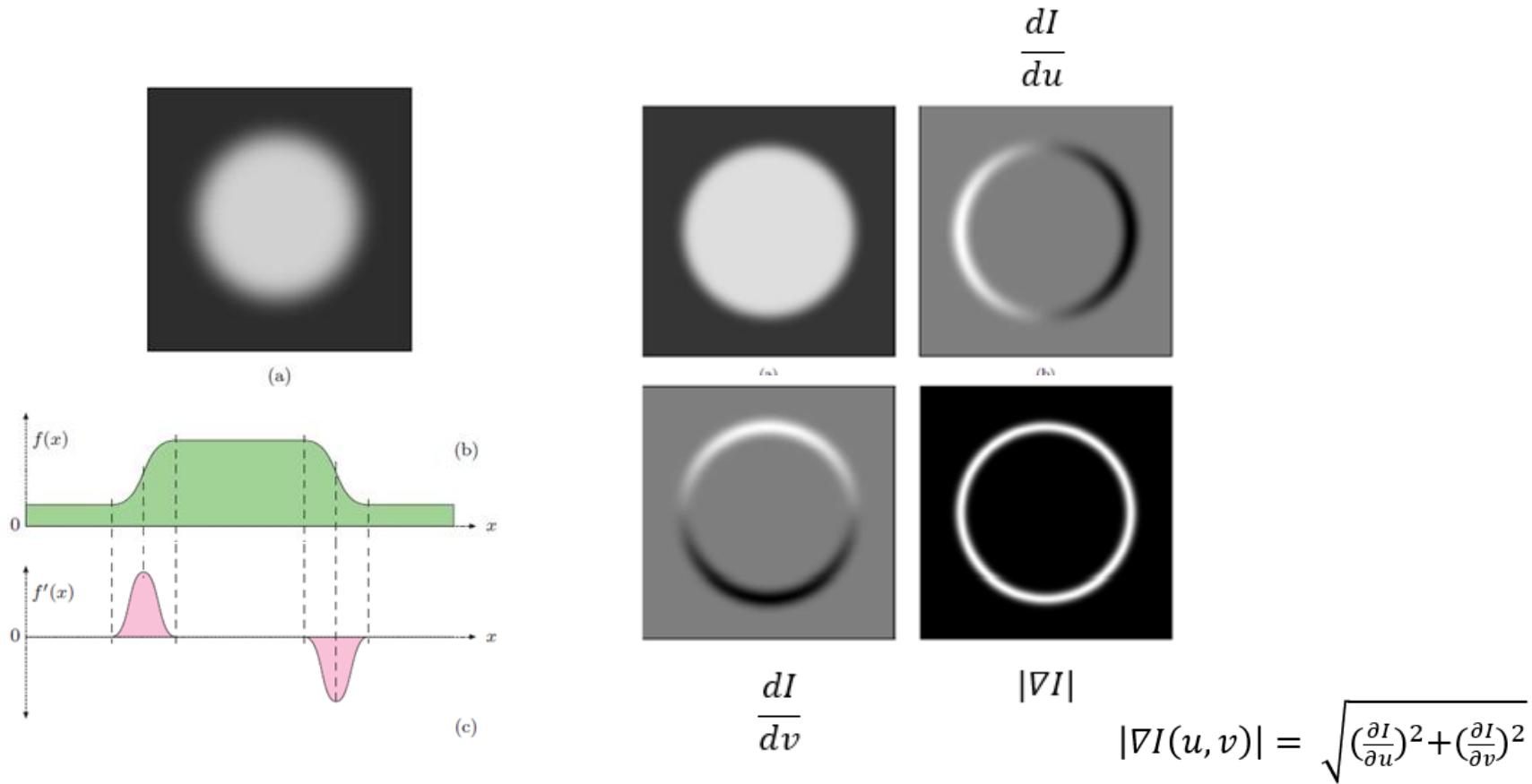
LGN



V1

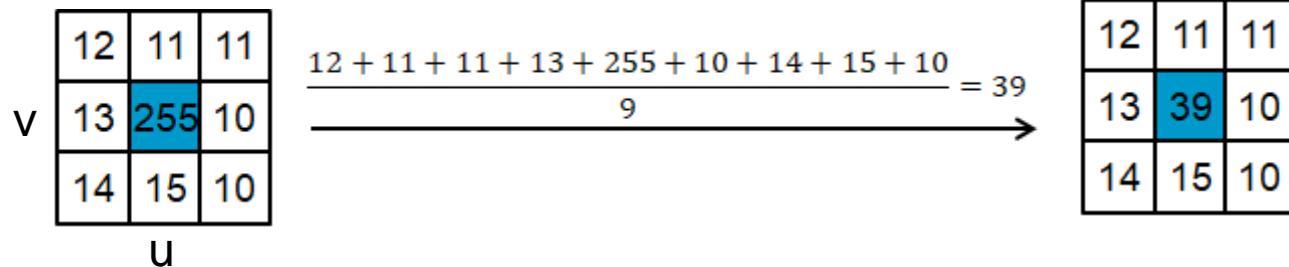


Edge detection



Linear filter

Just imagine a noisy pixel...



$$I'(u, v) = \frac{\sum_{i=-1}^1 \sum_{j=-1}^1 I(u+i, v+j)}{9}$$

1	1	1
1	1	1
1	1	1

Applying linear filter over whole image



$$\begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

=

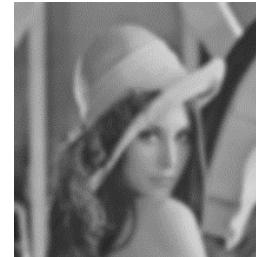


CONVOLUTION

Kernel size



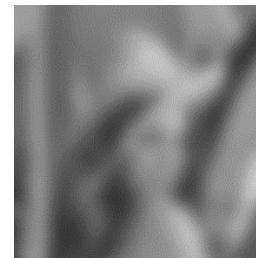
$$\otimes \quad \square =$$



$$\otimes \quad \square =$$



$$\otimes \quad \square =$$

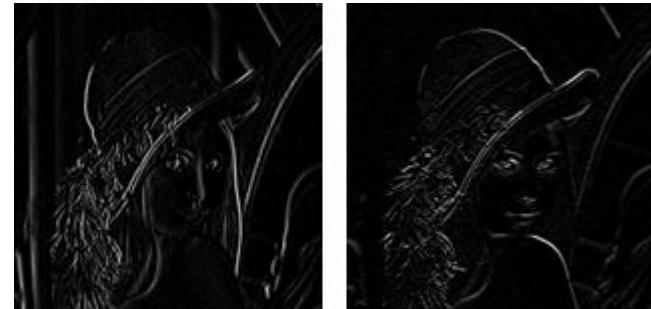


Increase of
receptive field

Edge detection with linear filters

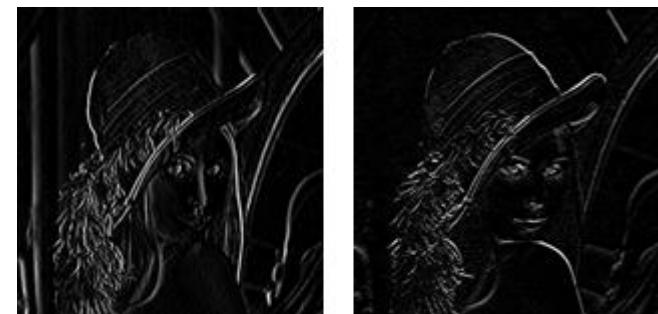
Prewitt-Filter

$$H_x^P = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } H_y^P = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

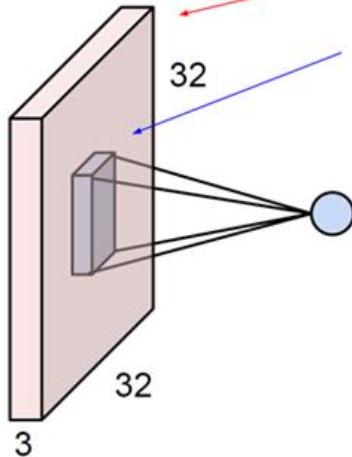


Sobel-Filter

$$H_x^S = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } H_y^S = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$



Convolutional neural networks

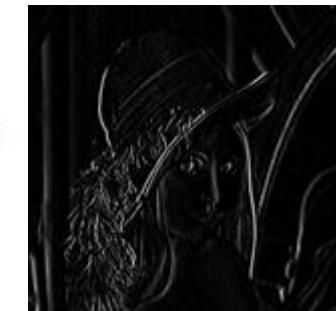
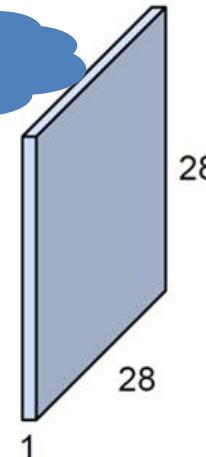


32x32x3 image
5x5x3 filter

Could be an edge
detection filter...

convolve (slide) over all
spatial locations

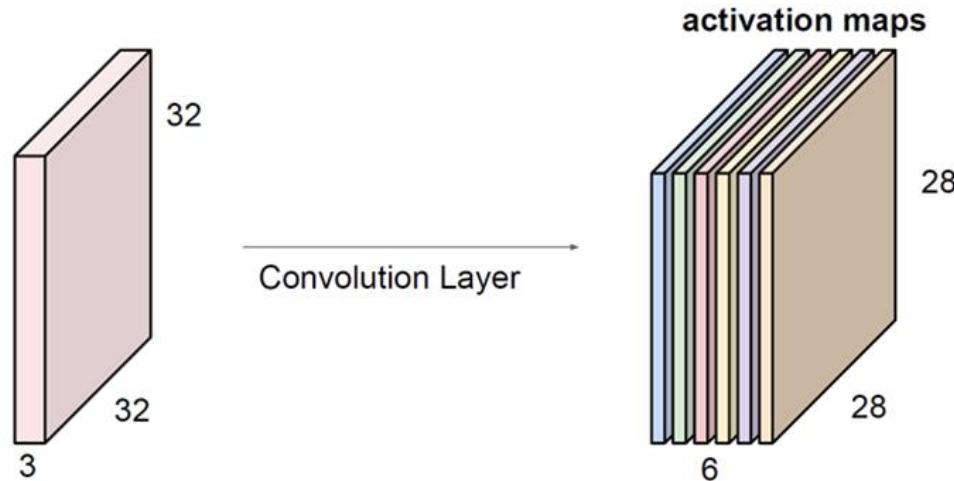
activation map



Color
image

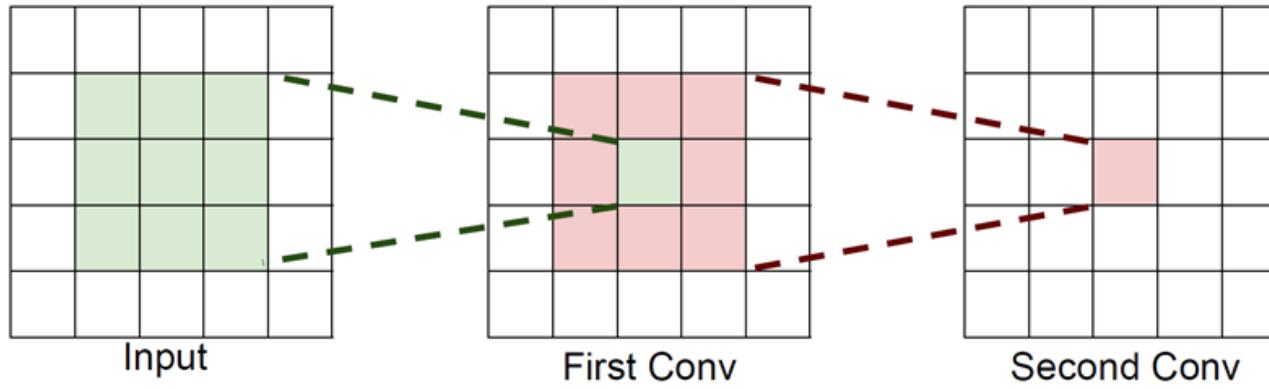
Many activation maps

For example, if we had 6 5×5 filters, we'll get 6 separate activation maps:

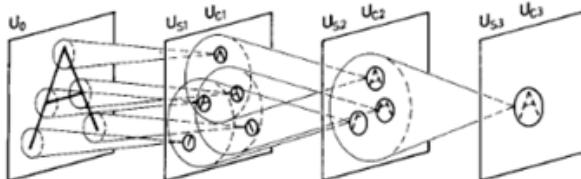
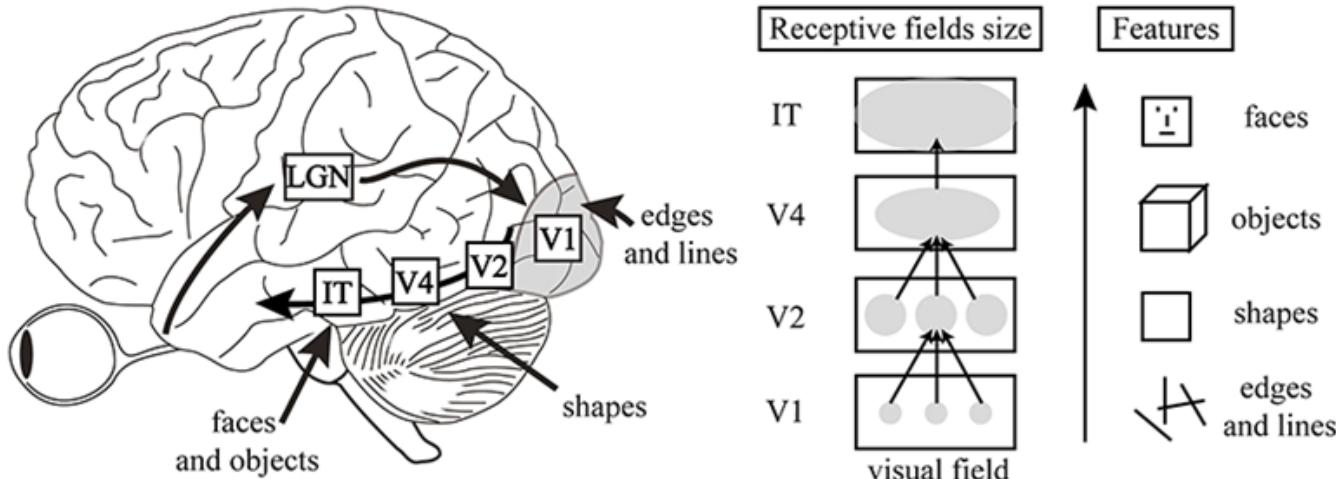


We stack these up to get a “new image” of size $28 \times 28 \times 6$!

Multiple rounds of applying filters

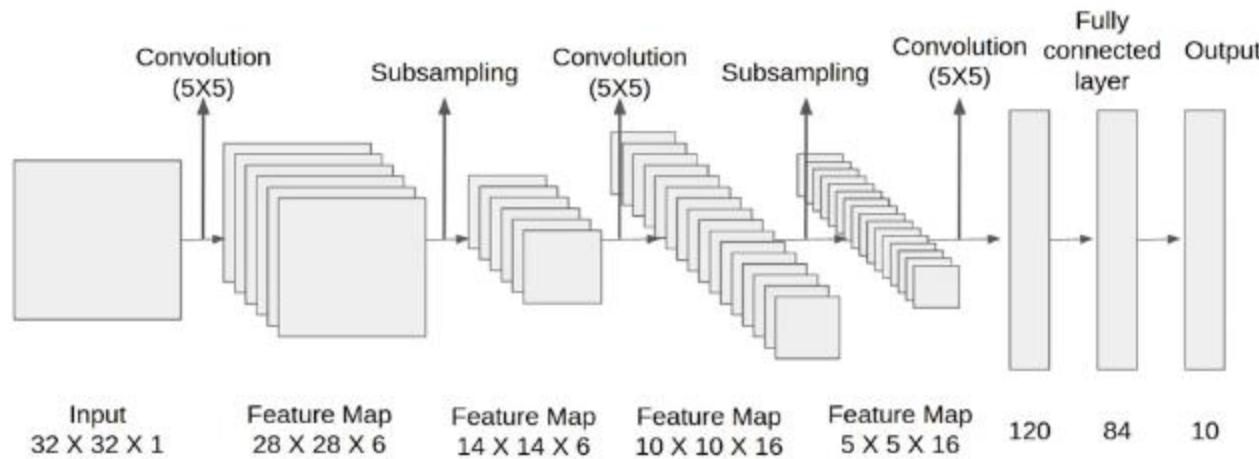


High-level features



<https://neurdiness.wordpress.com/2018/05/17/deep-convolutional-neural-networks-as-models-of-the-visual-system-qa/>

LeNet-5



High level features in network depth

