VR/AR Challenges

NBAY 6120
March 22, 2018
Prof. Donald P. Greenberg
Lecture 8

What will happen next?

It is useful to first compare the history of development acceptance and deployment of similar display technologies

Technical Requirements for VR/AR Satisfactory Delivery

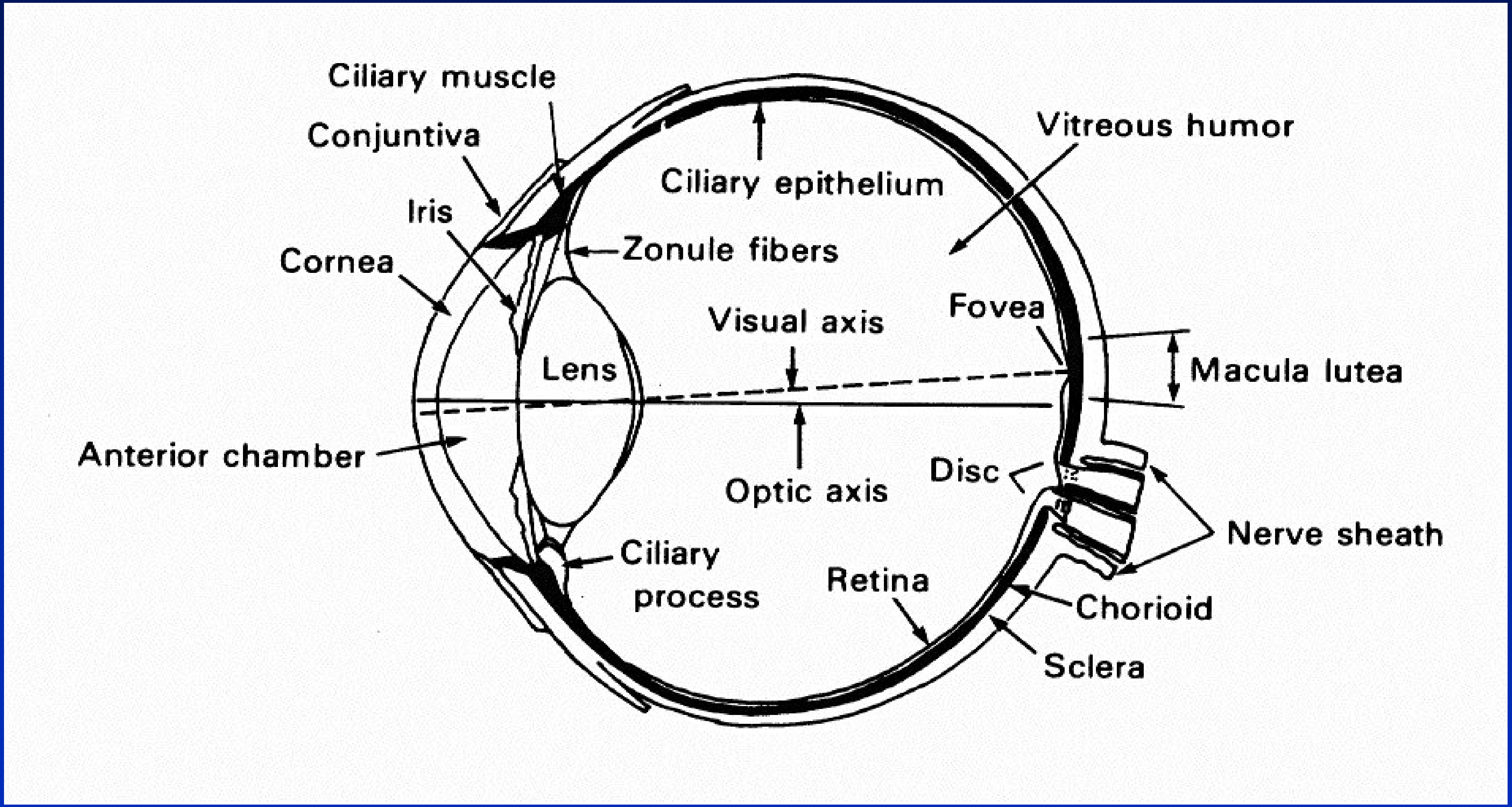
- Display resolution similar to the human visual system
- Display quality similar to human visual system (illumination, color, etc.)
- Sufficient display rates for motion perception
- Rendering speeds to satisfy display rate requirements
- Sufficient wireless bandwidth for data

All of this will depend on understanding the human visual system.

The Human Eye

Wikipedia

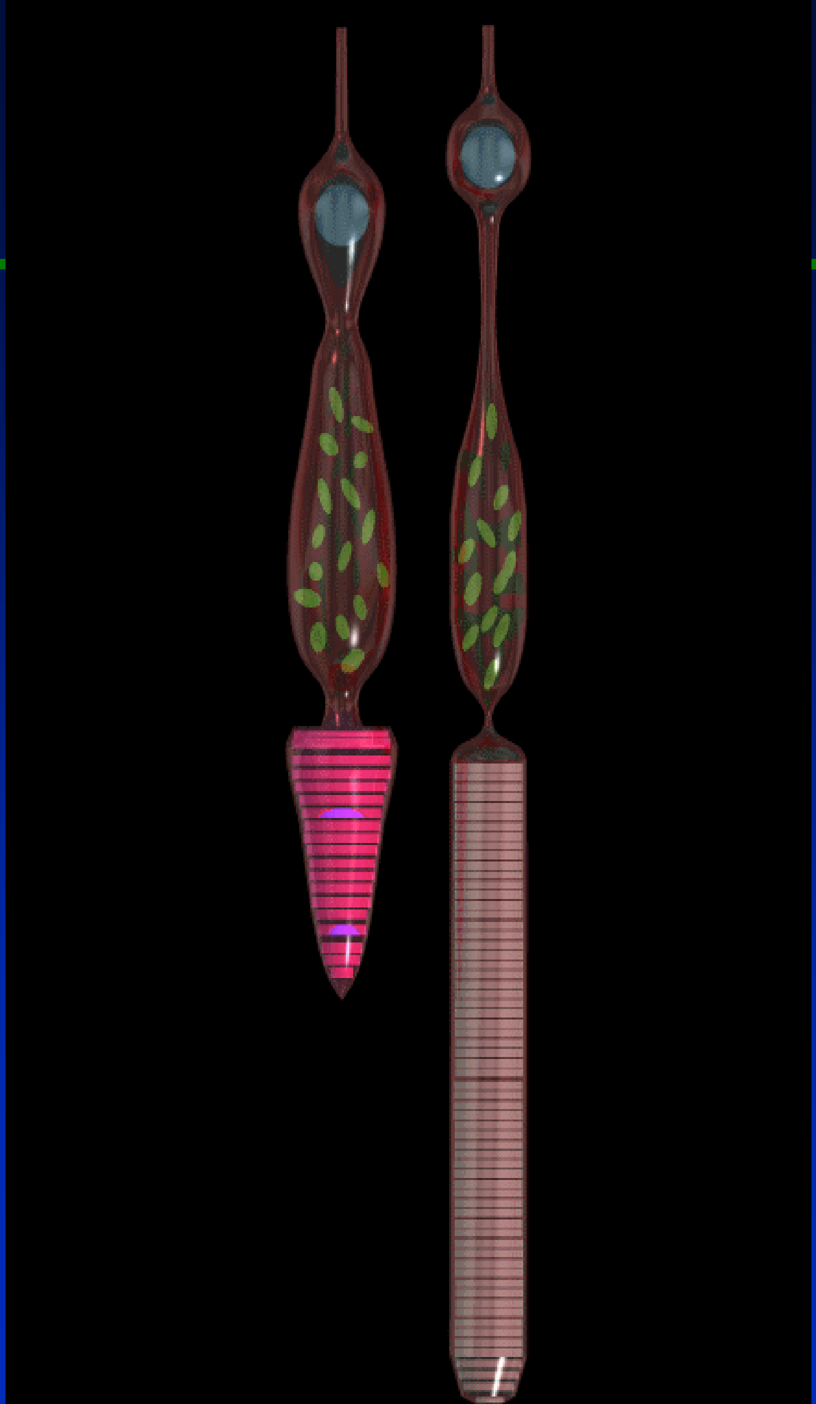
Cross Section of Eye & Retina



Rods & Cones

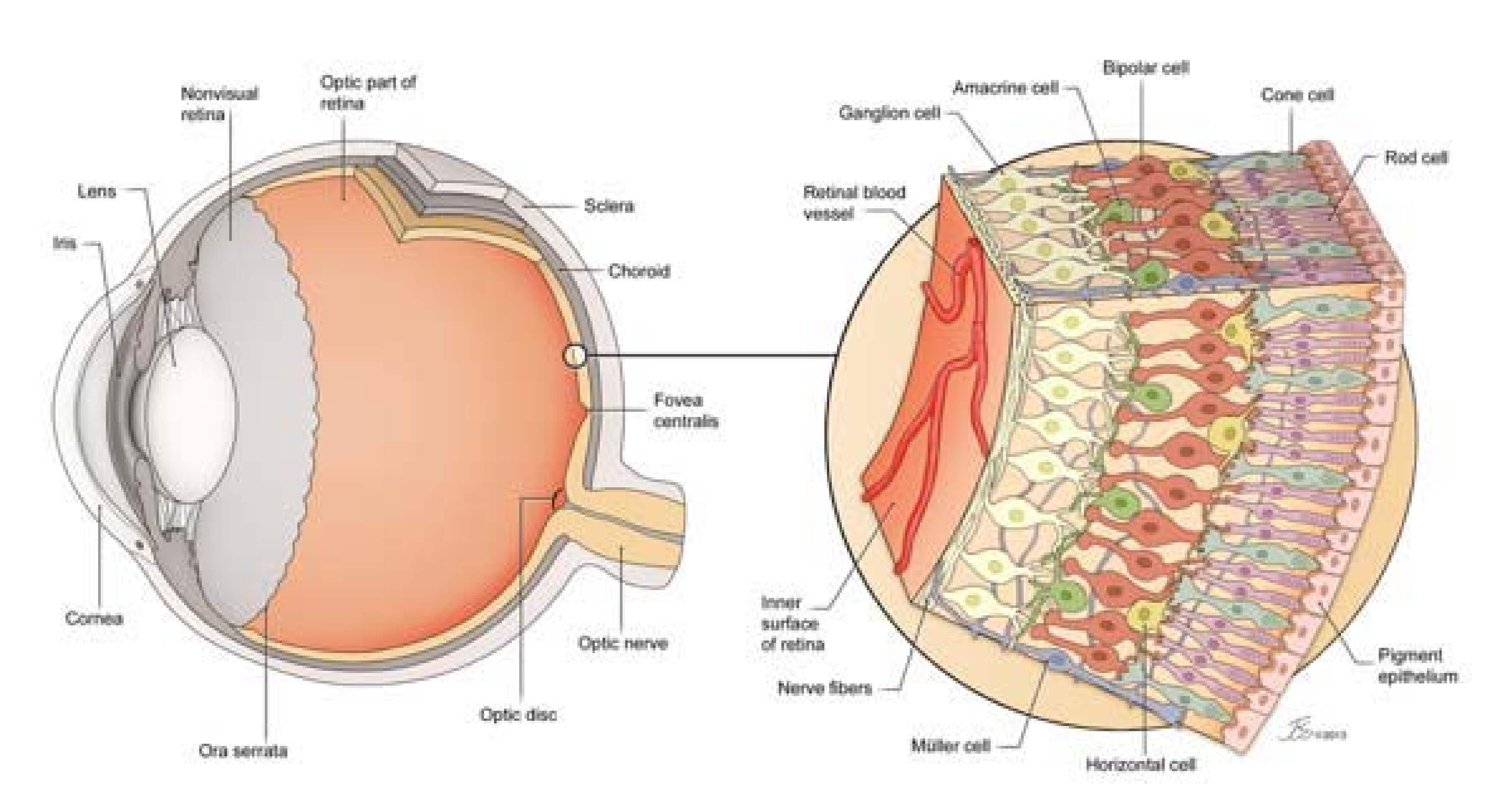
Comparison of a rod cell (right) and cone cell (left). This shows how each cell acquired its name from its shape.

- 120 million rods
- 7-8 million cones in each eye



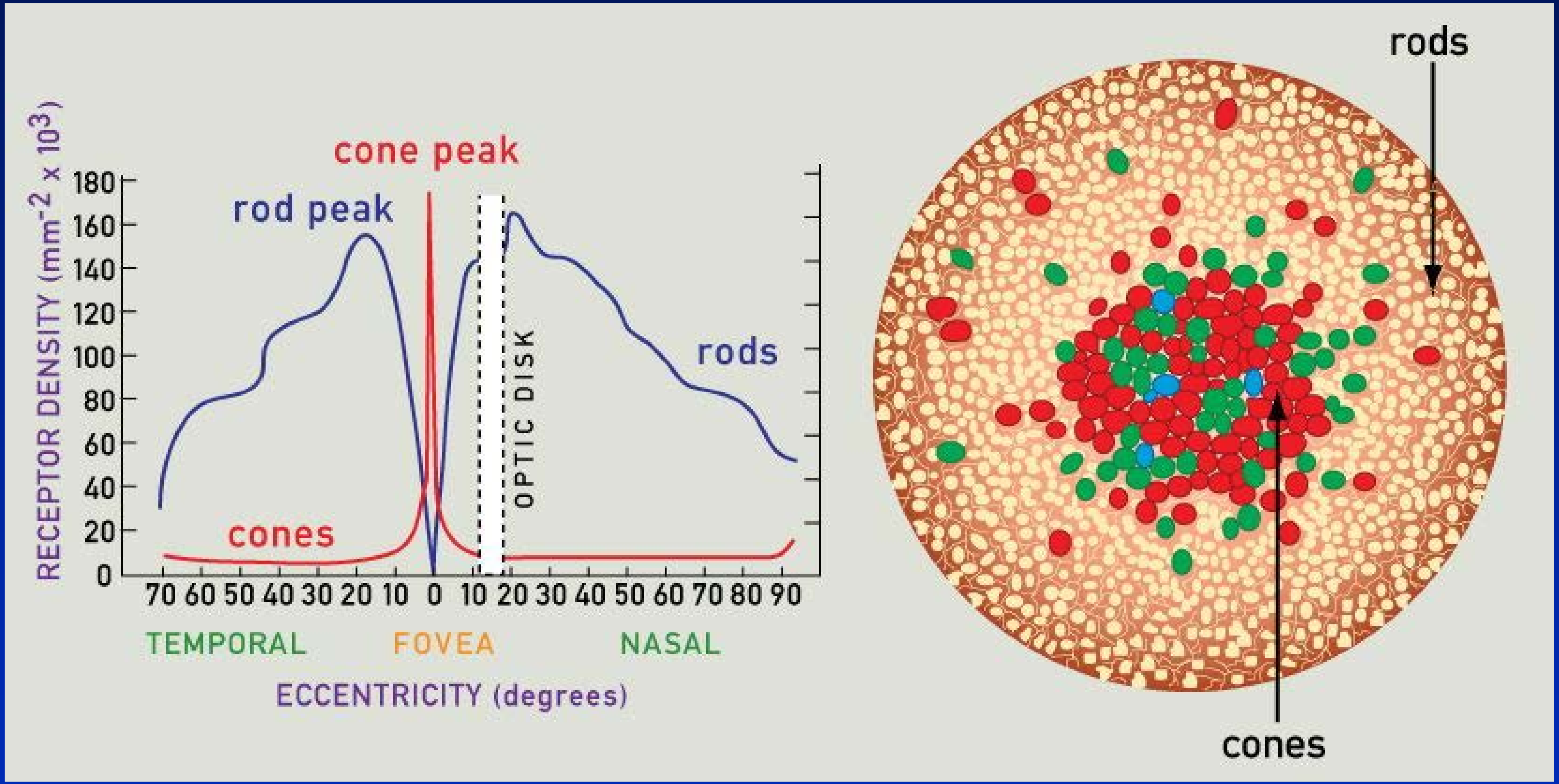
http://www.chemsoc.org/exemplarchem/entries/2002/upton/cones.htm

Rods & Cones

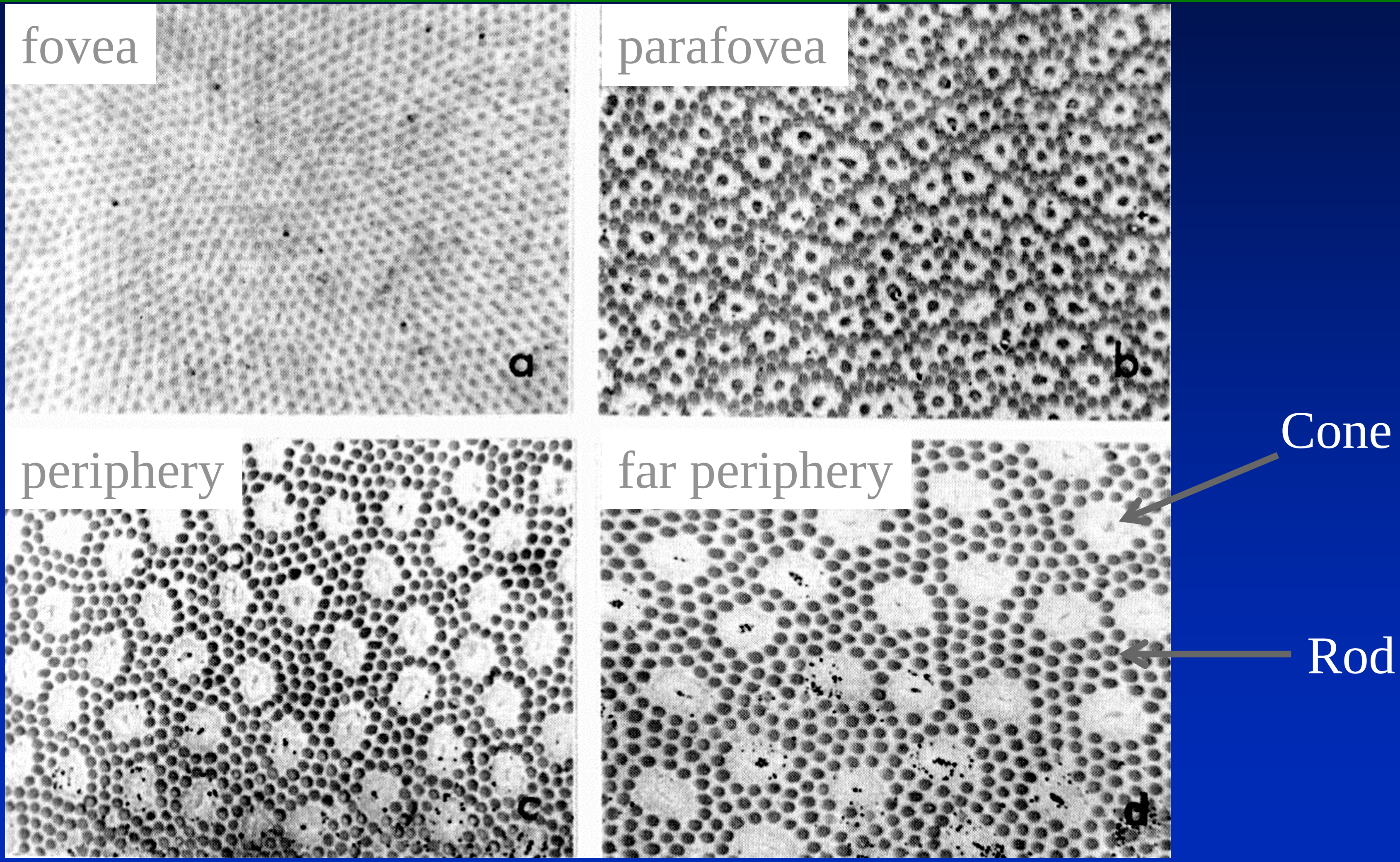


Nonvisual retina
Optic part of retina
Lens
Iris
Sclera
Choroid
Fovea centralis
Cornea
Optic nerve
Optic disc
Ora serrata
Bipolar cell
Amacrine cell
Ganglion cell
Cone cell
Rod cell
Retinal blood vessel
Inner surface of retina
Nerve fibers
Müller cell
Horizontal cell
Pigment epithelium

Receptor Distribution

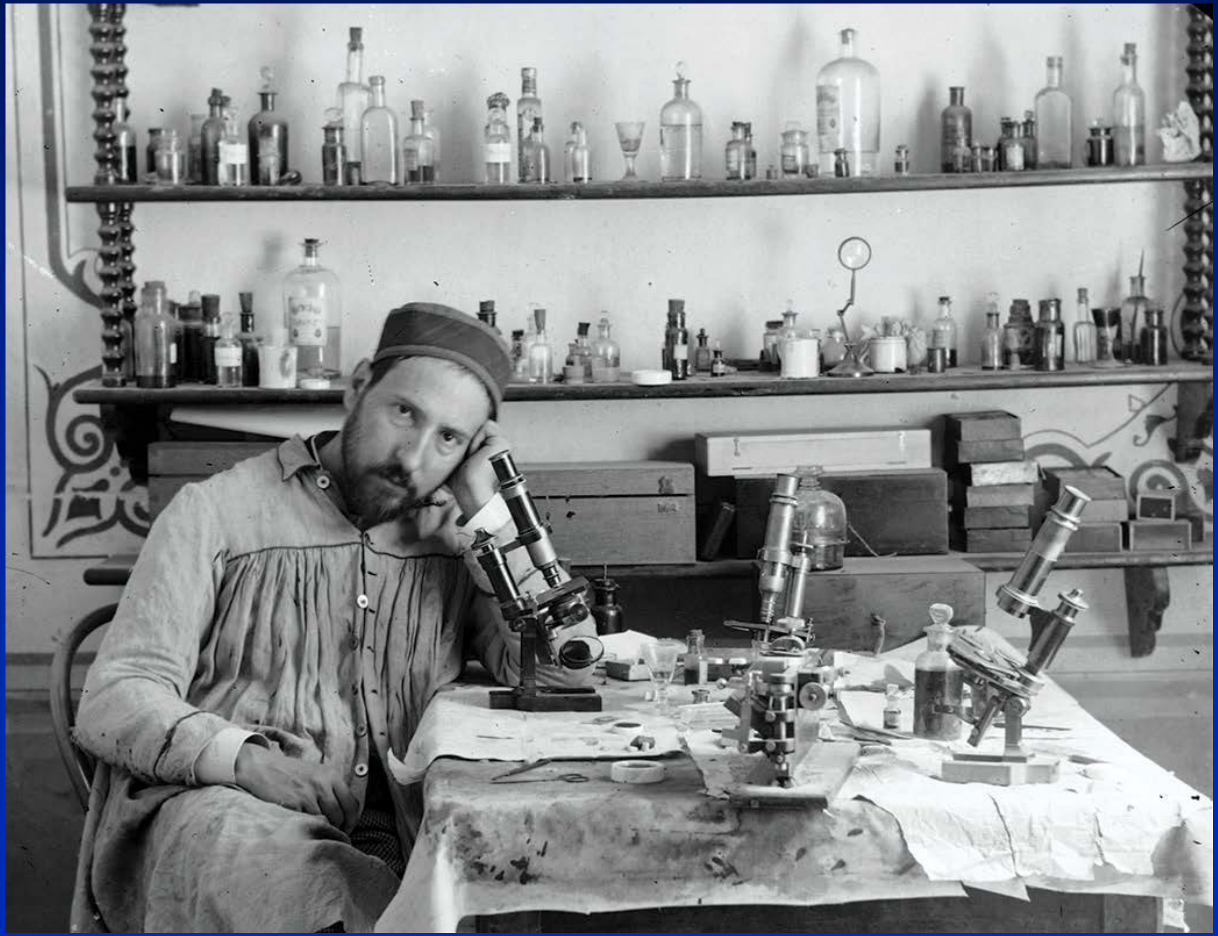


Receptor Distribution

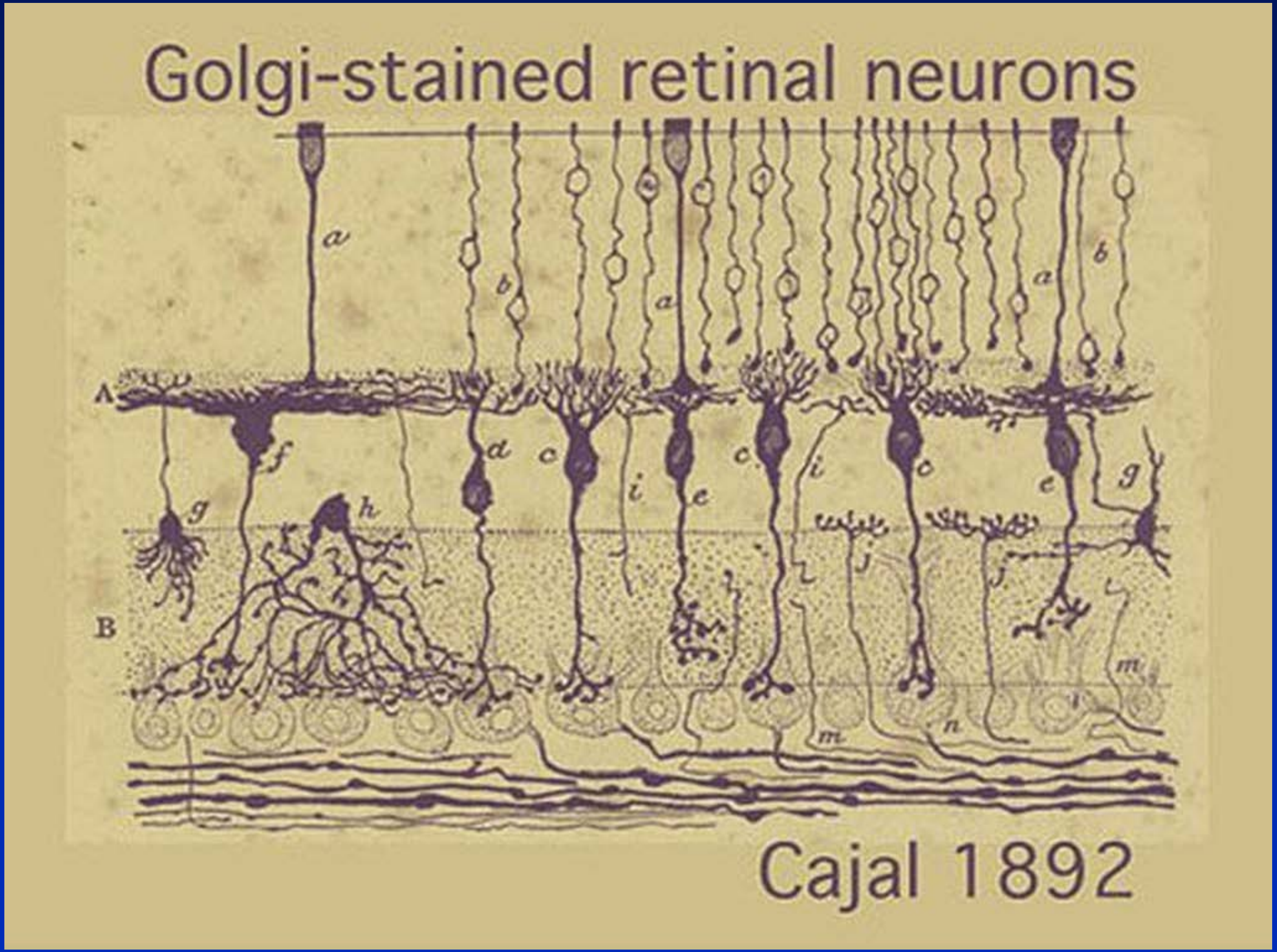


Adapted from Levine, Vision in Man and Machine © McGraw-Hill, 1985.

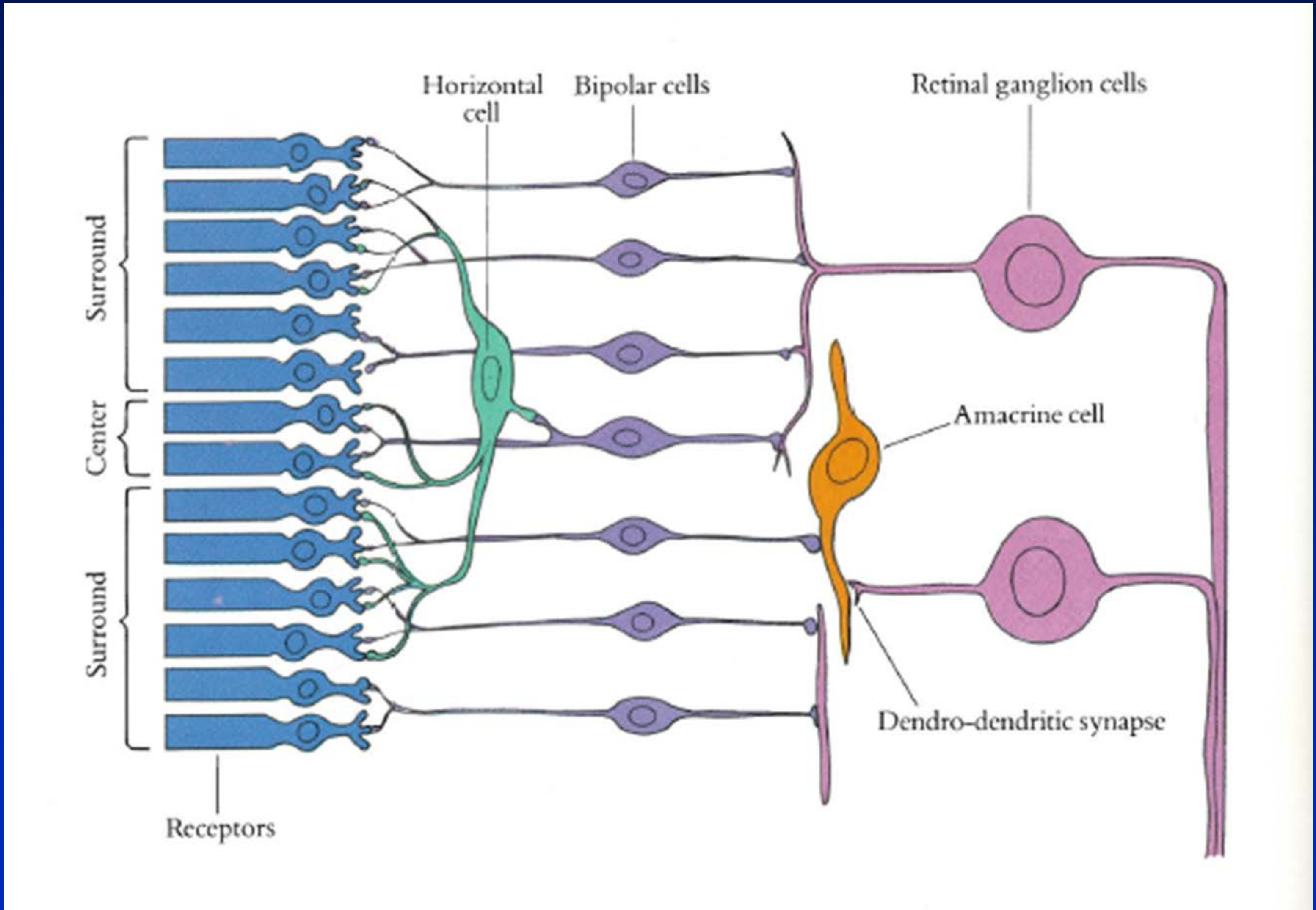
Santiago Ramon y Cajal & Camillo Golgi 1906



Drawing by Cajal



Cone & Rod Connections Hubel



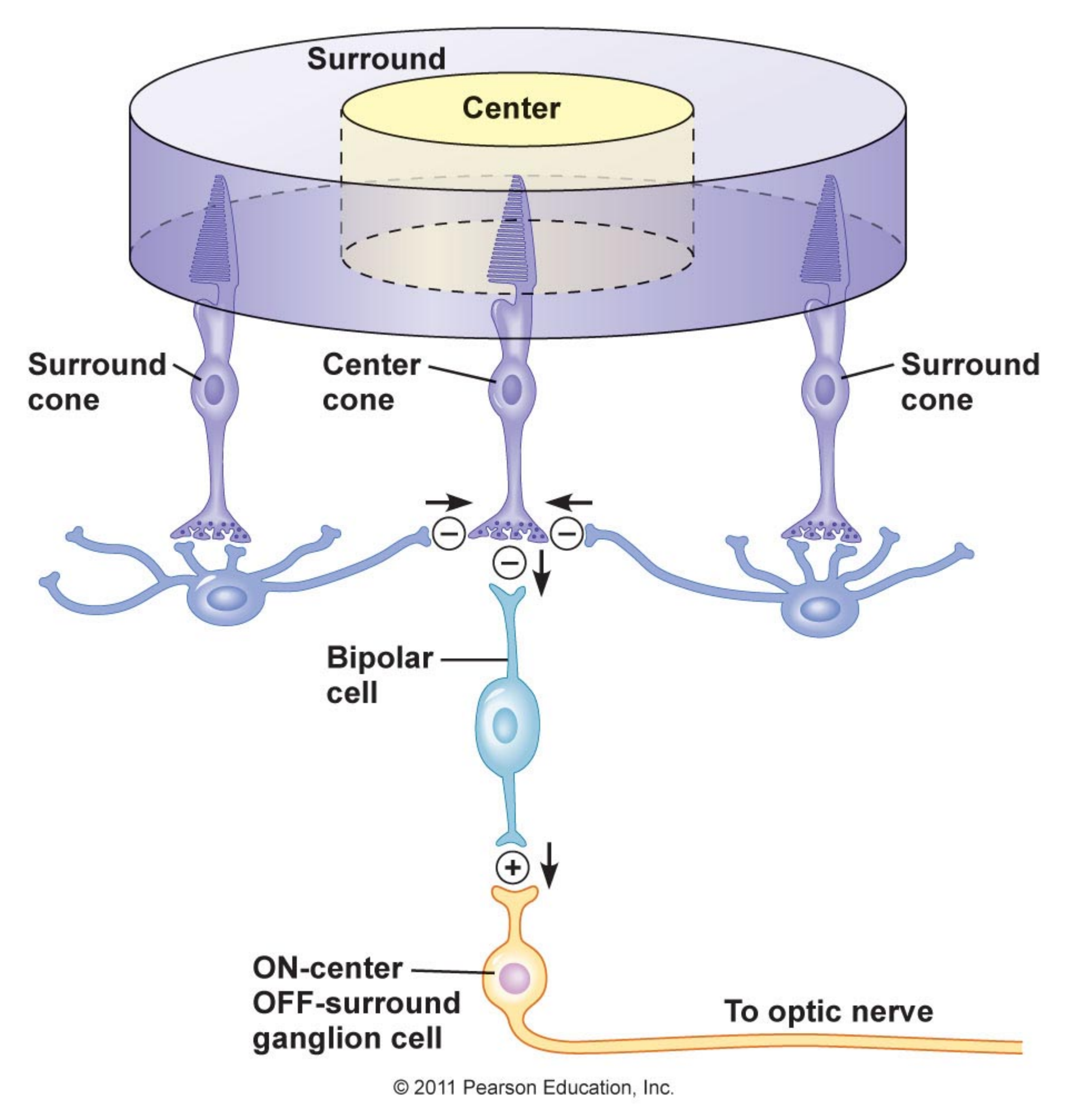
Retina Statistics

Receptive Fields –

Individual cone signals can either add together or be subtracted from one another.

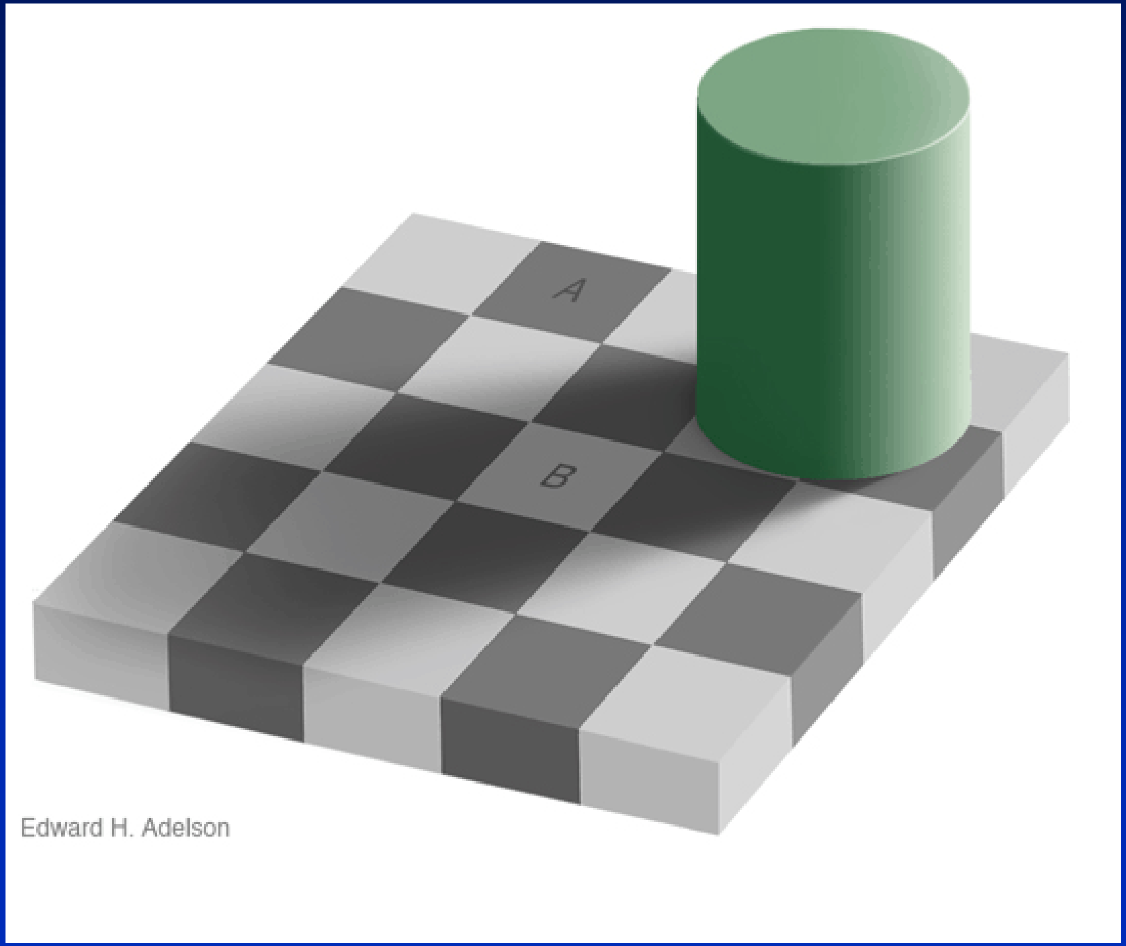
The ability to resolve fine details depends ultimately on both the spatial mosaic of the receptors and how they interconnect.

Receptive Fields



http://droualb.faculty.mjc.edu/Course%20Materials/Physiology%20101/Chapter%20Notes/Fall%202007/figure_10_39_labeled.jpg

Color Constancy



Saccadic Motion

The eye jumps, comes to rest momentarily (producing a small dot on the record), then jumps to a new locus of interest.

- David H. Hubel. EYE, BRAIN, AND VISION, 1988 Scientific American Books, Inc. p. 80.

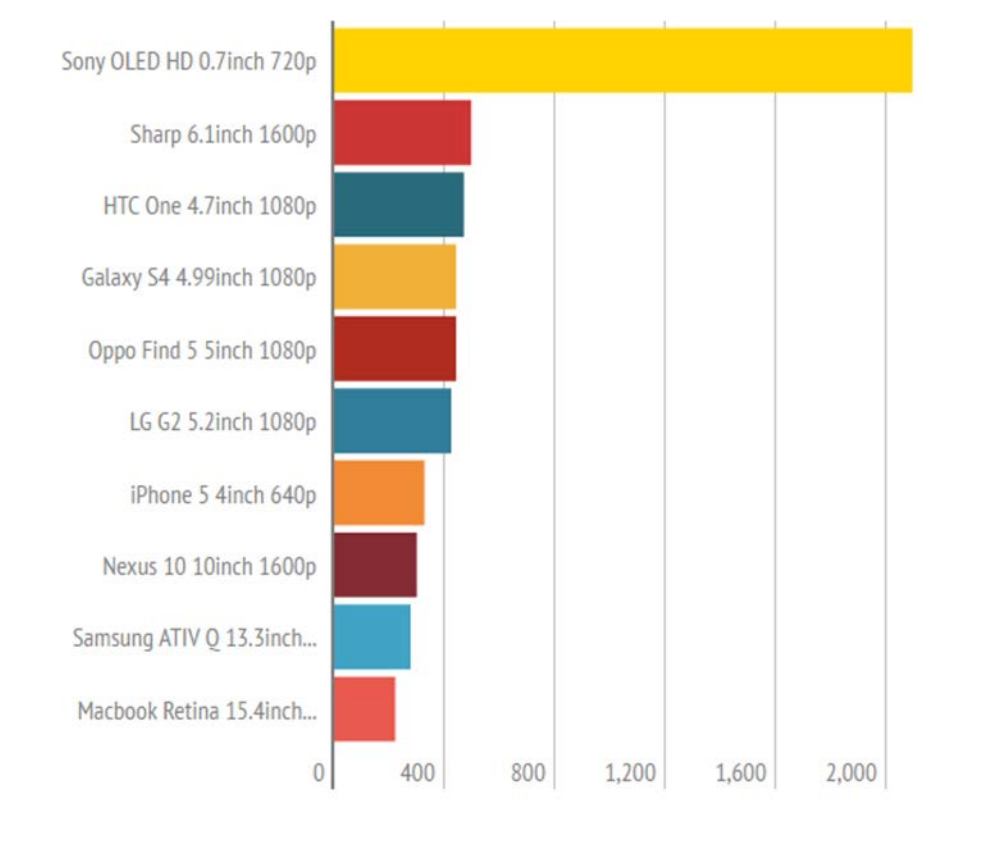
Resolution of the Human Eye

- Humans can tell visual details at distances larger than 0.3 arc minutes
- The Field of View (FOV) of the human eye can be generously estimated as 120 by 90 degrees

Resolution of the Human Eye

- (120 degrees x 60 arcminutes / degree x 1 pixel / 0.3 arcminutes) x (90 degrees x 60 arcminutes / degree x 1 pixel / 0.3 arcminutes)
- 431,568,000 pixels; 432 MegaPixels. A 1080p display is 2.1 megapixels.

Increasing Densities (ppi) of OLED Displays

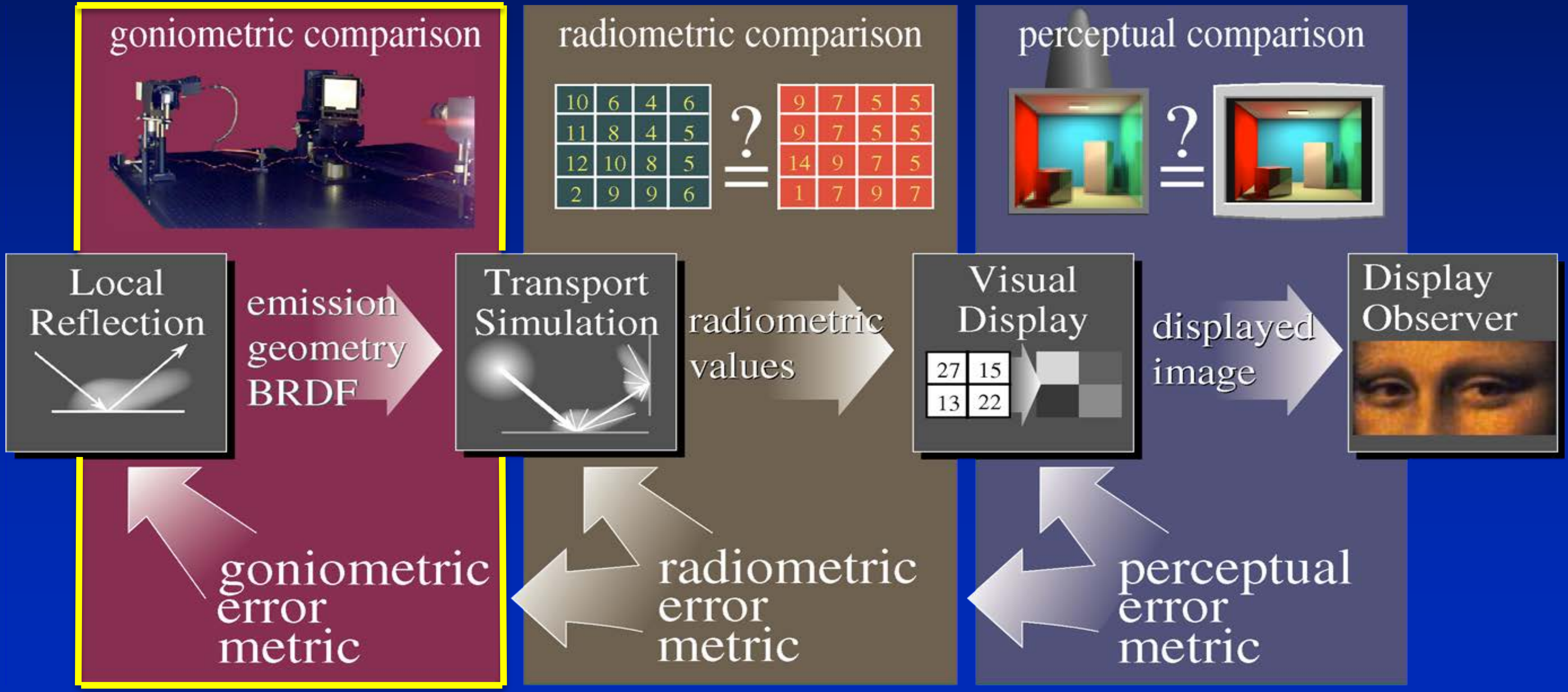


This is nowhere near the resolution of the human eye

Necessary Improvements

- Not currently possible to manufacture required pixel densities
- Higher resolution is required in the foveal region
- Reduction in bandwidth (High resolution at the periphery is not necessary)

Rendering Framework 1997



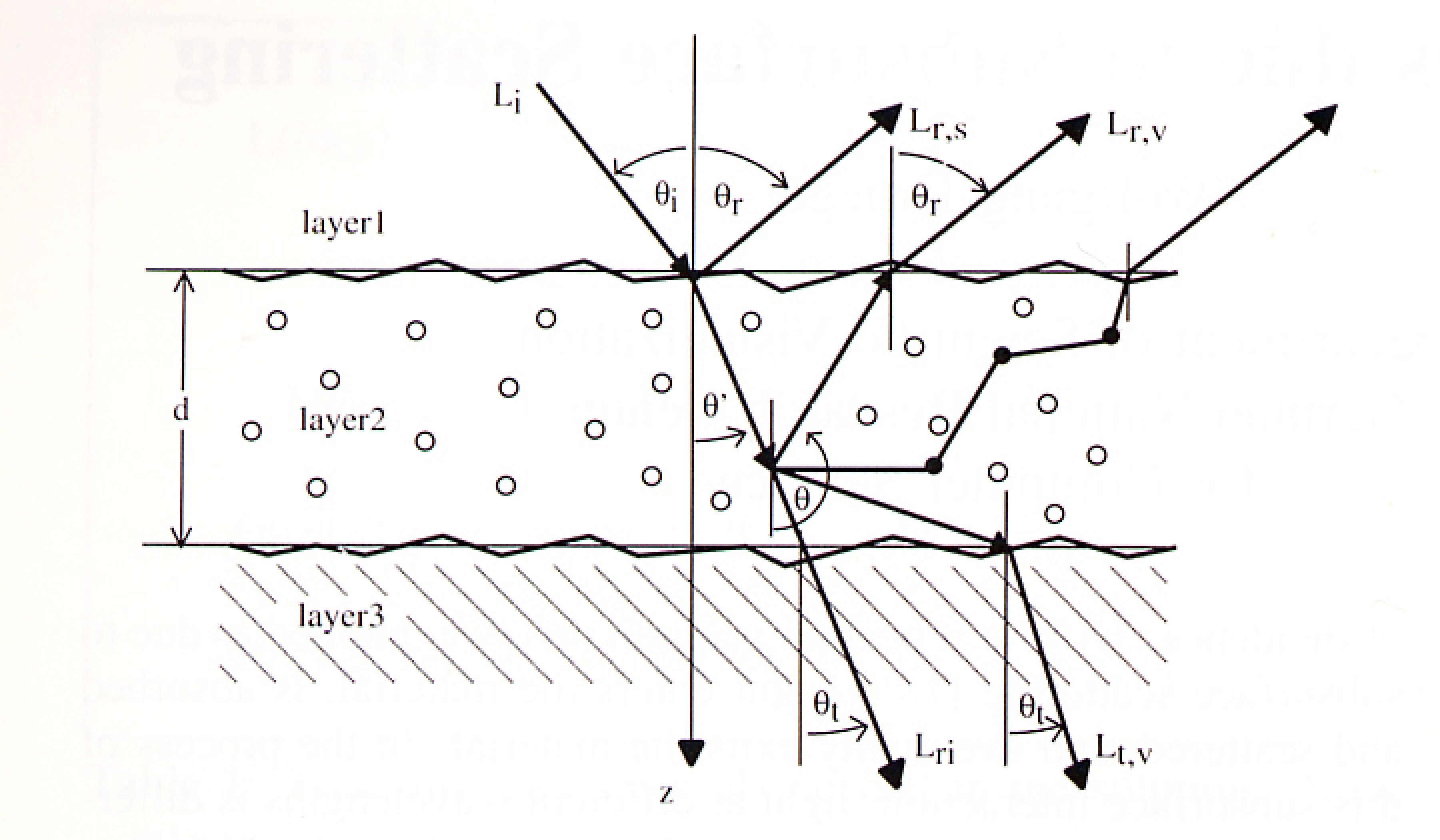
- The quality of the image must be **physically accurate** and **perceptually indistinguishable** from real world scenes
- Thus the reflective properties of the materials and the illumination properties of the light sources must be correct

Material Accuracy 1980

Cook-Torrance

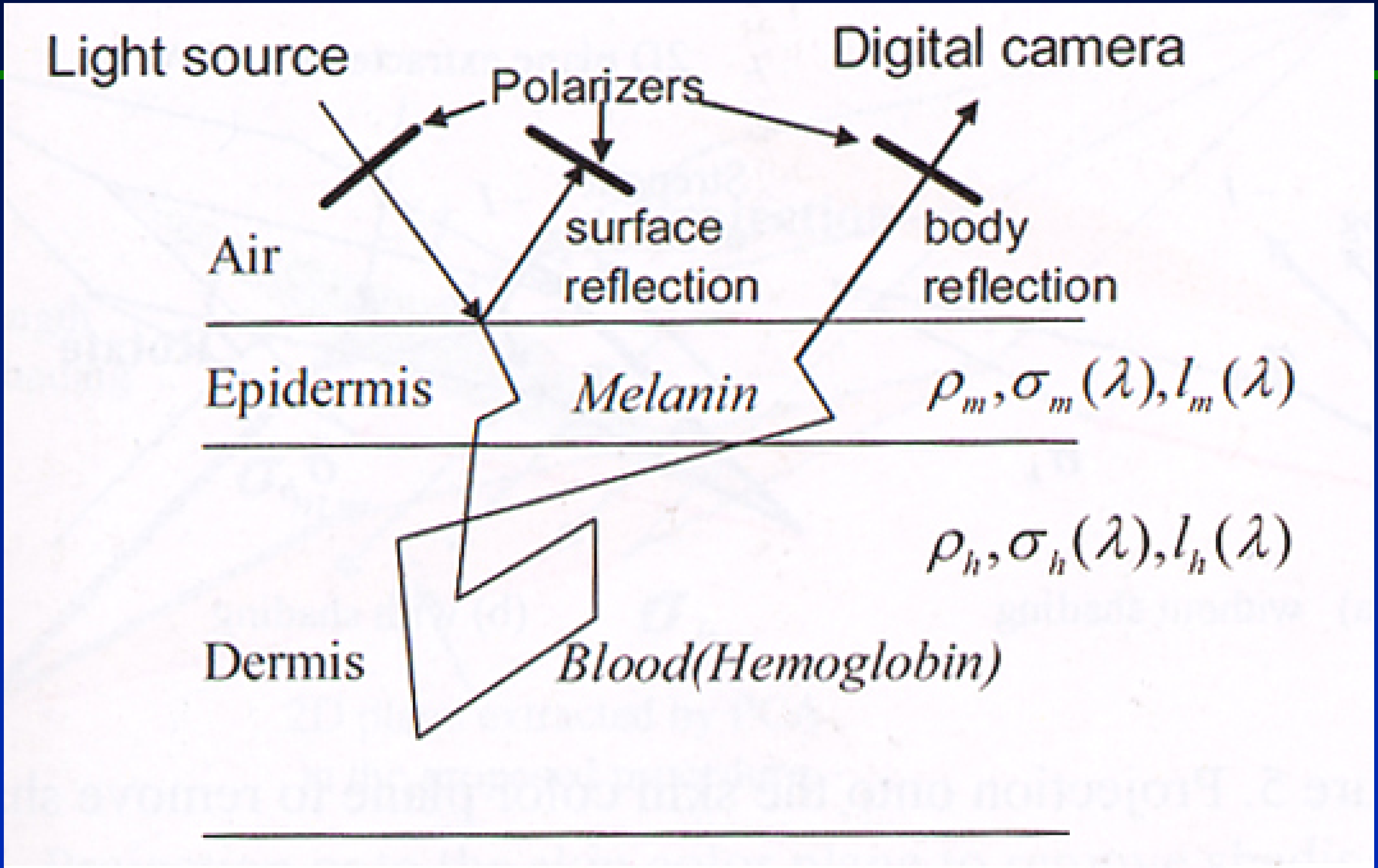
Material Accuracy

Henrik Wann Jensen, Stephen R. Marschner, Marc Levoy, Pat Hanrahan. "A Practical Model for Subsurface Light Transport," ACM Siggraph 2001, August 2001, Los Angeles, CA, pp. 511-518.



The geometry of scattering from a layered surface

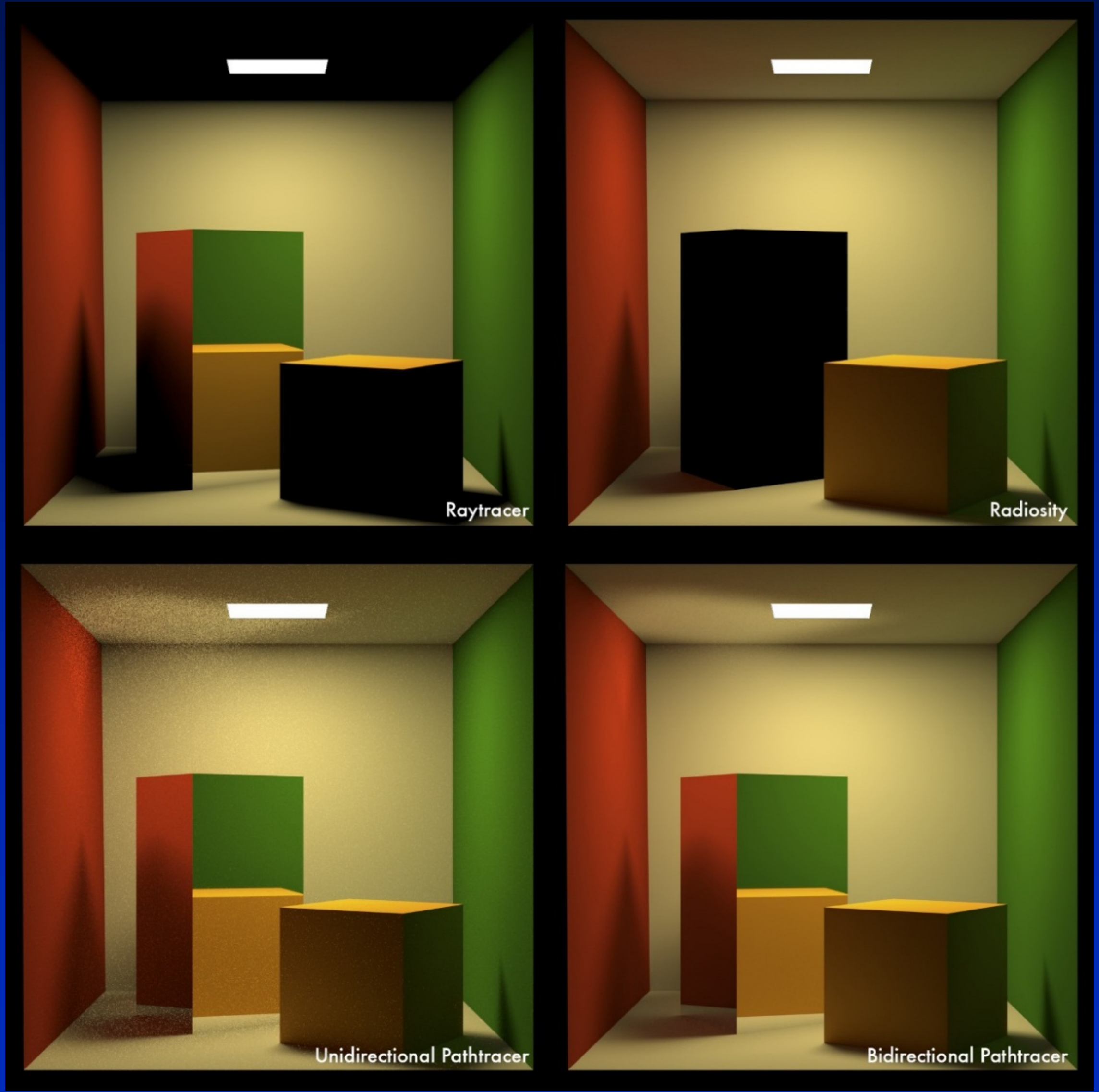
acm Computer Graphics, Siggraph 1993 p. 166



Schematic model of the image process

acm Transactions on Graphics, Siggraph 2003 p. 773

Bi-directional Path Tracing

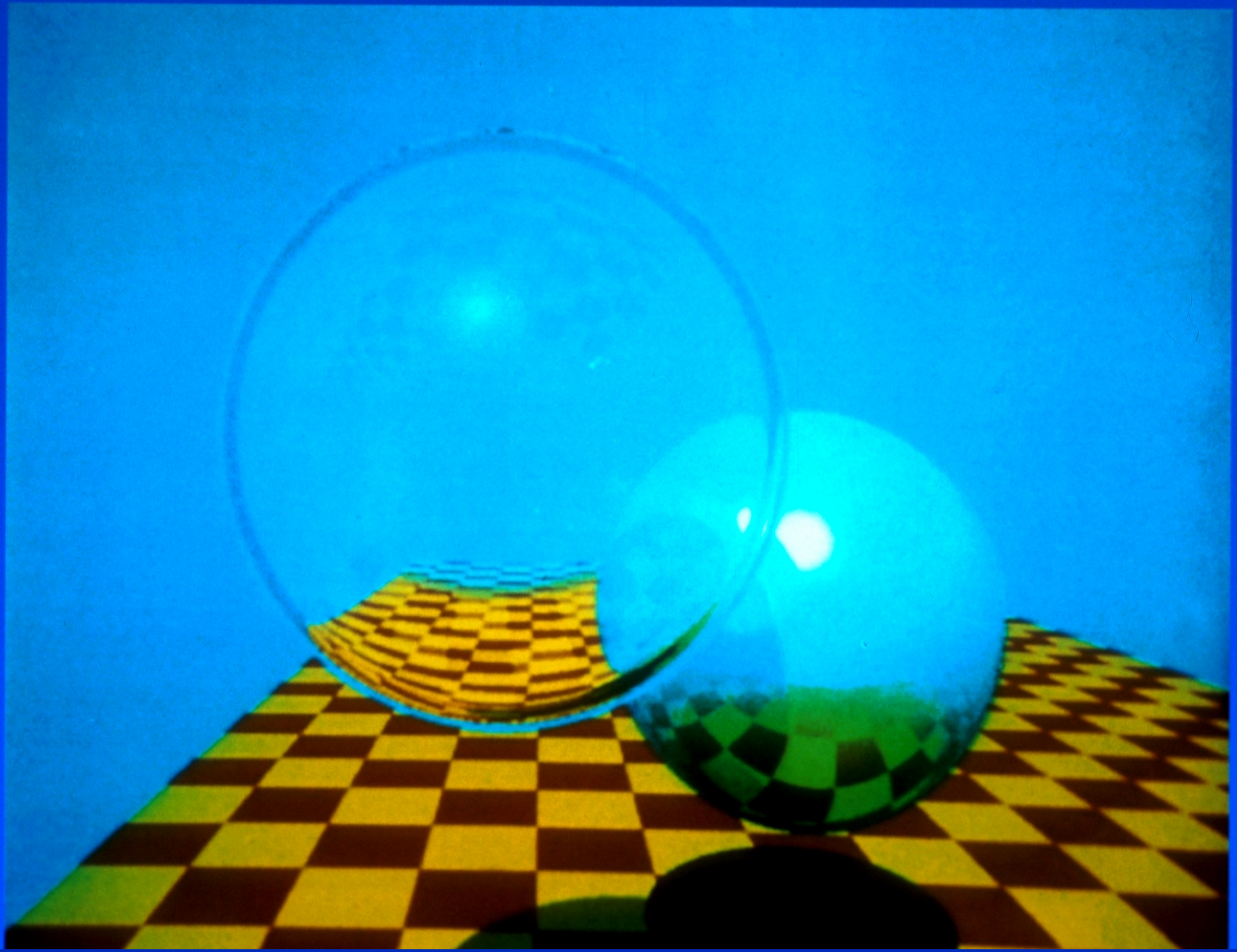


Bi-directional Path Tracing

Can we compute fast enough?

Ray Tracing

Turner Whitted, 1979



- Remember the nVidia demonstration with the DGX rendering system in the first laboratory session
- But even the increased speed of 10^6x – 10^8x may not be enough

Display Rates

- Currently, the refresh rate is 90 frames/sec, which translates to 11 milliseconds/frame for each eye

- Remember the nVidia demonstration with the DGX rendering system in the first laboratory session
- But even the increased speed of 10^6x – 10^8x may not be enough
- Currently, the refresh rate is 90 frames/sec, which translates to 11 milliseconds/frame for each eye

How can we increase the rendering speed to generate sufficient refresh rates?

Toy Story 3

John Lehrer. "How It's Done," Wired 18.06. http://www.wired.com/magazine/18-06

Online vs. Offline Rendering

10 hours

Off-line: 10 hours x 60 min./hour x 60 seconds/min. = 36,000 seconds

On-line: 10 milliseconds

Ratio = $\frac{36 \, x \, 10^3}{10 \, x \, 10^{-3}}$ = 3.6 x10^6

The ratio is even greater when one considers higher resolution (an increase in the number of pixels), both eyes, and the latency which occurs with eye tracking

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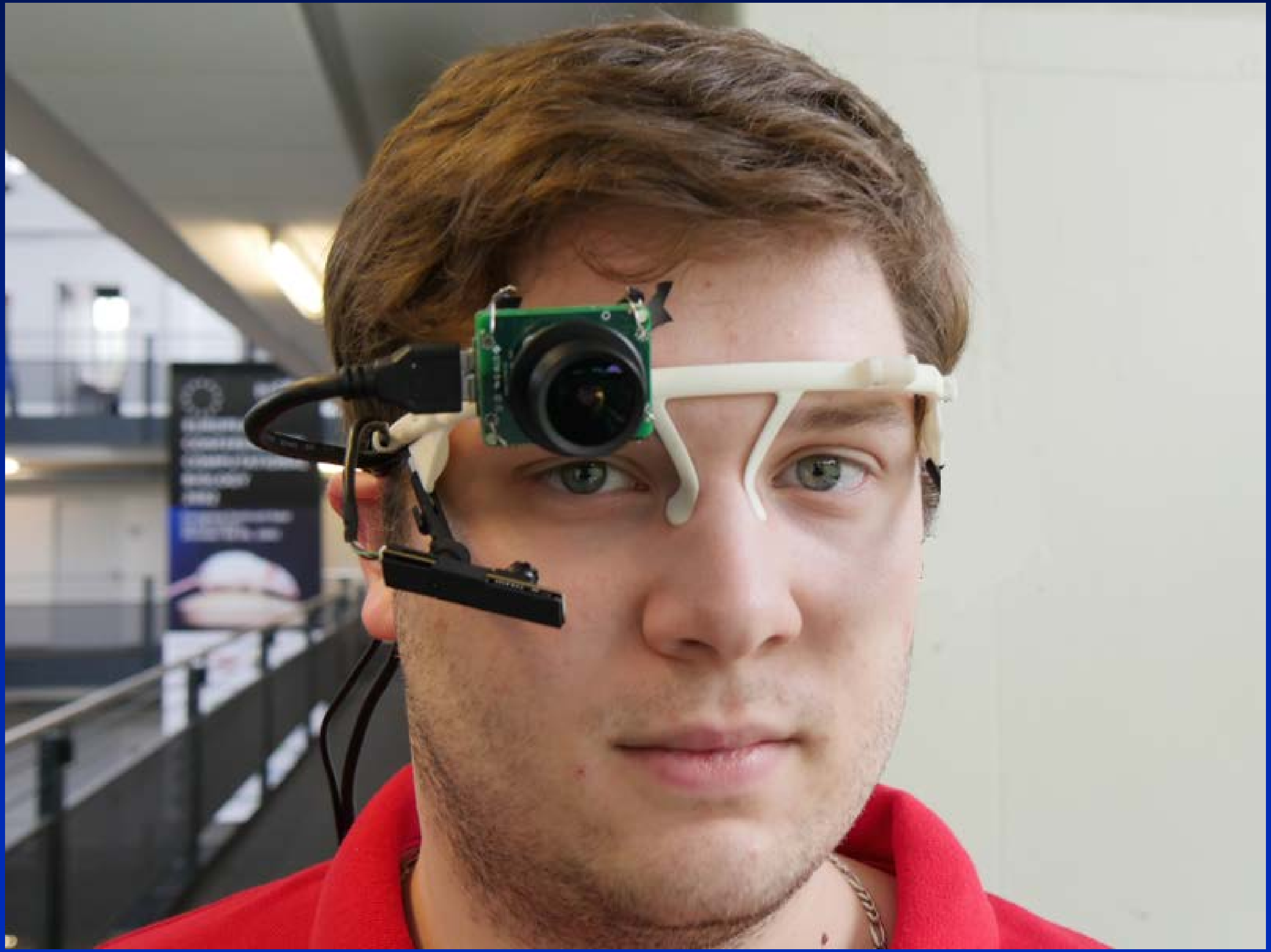
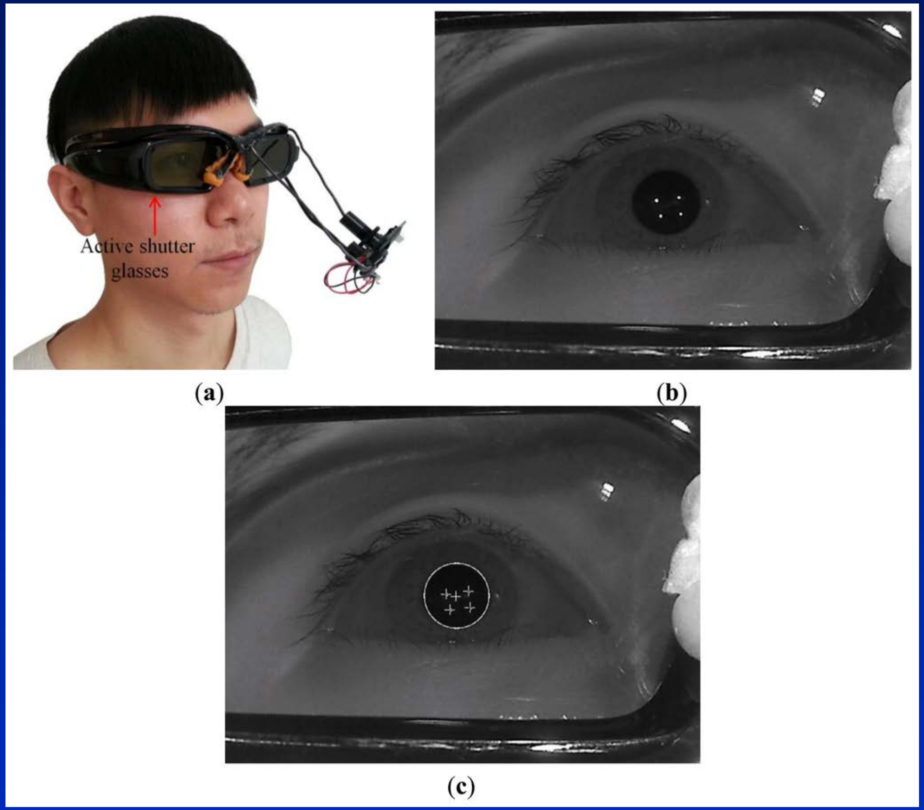
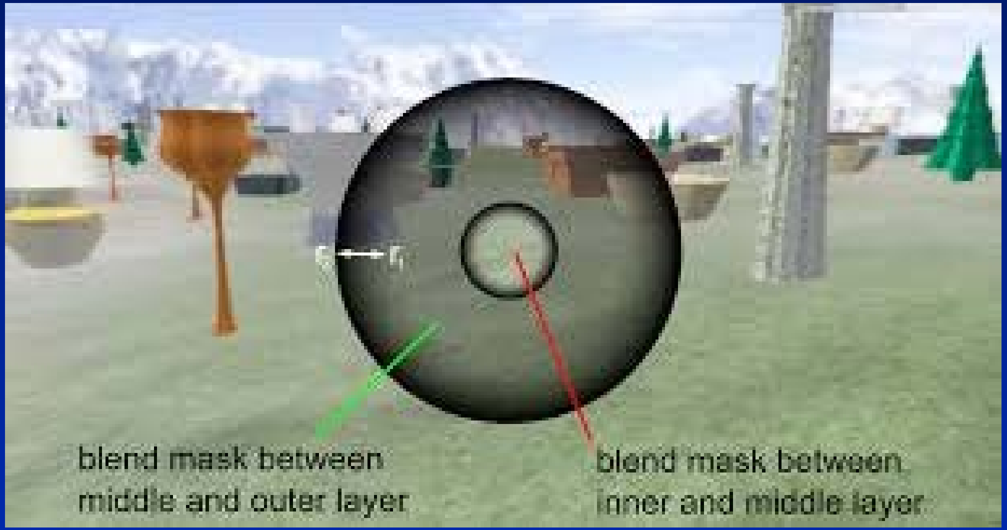
We probably need more than a million times more processing power

Eye Tracking



Research on Foveated Displays





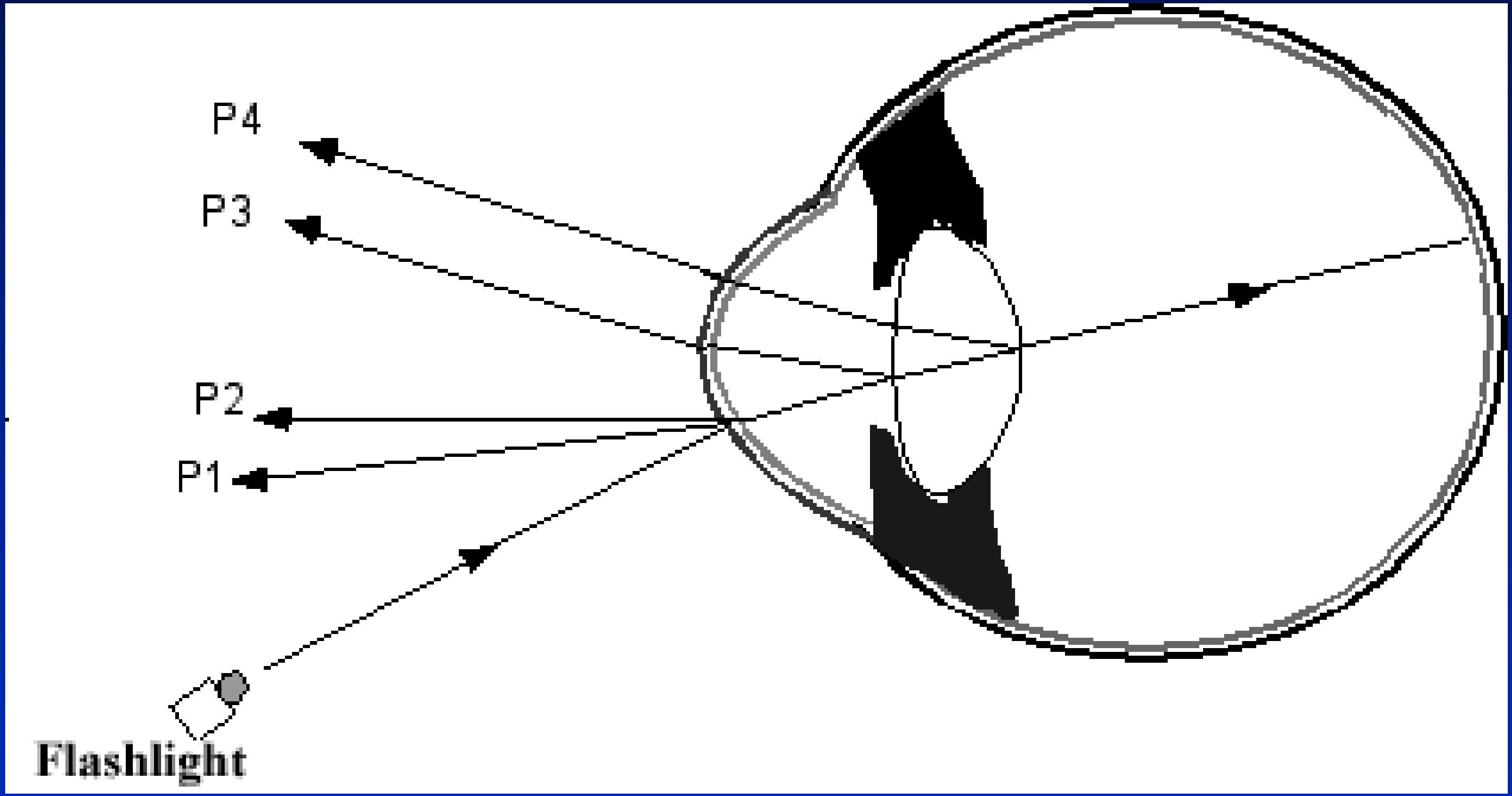
Foveal Eye Tracking Constraints 2016

- Speed- needs to be fast enough to meet update requirements
  (currently 11 milliseconds, 90 Hz)

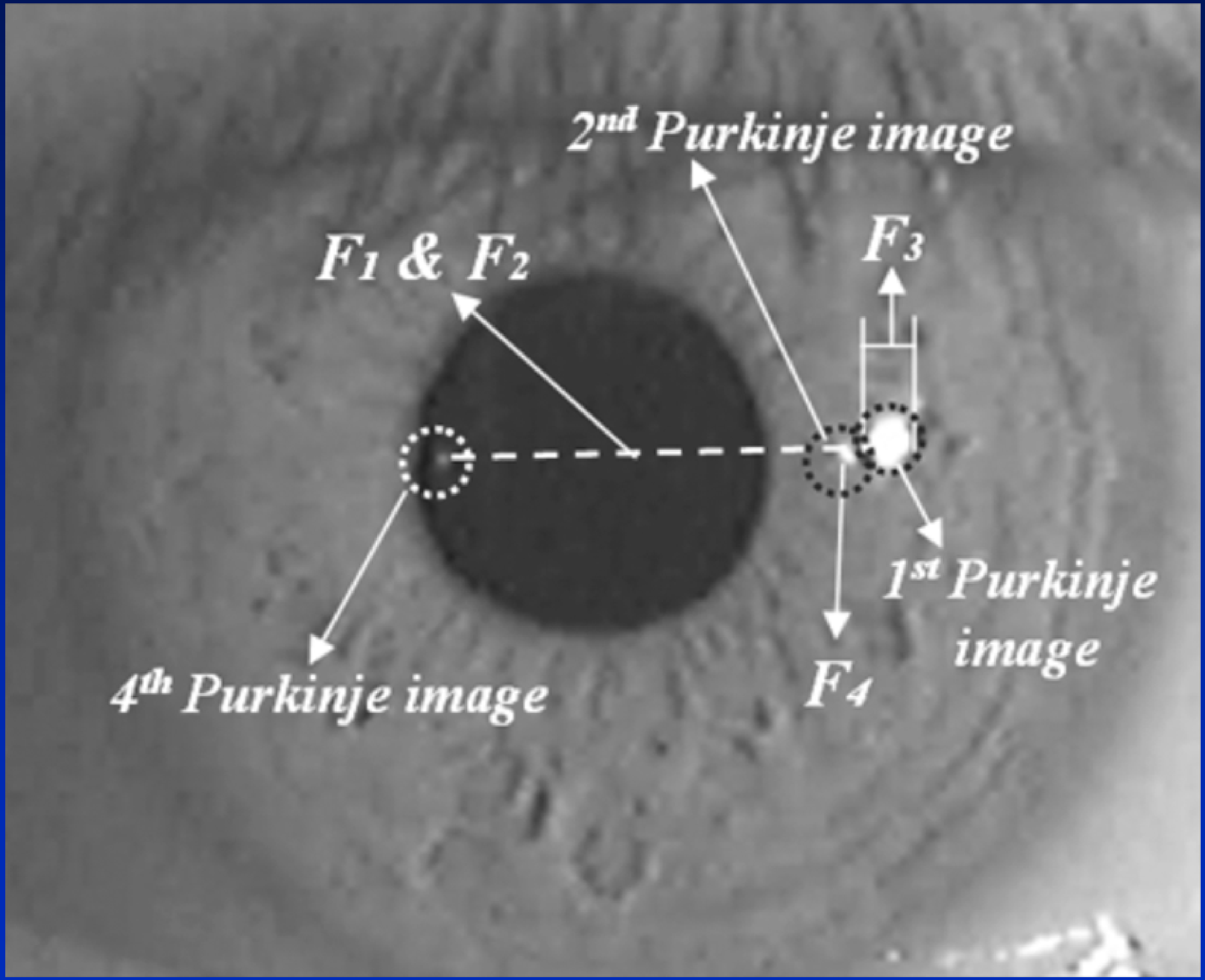
- Accuracy- Gaze direction is < 0.5 degree
  - Foveal direction accuracy can be ~ 1.0 arc minutes (1/60 of a degree)

- Non-invasive measurements- still need to see entire visual field

Purkinje Reflections



Purkinje Reflections



1st and 4th Purkinje Reflections

Foveal Eye Tracking Pros and Cons

Pros:

- Foveal eye tracking measurements to determine the gaze direction can be performed in 4-5 milliseconds.

Cons:

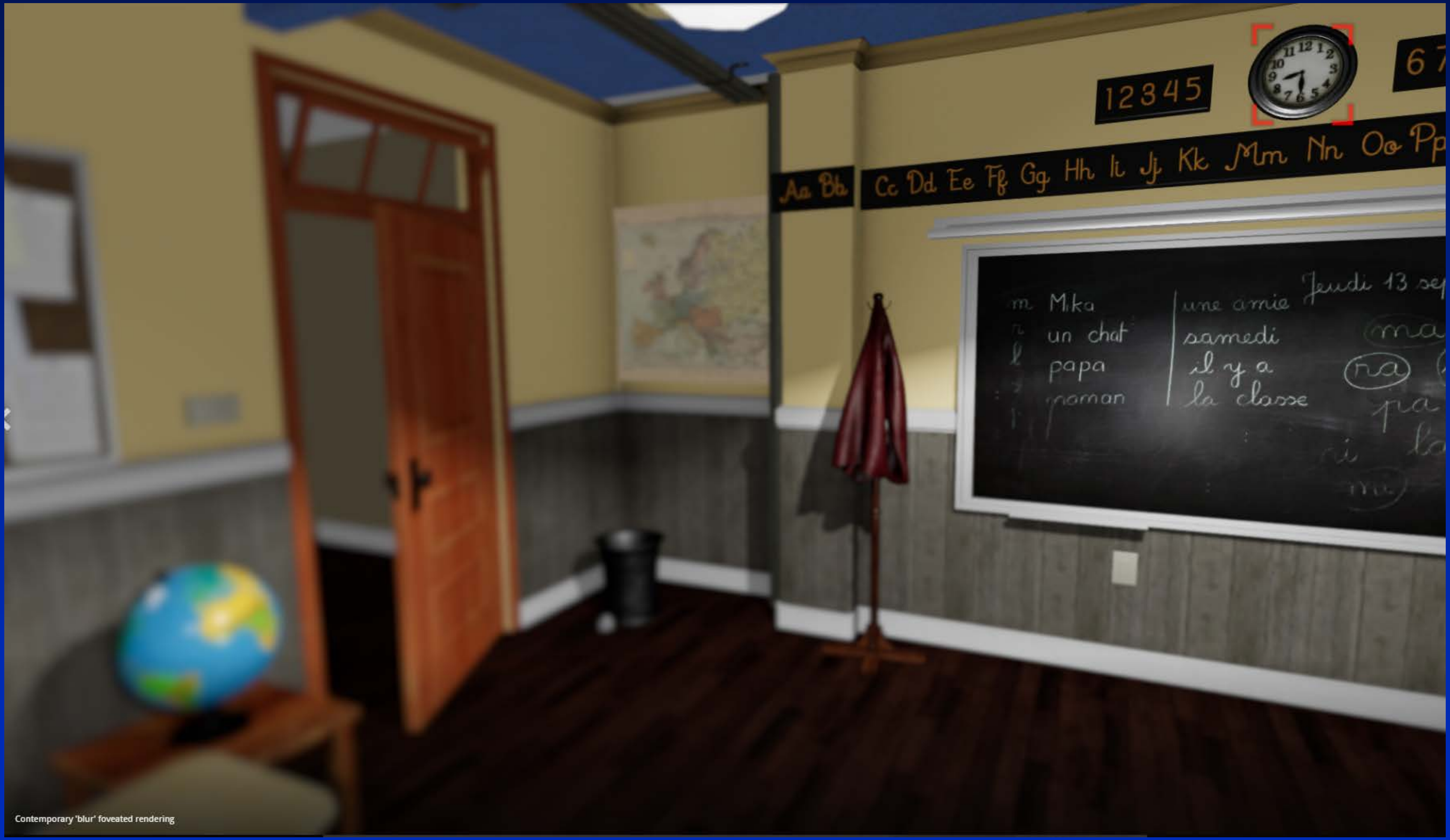
- The two best manufacturers were purchased by Google (Eyefluence) and Apple (SMI)

Displays with Variable Resolution and Variable Update Rates

No Foveated Rendering

Roadtovr.com

Contemporary ‘blur’ foveated rendering



Roadtovr.com

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