

Deep Learning for Computer Vision

Human Visual System

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Acknowledgements

- Most of this lecture's slides are based on **Lecture 8** of **CS455: Computer Vision** course taught by Prof. Rajesh Rao at University of Washington in 2009
- Unless specifically cited, assume that figures are taken from the above source

NPTEL

Human Visual System: Visual Pathway

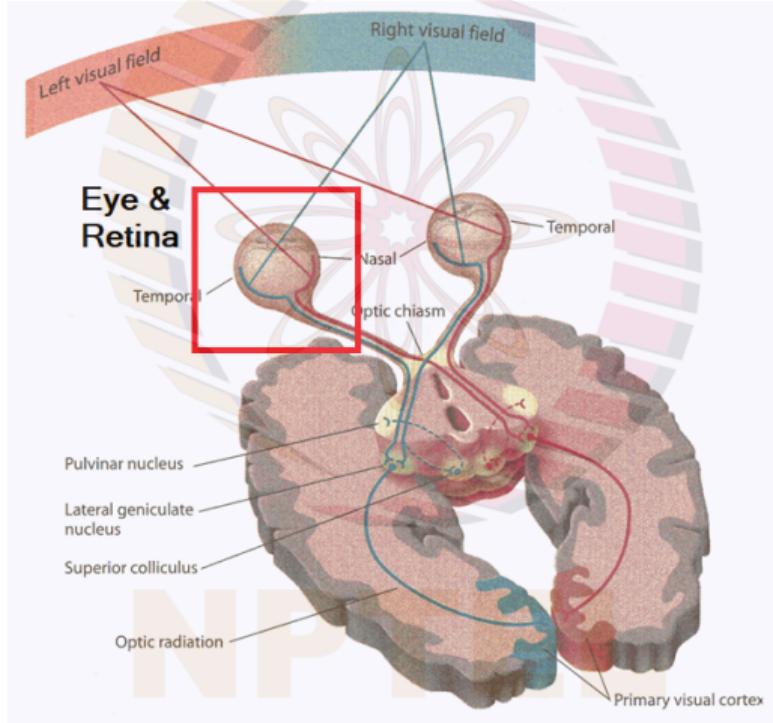


Image Source: Rafael Redondo [6]

Light Visible to Human Eye

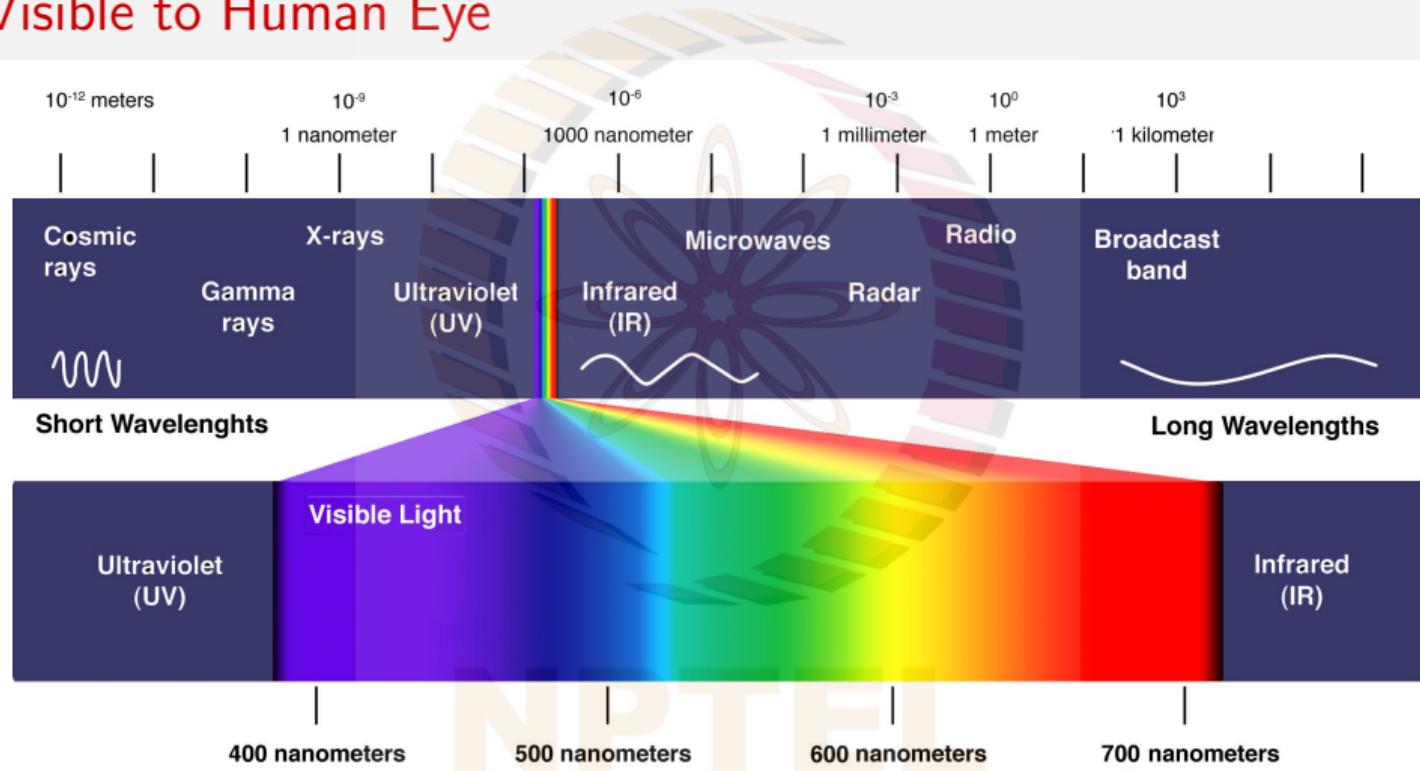
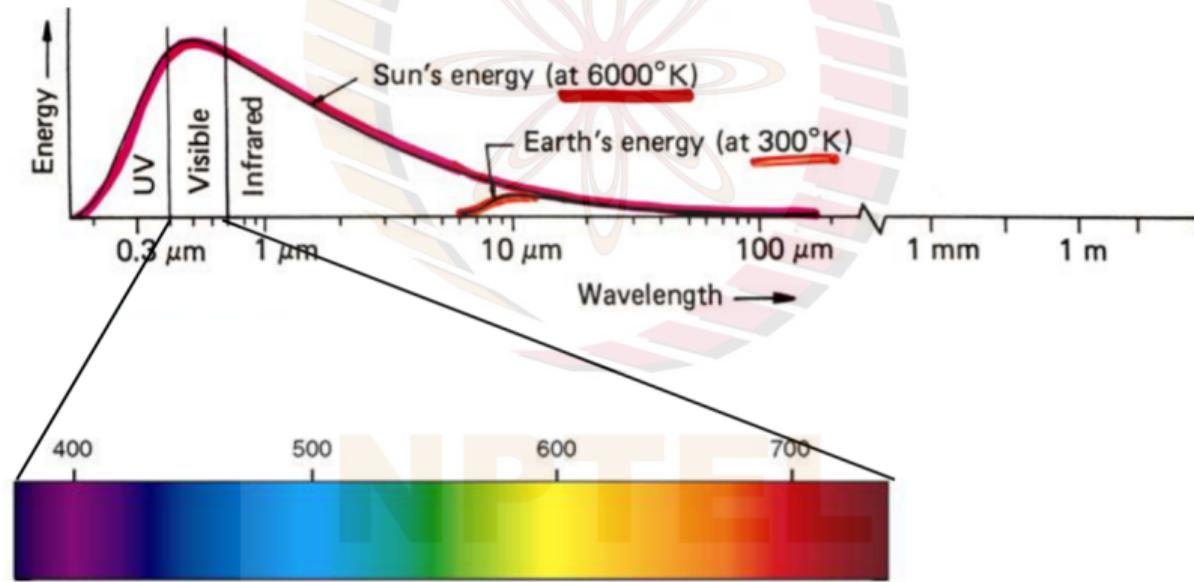


Image Source: www.astronomersgroup.org

Light Visible to Human Eye

Our vision appears to be optimized for receiving the most abundant spectral radiance our star emits



The Retina

The Retina = Photoreceptors + Image Filtering

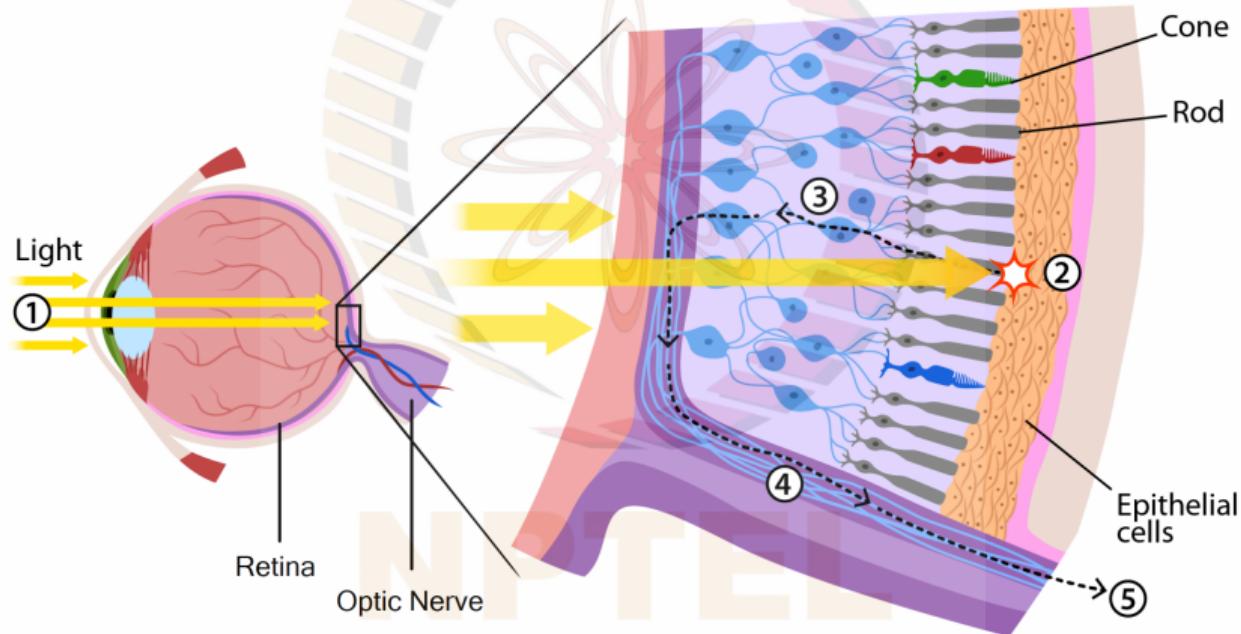
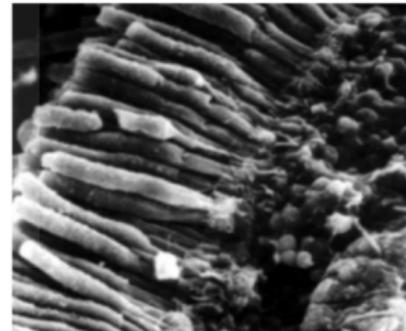
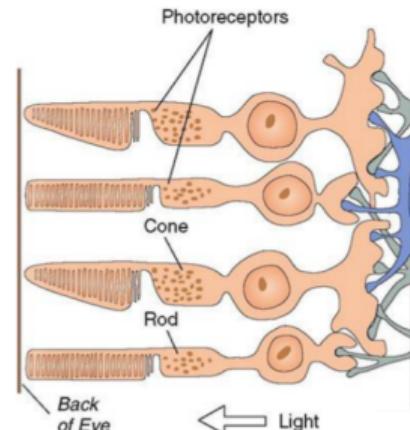
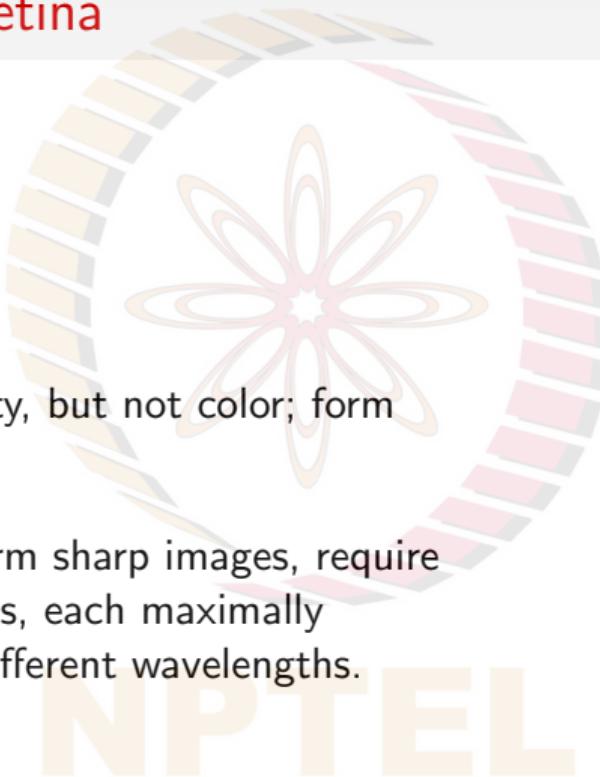


Image Source: mymacularjournal.com

Photoreceptors in the Retina

Two Types:

- **Rods:** Sensitive to intensity, but not color; form blurred images
- **Cones:** Color sensitive, form sharp images, require many photons. Three types, each maximally sensitive to one of three different wavelengths.



Coding of Light by Rods and Cones

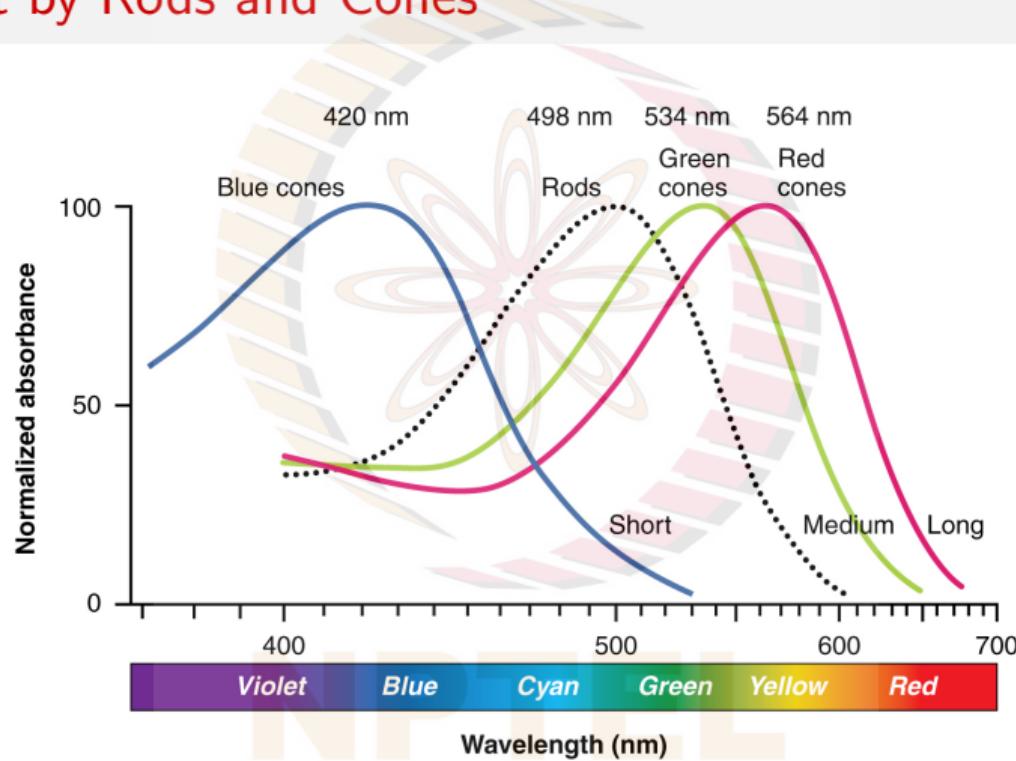


Image Source: Michael C ([StackExchange](#))

Image Filtering in Space and Time in the Retina

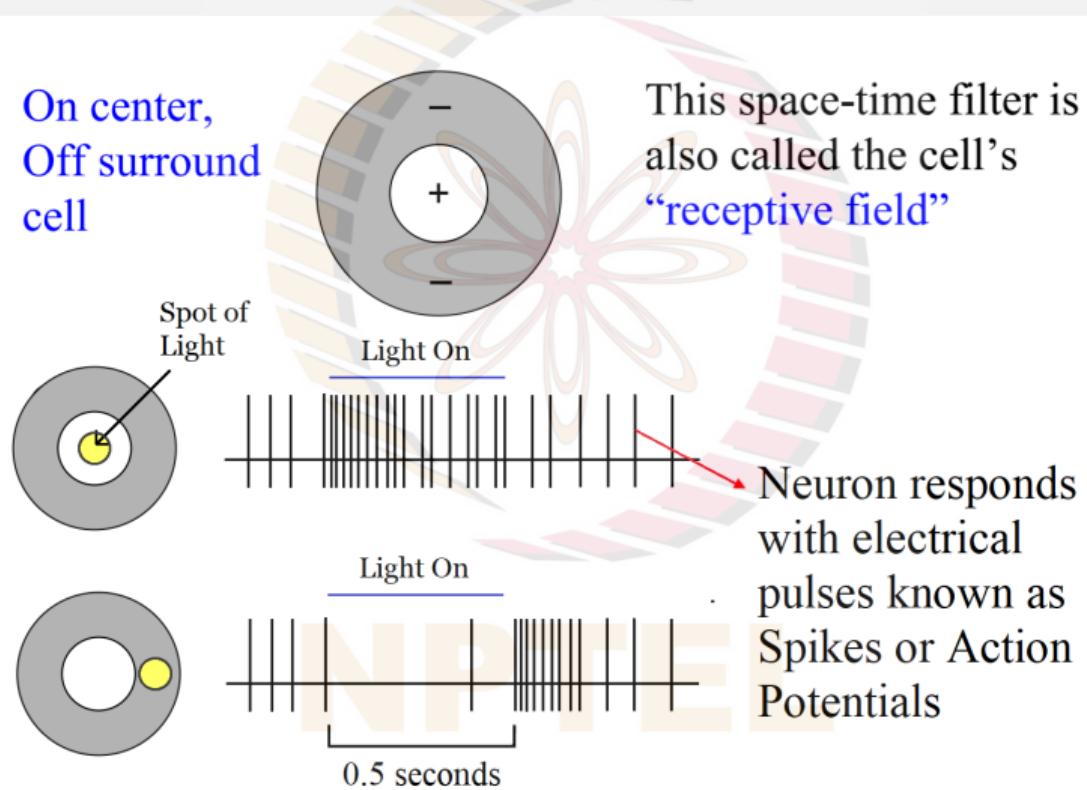
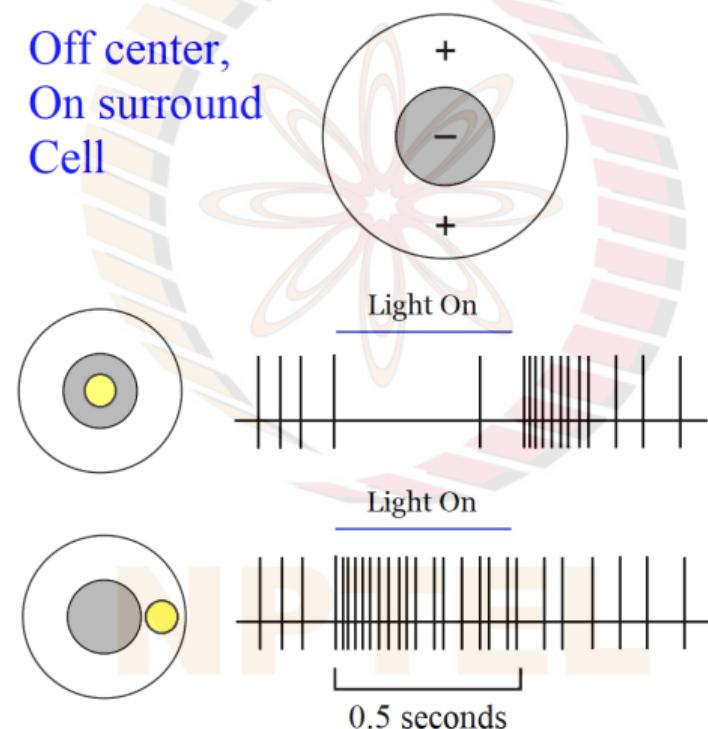
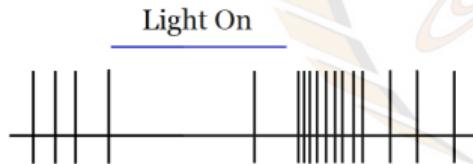
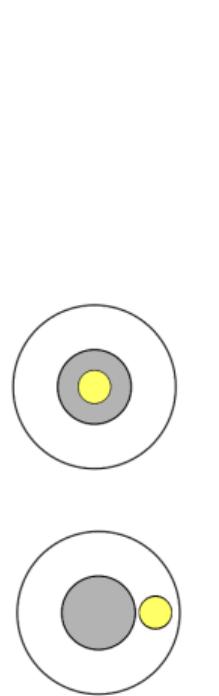


Image Filtering in Space and Time in the Retina

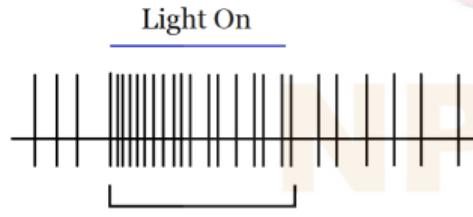
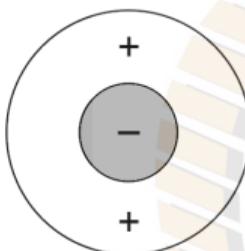


Retina takes Spatial and Temporal Derivatives



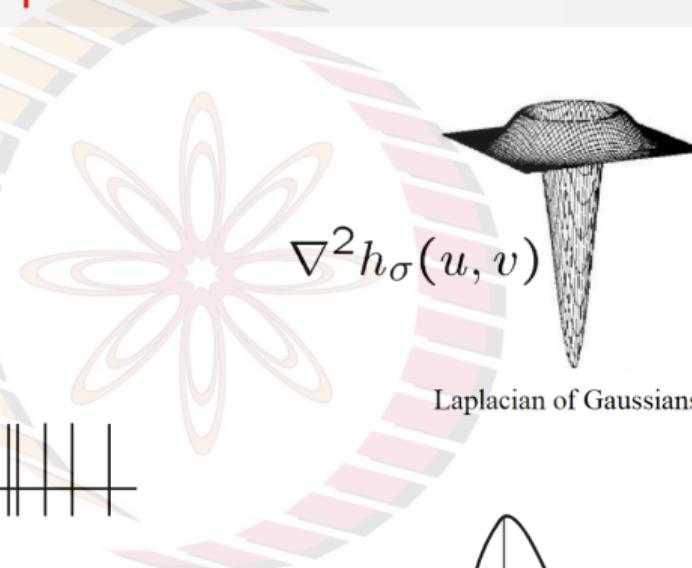
Light On

0.5 seconds



Light On

0.5 seconds

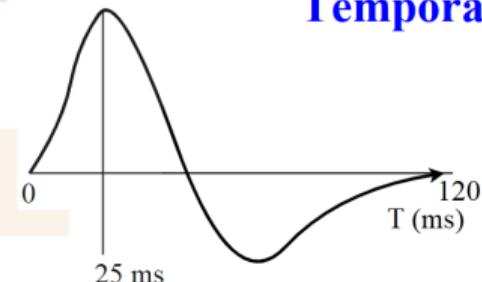


$$\nabla^2 h_\sigma(u, v)$$

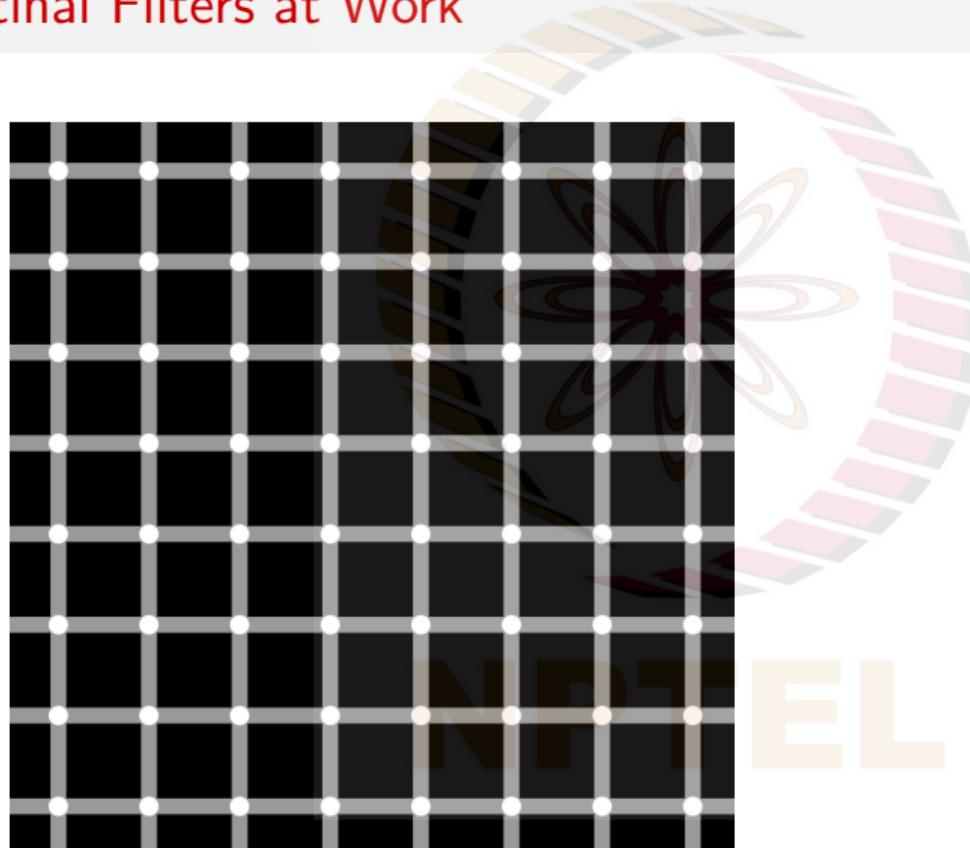
Laplacian of Gaussians

Spatial

Temporal



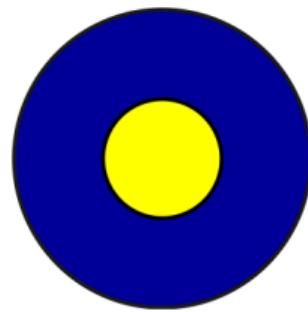
Your Retinal Filters at Work



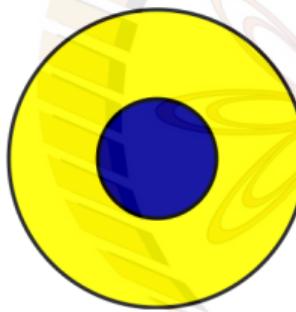
Black dots or white dots?

Retina also takes Derivatives in Color Space

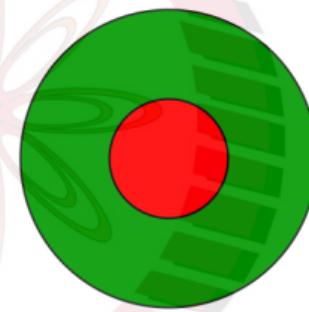
"Color-opponent" processing



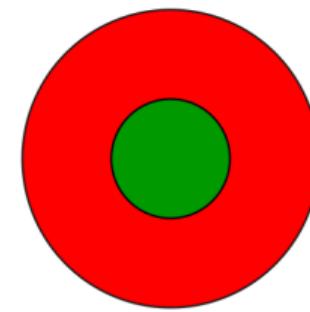
Yellow on,
Blue off



Blue on,
Yellow off



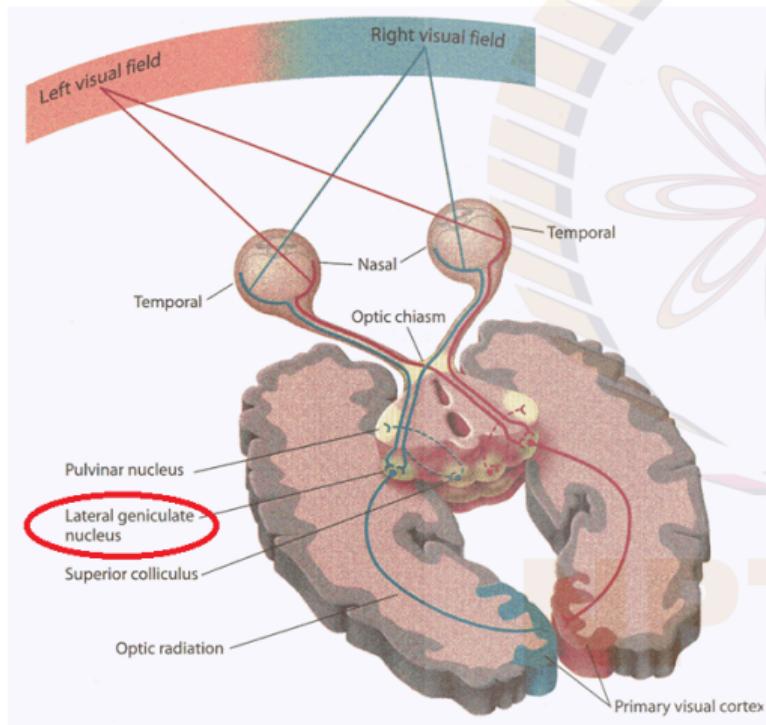
Red on,
Green off



Green on
Red off

Visual consequence: **Negative afterimage** - An image is seen after a portion of the retina is exposed to an intense visual stimulus (colors complementary to those of stimulus)

The Visual Pathway: LGN



- LGN receptive fields similar to retinal (center-surround, on-off)
- Thought to be a relay but receives massive feedback from cortex

Image Source: Rafael Redondo [6]

The Visual Pathway: V1

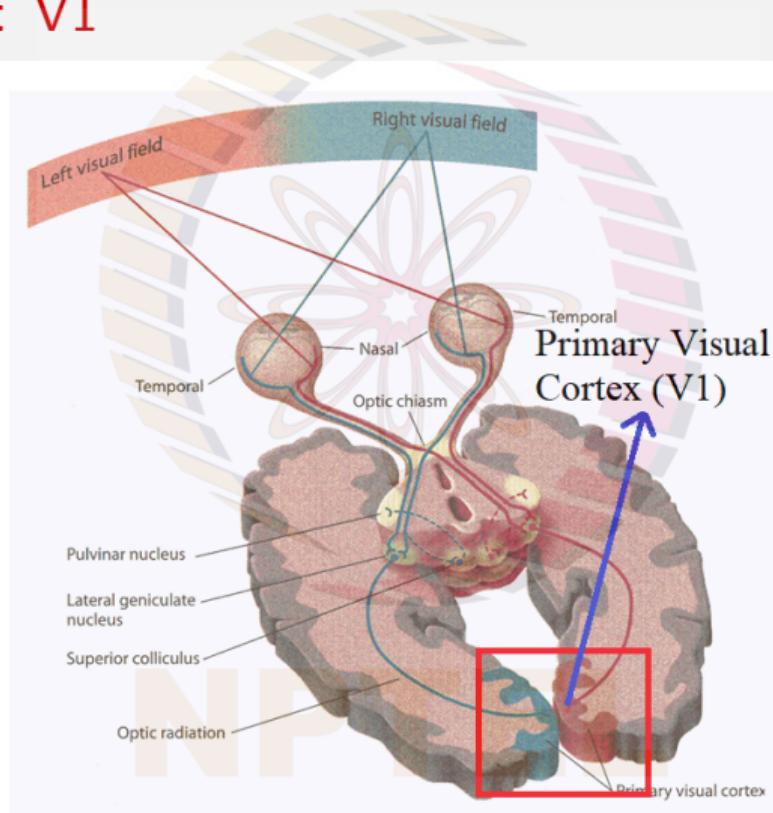


Image Source: Rafael Redondo [6]

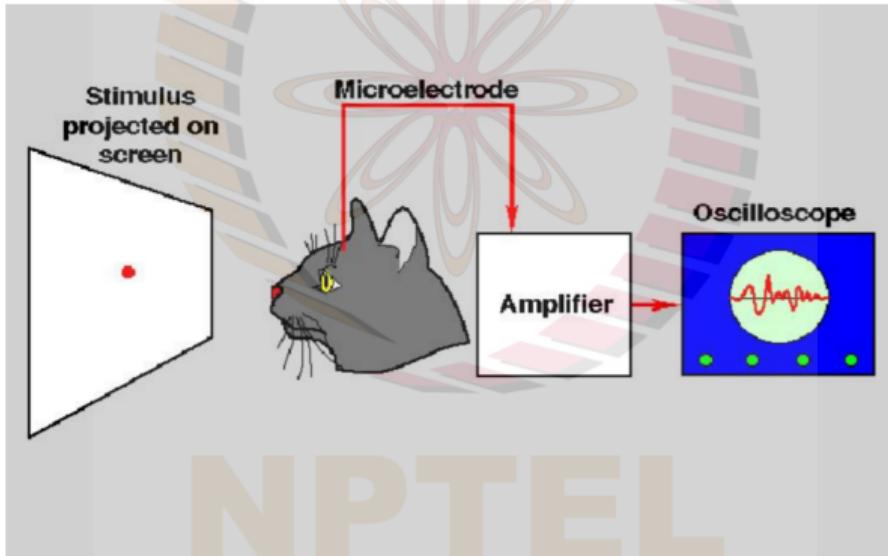
Vineeth N B (IIT-H)

§2.7 Human Visual System

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A Tale of Two Receptive Fields

Recall: David Hubel and Torsten Wiesel were the first to characterize V1 receptive fields by recording from a cat viewing stimuli on a screen



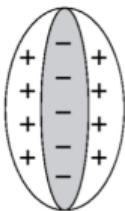
In 1981, they received a Nobel prize in physiology and medicine for their work

Simple and Complex Cell Receptive Fields

Receptive fields



“Bar” detectors



“Edge” detector

| | |
|---|---|
| + | - |
| + | - |
| + | - |
| + | - |

Position-invariant “bar” detector

- **Simple Cells:**

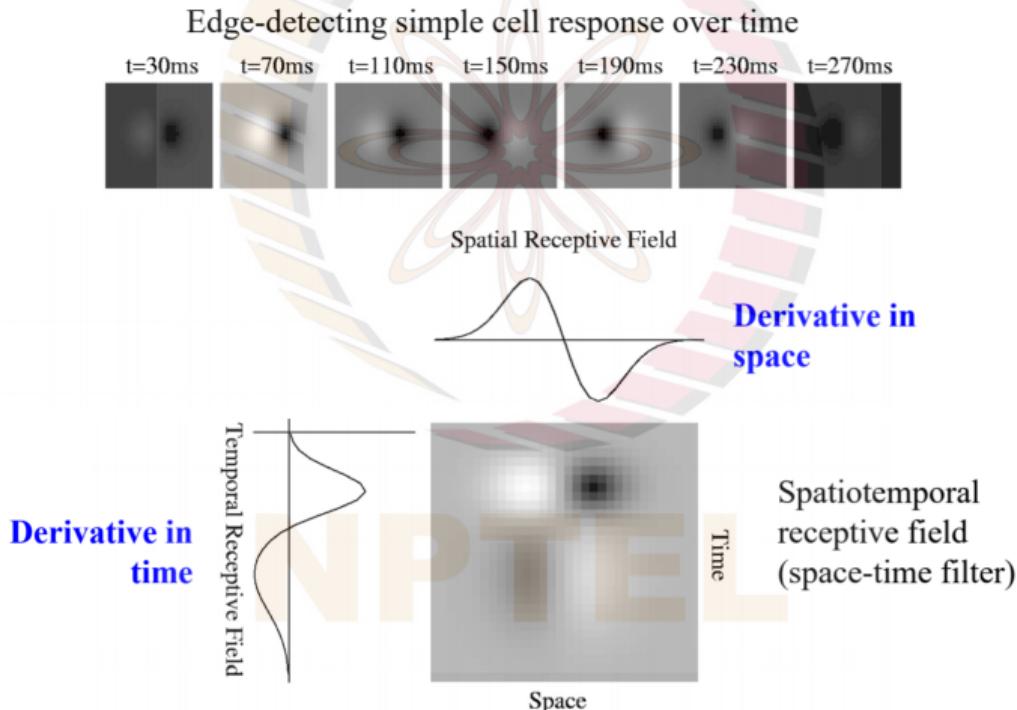
Detect oriented bars and edges at a specific location

- **Complex Cells:**

Sensitive to orientation but invariant to position

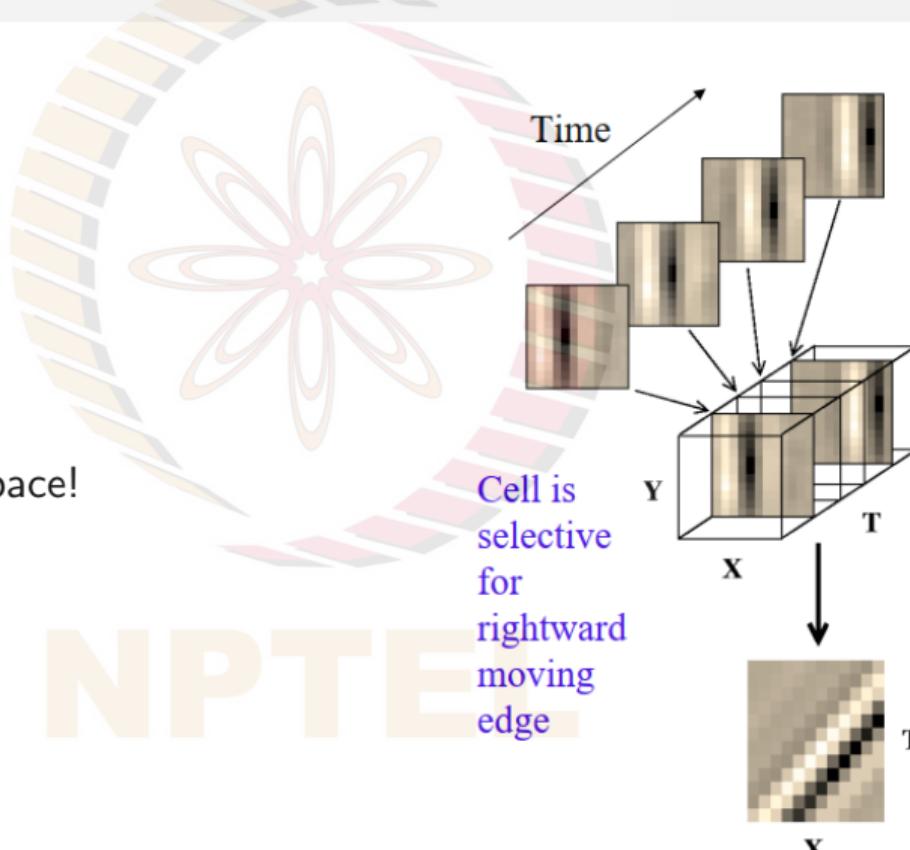
Cortical Cells Compute Derivatives

Spatial derivative is orientation-sensitive



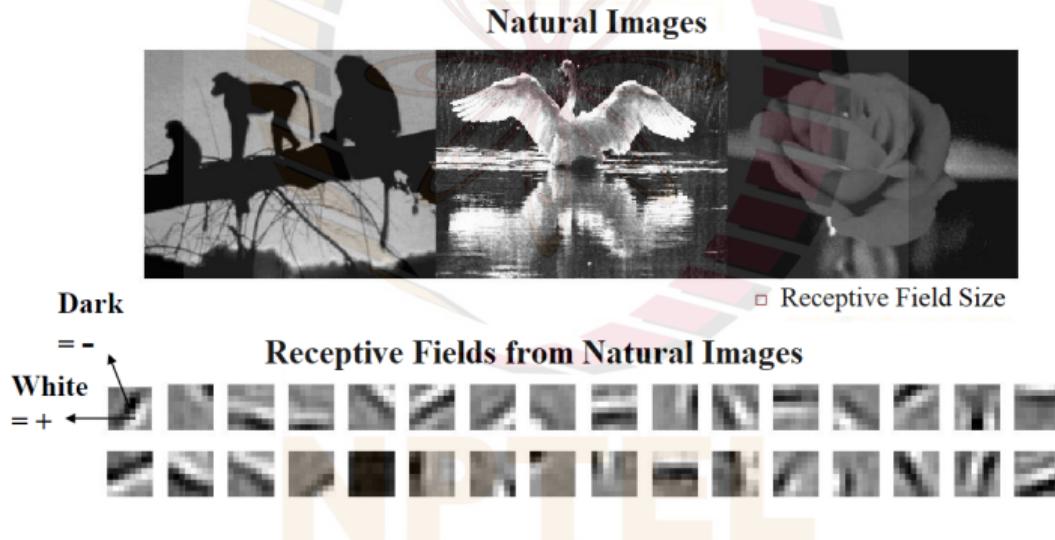
Direction Selectivity of Some Cortical Cells

Oriented derivative in X-T space!



Oriented Filters and Natural Images

- **Goal:** Learn independent filters whose linear combination best represents natural images
- Optimal set of such filters are oriented and localized to specific regions of image



See Olshausen and Field 1996, Rao and Ballard 1999 for more details

Dorsal and Ventral Pathways in the Visual Cortex

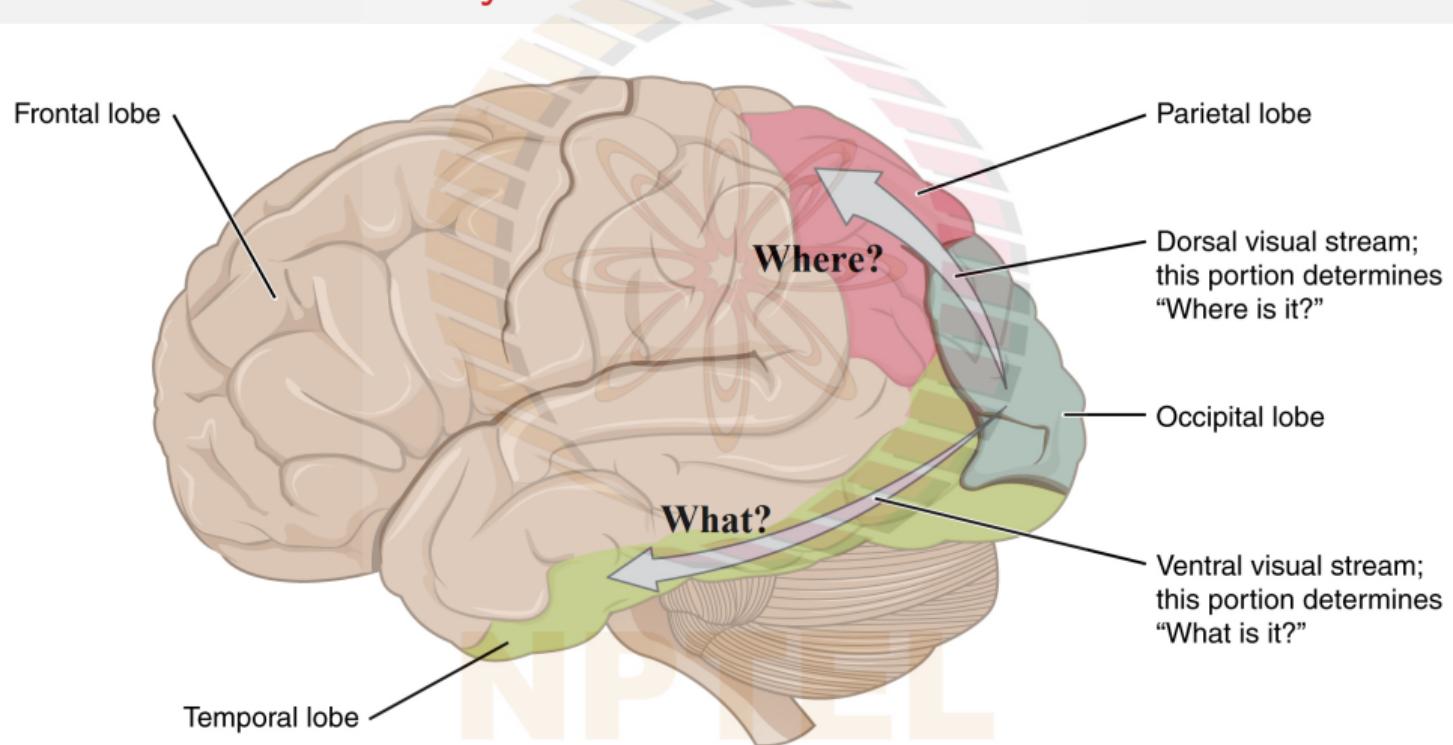


Image Source: [Rice University OpenStax](#)

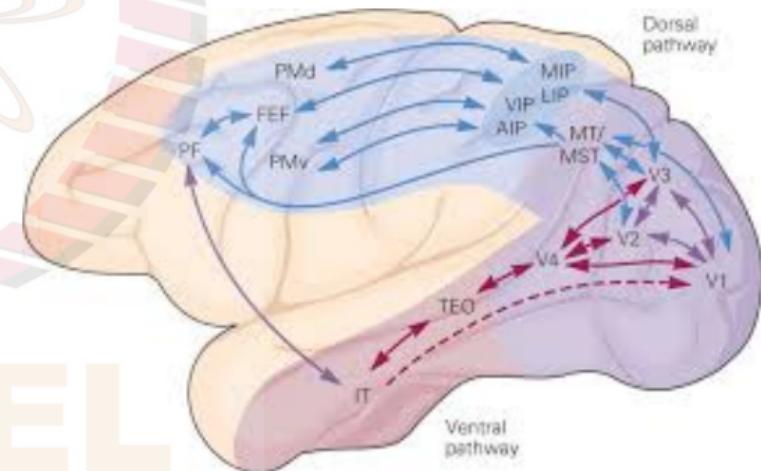
Visual Cortex is Hierarchically Organized: "What" Pathway

Object Pathway: V1 → V2 → V4 → TEO → TE

Cells respond to more and more complex stimuli as we go higher up

Example Receptive Fields

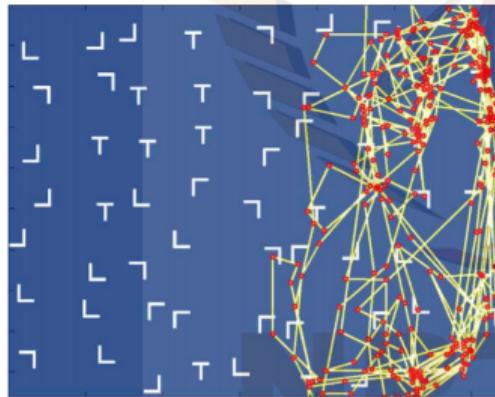
| V2 | V4 | TEO | TE |
|----|-----|-----|-------|
| ▲ | ○ X | ○ ○ | ○ ○ ○ |
| ○ | ○ * | ○ ○ | ○ ○ ○ |
| ■ | ○ ■ | ○ ○ | ○ ○ ○ |



"Where" Pathway

V1 → V2 → MT → MST → Posterior Parietal Cortex

- Cells respond to more and more complex forms of motion and spatial relationships
- Damage to right parietal cortex may result in spatial hemi-neglect - patient behaves as if the left part of the visual world doesn't exist



Eye movements only to right part of the screen



Only right side of clock drawn

Image Source: [Scholarpedia - Hemiagnosia](#)

The Visual Processing Hierarchy

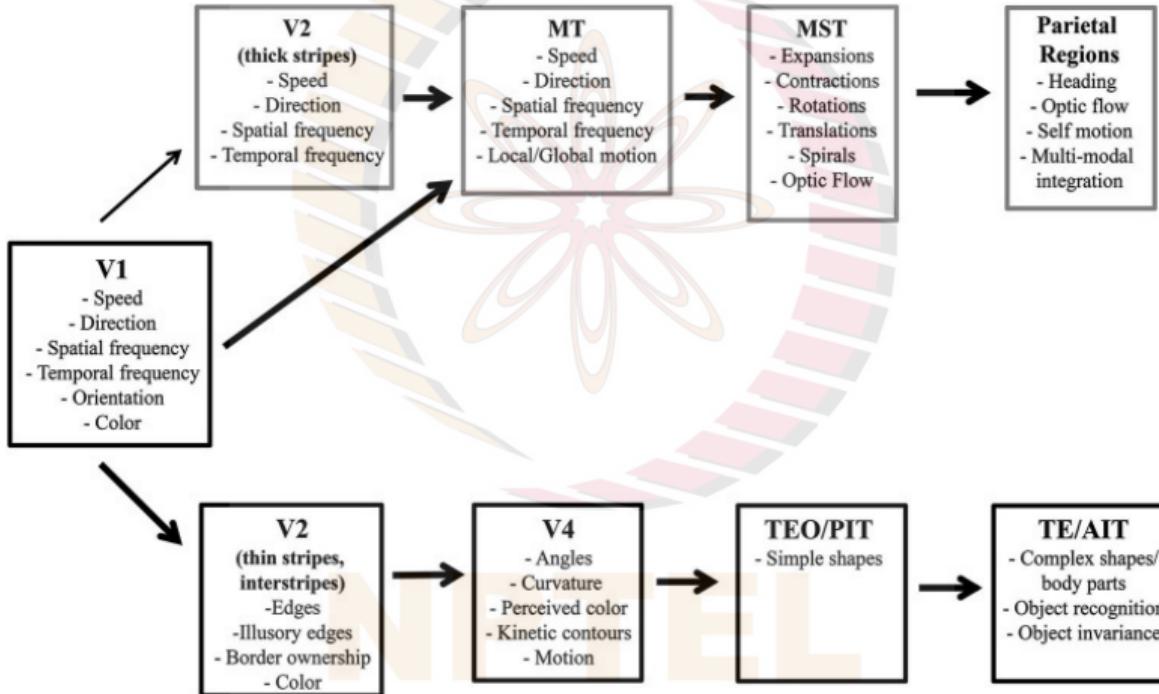


Image Source: Perry, Fallah 2014

Readings

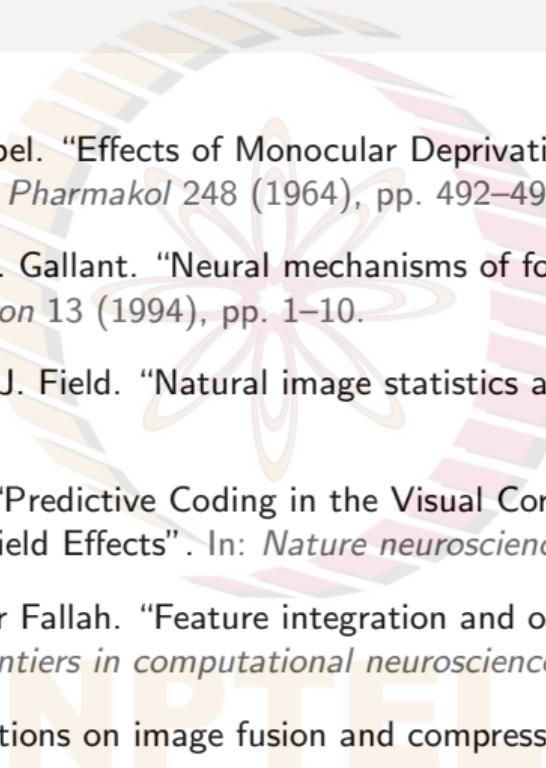
Summary of Human Visual System

- [Lecture Notes of Majumder, UCI on Visual Perception](#)

If you'd like to know more...

- [Chapter on Vision](#) by Martin A. Fischler and Oscar Firschein in [Intelligence: The Eye, the Brain, and the Computer](#)
- Nobel laureate David Hubel's book: [Eye, Brain, and Vision](#)
- [The Joy of Visual Perception](#) by Peter K. Kaiser (Web Book)
- [Lecture 8](#) of UWash's CS455: Computer Vision (Rao, 2009)

References

- 
-  Torsten N. Weisel David H. Hubel. "Effects of Monocular Deprivation in Kittens". In: *Naunyn Schmiedebergs Arch Exp Pathol Pharmakol* 248 (1964), pp. 492–497.
 -  David C. Van Essen and Jack L. Gallant. "Neural mechanisms of form and motion processing in the primate visual system". In: *Neuron* 13 (1994), pp. 1–10.
 -  Bruno A. Olshausen and David J. Field. "Natural image statistics and efficient coding.". In: *Network* 7 2 (1996), pp. 333–9.
 -  Rajesh Rao and Dana Ballard. "Predictive Coding in the Visual Cortex: a Functional Interpretation of Some Extra-classical Receptive-field Effects". In: *Nature neuroscience* 2 (Feb. 1999), pp. 79–87.
 -  Carolyn Jeane Perry and Mazyar Fallah. "Feature integration and object representations along the dorsal stream visual hierarchy". In: *Frontiers in computational neuroscience* 8 (2014), p. 84.
 -  Rafael Redondo. "New contributions on image fusion and compression based on space-frequencey representations". In: (July 2020).